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Special issue

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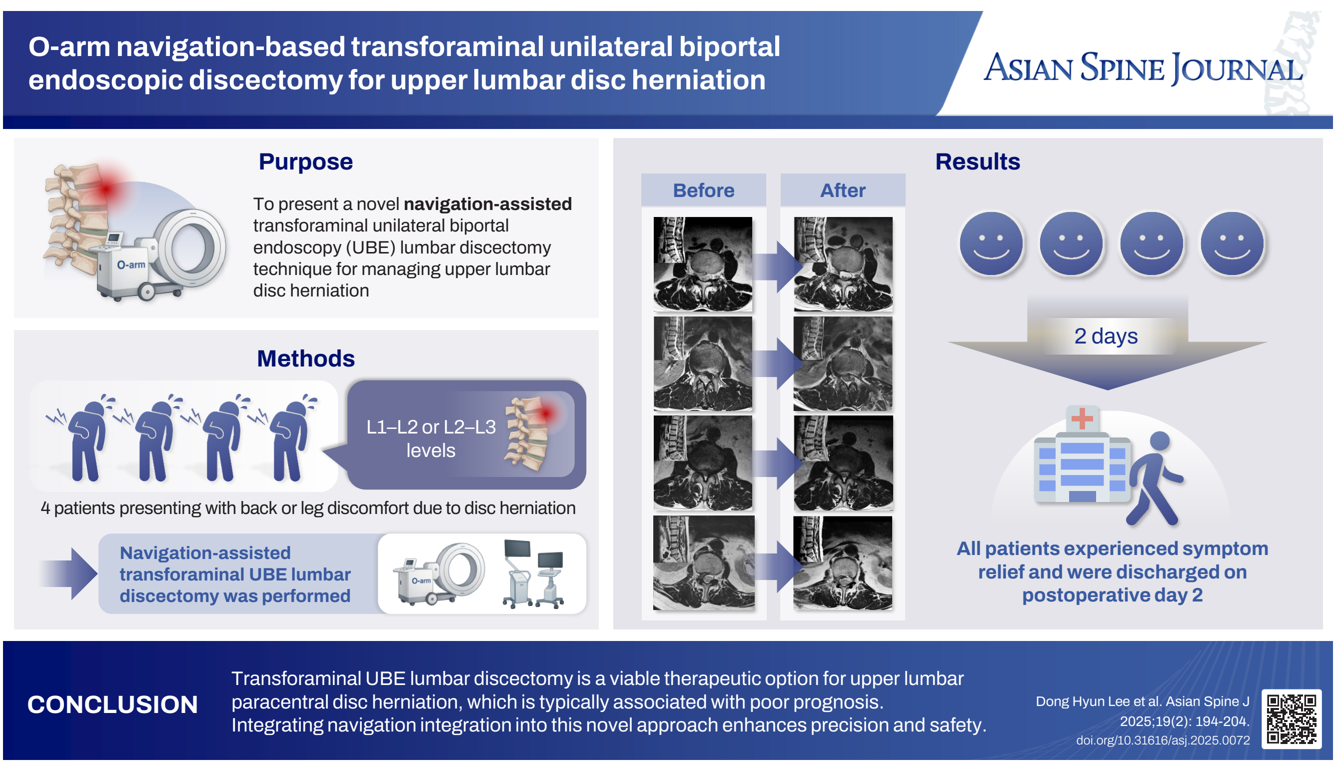

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Study Design: Technical case report.

Purpose: To present a novel navigation-assisted transforaminal unilateral biportal endoscopy (UBE) lumbar discectomy technique for managing upper lumbar disc herniation.

Overview of Literature: Upper lumbar disc herniation is significantly less common than lower lumbar disc herniation, accounting for only 1%–2% of cases. However, treatment is more challenging and is associated with worse outcomes. Anatomical differences between the upper and lower lumbar spine complicate the standard interlaminar approach using UBE, making it insufficient for complete removal of herniated discs. Integrating endoscopic spine surgery with intraoperative navigation provides three-dimensional computer-reconstructed visual data, thereby enhancing the feasibility of the technique.

Methods: The UBE approach targeted the ventral part of the superior articular process in the transforaminal UBE setup, specifically for upper lumbar disc herniation, with an approach angle of approximately 30º on the axial plane. Intraoperative navigation was employed to improve puncture accuracy for this relatively unfamiliar surgical technique. Navigation-assisted transforaminal UBE lumbar discectomy was performed on four patients presenting with back or leg discomfort due to disc herniation at the L1–L2 or L2–L3 levels.

Results: All patients experienced symptom relief and were discharged on postoperative day 2.

Conclusions: Transforaminal UBE lumbar discectomy is a viable therapeutic option for upper lumbar paracentral disc herniation, which is typically associated with poor prognosis. Integrating navigation integration into this novel approach enhances precision and safety.

