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Application Research of PETD Combined with MRI Nerve Root Water Imaging in the Minimally Invasive Treatment of LDH

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Abstract

Objective: This study aims to evaluate the safety and efficacy of PETD combined with nerve root water imaging of MRI for the treatment of lumbar disc herniation. **Methods:** A retrospective review was performed on 62 patients with lumbar disc herniation from March 2019 to March 2021. The study included an experimental group of 30 patients and a control group of 32 patients. The experimental group underwent PETD combined with nerve root water imaging of MRI, while the control group received traditional PETD treatment. The visual analogue scoring method (VAS score), and JOA lumbar spine function score before and after surgery were compared between the two groups, and efficacy was assessed and compared using the MacNab score. **Results:** The mean operation time was significantly reduced in the experimental group (56.43 ± 10.40 minutes) compared to the control group (65.69 ± 14.12 minutes). The VAS score was compared between the two groups with preoperative ($p = 0.624$), one month after surgery ($p = 0.325$), three months after surgery ($p = 0.676$), one year after surgery ($p = 0.341$); The JOA score was compared between the two groups with preoperative ($p = 0.961$), one month after the surgery ($p = 0.266$), three months after surgery ($p = 0.185$), one year after surgery ($p = 0.870$), they were no significant statistical difference; The efficacy evaluation of the last follow-up Macnab showed that all the 30 patients in the experimental group were excellent, 31 of 32 patients in the control group were excellent, 1 case was good; There was no statistical difference in the comparison between the two groups ($p > 0.05$). **Conclusion:** The study concludes that the combined approach of PETD with nerve root water imaging of MRI is a safe, effective, and more efficient alternative to conventional PETD for treating lumbar disc herniation.

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*These authors contributed equally to this work.

Keywords

Lumbar Disc Herniation, Nerve Root Water Imaging, Percutaneous Interforaminal Endoscopy, Minimally Invasive Spine Surgery, Discectomy

1. Introduction

Lumbar disc herniation (LDH) is the most common spinal disorder in clinical practice and a frequent cause of low back and lower limb pain [1]. Surgical intervention becomes necessary when non-surgical treatments fail to adequately alleviate pain in patients with LDH, or in cases presenting with cauda equina syndrome, characterized by bladder dysfunction, progressive muscle weakness, and progressive neurological deficits, where lumbar discectomy is the only absolute indication [2]. With the evolution of surgical techniques, percutaneous endoscopic transforaminal discectomy (PETD) has emerged as a minimally invasive approach for treating LDH and has been widely applied in clinical settings. The procedure's most challenging and crucial aspects, contributing to its steep learning curve, include the determination of the initial puncture site and the placement of the working cannula under local anesthesia through a percutaneous single-channel approach [3]. Accurate preoperative localization of the herniation and its relationship with the compressed nerve root (NR) are essential for determining the puncture site and cannula insertion. Magnetic resonance imaging (MRI) serves as the primary diagnostic tool and gold standard for evaluating spinal pathologies [4]. The 3D MRI neurography technique, utilizing selective water excitation and Proset imaging, provides detailed visualization of the spinal nerve roots and dorsal root ganglia (DRG) [5]. It also clearly delineates the three-dimensional spatial relationship between the herniated disc and the nerve root [6]. Leveraging the capability of MRI neurography to accurately display the interaction between the herniated disc and nerve root, this study aims to investigate the safety and efficacy of using MRI neurography for guiding the determination of puncture sites and the placement of working sheaths during PETD, by establishing the precise location of disc herniations.

2. Materials and Methods

2.1. General Information

Patients admitted to the Department of Spine Surgery at Wenzhou Integrated Traditional Chinese and Western Medicine Hospital, who met the specified inclusion and exclusion criteria and underwent conventional PETD treatment for lumbar disc herniation between March 2019 and March 2021, were included in the control group. Patients meeting the same criteria and receiving minimally invasive treatment with PETD combined with MRI neurography for lumbar disc herniation from April 2021 to April 2022 were allocated to the experimental group.

2.2. Inclusion and Exclusion Criteria

Inclusion Criteria: Patients with clear symptoms of lower limb radicular pain, with or without back pain, and single-segment lumbar disc herniation shown on X-ray, CT, or MRI examinations, without disc calcification or posterior vertebral edge detachment.

