

Whole-Workflow Robotic-Assisted Percutaneous Endoscopic Lumbar Discectomy via a Two-Step Access Method: Technical Report and Preliminary Results

Wenjie Zheng^{1,*}, Junlong Wu^{1,2,*}, Wen Xia^{1,*}, Rui Zuo¹, Xian Chang¹, Hong Yin¹, Changqing Li¹, Chao Zhang¹

¹Department of Orthopaedics, Xinqiao Hospital of Army Medical University, Chongqing, People's Republic of China; ²Department of Orthopaedics, The 941th Hospital of Joint Logistic Support Force of Chinese People Liberation Army, Xining, Qinghai, People's Republic of China

*These authors contributed equally to this work

Correspondence: Changqing Li; Chao Zhang, Department of Orthopaedics, Xinqiao Hospital of Army Medical University, No. 183, Xinqiao Main Street, Shapingba District, Chongqing, 400037, People's Republic of China, Email changqli@tmmu.edu.cn; tmmuzc@tmmu.edu.cn

Purpose: The spinal surgery robot can provide precise preoperative or intraoperative surgical planning and guide the implementation of the surgical plan under real-time navigation monitoring. Researchers have recently begun exploring the use of robotic systems to assist in performing Percutaneous Endoscopic Lumbar Discectomy (PELD). However, prior studies have primarily focused on robotic-assisted transforaminal puncture. In this study, we establish a two-step cannulation surgical workflow using specialized instruments to facilitate the whole-process robotic-assisted PELD.

Patients and Methods: In this study, 14 patients with lumbar disc herniations were enrolled to undergo PELD assisted by a robotic system. Preoperative CT images were registered in the navigation system for surgical planning. The whole procedure was performed under spinal robotic guidance, including puncture, dilation, foraminoplasty, and working tube placement. A retrospective analysis was conducted to evaluate its feasibility and safety, as well as to summarize the surgical workflow.

Results: All patients successfully completed the robotic-assisted PELD surgery. The average robot preparation time was 31.42 ± 6.45 minutes, the cannula placement time was 9.85 ± 2.59 minutes, and the mean operative time was 92.21 ± 18.65 minutes. The average number of intraoperative fluoroscopy shots was 3.35 ± 0.84. Postoperative follow-up showed significant improvement in back pain/leg pain VAS scores and ODI scores compared with preoperative values. According to the modified Macnab criteria, 8 cases were rated as excellent (57.1%), and 6 cases as good (42.9%), resulting in an overall satisfaction rate of 100%. No patients experienced severe complications such as nerve root injury or deep infection.

Conclusion: Robotic assistance in PELD surgery ensures a precise preoperative planning and safe implementation, also reducing radiation exposure both patients and surgeons. With specialized instruments, the two-step access method simplifies PELD as a safe and effective surgery.

Keywords: robotic assistance, spinal surgery robot, navigation, percutaneous endoscopic lumbar discectomy, PELD, lumbar disc herniation

Introduction

As a minimally invasive disc removal surgery, Percutaneous Endoscopic Lumbar Discectomy (PELD) has gained increasing acceptance among surgeons in recent years.¹ Literature has confirmed that compared to traditional surgery, PELD offers several advantages, such as less muscle damage, reduced bleeding, fewer postoperative epidural adhesions, less perioperative pain, and rapid postoperative recovery.^{2,3} Moreover, its efficacy is comparable to that of traditional discectomy for herniated discs.⁴

However, PELD is currently considered to have two main limitations as follows: 1) PELD is highly dependent on fluoroscopic image guidance, which can lead to prolonged cannulation times, potential contamination of the surgical area, and significant radiation exposure; 2) The challenge of the technique lies in the complex anatomical structures of the surgical approach, resulting in a long learning curve that is particularly unfriendly to beginners.⁵⁻⁷ Additionally, due to the limited exploration capabilities of endoscopic surgery, PELD surgery demands high precision in accurately locating herniated lesions. Any deviation in positioning may result in inadequate decompression or even severe neurological complications.⁸ Therefore, related literature generally suggests that to address these challenges, the surgeon must possess a nuanced three-dimensional understanding of the local area and matching capabilities, as well as require extensive practice and experience.⁹

How to safely and accurately reach the area of intervertebral disc herniation is the key to the success of PELD surgery.¹⁰ Traditional fluoroscopic procedures do not adequately provide three-dimensional information about the anatomical structures of the surgical pathway and cannot offer precise guidance and prediction regarding the depth and angle of surgical instruments.¹¹ This often leads inexperienced surgeons to make repeated trial-and-error maneuvers under fluoroscopy, which undoubtedly increases surgical trauma, radiation exposure, and the risk of dural and nerve root injuries.^{7,12}

In recent years, various imaging navigation technologies, including CT, MRI, and ultrasound, have been utilized for puncture guidance, improving the fluency and accuracy of the procedure to some extent.¹³⁻¹⁵ However, these approaches still fall under the trial-and-error model, and achieving accurate route design, along with the swift, precise, and direct execution of such designs, remains a significant challenge.

