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Original Article

Percutaneous transforaminal endoscopic discectomy for lumbar disc herniation: an efficacy analysis

Yusen Dai, Daoyou Li, Xile Wen

Department of Orthopedics, The People's Hospital of Pingyang, Pingyang County, Wenzhou 325400, Zhejiang, China

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Abstract: Objective: This retrospective study evaluated the clinical efficacy of percutaneous transforaminal endoscopic discectomy (PTED) in the treatment of lumbar disc herniation (LDH). Methods: Data of 107 LDH patients admitted to the People's Hospital of Pingyang between July 2019 and May 2023 were analyzed retrospectively, including 51 cases treated with conventional open discectomy (control group) and 56 cases undergoing PTED (research group). We compared curative effects, operation time, intraoperative blood loss (IBL), incision length, time until ambulation, hospital stay, pre- and post-treatment pain intensity, lumbar function, and complications. Pain intensity was measured using the the Visual Analogue Scale (VAS), and the lumbar function was assessed by the Oswestry Disability Index (ODI). In addition, the factors influencing the efficacy in LDH patients were analyzed. Results: The research group showed a statistically higher overall efficacy (P=0.034, χ^2=4.479), longer operation time (P=0.002, t=3.114), less IBL (P<0.001, t=29.725), earlier ambulation (P<0.001, t=8.628), shorter hospital stay (P<0.001, t=8.628), and smaller incision length (P<0.001, t=15.948) than the control group. In addition, the postoperative VAS score (P<0.001, t=5.621) and ODI score (P<0.001, t=4.909) were reduced significantly after treatment and were lower in the research group than in the control group. The research group was also associated with a significantly lower overall complication rate (7.14% vs. 21.57%; P=0.032, χ^2=4.608), including reduced incidence of lumbar spinal mobility limitation, incontinence, postoperative infection, and cauda equina syndrome. Furthermore, age, course of disease, and treatment method were strongly associated with the treatment efficacy in LDH patients. Conclusions: PTED is more effective than conventional open discectomy for LDH treatment. It reduces IBL, shortens incision length, facilitates patient recovery, alleviates postoperative pain, improves lumbar function, and minimizes the risk of postoperative complications.

Keywords: Lumbar disc herniation, percutaneous transforaminal endoscopic discectomy, clinical efficacy, safety

Introduction

Lumbar disc herniation (LDH) is the most prevalent cause of sciatica, characterized by the displacement of disc material - either nucleus pulposus or annulus fibrosis - beyond the normal confines of the intervertebral disc space [1, 2]. This condition stems from the annulus fibrosus' deterioration, nucleus pulposus extrusion, and nerve fiber stimulation, leading to symptoms such as low back pain and numbness in the lower limbs [3, 4]. Pathologically, LDH is associated with lumbar disc degeneration and the cumulative damage from prolonged sedentary lifestyles, bending, and head bowing [5-7]. According to statistics, LDH predominantly affects males and is most commonly located between the fourth and fifth lumbar vertebrae (L4-L5) and between the fifth lumbar and first sacral vertebrae (L5-S1), severely impacting patients' quality of life as it progresses [8]. Therefore, optimizing LDH treatment is crucial for providing effective symptom relief and preventing further disease progression.

Currently, treatment options for LDH range from non-surgical to surgical interventions, with the former recommended for specific cases (such as bulging herniations or Schmorl's nodes) and the latter for more severe conditions [9]. Among surgical options, percutaneous transforaminal endoscopic discectomy (PTED) stands out as an ultra-minimally invasive technique performed under local anesthesia, noted for facilitat-

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ing patient rehabilitation, shortening hospital stays, and preserving spinal biomechanical integrity [10, 11]. In the report of Zhong-Sheng et al. [12], PTED was found to be effective for both LDH patients aged <60 or ≥60. Besides LDH, PTED also demonstrates significant potential in treating other diseases. For example, Wang et al. [13] reported that PTED was equivalent to fenestration discectomy in terms of efficacy in the treatment of posterior lumbar ring apophyseal fractures, while offering benefits in terms of reduced operation time, trauma, and quicker recovery. According to Jin et al. [14], PTED shows promising clinical efficacy and safety in elderly patients with degenerative scoliosis and lumbar spinal stenosis, but with limitations for those with Cobb angle greater than 30 and lateral subluxation.