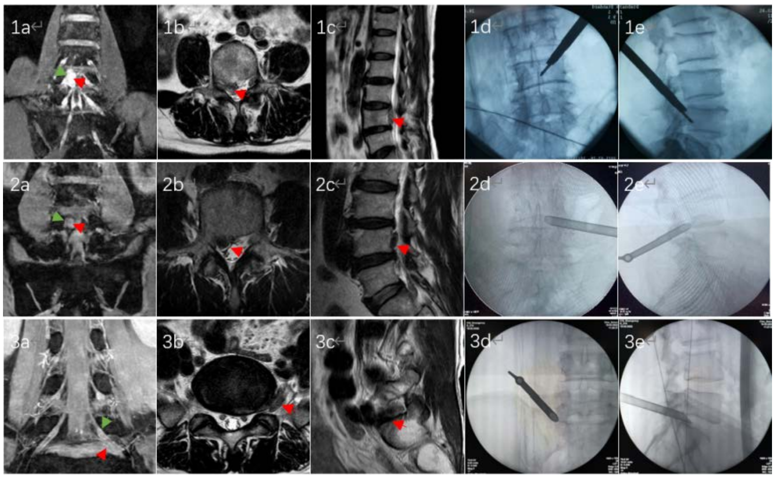
Exclusion Criteria: Patients with a history of lumbar spine fracture, spinal tumor, infection, deformity, lumbar spinal stenosis, spondylolisthesis, etc. This study was approved by the ethics committee of the hospital.

2.3. Methods

2.3.1. Division and Localization of the Herniated Disc Area

Based on the pathology and extent of disc herniation, the herniated disc tissue can be located anywhere from the spinal canal, intervertebral foramen to the paravertebral soft tissues. From a three-dimensional perspective, the positions of the herniated disc tissue in sagittal, horizontal, and coronal views are as follows: 1) Sagittal View: Divided into three levels: a) Level I: Disc level; b) Level II: Upper disc level, from the inferior notch of the pedicle of the upper vertebra to the upper boundary of the disc; c) Level III: Lower disc level, from the lower boundary of the disc to the plane of the inferior notch of the pedicle of the lower vertebra. 2) Horizontal View: Divided into four zones based on the posterior edge of the vertebral body; Zones 1 and 2 are within the inner boundary of the pedicles, divided into three equal parts, with the middle third as Zone 1 and the left and right thirds as the left and right Zone 2, *i.e.*, paramedian zones; Zone 3 is between the inner and outer boundaries of the pedicles, *i.e.*, the lateral zone; Zone 4 is outside the lateral boundary of the pedicles, *i.e.*, the far lateral zone. 3) Coronal View: Divided into four equal parts from the midline of the posterior edge of the vertebral body to the anterior edge of the spinous process, named as areas a, b, c, and d, respectively.

2.3.2. Three-Dimensional Localization of MR Neurography: The Three-Dimensional Coordinates of the Herniation Are Determined (Figures 1(1a)-(1c))



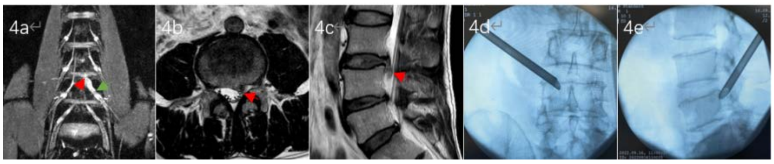


Figure 1. Showcases MR imaging for the localization of herniated or extruded discs (indicated by red arrows) and compressed nerve roots (indicated by green arrows), along with intraoperative catheter placement images. **Figures 1(1a)-(1c)** depict the localization of a right-sided extruded disc at L3/L4 in zones 1 and 2, level III, area C. **Figures 1(2a)-(2c)** show a right-sided extruded disc at L4/L5 in zones 1 and 2, level II, area B. **Figures 1(3a)-(3c)** illustrate a left-sided far lateral protrusion at L5/S1 in zone 4, level I, area a. **Figures 1(4a)-(4c)** display a left-sided protruded disc at L3/L4 in zone 2, levels I and III, area b. Figures d and e demonstrate the needle insertion and catheter placement guided by the localization images.

2.3.3. Localisation Mapped on X-Ray and Guidance for Puncture

Preoperative anteroposterior and lateral lumbar spine X-rays are used to draw localization diagrams and determine the direction of needle insertion (**Figure 2**); the localization diagrams guide the surgical positioning for needle insertion and catheter placement.