CT navigation systems have gained popularity in spinal surgery recently,¹⁶ primarily for the placement of pedicle screws in the spine, as well as for real-time positioning and guidance during surgery. The accuracy of navigation technology has been clinically validated through years of development, sometimes even proving superior to traditional fluoroscopy methods.¹⁷ Based on this, spinal robotic surgery can complete the surgical trajectory design preoperatively or intraoperatively based on two-dimensional or three-dimensional structures. The robotic arm automatically adjusted its position according to the planing trajectory, and then accurately performing the procedure under navigational guidance.¹⁸ Therefore, spinal surgical robots can theoretically provide precise trajectory and establish a safe and quick access channel for percutaneous endoscopic procedures.

Some scholars have attempted to use robots to complete the trajectory design and puncture guidance for PELD surgery with satisfactory initial results.^{19,20} However, relevant literature has not reported on subsequent procedures such as dilation and foraminoplasty under robotic guidance. In this study, we firstly establish an optimized whole-process robotic-guided PELD procedure. Cannulation is accomplished through a two-step process: the first step involves puncture and dilation, while the second step entails foraminoplasty. This study evaluates the feasibility and safety of this technique.

Materials and Methods

Patients

Between July 2024 and August 2024, a total of 14 patients with symptomatic lumbar disc herniation underwent percutaneous endoscopic lumbar discectomy (PELD) assisted by robot were enrolled. The detailed inclusion criteria were as follows: (1) age ≥ 18 and ≤ 78 years, (2) definite diagnosis of typical symptomatic single-level lumbar disc herniation with neurologic signs, including sensory changes, motor weakness, or the presence of abnormal reflex, that corresponded with the preoperative images, including radiographic screening and MRI, (3) no response to appropriate conservative treatment over 3 months. The exclusion criteria were as follows: (1) intraoperative response was not possible because of mental condition, (2) preoperative concomitant spondylolisthesis or deformity warranting correction or fusion, previous lumbar spine surgery, preoperative spinal infection, spinal tumor, or uncontrolled systemic diseases, (3) Patients with less than 6 months follow-up and incomplete clinical data. All patients' data would be kept confidential and only analyzed for this research.

All surgeries were performed by the same team of 2 experienced surgeons. The two experienced surgeons both have more than five years' experience in endoscopic and robotic-assisted surgeries. The Visual Analog Scale (VAS) score, Oswestry Disability Index (ODI) score, surgical parameters, and all surgery-related adverse events were recorded

preoperative, at 2 weeks postoperative (first assessment) and at 6 months postoperative (final assessment). Clinical result was assessed using the MacNab criteria (excellent, good, fair, and poor) at the final follow-up. This study was approved by the Ethics Committee of the Second Affiliated Hospital of Army Medical University.

Robot System

The Mazor X Stealth Edition Spine Robotics

The Mazor X robotic system (MAZOR Robotics Inc, Orlando, Florida) was used in this study.²¹ It utilizes customized software to facilitate preoperative or intraoperative surgical planning based on three-dimensional CT imaging, allowing for the design of surgical access trajectories, angles, and diameters. Following general anesthesia, the patient was positioned prone on a Jackson surgical table, with intraoperative neuromuscular electrical monitoring of the relevant nerve roots. The surgical robotic arm was mounted to the table frame (Figure 1A). After disinfection and draping, preoperative data were imported and registered in accordance with the Mazor X robotic system guidelines (Figure 1B), followed by accuracy verification. Under navigational visualization, the system guides the puncture dilation and instrument insertion along the defined surgical path.

Design of Specialized Navigated Surgical Instruments

As shown in (Figure 1C), we designed a navigated puncture guiding rod (length 230mm, outer diameter 7.5mm) and sheath (length 210mm, outer diameter 8.5mm, inner diameter 7.5 mm), as well as a navigated foraminoplasty tripine (length 230mm,



Figure 1 Operating Room Setup and Instrument Preparation (A) Operating Room Setup (B) registration of Mazor X SE (C) The specialized instruments, listed from top to bottom: dilator, trephine, outer sheaths (lengths: 190 cm and 210 cm), reciprocating electrotrepine (60000rpm). (D) The reciprocating electrotrepine is used for pre-cutting in SAP to prevent slippage.

outer diameter 7.5mm), and a patented specially designed reciprocating foraminoplasty tripine (Guizhou Zirui Technology Co. LTD, Gui Zhou, China). The reciprocating tripine has a maximum rotation speed of 60,000 RPM and is used for the initial cutting of the vertebral foramen bone structure and to prevent slippage on facet joint (Figure 1D).

Surgical Procedures

Before the surgery, the patient's preoperative CT image were used for planning of the trajectories of puncture, foraminoplasty, and channel placement by robot system. The design of the puncture trajectory drew on prior experience with the TESSYS technique targeting the posterior wall of the vertebral body at lateral view and connecting line of the inner wall of adjacent pedicle at AP view while directing towards the herniated disc location.²² The posterior tilt angle was set between 25° and 40°, while the cephalad tilt angle ranged from 25° to 45°. The cephalad refers to the deviation of the tail end of the surgical instruments towards the cephalad. All trajectories were designed to traverse the lower part of the intervertebral foramen and partially encroach upon the apex of the superior articular process, minimizing potential stimulation of the exiting nerve roots. The trajectory diameter was established at 7.5 cm, consistent with the foraminoplasty tripine diameter.