This study primarily examines PTED's clinical efficacy in LDH treatment, aiming to enrich the management strategy for LDH patients. Of note, the innovations of this study are reflected in the following aspects: (1) Affirming PTED's clinical effectiveness and safety in alleviating symptoms and enhancing mobility while maintaining a low complication rate; (2) Demonstrating PTED's superior surgical outcomes, including minimized intraoperative blood loss (IBL), reduced incision lengthsize, earlier ambulation, and shorter hospital stay, despite longer operation time; (3) Validating its functional benefits in diminishing postoperative pain and facilitating lumbar recovery, as evidenced by Visual Analogue Scale (VAS) and Oswestry Disability Index (ODI) scores.

Participants and methods

Patient information

Inclusion criteria: Patients met the diagnostic criteria for LDH [2]; patients met the surgical criteria for PTED or conventional open discectomy; patients with signs such as scoliosis, limited flexion and extension, and low back and leg pain when bending over; patients with positive responses to straight leg elevation and femoral nerve traction tests; patients with lumbar spinal abnormalities confirmed by X-ray, computerized tomography (CT), or magnetic resonance imaging (MRI).

Exclusion criteria: Patients with lumbar spinal stenosis, sacroiliac sprain, lumbar tuberculosis or tumor; patients with functional or structural abnormalities of the lumbar spine caused by non-pathological factors; patients with surgical contraindications; patients with serious cardiocerebrovascular disorders or organic diseases; patients with cognitive dysfunction.

This is a retrospective study with ethical approval received from the Ethics Committee of the People's Hospital of Pingyang, Pingyang County. This study selected 107 LDH patients consecutively admitted to the People's Hospital of Pingyang between July 2019 and May 2023 based on the above inclusion and exclusion criteria. Among them, 51 cases in the control group (Con) received conventional open discectomy, and 56 patients in the research group (Res) received PTED. No statistical inter-group difference was identified in general data ($P > 0.05$), suggesting comparability.

Methods

For the Con group, conventional open discectomy [15] involved making a 4 cm longitudinal incision at the lumbar midline in prone patients after anesthesia, with interspinous space of the intervertebral disc protrusion as the center. The procedure entailed dissecting the skin and lumbodorsal fascia, incising the sacrospinous muscle on both sides of the spinous process, and performing subperiosteal dissection along the spinous process and lamina with a stripper at the attachment point of the spinous process to separate the sacrospinous muscle. After identifying the herniated space, laminectomies were performed on part of the lamina, and ligamentum flavum was performed to expose the dura mater. After ensuring nerve root and dura mater integrity, the protruding nucleus pulposus was then nipped with a pituitary rongeur to enlarge the nerve root canal and relieve the compression. Then, comprehensive hemostasis, irrigation, and drainage were performed before suturing the incision.

The Res group underwent PTED [16], initiated with the patient in a lateral decubitus position. The needle entry point was 8-10 cm from the midline of the left (right) side. After successful local anesthesia, a puncture needle was inserted to adjust the puncture position. Local anesthetics were then injected into the articular capsule of the facet joint through subcutaneous, fascia, and muscle. Thereafter, a guide

wire was inserted and the puncture needle was replaced with a TOM probe, which was accurately positioned into the spinal canal space under the repeated perspective of C-arm. After the placement of a thick guide wire and the removal of the TOM probe, a small incision (8 mm) was created along the guide wire with a leather knife, and the soft tissue was gradually expanded. Part of the bone in the facet joint was then removed, a cannula was placed, and the PTED light source and imaging systems were connected. After irrigation with normal saline, the protruding nucleus pulposus, proliferative ligamentum flavum, posterior longitudinal ligament, and other soft tissues in the spinal canal, as well as the bony hyperplasia, were removed with a bipolar radiofrequency device and nucleus pulposus forceps. The annulus fibrosus was trimmed, the nerve roots were exposed and relaxed, and the nerve roots and dural sac were observed microscopically. After sufficient decompression and confirmation that there was no bleeding, the cannula was removed, and the incision was bandaged.