2.3.4. Surgical Procedures

During the operation, positioning markers were placed on the body surface (**Figure 4(a)**), C-arm fluoroscopy standard front and side view film, according to the preoperative positioning film, the body surface markings were drawn to confirm the puncture entry point and the direction of needle insertion (**Figure 4(b)**), routine disinfection and spreading of towels, the puncture point was anaesthetised with 15% lidocaine 15 ml of local anaesthesia of the skin and the skin subcutaneously, according to the markings, the 18 G puncture needle was punctured to achieve the expected position and then the insertion was pulled out, and 0.5% lidocaine was inserted and then removed the puncture needle. Local anaesthesia was applied around the articular eminence, the guidewire was inserted and the puncture needle was removed, a transverse incision was made at the skin entry point of the guidewire of about 0.8 cm, a hollow guide rod was inserted along the guidewire and the soft tissue channels were expanded step by step at the 3 levels, and finally the working channel was inserted, the C-arm fluoroscopy was used to confirm that the working channel had reached the desired position, the intervertebral foramenoscope (joimax) was connected, the soft tissue was peeled off under the lens, and the articular eminence was formed by the circular saw under the lens, and the working channel was finally placed into the predetermined The nucleus pulposus was removed under the intervertebral foramenoscope (**Figure 1(4d)** and **Figure 1(4e)**).

2.4. Observational Indicators and Efficacy Assessment

The study records patient demographics (gender and age), operation duration, incidences of re-herniation, and complications. Regular outpatient follow-ups or

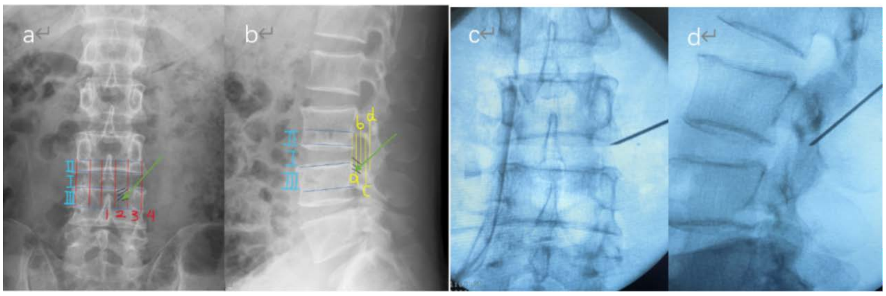


Figure 2. Presents preoperative X-ray images of a 44-year-old male patient with a left-sided L3/L4 disc herniation, showing the localization area (marked by black diagonal lines) and the direction of needle insertion (indicated by green arrows) in images (a) and (b); intraoperative fluoroscopic images of the needle insertion are shown in (c) and (d).

phone consultations are conducted to compare preoperative and postoperative VAS scores and lumbar spine JOA scores. The MacNab criteria are used to evaluate clinical outcomes.

2.5. Data Presentation and Statistical Analysis

Statistical analyses were performed using SPSS 26.0 software, and differences were considered statistically significant at $p < 0.05$ (two-sided test). Measurement information was tested for normality using the Shapiro-Wilk test. Normal distribution and approximate normal distribution of measurement data were described using mean ± standard deviation Paired t-test was used for comparison before and after treatment within groups, independent samples t-test was used for comparison between groups, and chi-square test was used for comparison of rates between two groups. The use of independent samples t-test needs to satisfy that the data follow a normal distribution, the overall variance of the two groups of samples is xiang t, and the data of the two groups of samples are independent. The chi-square test compares both rank distributions and rates.

3. Results

A retrospective analysis was conducted on 62 patients who underwent PETD treatment for lumbar disc herniation at Wenzhou Integrated Traditional Chinese and Western Medicine Hospital from March 2019 to April 2022. The study comprised 30 patients in the experimental group and 32 in the control group, with follow-up periods ranging from 12 to 18 months. No statistical difference was found in the ages between the two groups ($p > 0.05$). The average operation time for the experimental group was 56.43 ± 10.40 minutes, significantly shorter than the 65.69 ± 14.12 minutes for the control group ($p = 0.005 < 0.05$) (**Table 1**).

We compared the efficacy of the experimental group with that of the control group from three perspectives: VAS score, lumbar JOA score and MacNab efficacy assessment. Comparing the preoperative and postoperative VAS scores between the two groups, there was no significant difference observed at pre-operation ($p = 0.624$), 1 month post-operation ($p = 0.325$), 3 months

Table 1. Comparison of operation times between experimental and control groups.