The robot sent instructions to guide the robotic arm in providing the puncture trajectory, the skin entry point was located, and an incision of approximately 1 cm was made. The navigated rod and sheath were then integrated and advanced into the body, ultimately docking on the lateral aspect of the upper articular process (Figure 2A–C). Avoid excessive force to prevent slippage into the intervertebral foramen from the ventral aspect of superior articular process (SAP). A reciprocating tripine is employed for initial cutting to create a circumferential notch, minimizing the risk of slippage in subsequent operations. Similar to the TESSYS technique, the navigated tripine performs foraminoplasty under visual navigation monitoring (Figure 2D–F), ensuring that it does not exceed the inner pedicle wall by 2–3 mm. Once foraminoplasty is complete, the surgical channel is established under robotic guidance, followed by routine endoscope-assisted intervertebral disc prolapse resection and nerve decompression (Figure 2G–I).

Outcome Evaluation

Patient demographics and surgical parameters were recorded. We also documented the cannula introduction time and the number of fluoroscopic shots. Cannula introduction time was from the beginning of the incision design to the completion

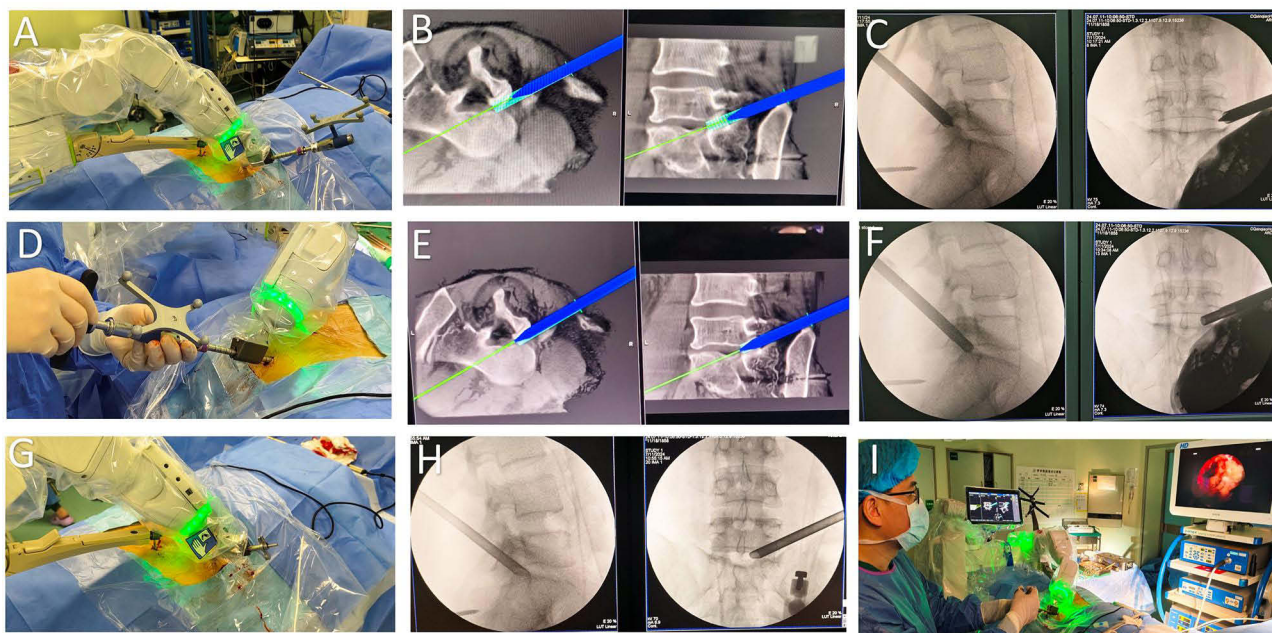


Figure 2 Workflow of two-step access technique: (A–C) Puncture dilation under navigation and fluoroscopic verification (D–F) Trephine foraminoplasty under navigation and its fluoroscopic verification. (G and H) Channel implantation and fluoroscopic verification. (I) Endoscopic discectomy.

of the navigated working channel placement. The operation time was defined as the duration from making a skin incision (0.8 cm) for the trajectory to wound dressing. We collected visual analog scale (VAS) scores for back and leg pain ranging from 0 to 100 with higher scores indicating more pain, along with Oswestry Disability Index (ODI) scores. Surgical success was assessed using the modified Macnab criteria. Patients' clinical data were collected by chart reviews and patient-based outcome questionnaires or telephone interviews.

Results

Demographic Characteristics and Surgical Data

Between Jul, 2024 to Aug, 2024, 14 patients (7 males and 7 females) were enrolled, with a mean age of 50.35 ± 14.42 years (range, 20–74 years). The surgery levels were L3-4 in 1 patients, L4-5 in 8, and L5-S1 in 5. The mean operative time was 92.21 ± 18.65 minutes (range, 73–131 minutes). The mean cannula placement time was 9.85 ± 2.59 minutes (range, 6–15 minutes). The mean post-operative hospital stay was 2.07 ± 0.47 days (range, 1–3 days) (Table 1).

Clinical Outcomes

At the final follow-up, the MacNab criteria were rated as follows: excellent in 8 patients (57.1%), and good in 6 patients (42.9%). Therefore, excellent or good results were obtained in 100% of the patients (Table 2). At the first and final follow-up, the VAS score for leg and back pain, and ODI score of all patients was significantly improved. No major complications was observed in the case series. No revision surgeries were required during the 6-month follow-up period due to symptomatic residual disc herniations or other reasons.