Analysis indexes

Efficacy [17] was classified as excellent (complete resolution of postoperative symptoms and unrestricted mobility), good (mild symptoms and slightly restricted mobility), fair (eased symptoms but restricted mobility), or poor (no significant symptom improvement or worsening condition). The sum of excellent and good outcomes as a percentage of total cases represents the total response rate.

Intra- and post-operative indexes [18] were recorded, primarily including operation time, IBL, incision length, time until ambulation, and hospital stay.

Pain intensity was assessed before and after surgery using the Visual Analogue Scale (VAS) on a scale from 0 to 10, with higher scores indicating greater pain [19].

Lumbar function [20] was evaluated using the ODI (10 statements answered on a five-point scale), where lower scores signify better lumbar function.

Complications such as reduced lumbar spinal mobility, incontinence, postoperative infections, and cauda equina syndrome (CES) were observed, and the incidence rate was calculated [21].

Statistical analyses

Measured data were statistically described by mean ± SEM and compared using the independent samples t test (between groups) and paired t test (within groups). The χ^2 test was used to analyze counted data expressed as the ratio (percentage). All analyses were performed in SPSS/22 with a significant threshold set at $P<0.05$.

Results

General data of 107 LDH patients

The two patient cohorts showed similar general data (age, sex, course of disease, onset location, type of disc herniation, family history of LDH, etc.) ($P>0.05$), indicating comparability at baseline. See **Table 1**.

Comparative analysis of treatment efficacy

We analyzed the efficacy of the two treatment modalities in patients with LDH. Data showed that the numbers of cases with excellent, good, fair, and poor outcomes in the Con group were 15, 20, 7, and 9, respectively, while the corresponding numbers of cases in the Res group was 23, 25, 5, and 3, respectively. There were 35 cases in the Con group and 48 cases in the Res group who exhibited a favorable response. The inter-group comparison revealed an obviously higher response rate in the Res group than in the Con group (85.71% vs. 68.63%; $P<0.05$). Moreover, factors affecting the treatment efficacy in patients with LDH were analyzed. Sex, onset location, type of intervertebral disc herniation, and family history were not significantly related to the treatment efficacy in LDH patients ($P>0.05$). In contrast, age, course of disease, and treatment method were significantly associated with the efficacy ($P<0.05$). See **Tables 2** and **3**.

Comparative analysis of intraoperative indexes

By exploring the impact of these two surgical techniques on LDH outcome, it was found that the operation time was (45.25±5.07) min for the Con group and (47.64±2.58) min for the Res group. The IBL of the Con group was

Table 1. General data of 107 LDH patients

Factor	Control group (n=51)	Research group (n=56)	χ^2/t	P
Age (years)	53.71±7.08	54.70±8.56	0.648	0.518
Sex (male/female)	35/16	33/23	1.084	0.298
Course of disease (years)	6.31±1.50	6.02±1.79	0.904	0.368
Onset location (L4-L5/L5-S1)	29/22	38/18	1.378	0.240
Type of intervertebral disc herniation (prolapsed/central)	26/25	26/30	0.221	0.638
Family history (yes/no)	14/37	10/46	1.412	0.235

Note: LDH, lumbar disc herniation.