	Experimental Group (n = 30)	Control Group (n = 32)	P-value
Age (years)	51.73 ± 15.81	55.25 ± 12.09	0.327
Gender (Male/Female)	16/14	20/12	
Disc Herniation Segment (L34/L45/L5S1)	4/18/8	2/22/8	
Operation Time (min)*	56.43 ± 10.40	65.69 ± 14.12	0.005

*The operation time includes the time for needle insertion, catheter placement, and endoscopic procedures.

post-operation (p = 0.676), and 1 year post-operation (p = 0.341). Similarly, when comparing the preoperative and postoperative lumbar spine JOA scores, no significant difference was found at pre-operation (p = 0.961), 1 month post-operation (p = 0.266), 3 months post-operation (p = 0.185), and 1 year post-operation (p = 0.870), with all the mentioned statistical results showing a P-value greater than 0.05, indicating no statistical significance. The final follow-up MacNab efficacy assessment showed that all 30 patients in the experimental group had excellent outcomes. In the control group, 31 out of 32 patients had excellent outcomes, and 1 had good outcomes, with no significant difference in the excellent-good rate between the two groups (p = 0.329 > 0.05). Both groups showed excellent surgical efficacy with no significant differences between them (**Table 2**).

When comparing the number of complications between the experimental group and the control group, there was no statistical difference in the total number of complications between the two groups (p = 0.756) (**Table 3**).

4. Discussion

Percutaneous endoscopic transforaminal discectomy (PETD) has gradually become a common surgical procedure for lumbar disc herniation due to its minimal invasiveness, low bleeding risk, reduced scar formation within the spinal canal, and shorter hospital stays [7] [8]. The precision required in needle entry point selection and puncture technique [9], along with subsequent foraminoplasty, results in a steep learning curve for conventional PETD procedures [10]. This study utilized MRI neurography to determine the relationship between herniated discs and compressed nerve roots (**Figure 3**), and to define the location of herniated discs based on disc region division, marking them on standard anteroposterior and lateral lumbar spine X-rays. Intraoperatively, these markings were used to guide the placement of surface markers and fluoroscopy of standard anteroposterior and lateral lumbar spine X-rays (**Figure 4(a)**) to determine needle entry points (**Figure 4(b)**) and guide puncture (**Figure 2(c)** and **Figure 2(d)**) to catheter placement (**Figure 1(4d)** and **Figure 1(4e)**) to reach the target location. This approach standardizes the process of determining needle

Table 2. Comparison of efficacy between experimental and control groups.

	Experimental Group (n = 30)	Control Group (n = 32)	P-value
VAS Score			
Pre-operation	6.77 ± 0.96	6.66 ± 0.83	0.624
1 Month Post-operation	2.60 ± 0.56	2.75 ± 0.62	0.325
3 Months Post-operation	0.47 ± 0.57	0.41 ± 0.56	0.676
1 Year Post-operation	0.07 ± 0.25	0.16 ± 0.45	0.341
Lumbar JOA Score			
Pre-operation	12.06 ± 3.17	12.03 ± 2.42	0.961
1 Month Post-operation	24.00 ± 1.68	24.47 ± 1.61	0.266
3 Months Post-operation	27.27 ± 1.14	26.88 ± 1.16	0.185
1 Year Post-operation	28.43 ± 0.86	28.47 ± 0.84	0.870
MacNab Efficacy Assessment			
Final Follow-up	30:0:0:0	31:1:0:0	0.329

Table 3. Comparison of complications between experimental and control groups.

	Experimental Group (n = 30)	Control Group (n = 32)	P-value
Infection	0	0	
Short-term Sensory Abnormality	3	2	
Annular Tear of Nerve Root	0	1	
Minor Nerve Root Injury	0	1	
Recurrence	0	0	
Total Complications	3	4	0.756

entry points, with surface marking lines also indicating the direction of puncture. This is particularly beneficial for beginners in mastering and becoming proficient in localization and puncture techniques.