Case Presentation

A 45-year-old woman complained of low back pain and right leg pain 6 years ago. The patient was diagnosed as lumbar disc herniation with sciatica at L5/S1 level (Figure 3A and B). The patient underwent PELD at the L5/S1 level assisted by robot. The trajectories plan of puncture, foraminoplasty, and channel placement by robot system were made according to the method described above (Figure 3E and F). The pain of right lower limb and lower back was significantly improved after operation. Postoperatively, we performed lumbar MRI and CT scans, which, when compared to preoperative imaging, indicated a successful decompression (Figure 3C, D and G).

Table 1 Demographic Characteristics and Surgical Data

Case Number	Sex/Age	Body Mass Index	Surgical Level	Operation Time (Minute)	Robot Preparation Time (Minute)	Cannula Placement Time (Minute)	Intraoperative Fluoroscopy (Time)	Postoperative Hospital Stay (Day)
1	Female/46	27.96	L4/5	121	35	10	4	3
2	Male/52	18.06	L4/5	115	28	11	4	2
3	Female/66	27.22	L3/4	131	45	15	3	2
4	Female/50	25.63	L5/S1	105	29	9	3	2
5	Female/68	23.37	L4/5	97	41	9	5	2
6	Male/20	27.99	L4/5	75	20	6	2	2
7	Female/45	22.83	L5/S1	81	26	7	2	2
8	Female/39	23.59	L4/5	84	30	8	4	2
9	Male/58	19.05	L4/5	73	28	11	3	2
10	Female/63	24.83	L4/5	80	27	14	4	1
11	Male/38	29.70	L5/S1	77	34	10	4	2
12	Male/41	21.87	L5/S1	79	36	9	3	2
13	Male/45	26.72	L4/5	88	28	12	3	3
14	Male/74	25.71	L5/S1	85	33	7	3	2
Mean \pm Standard Deviation				92.21 ± 18.65	31.42 ± 6.45	9.85 ± 2.59	3.35 ± 0.84	2.07 ± 0.47

Table 2 Clinical Outcomes

Case Number	Visual Analog Score for Leg Pain			Visual Analog Score for Back Pain			Oswestry Disability Index			MacNab Criteria (Postoperative at 6 Months)
	Preoperative	Postoperative 2 Weeks	Postoperative 6 Months	Preoperative	Postoperative 2 Weeks	Postoperative 6 Months	Preoperative	Postoperative 2 Weeks	Postoperative 6 Months	
1	74	18	15	56	21	23	59	21	15	Good
2	67	15	10	60	26	15	53	16	17	Excellent
3	83	12	11	44	23	10	66	17	13	Excellent
4	72	17	16	53	19	16	65	22	19	Good
5	66	20	12	55	10	15	68	14	15	Excellent
6	70	10	10	42	15	13	51	19	16	Excellent
7	62	13	12	53	7	10	54	25	20	Good
8	85	15	10	58	25	20	57	21	14	Excellent
9	73	14	13	49	23	21	69	19	16	Excellent
10	77	18	14	45	18	18	55	25	14	Excellent
11	79	11	11	55	14	15	48	14	9	Good
12	68	13	10	56	9	13	52	16	11	Good
13	64	16	12	50	24	20	50	25	17	Excellent
14	81	14	11	47	14	9	47	18	12	Good