Keywords: Navigation; Transforaminal; Upper lumbar disc; Biportal endoscopy; Discectomy

Introduction

Compared with the lower lumbar spine, the upper lumbar spine experiences disc herniation less frequently. The L1–L2, L2–L3, and L3–L4 levels collectively account for 5% of all lumbar disc herniations [1]. When excluding the L3–L4 level, upper lumbar disc herniation represents only 1%–2% of all lumbar disc herniations [2]. In this study, despite some controversy, the upper lumbar spine was delineated as L1–L2 and L2–L3 based on previous research [3,4].

Transforaminal endoscopic lumbar discectomy (TELD) is associated with several advantages over open discectomy, including reduced bleeding, minimized muscle damage, decreased spinal canal scarring, and shorter hospitalization [5-8]. Consequently, TELD has been extensively adopted in lumbar discectomy procedures [9,10], particularly in addressing upper lumbar spine issues [11].

Recently, unilateral biportal endoscopic (UBE) spine procedures—a novel minimally invasive spine surgery technique—have gained popularity [12-16]. Although the transforaminal UBE approach has been described [17], most spine surgeons continue to favor the interlaminar approach [18-20]. The surgical anatomy for the extraforaminal approach may be complex and challenging to navigate, requiring advanced surgical skills and competency for design and intraoperative application to determine the appropriate puncture trajectory foraminoplasty [11,21,22].

Navigation image-guiding systems enable surgeons to monitor surgical instruments in real-time within three-dimensional (3D) space, allowing for precise visualization of the spine's anatomical structures through multiplanar imaging reconstruction. Navigation-assisted endoscopic surgery has demonstrated safety and efficacy, significantly reducing operating challenges, improving puncture accuracy, and minimizing radiation exposure for medical personnel [23-26]. While previous reports have documented the precision, safety, and viability of integrating navigation in lumbar UBE procedures [27], O-arm-based navigation in transfo-

Table 1. Summary of patient characteristics

Case no.	Age (yr)	Sex	Level	Side of approach	Location of skin incision[a] (mm)	Location of LDH	Operation time (min)
1	59	M	L2–3	Rt	85	Paracentral	60
2	47	M	L1–2	Lt	75	Paracentral	70
3	71	M	L2–3	Lt	86	Paracentral	60
4	58	M	L1–2	Rt	75	Paracentral	65

LDH, lumbar disc herniation; M, male; L, lumbar spinal segment; Rt, right; Lt, left.
[a]Distance from the midline to the skin incision.

raminal UBE discectomy remains undocumented.

In this study, a novel navigation-assisted transforaminal UBE lumbar discectomy technique was introduced, which may improve treatment outcomes for upper lumbar disc herniation. It also presented cases successfully treated with this novel treatment approach.

Materials and Methods

Ethical statement

Data access and usage were approved by the relevant Institutional Review Board. Pre-approval was not required for this study, as it involved the use of anonymous secondary data published for research purposes.

Study design

All procedures were performed by a single surgeon with extensive experience, having conducted over 1,200 cases involving UBE laminotomy for bilateral decompression, UBE interlaminar discectomy, endoscopic fusion surgery, microscopic spine surgery, and uniportal full endoscopic spine surgery. Table 1 summarizes the patient demographics.

This approach was employed for paracentral disc herniations at the upper lumbar levels, specifically L1–L2 and L2–L3. The exclusion criteria were as follows: (1) high-grade migrated lumbar disc herniation, such as zone 1 or 5; (2) need for resection of >50% of the superior articular process (SAP) on preoperative computed tomography (CT) or magnetic resonance imaging (MRI); (3) spinal stenosis due to causes other than disc herniation; (4) spondylolisthesis with Meyerding grade >2 on simple lateral radiographs; (5) lumbar instability (motion >3 mm at the surgical level, as measured on flexion-extension radiographs of the lumbar spine); and (6) history of spine surgery or infection at the same lumbar level.