Table 2. Comparative analysis of treatment response

Factor	Control group (n=51)	Research group (n=56)	χ^2	P
Excellent	15 (29.41)	23 (41.07)		
Good	20 (39.22)	25 (44.64)		
Fair	7 (13.73)	5 (8.93)		
Poor	9 (17.65)	3 (5.36)		
Favorable response	35 (68.63)	48 (85.71)	4.479	0.034

Table 3. Analysis of factors influencing the efficacy of LDH patients

Factor	Favorable response group (n=83)	Unfavorable response group (n=24)	χ^2	P
Age (years)			9.528	0.002
<60	72 (86.75)	14 (58.33)		
≥60	11 (13.25)	10 (41.67)		
Sex			1.751	0.186
Male	50 (60.24)	18 (75.00)		
Female	33 (39.76)	6 (25.00)		
Course of disease (years)			10.746	0.001
<8	73 (87.95)	14 (58.33)		
≥8	10 (12.05)	10 (41.67)		
Onset location			0.217	0.642
L4-L5	51 (61.45)	16 (66.67)		
L5-S1	32 (38.55)	8 (33.33)		
Type of intervertebral disc herniation			0.384	0.535
Prolapsed	39 (46.99)	13 (54.17)		
Central	44 (53.01)	11 (45.83)		
Family history			2.114	0.146
Yes	16 (19.28)	8 (33.33)		
No	67 (80.72)	16 (66.67)		
Treatment method			4.479	0.034
Conventional open discectomy	35 (42.17)	16 (66.67)		
PTED	48 (57.83)	8 (33.33)		

Note: LDH, lumbar disc herniation; PTED, percutaneous transforaminal endoscopic discectomy.

(44.88±5.4) mL, more than (16.46±4.48) mL in the Res group. The incision length of the Con and the Res groups were (1.88±0.38) cm and (1.02±0.13) cm, respectively (P<0.05), indicating less invasive procedures in the Res group despite longer operation time. See **Figure 1**.

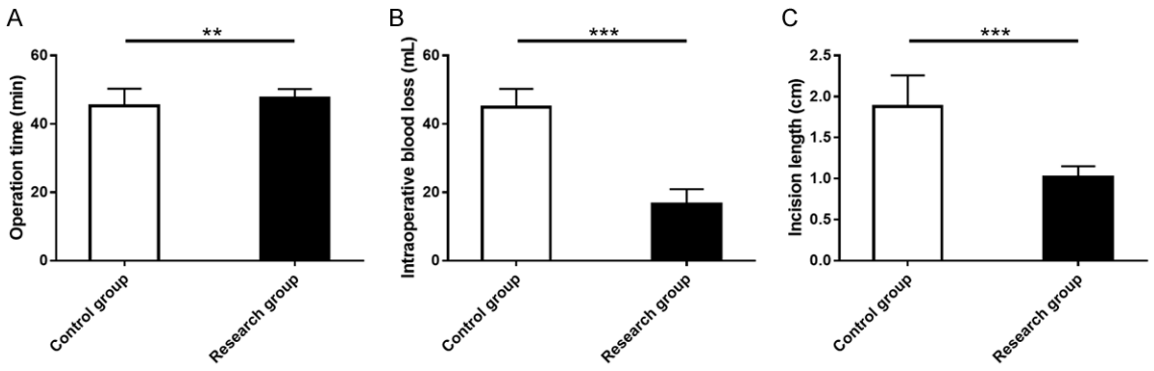

Figure 1. Comparison of operation time, intraoperative blood loss, and incision length. A. Operation time. B. Intraoperative blood loss. C. Incision length. Note: ** and *** represent P<0.01 and P<0.001, respectively.