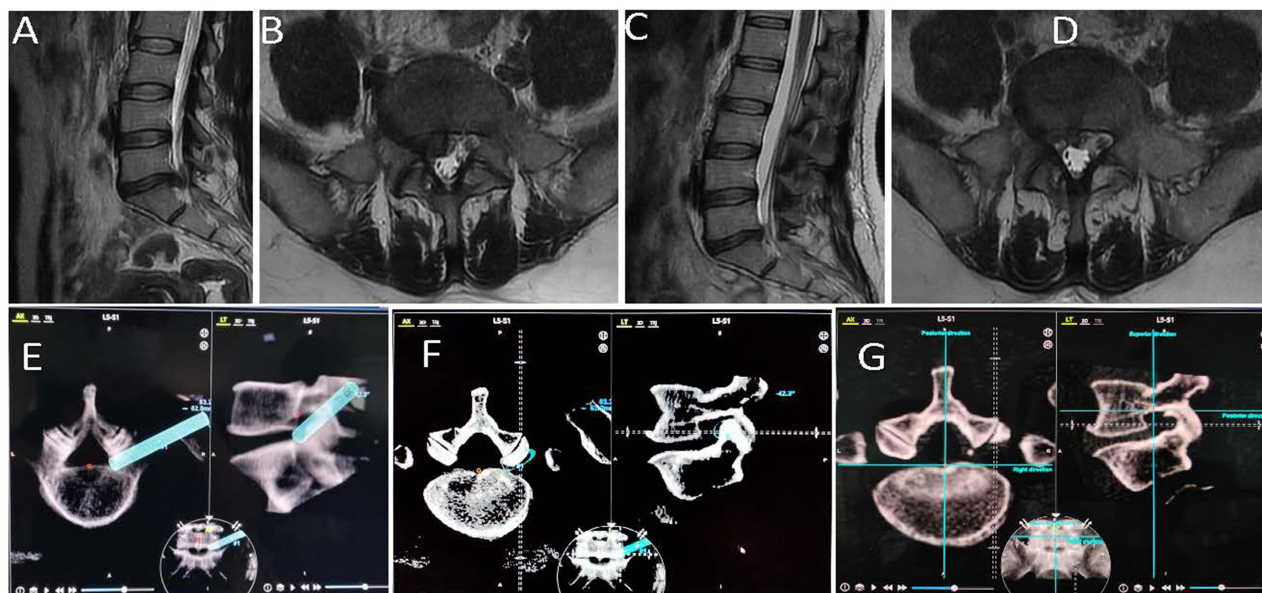


Figure 3 A patient with lumbar disc herniation underwent robot assisted discectomy. (A and B) MRI scans showing lumbar disc herniation at the L5-S1 level. (C and D) postoperative MRI scan of lumbar spine. (E) Preoperative trajectory planning on a 2-dimensional image. (F) preoperative planning of foraminoplasty on sagittal and axial planes (G) Postoperative validation of sagittal and axial foramen plasty.

Discussion

In this study, we designed specialized navigational instruments for robotic-assisted PELD and established a streamlined two-step surgical protocol for cannulation. Preoperative CT data were utilized to facilitate efficient preoperative planning, guiding the accurate and swift completion of puncture dilation, foraminoplasty, and channel placement during the procedure. An endoscopic approach was then employed to perform intervertebral disc removal and decompression.

The design and selection of the puncture entry point and trajectory pose significant challenges in PELD, especially for inexperienced surgeons. Literature recommends a dorsal tilt angle of 40°-50° at the L5-S1 level, 30°-40° at the L4-L5 level, and 25°-35° at the L3-L4 level, along with a head tilt angle of 30°-40°.²³ Additionally, reports indicate that the distance from the midline for the puncture point should be 8–10 cm at the L3-L4 level, 11–14 cm at the L4-L5 level, and 12–16 cm at the L5-S1 level.²⁴ These studies provide ranges rather than fixed values, complicating quantitative application in practice. Actually, the angles and distances necessary for safe and effective surgery are within a specific range, yet the precise execution is highly dependent on the surgeon's clinical experience. Surgeons must match preoperative CT and MRI findings with real-time fluoroscopic images during the procedure, which necessitates cognitive integration. The challenges in designing and selecting the appropriate approach contribute significantly to the steep learning curve associated with PELD.^{6,8}

The establishment of the access channel during PELD procedures presents significant technical challenges.²⁵ PELD surgery offers substantial minimally invasive advantages by utilizing simple puncture dilation without the need for muscle incision or separation, it inherently results in the completion of the initial phase of the procedure under “blind” conditions. The predominant method for monitoring involves the use of fluoroscopy to guide all the intricate procedures, including puncture, dilation, foraminoplasty, and channel insertion.²⁶ The puncture phase often involves a repetitive “trial-and-error” style leading to a complex surgical workflow that heavily relies on fluoroscopic imaging guidance. This reliance complicates the procedure, prolongs operation time, increases radiation exposure, and is heavily dependent on the clinician's accumulated experience.⁶

Navigation technology provides real-time guidance for minimally invasive spinal surgeries, enhancing surgical workflow, improving procedural accuracy, and significantly reducing intraoperative fluoroscopy exposure, as substantiated by extensive literature.¹⁷ Some studies indicate that navigated PELD techniques facilitate visual instrument guidance, expedite the surgical process, enhance precision, and markedly improve the surgical learning curve.^{16,27}

Robotic surgery builds upon navigation and imaging technologies to offer preoperative and intraoperative surgical planning, employing robotic arms for instrument guidance, thus ensuring a more stable and reliable execution process, while eliminating the trial-and-error aspect of the procedure.^{16,19} Theoretically, this can further minimize trauma, optimize surgical workflow, and enhance operational stability and accuracy.

The advantage of robotic-assisted PELD lies in its ability to facilitate comprehensive preoperative planning.¹⁹ Given the intricate structure of the intervertebral foramen and the proximity of critical neural structures, precise trajectory design and implementation are crucial in PELD procedures due to the limited surgical exploration.²⁸ Any deviation in either design or execution may result in surgical failure or even severe complications.⁸ There is extensive application and literature documenting the use of robotic assistance in spinal surgery, particularly for the placement of pedicle screws.²⁹ Most clinical studies^{30,31} recognize that robotic-assisted surgery provides superior accuracy in pedicle screw placement compared to traditional manual insertion, and is on par with CT-based image navigation. In the preoperative planning conducted at the workstation, surgeons can accurately and clearly measure the angles in three dimensions, assess the entire structure along a 7.5 cm diameter path for potential conflicts with the iliac crest or other neighboring bone, and evaluate the extent of bone resection from the SAP using a virtual tripine. Additionally, surgeons can better understand the relationship between instruments and exiting nerve roots, thereby reducing the risk of nerve injury. Crucially, the precision of the final target position ensures effective targeted discectomy and neural decompression. Another potential benefit is that during surgical planning, surgeons can engage in individual or collective discussions that lead to quantitative approaches rather than relying solely on subjective estimates and visual assessments. This transforms PELD into a procedure that is not just “subjective and experience-dependent”.