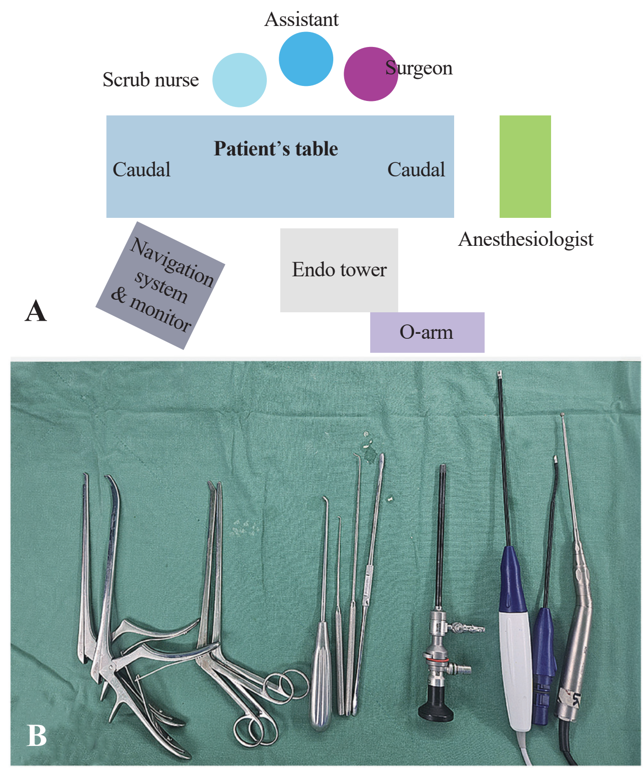

Fig. 1. (A) Operating room setup. **(B)** Standard tools used in unilateral biportal endoscopy.

Surgical technique

Operating room setup

The O-arm/StealthStation system (Medtronic Inc., Minneapolis, MN, USA), a 3D real-time image-guided navigation system, was employed to provide automated registration with intraoperative post-positioning CT. The SureTrak II Universal Tracker (Medtronic Inc.) was attached to the biportal endoscope trocar, allowing real-time observation of the endoscopic working channel's depth and position on the O-arm/StealthStation monitor. Both the endoscopic and O-arm systems were utilized concurrently throughout the procedure. All surgeons were on the patient's operating side, with the operating table centrally placed and the endoscopic monitors and O-arm camera positioned on the opposite side (Fig. 1A).

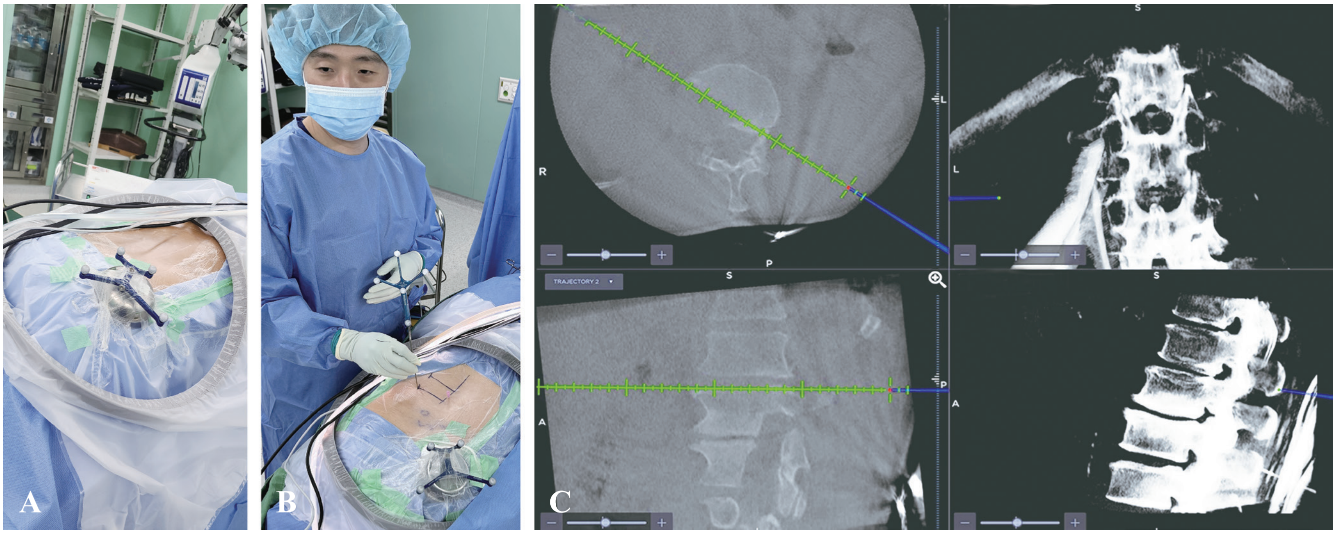

Fig. 2. (A) The navigation system receiver was placed on the patient's skin and secured using the adhesive surgical drape. **(B)** The navigation probe was used to register and plan the incision for the unilateral biportal endoscopy. **(C)** Navigation images in each anatomical plane during the incision planning.

A 4.0-mm diameter 0° viewing lumbar endoscope, certified for spine surgery in the Republic of Korea (Techcord Inc., Daejeon, Korea), was used. Additional equipment included a VAPR side effect electrode and wedge electrode as a bipolar radiofrequency probe (Depuy Mitek Inc., Raynham, MA, USA), a high-speed electric diamond bur of 3- or 4-mm diameter (Primado 2; NSK, Fukushima, Japan), serial dilators, and standard spinal discectomy instruments, such as hook dissectors, Kerrison punches, and forceps (Fig. 1B).