The THESSYS surgical system, which employs foraminoplasty to enlarge the intervertebral foramen, facilitates easier access to the disc, laying the foundation for PETD development [9]. In this study, the herniated disc serves as a guide for puncture and localization. Given the variability in herniated disc positions, foraminoplasty plays a critical role in the surgery, particularly in cases of narrow foramina or disc prolapse across levels, where traditional PETD may struggle to reach the herniated disc without extensive foraminoplasty or may even fail to reach it. Building on traditional PETD, this study extends the safe zone of

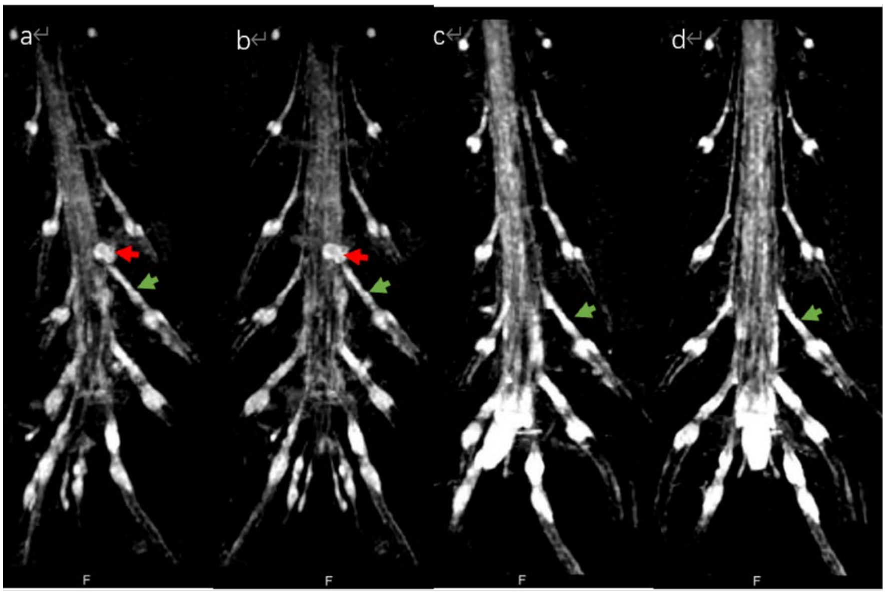


Figure 3. Presents a 3D imaging of a 44-year-old male patient with a left-sided L3/L4 herniated disc (indicated by a red arrow) in relation to the compressed nerve root (indicated by a green arrow), showing the herniated disc anterior to the nerve root ((a) and (b)). Postoperative 3D imaging demonstrates the removal of the herniated disc, with the nerve root (green arrow) relieved from compression ((c) and (d)).

Figure 4. Depicts the same 44-year-old male patient with a left-sided L3/L4 disc herniation during surgery, showing the placement of surface markers (a) and the drawing of surface marking lines (b).

Kambin's triangle [11], involving oblique foraminoplasty of the superior border of the pedicle of the lower vertebra to open the lateral recess (**Figure 1(1d)** and **Figure 1(1e)**) for removing downward prolapsed discs, and foraminoplasty of the tip of the superior articular process followed by foraminoplasty of the inferior articular process to expose the exit and surrounding space (**Figure 1(2d)** and **Figure 1(2e)**) for removing upward prolapsed nucleus pulposus.

While expanding Kambin's triangle may increase the risk of nerve injury, MRI neurography reveals the relationship between the herniated disc and compressed nerve root, and the pre-designed puncture path ensures that each step of the surgery has a clear target. Additionally, the use of an endoscopic saw and feedback from the patient under local anesthesia contribute to the study's conclusion that complications did not increase despite these surgical maneuvers (**Table 3**). Moreover, the frequency of foraminoplasty and the extent of articular process resection were correspondingly reduced.

In conclusion, PETD combined with MRI neurography for lumbar disc herniation treatment is demonstrated to be as safe and effective as traditional PETD but offers improved efficiency.

The surgical teams in this study all have accumulated more than 200 cases of PETD surgical techniques, and have demonstrated high efficiency and safety for the application of PETD combined with MR nerve root imaging. The shortcomings of this study are that no beginners were selected to compare the two methods, which could not more accurately reflect the advantages of PETD combined with MR nerve root hydrographic imaging, and could not react to the advantage in terms of smoothing out the learning curve. Besides, the VAS and JOA scores are widely used as assessment scales in this topic, but there is a certain degree of subjectivity, patients' self-assessment and understanding of the disease are different, and there are large individual differences, and more objective indexes can be added in subsequent studies. This trial is a single-centre clinical trial with a small sample size of participants. The search for universal laws needs to be further verified. The later stage can expand the sample size and carry out multi-centre, large-sample randomized controlled trials to reduce bias.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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