The whole-process of PELD, guided by robotics, ensures the precise implementation of the designed trajectory during surgery. Reports have demonstrated PELD surgeries guided by the robot system, where a safe and applicable puncture trajectory was designed through the robotic system, allowing for accurate puncture under robotic arm guidance.^{19,20} All operations in the literature have been completed in a single attempt, efficiently and rapidly, significantly reducing the repeated trial-and-error procedures and fluoroscopic radiation exposure associated with the puncture stage. However, relevant studies primarily employed fine needle punctures to access the intervertebral foramen. In our early clinical practices, we observed that the rigidity of fine needle structures was insufficient, leading to potential deviations during long-distance punctures in optical navigation systems, particularly when encountering harder tissues such as bone, which resulted in unstable puncture outcomes.

Additionally, the literature does not present the procedures for dilation and foraminoplasty under robotic guidance after puncture completion, nor does it address the specialized instruments required for these tasks.^{19,20} We suspect that subsequent operations may still rely on fluoroscopic guidance to complete foraminoplasty and channel implantation according to standard surgical protocols. It is likely that the subsequent soft tissue dilation, as well as the critical foraminoplasty, may not be stable and could depend heavily on fluoroscopy and manual techniques, which could significantly undermine the value of robotic surgery.

In the Mazor X robotic surgical system, we designed a navigation-guided 7.5 cm rod and protective sheath that possess the appropriate rigidity for long-distance puncture dilation. All puncturing, dilation, and foraminoplasty procedures were conducted under navigational visualization, ensuring the precise realization of the planned trajectory. We have established a two-step method for robotic-assisted PELD as follows: First, a pointed rod and its sheath are directly dilated under navigational monitoring to reach the lateral aspect of the superior articular process. Second, the second step involves directly foraminoplasty with a tripine in the sheath under visual monitoring, followed by the insertion of the working channel. This two-step approach simplifies the process, avoiding the cumbersome puncture, dilation, and foraminoplasty steps typical of conventional PELD techniques. It also minimizes the radiation exposure and operational inconveniences associated with repeated fluoroscopy during surgery.

In robotic spine surgery, steep angles between the bone surface and surgical instruments can generate lateral opposing forces, leading to tip deviation and incorrect entry into the bone, commonly referred to as slippage or skiving.³² The standard approach to mitigate this issue is to use specialized sharp high-speed drill bits to penetrate the cortical bone at the entry point.³³ However, the use of high-speed drills can result in severe soft tissue damage and excessive heat generation, which may lead to catastrophic consequences, including neural structure injury, especially in the event of

instrument deviation.³⁴ Consequently, the application of powered burr systems in the intervertebral foramen during robotic spine surgeries has been approached with caution and remains underutilized in clinical settings.

In contrast, reciprocating burr systems, which are similar to ultrasonic bone cutting technologies, cause minimal damage to the surrounding soft tissues and generate less heat. Wang et al reported a series of cases demonstrating that the reciprocating burr safely and efficiently shapes the intervertebral foramen, suggesting its reliability and stability as a foraminoplasty technique with low thermal impact.³⁵ We have developed a specialized reciprocating high-speed tripine instrument designed to create a circular cutting prior to intervertebral foraminoplasty. Our follow-up results indicate that none of the cases exhibited slippage on the inclined bone surface of the superior articular process (SAP), and no instances of neural damage were identified. This method effectively addresses the potential slippage and deviation issues during the intervertebral foramen shaping process, while maintaining enhanced safety for surrounding soft tissues provided by the reciprocating power system.

Another advantage of the robotic system is its facilitation of remote and expert guidance. The PELD surgical process, fully guided by robotics, may also possess this significant advantage. Preoperatively, remote collaboration with experts can assist in planning the approach, while the comprehensive navigation and visualization capabilities during the surgical procedure allow for effective on-site or remote medical guidance. Additionally, the ability to review well-planned surgical trajectories on three-dimensional CT images and two-dimensional images aids junior surgeons in quickly learning and mastering the anatomical correlations in imaging. Therefore, robotic-assisted techniques throughout the entire process are expected to address the longstanding issue of a poor learning curve associated with PELD technology.

Despite the promising visual preoperative planning and precise, smooth execution offered by robotic-assisted spinal surgeries, including PELD, several issues persist in actual use. These challenges include: the high cost of equipment, the need for specialized training and personnel assistance, extended preparation times, and the requirement for general anesthesia during procedures. Recent literature on robotic-assisted PELD has also mentioned these limitations.^{19,20} For most hospitals, surgical robots remain a relatively expensive equipment, which undoubtedly increases the overall costs associated with surgical procedures. During the surgical process, professional radiology personnel are required to provide assistance. Moreover, multiple cumbersome tasks, including robotic arm mounting, fluoroscopic registration, image registration, and verification, can result in a considerably long preparation time.^{33,34}

Overall, we have designed specialized instruments for PELD based on the robotic system and established a two-step access method for rapid channel creation (one step for puncture dilation and one step for foraminoplasty). The feasibility of this approach has been preliminarily confirmed through an early series of cases. The preliminary clinical results, though limited, indicate that the procedure is safe, fast, and uneventful.

This article presents a technical report based on a small number of cases. Further extensive comparative studies are needed to confirm its safety and efficacy, as well as the advantages observed in the initial performance. Additionally, how to develop personalized and suitable preoperative planning rapidly based on the anatomical variations and types of lesions in different patients remains an important topic for future research.