Patient positioning

All procedures were performed under general endotracheal anesthesia, with patients placed in a prone position on a well-cushioned, supportive, radiolucent table, allowing the abdomen to hang freely. Waterproof draping was applied in all cases, with a customized drape preferred for lumbar endoscopic procedures. Assuming that the surgeon is right-handed, the right side was designated the working instruments portal, whereas the left side served as the endoscopic portal. The saline irrigation bag was positioned 30–50 cm above the patient.

O-arm navigation system setup

The patient's skin surface served as the navigation reference, secured with a surgical adhesive drape for stability. The navigation probe was registered, and intraoperative CT imaging was performed using the O-arm imaging system. The surgical site was traversed in each of the four anatomical planes using the probe (Fig. 2A–C).

Incision planning and application of the biportal endoscope

The left-hand approach was used in this description. The navigation dilator probe was extended longitudinally (Fig. 2C), facilitating precise puncture trajectory targeting the ventral tip of the SAP. The appropriate skin entry point was easily determined using axial views that aligned with the anterolateral margin of the facet joint while sagittal reconstructions were aimed at the ventral tip of the SAP. The dilator probe was inserted at a typical distance of 7–11 cm from the midline (Fig. 3A), avoiding bone obstructions such as the thickened transverse processes. To mitigate the risk of nerve root damage, the dilator was positioned within the foraminal region of the ventral SAP (Fig. 3B, C). A serial dilator was subsequently inserted to separate fascia and muscle layers, facilitating instrument insertion through the working portal and preventing disorientation.

A second vertical incision (0.7 cm) was made approximately 2.5–4.5 cm cranially from the first caudal incision to accommodate the endoscope (cranial UBE portal) (Fig. 3D, E). The SureTrak II Universal Tracker was attached to the UBE trocar, inserted through the cranial portal, and positioned within the foraminal region of the ventral part of the SAP. The UBE endoscope was then inserted. Endoscopic irrigation was performed using a gravity-based pressure system, and surgical instruments were inserted through the caudal working portal. As the UBE canular point approached the lateral pedicular margin, its position at the ventral part of the SAP was verified.

O-arm-based navigation surgical procedure

The endoscope (Techcord Inc.) was positioned at the extraforaminal region, specifically at the foramen entry point (Fig. 4A). Hemostasis was maintained via en-