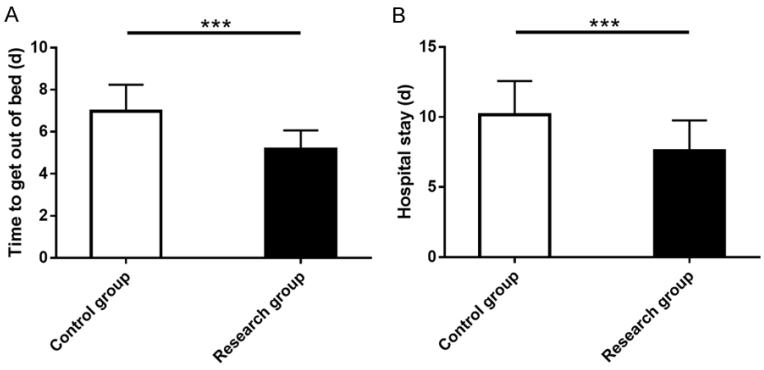

Figure 2. Comparison of ambulation time and hospital stay. A. Ambulation time. B. Hospital stay. Note: ***P<0.001.

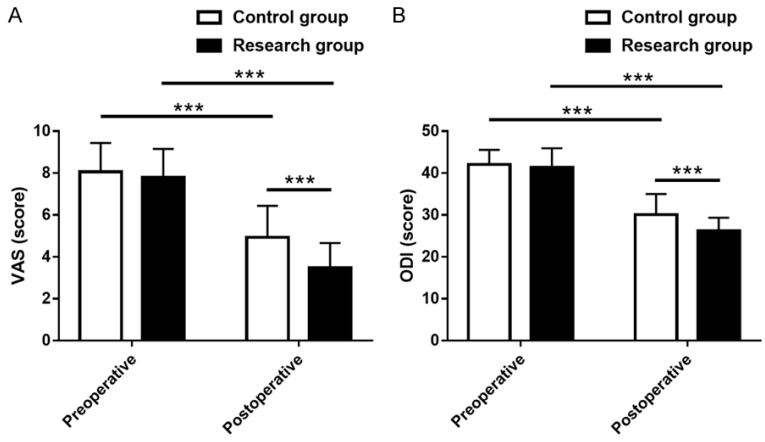

Figure 3. Comparison of VAS and ODI scores. A. VAS. B. ODI. Note: ***P<0.001. VAS, Visual Analogue Scale; ODI, Oswestry Disability Index.

Comparative analysis of postoperative indexes

We further conducted an assessment to investigate the effects of two surgical approaches on postoperative recovery in LDH patients. The data showed that the ambulation time was (6.98±1.26) days and (5.18±0.88) days in the Con and Res groups, respectively, and the hospital stay was (10.16±2.41) days in the Con and (7.61±2.15) days in the Res group. The statistical analysis of postoperative recovery indexes showed that the ambulation time and hospital stay were shorter in the Res group than the Con group (P<0.05). See **Figure 2**.

Comparative analysis of pain and lumbar function

The VAS score (8.06±1.38) points in the Con group and (7.79±1.36) points in the Res group before the intervention, and the scores were reduced to (4.94±1.5) points and (3.48±1.18) points, respectively after the intervention. The pre- and post-interventional ODI scores of the Con group were (42.06±3.51) points and (30.1±4.92) points, respectively, and those of the Res group were (41.41±4.53) and (26.21±3.16), respectively. No significant inter-group difference was identified in the the two scores before surgery (P>0.05), but both groups showed markedly reduced VAS and ODI scores postoperatively, with significantly lower scores in the Res group (P<0.05). See **Figure 3**.

Table 4. Comparative analysis of complications

Factor	Control group (n=51)	Research group (n=56)	χ^2/t	P
Limited lumbar spinal mobility	2 (3.92)	1 (1.79)		
Incontinence	3 (5.88)	1 (1.79)		
Postoperative infections	4 (7.84)	2 (3.57)		
Cauda equina syndrome	2 (3.92)	0 (0.00)		
Total	11 (21.57)	4 (7.14)	4.608	0.032

Comparative analysis of complications

The number and percentage of cases of reduced lumbar spinal mobility, incontinence, postoperative infections, and CES were counted and compared between the two groups. The number of cases with limited lumbar spinal mobility, incontinence, postoperative infection, and CES in the Con group were 2, 3, 4, and 2, respectively, and the corresponding cases in the Res were 1, 1, 2, and 0, respectively. There was, overall, a lower incidence of complications in the Res group than in the Con (7.14% vs. 21.57%, P<0.05). See **Table 4**.