Conclusion

Robotic guidance allows for the safe and effective execution of preoperative planning, implementation, and foraminoplasty during PELD surgery, significantly reducing intraoperative fluoroscopy. The foraminoplasty performed under robotic guidance is precise and reliable, with the aid of specialized instruments. Preliminary results suggest that the two-step access method forms a safe and effective technical system, significantly simplifying the PELD procedure.

Abbreviations

PELD, percutaneous endoscopic lumbar discectomy; VAS, visual analog scale; ODI, Oswestry disability index.

Data Sharing Statement

The datasets used and analysed during the current study are available from the corresponding author on reasonable request.

Ethics Approval and Consent to Participate

In accordance with the Declaration of Helsinki, the institutional ethics committee of the Xinqiao Hospital (Chongqing, China) approved this study and waived the requirement for informed consent due to the retrospective nature of the study.

Author Contributions

Wenjie Zheng, Junlong Wu, Wen Xia are co-first authors. Changqing Li and Chao Zhang are co-corresponding authors. All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

Funding

“Artificial Intelligence - Assisted Remote Orthopedic Operating Surgical Robot” (No. 2024YFB4710100).

Disclosure

The authors declare no competing interests.

References

1. Wang L, Wang T, Fan N, et al. Clinical outcome of percutaneous endoscopic lumbar decompression in treatment of elderly patients with lumbar spinal stenosis: a matched retrospective study. *Int Orthop*. 2024;48(1):201–209. doi:10.1007/s00264-023-05947-y
2. Pravesh SG, Sidney MR, Wilco CP, et al. Full endoscopic versus open discectomy for sciatica: randomised controlled non-inferiority trial. *BMJ*. 2022;376:e065846. doi:10.1136/bmj-2021-065846
3. Liu Y, Wu T, Tan J, et al. Minimally Invasive versus traditional surgery: efficacy of PELD and PLIF in treating pyogenic spondylodiscitis. *Med Sci Monit*. 2024;30:e943176. doi:10.12659/MSM.943176
4. Pan M, Li Q, Li S, et al. Percutaneous endoscopic lumbar discectomy: indications and complications. *Pain Physician*. 2020;23(1):49–56.
5. Yörükoğlu AG, Göker B, Tahta A, et al. Fully endoscopic interlaminar and transforaminal lumbar discectomy: analysis of 47 complications encountered in a series of 835 patients. *Neurocirugia*. 2017;28(5):235–241. doi:10.1016/j.neucir.2017.03.003
6. Lee DY, Lee SH. Learning curve for percutaneous endoscopic lumbar discectomy. *Neurol Med Chir*. 2008;48(9):383–388. doi:10.2176/nmc.48.383
7. Wang H, Zhou Y, Li C, et al. Risk factors for failure of single-level percutaneous endoscopic lumbar discectomy. *J Neurosurg Spine*. 2015;23(3):320–325. doi:10.3171/2014.10.SPINE1442
8. Choi KC, Lee JH, Kim JS, et al. Unsuccessful percutaneous endoscopic lumbar discectomy: a single-center experience of 10,228 cases. *Neurosurgery*. 2015;76(4):372–380. doi:10.1227/NEU.0000000000000628
9. Zhang Y, Chu J, Xia Y, et al. Research trends of percutaneous endoscopic lumbar discectomy in the treatment of lumbar disc herniation over the past decade: a bibliometric analysis. *J Pain Res*. 2023;16:3391–3404. doi:10.2147/JPR.S421837
10. Yeung AT, Tsou PM. Posterolateral endoscopic excision for lumbar disc herniation: surgical technique, outcome, and complications in 307 consecutive cases. *Spine*. 2002;27(7):722–731. doi:10.1097/00007632-200204010-00009
11. Ran B, Chen R, Song C, et al. Percutaneous endoscopic discectomy via a transforaminal approach for L5/S1 far-lateral disc herniation assisted by intraoperative computed tomography. *World Neurosurg*. 2022;166:e823–e831. doi:10.1016/j.wneu.2022.07.103
12. Støttrup CC, Andresen AK, Carreon L, et al. Increasing reoperation rates and inferior outcome with prolonged symptom duration in lumbar disc herniation surgery - a prospective cohort study. *Spine J*. 2019;19(9):1463–1469. doi:10.1016/j.spinee.2019.04.001
13. Quillo-Olvera J, Lin GX, Suen TK, et al. Anterior transcorporeal tunnel approach for cervical myelopathy guided by CT-based intraoperative spinal navigation: technical note [Technical note]. *J Clin Neurosci*. 2018;48:218–223. doi:10.1016/j.jocn.2017.11.012
14. Xie P, Feng F, Cao J, et al. Real-time ultrasonography-magnetic resonance image fusion navigation for percutaneous transforaminal endoscopic discectomy. *J Neurosurg Spine*. 2020;33(2):192–198. doi:10.3171/2020.1.SPINE191223
15. Chi M, Chen AS. Ultrasound for lumbar spinal procedures. *Phys Med Rehabil Clin N Am*. 2018;29(1):49–60. doi:10.1016/j.pmr.2017.08.005
16. Lee YS, Cho DC, Kim KT, et al. Navigation-guided/robot-assisted spinal surgery: a review article. *Neurospine*. 2024;21(1):8–17. doi:10.14245/ns.2347184.592
17. Heydar AM, Tanaka M, Prabhu SP, et al. The impact of navigation in lumbar spine surgery: a study of historical aspects, current techniques and future directions. *J Clin Med*. 2024;13(16):4663. doi:10.3390/jcm13164663
18. Li X, Chen J, Wang B, et al. Evaluating the status and promising potential of robotic spinal surgery systems. *Orthop Surg*. 2024;16(11):2620–2632.
19. Wang ZJ, Tan Y, Fu K, et al. Minimally invasive trans-superior articular process percutaneous endoscopic lumbar discectomy with robot assistance. *BMC Musculoskeletal Disord*. 2022;23(1):1144. doi:10.1186/s12891-022-06060-8
20. Jin MR, Lei LY, Li FQ, et al. Does robot navigation and intraoperative computed tomography guidance help with percutaneous endoscopic lumbar discectomy? A match-paired study. *World Neurosurg*. 2021;147:e459–e467. doi:10.1016/j.wneu.2020.12.095
21. Jiang B, Azad TD, Cottrill E, et al. New spinal robotic technologies. *Front Med*. 2019;13(6):723–729. doi:10.1007/s11684-019-0716-6
22. Zhi P, Yoon H, Seong Y, et al. Efficacy of transforaminal endoscopic spine system (TESSYS) technique in treating lumbar disc herniation. *Med Sci Monit*. 2016;22:530–539. doi:10.12659/MSM.894870