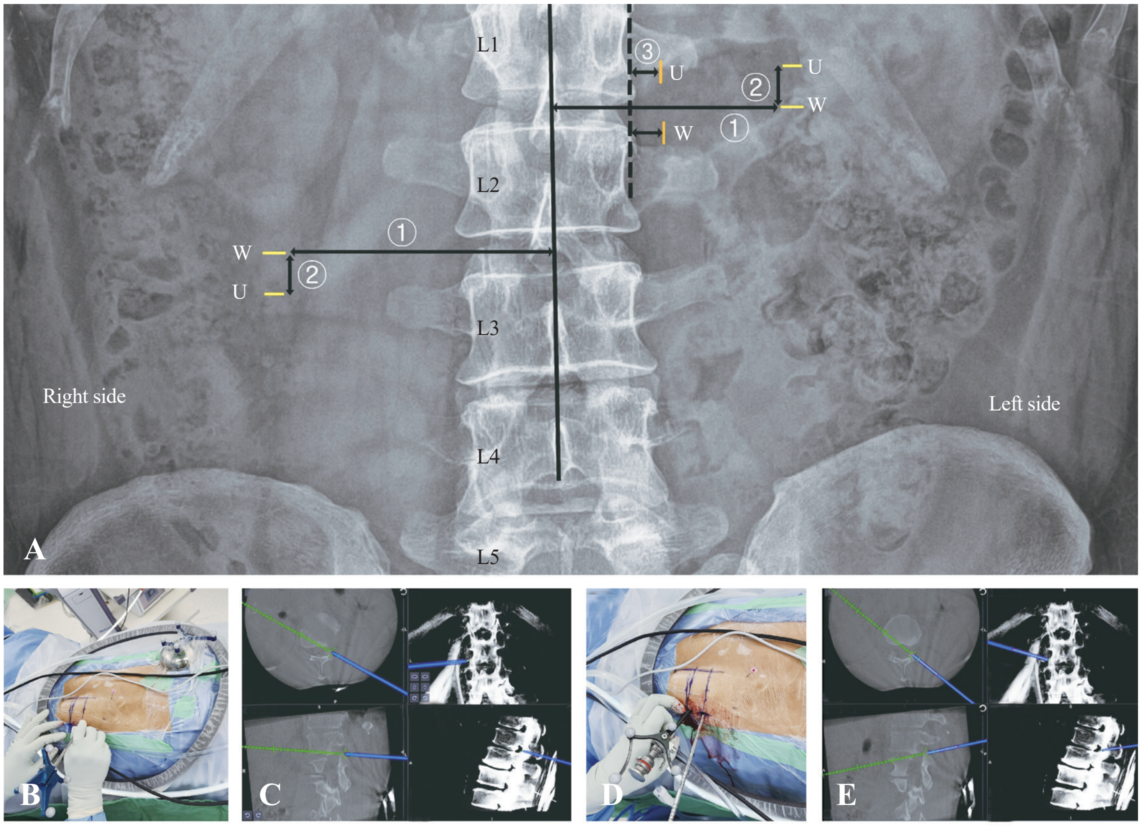

Fig. 3. (A) W denotes the working portal, whereas U denotes the unilateral biportal endoscopy (UBE) portal. Orange vertical lines: the placement of portals in the paraspinal approach. Yellow horizontal lines: the placement of portals in the transforaminal-UBE. Dashed line: the lateral margin of the pedicle line. 1, 2, and 3: distances to portals, where 1 is 7.0–11 cm, 2 is 2.5–4.5 cm, and 3 is 2.0 cm. The working portal in the transforaminal UBE is made parallel to the target disc level. The endoscopic portal is made approximately 2.5–4.5 cm cranial or caudal to the working portal. **(B)** Insertion of the navigation dilator probe into the working portal incision. **(C)** During probe insertion, intraoperative computed tomography (CT) navigation was used to accurately identify the anatomic location. **(D)** Insertion of the UBE trocar with SureTrak II Universal Tracker (Medtronic Inc., USA) into the UBE portal incision. **(E)** During UBE trocar insertion, intraoperative CT navigation was used to accurately identify the anatomic location.

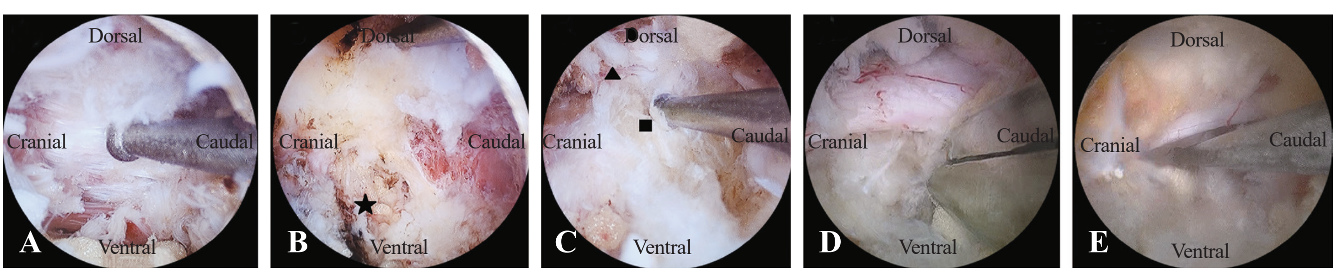

Fig. 4. Navigation-assisted transforaminal unilateral biportal endoscopy (UBE) discectomy. **(A)** An endoscope (Techcord Inc., Korea) positioned at the extraforaminal region. The anatomy visualized using the navigation tracker before drilling. **(B)** The endoscope is advanced while the ventral part of the superior articular process is being drilled. While viewing the exiting nerve root (black star) the depth of the foramen may be continuously monitored under navigation. **(C)** The black circle indicates the traversing nerve root, the black triangle indicates the posterior longitudinal ligament, and the black square indicates the disc space. **(D)** The sequestrated nucleus is removed. **(E)** Using the navigation tracker, procedure success can be achieved by checking the anatomical positions.

doscopic visualization using a bipolar radiofrequency coagulator (Depuy Mitek Inc.) (Supplement 1).

Depending on the anatomical structure of the SAP, partial resection was performed as necessary. Navigation tracking allowed continuous visualization of SAP anatomy before drilling, ensuring precise navigation (Fig. 4A). The endoscope advanced while drilling the part of the SAP, with continuous monitoring of foramen depth to avoid potential injury to intracanal neurological structures.

The endoscope was maneuvered within Kambin's triangle, and the position of the exiting nerve root was verified (Fig. 4B). Partial resection of the lateral margin of the ligamentum flavum allowed for the opening of

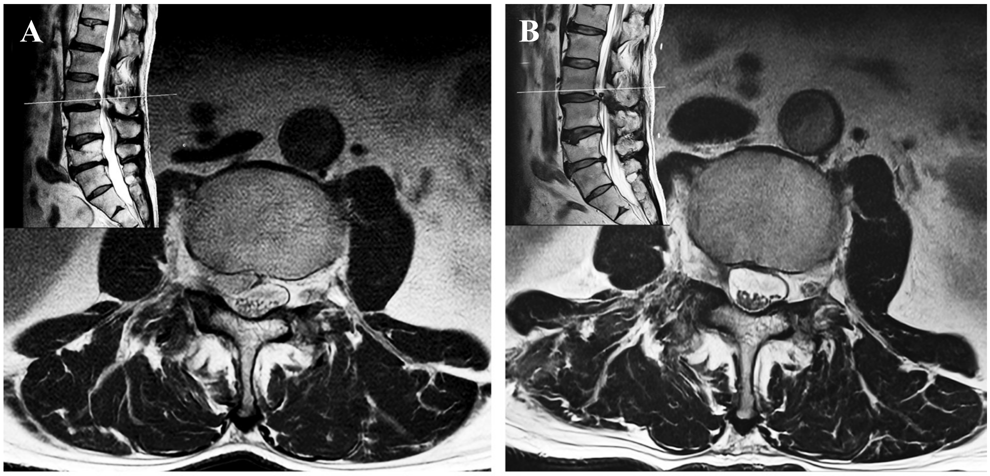

Fig. 5. (A) Preoperative axial magnetic resonance imaging (MRI) shows a paracentral up-migration ruptured disc compressing right exiting the L2 nerve root with spondylolisthesis (left upper corner). **(B)** Postoperative axial MRI shows complete removal of the herniated disc.

the epidural space. To enhance horizontal alignment, the distal UBE was tilted downward before inserting the endoscope into the spinal canal, providing direct visualization of the epidural space.

Given that the lateral margin of the posterior longitudinal ligament (PLL) could not be initially observed, partial resection of the ligamentum flavum was performed to reveal the PLL. Upon inserting the endoscope into the spinal canal, the herniated disc became visible on the endoscopic image (Fig. 4C). The working instruments were positioned near the herniated disc without causing neurological damage. The sequestered nucleus beneath the PLL was extracted using various forceps, and discectomy was completed. The ability to use multiple forceps during UBE is advantageous (Fig. 4D).

Thermal annuloplasty was then performed using a bipolar radiofrequency coagulator following the excision of the herniated disc. The paracentral disc was removed, and the exiting and traversing roots were decompressed. Postoperative assessment using the navigation tracker confirmed the procedure's success by verifying the upward, downward, and midline positions within the disc space (Fig. 4E).

If bleeding occurred within the epidural space or foraminal/extraforaminal region, a closed suction drain was placed and subsequently removed 12 hours after surgery. The patient was discharged the following day after drain removal.

Cases

Case 1

A 59-year-old man presented with tingling sensation in his right anterior thigh and severe back discomfort persisting for three months. A right femoral nerve stretch test yielded positive results. MRI revealed compression of the right L2 nerve root and an up-migrated ruptured disc at L2–L3 in the right paracentral region, accompanied by grade 1 spondylolisthesis (Fig. 5A). Transforaminal UBE discectomy was performed via the right side. Postoperative MRI revealed successful removal of the herniated disc, and the patient's symptoms subsided (Fig. 5B). The suction drain was removed on postoperative day 1, having collected 22 mL of blood. The patient was discharged on postoperative day 2.

Case 2

A 47-year-old man with a 10-month history of severe middle back discomfort underwent MRI, which revealed a paracentrally located disc compressing the L1–L2 dural sac (Fig. 6A). Neurological examination showed positive bilateral femoral nerve stretch test results. Previous conservative treatments, including medication, physical therapy, and epidural steroid injections, failed to alleviate the pain. Transforaminal UBE discectomy was performed via the left side (Fig. 2) (Supplement 1). Postoperative MRI confirmed complete removal of the herniated disc, and the symptoms subsided (Fig. 6B). The patient was discharged on postoperative day 2.

Case 3

A 71-year-old man presented with significant radicular pain in the left leg and gait disturbance. Motor weakness in the quadriceps femoris and tibialis anterior were graded as 4. MRI revealed a significant paracentral disc herniation with spinal stenosis compressing the dural sac at L2–L3. The herniated disc compressed the cauda equina, with redundant nerve roots observed in the T2 sagittal scan (Fig. 7A). Transforaminal UBE discectomy was performed via the left side. Postoperative MRI showed successful removal of the herniated disc, with dural ex-