23. Guan X, Gu X, Zhang L, et al. Morphometric analysis of the working zone for posterolateral endoscopic lumbar discectomy based on magnetic resonance neurography. *J Spinal Disord Tech.* 2015;28(2):E78–E84. doi:10.1097/BSD.0000000000000145
24. Hoogland T, Schubert M, Miklitz B, et al. Transforaminal posterolateral endoscopic discectomy with or without the combination of a lowdose chymopapain: a prospective randomized study in 280 consecutive cases. *Spine.* 2006;31(24):E890–E897. doi:10.1097/01.brs.0000245955.22358.3a
25. Sairyo K, Sakai T, Higashino K, et al. Complications of endoscopic lumbar decompression surgery. *Minim Invasive Neurosurg.* 2010;53(4):175–178. doi:10.1055/s-0030-1262814
26. Kanno H, Aizawa T, Hahimoto K, et al. Minimally invasive discectomy for lumbar disc herniation: current concepts, surgical techniques, and outcomes. *Int Orthop.* 2019;43(4):917–922. doi:10.1007/s00264-018-4256-5
27. Wu J, Ao S, Liu H, et al. Novel electromagnetic-based navigation for percutaneous transforaminal endoscopic lumbar decompression in patients with lumbar spinal stenosis reduces radiation exposure and enhances surgical efficiency compared to fluoroscopy: a randomized controlled trial. *Ann Transl Med.* 2020;8(19):1215. doi:10.21037/atm-20-1877
28. Sairyo K, Matsuura T, Higashino K, et al. Surgery related complications in percutaneous endoscopic lumbar discectomy under local anesthesia. *J Med Invest.* 2014;61(3–4):264–269. doi:10.2152/jmi.61.264
29. Lee NJ, Lombardi JM, Qureshi S, et al. Robot-assisted spine surgery: the pearls and pitfalls. *J Am Acad Orthop Surg.* 2024;00:1–12.
30. Zhou LP, Zhang RJ, Shang Y, et al. Comparison of robotic or computer-assisted navigation versus fluoroscopic freehand techniques in the accuracy of posterior cervical screw placement during cervical spine surgery: a meta-analysis. *J Neurosurg Spine.* 2024;41(6):746–756. doi:10.3171/2024.5.SPINE24207
31. Łajczak P, Żerdziński K, Jóźwik K, et al. Enhancing precision and safety in spinal surgery: a comprehensive review of robotic assistance technologies. *World Neurosurg.* 2024;191:109–116. doi:10.1016/j.wneu.2024.08.051
32. Gautam D, Vivekanandan S, Mazur MD, et al. Robotic spine surgery: systematic review of common error types and best practices. *Oper Neurosurg.* 2025;28(3):295–302. doi:10.1227/ons.0000000000001293
33. Joseph JR, Smith BW, Liu X, et al. Current applications of robotics in spine surgery: a systematic review of the literature. *Neurosurg Focus.* 2017;42(5):E2. doi:10.3171/2017.2.FOCUS16544
34. Ghasem A, Sharma A, Greif DN, et al. The arrival of robotics in spine surgery: a review of the literature. *SPINE.* 2018;43(23):1670–1677. doi:10.1097/BRS.0000000000002695
35. Wang Y, Wu J, Wang T, et al. Modified lumbar foraminoplasty using a power-aided reciprocating burr for percutaneous transforaminal endoscopic lumbar discectomy: a technical note and clinical report. *Front Surg.* 2023;9:1091187. doi:10.3389/fsurg.2022.1091187

Journal of Pain Research

Publish your work in this journal

The Journal of Pain Research is an international, peer reviewed, open access, online journal that welcomes laboratory and clinical findings in the fields of pain research and the prevention and management of pain. Original research, reviews, symposium reports, hypothesis formation and commentaries are all considered for publication. The manuscript management system is completely online and includes a very quick and fair peer-review system, which is all easy to use. Visit <http://www.dovepress.com/testimonials.php> to read real quotes from published authors.

Submit your manuscript here: <https://www.dovepress.com/journal-of-pain-research-journal>

Dovepress
Taylor & Francis Group