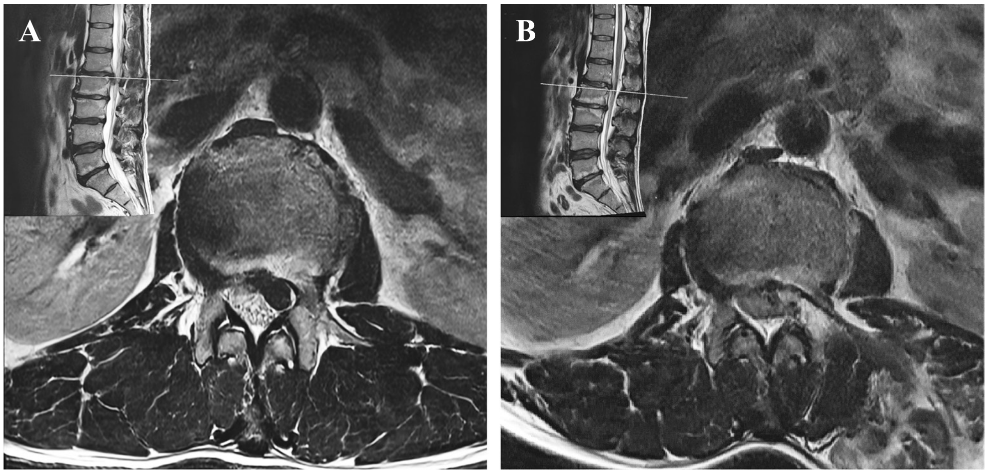

Fig. 6. (A) Preoperative axial magnetic resonance imaging (MRI) shows a paracentral down-migration ruptured disc compressing the dural sac at L1–L2. **(B)** Postoperative axial MRI shows complete removal of the herniated disc.

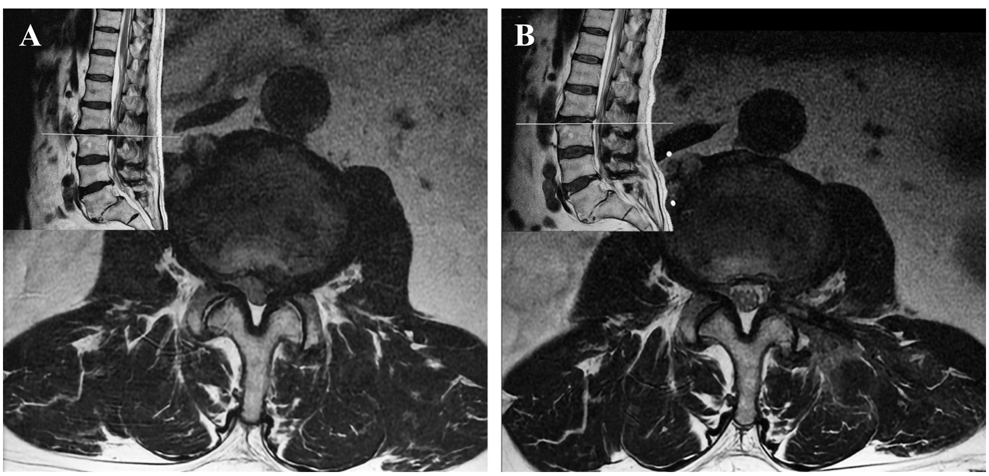

Fig. 7. (A) Preoperative axial magnetic resonance imaging (MRI) shows a paracentral ruptured disc compressing the dural sac at L2–L3. Sagittal scout image (left upper corner) shows the redundant nerve roots caused by compression of the cauda equina. **(B)** Postoperative axial MRI shows complete removal of the herniated disc. A closed suction drain was inserted via the left percutaneous endoscopic lumbar discectomy trajectory.

pansion observed (Fig. 7B). The patient was discharged on postoperative day 2 after symptom resolution.

Case 4

A 58-year-old man with a history of radiating discomfort in his right anterior thigh persisting for over 12 months underwent MRI, which revealed an up-migrated ruptured disc in the right paracentral region at L1–L2 (Supplement 2A). Transforaminal UBE discectomy was performed via the right side. Postoperative MRI confirmed successful removal of the herniated disc with dural expansion, although a small, migrated fragment remained (Supplement 2B). Postoperatively, the patient's symptoms were alleviated. The suction drain was removed on postoperative day 1, having collected 19 mL of blood. The patient was discharged on postoperative day 2.

Discussion

Surgical access to the upper lumbar spine is challenging because of the limited foraminal size, the relatively small canal housing dense neural tissue tissues, the narrow gap between the exiting nerve root and dura, and the dorsal expansion of the abdominal cavity [28-31]. Anatomically, the upper lumbar spine differs significantly from the lower lumbar spine, necessitating independent surgical strategies [3,32-36]. Choi et al. [33] described a posterior transdural technique for calcified upper lumbar disc herniation, which preserves bilateral facets but requires both dorsal and ventral durotomies, increasing the risk of nerve root damage and cerebrospinal fluid leakage. Therefore, a microscopic oblique paraspinal technique was developed, which involves the removal of only the anterolateral portion of the ipsilateral facet joint and a narrow strip of the lateral pars [34]. For endoscopic treatment, TELD is a successful surgical procedure for upper lumbar disc herniation, offering reduced invasiveness, lower complication rates, and improved return-to-work capacity [3,11]. However, the steep learning curve of the transforaminal approach poses significant challenges for full endoscopic surgery [37]. Biportal endoscopy addresses some of these challenges by allowing separation between the working portal and the viewing field, thereby expanding the viewing field from multiple angles [38-41]. Despite the introduction of the transforaminal approach using UBE [17], it is predominantly associated with full endoscopic techniques, making it unfamiliar to spine surgeons who are accustomed to interlaminar approaches.

Chen et al. [42] utilized the O-arm navigation system during interlaminar contralateral endoscopic lumbar foraminotomy and demonstrated its safety and efficacy in treating lumbar foraminal stenosis. Their findings indicated that this navigation system reduces facet joint violation, shortens the surgeon's learning curve, and minimizes radiation exposure. Positive outcomes have also been reported with UBE-transforaminal lumbar interbody fusion under O-arm navigation [43,44], as well as thoracic disc removal [45,46]. Real-time intraoperative anatomical orientation mitigates operating challenges, improves puncture accuracy, shortens the surgeon's learning curve, and minimizes radiation exposure for medical personnel [23-27]. In this study, the navigation system was used to safely and efficiently implement new transforaminal UBE approaches. Navigation-predicted trajectory measurement helped prevent abdominal injury and allowed horizontal endoscope tilting to access the ventral portion of the SAP while minimizing unnecessary facet joint resection. Damage to the exiting nerve root is a significant complication of TELD, with reported incidences ranging from 9.3% to 26% [47,48]. However, navigation-guided transforaminal UBE effectively prevented this complication by enabling precise targeting and facilitating direct visualization of the entry process without close proximity to the exiting nerve roots. Additionally, navigation guidance during endoscope insertion into the foramen allowed the assessment of epidural canal entry from the extraforamen without requiring repeated C-arm confirmation, improving anatomical accuracy and safety.

Efforts to reduce posterior stabilizing structural damage continue to increase [49,50]. Transforaminal UBE discectomy minimizes facet involvement without compromising posterior stability. Compared with the interlaminar approach, it requires less bone and ligamentum flavum excision, leading to shorter operative times. This technique also allows direct access to the herniated disc, eliminating the need for intraoperative discography, which may otherwise contribute to disc degeneration [51].

Instrumental flexibility is a notable advantage of the transforaminal UBE method, as it separates the working entrance from the endoscope, allowing for the use of various instrument configurations, such as the upward pivot and angled ball tip probes of various sizes, without frequent repositioning. This flexibility provides different perspectives and magnifications, facilitating an easier surgical environment, especially for surgeons who are less familiar with the transforaminal approach.

However, the technique is particularly advantageous for paracentrally protruding discs rather than centrally located discs and is unsuitable for calcified disc herniations due to the difficulty of disc removal and increased risk of dura mater injury caused by adhesions. Although some of this study's patients had lower lumbar disc herniation, we refrained from performing discectomy in the lower lumbar region to avoid muscle damage and bleeding control challenges associated with the longer surgical trajectory.

One limitation of this approach is the increased surgical duration, primarily due to the additional time required for the navigation system setup. However, proper cooperation among the surgical staff can help reduce the setup time. As surgeons become proficient with this approach, navigation can be selectively employed based on the surgeon's preference to minimize surgical time. Due to the rarity of upper lumbar disc herniation, the limited patient population and the lack of long-term follow-up are major limitations of this study. Therefore, future studies should address these limitations to validate the findings.

Conclusions

Navigation-assisted transforaminal UBE discectomy is an effective approach for treating upper lumbar paracentral disc herniation, offering favorable surgical outcomes. The integration of navigation technology enhances the precision and adaptability of transforaminal UBE approaches.

Key Points

- Navigation-assisted endoscopic surgery reduces operating challenges, improves puncture accuracy, and decreases radiation exposure for medical personnel.
- Navigation-assisted endoscopic surgery improves the surgeon's learning curve.
- Transforaminal unilateral biportal endoscopic discectomy demonstrates favorable surgical outcomes in cases of upper lumbar disc herniation, with navigation aiding the adaptation to this new approach.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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Author Contributions

Conceptualization: DHL, CKP, JSH. Data curation: DHL, JYL. Formal analysis: DHL, JYL. Investigation: DHL, CKP, JSK. Methodology: DHL, JSH, JYL, DGL, JYK. Software: DHL, JYL, JYK. Resources: DHL, JWJ. Validation: DHL, JSK. Visualization: DHL, JYL. Supervision: DHL, JSK, JWJ. Writing–original draft: DHL, JYL. Writing–review & editing: DHL, JSK, JYL, YEC, DCL. Funding acquisition: CKP. Project administration: CKP, DGL. Final approval of the manuscript: all authors.

Supplementary Materials

Supplementary materials can be available from https://doi.org/10.31616/asj.2025.0072. Supplement 1. A clip from case 2 demonstrating the surgical set up and step-by-step procedure of O-arm navigation-based transforaminal unilateral biportal endoscopic discectomy at the L2–3 level from the left side. Supplement 2. (A) Preoperative axial magnetic resonance imaging (MRI) shows a paracentral up-migration ruptured disc compressing the right exiting L1 nerve root. (B) Postoperative axial MRI shows successful removal of the herniated disc with dural expansion. Sagittal scout image (left upper corner) shows the remnants of a small migrated fragment.

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