Discussion

Between 7% and 18% of LDH patients are shown to experience relapse within two years, necessitating reoperation in as many as 80% of cases [22, 23]. However, a second operation often presents increased challenges due to epidural fibrosis and scarring [24]. The current study comparatively analyzed the clinical efficacy of PTED vs. conventional open discectomy in LDH treatment, aiming to offer a reliable reference for improving patient outcome.

Efficacy assessment revealed a higher response rate in the Res group compared to the Con, suggesting that PTED is beneficial to relieve clinical symptoms and restore mobility for LDH patients. Similar findings were reported by Zhou et al. [25], who pointed out that PTED in adolescent LDH patients had an excellent treatment rate of up to 94.44%. The high efficacy of PTED in LDH patients may be due to its small surgical incision, preserving posterior muscles of the lumbar spine, lumbar vertebrae, articular ligament structure, and the lumbar spine stability without causing obvious lumbosacral pain [26, 27]. Moreover, there is no separation nor distraction of nerve roots and dural sac in this operation, therefore no interference with the nerve tissue in the spinal canal, minimizing the likelihood of related complications [28].

The analysis of the factors affecting the treatment efficacy found that old age (≥60 years old), long course of disease (≥8 years), and treatment method (conventional open discectomy) were adverse factors affecting efficacy in LDH patients. This is in agreement with Jiang et al. [29], who found that age ≥45 years and disease course over 12 months were influencing factors of the surgical outcome in LDH patients undergoing PTED and endoscopic interlaminar lumbar discectomy. Intra- and post-operative index evaluation showed that despite longer operation time, the Res group experienced less IBL, smaller incision length, and shorter ambulation time and hospital stay than the Con group. This suggests PTED's superior surgical impact and its role in reducing surgical risks and accelerating rehabilitation, consistent with the research results of Pan et al. [30]. This may be attributed to the fact that PTED is a minimally invasive procedure with a short length of skin incision of 8 mm, coupled with the absence of laminectomy that is associated with destructive manipulation of the paravertebral muscles and ligaments, which help maintain spinal stability without affecting the patient's recovery process [31, 32]. As reported by Jarebi et al. [33], PTED significantly shortened hospital stay and facilitated the return to work and daily activities in PTED patients, aligning with our findings.

Additionally, we observed statistically significant improvements in postoperative VAS and ODI scores in the Res group compared to both baseline and the Con group, demonstrating the technique's ability to alleviate postoperative pain and promote lumbar function recovery. This effect may stem from PTED's precise approach to widening the intervertebral foramen and minimizing surgery-induced irritation and injury of the surrounding tissues. PTED

trims the annulus fibrosus, which is helpful for preserving intervertebral disc function, relieving lower back pain, and accelerating lumbar function recovery [34]. At the same time, the relief of lumbar pain can also promote the recovery of lumbar function, mainly because patients can better carry out functional rehabilitation training under relatively tolerable pain [35]. Similar results were reported by Ahn et al. [36], who found reduced postoperative VAS and ODI scores as well as a symptom improvement rate as high as 92.3% after PTED.

In terms of safety, the overall incidence of complications such as reduced lumbar spinal mobility, incontinence, postoperative infections, and CES was significantly lower in the Res group compared to the Con (7.14% vs. 21.57%), indicating the preventive capabilities of PTED against postoperative complications in LDH patients. CES is a known rare neurological disorder caused by cauda equina compression, which is primarily associated with LDH-induced neural tube compression [37]. In an extreme case study involving PTED for foraminal stenosis in adults with degenerative scoliosis, previous posterior open decompression surgery, and adjacent segment disease after prior spinal fusion, significant improvements in VAS and ODI were observed, with no major perioperative adverse events, similar to our observations [38]. The relatively higher safety of PTED in LDH patients in this study may also be due to the use of local anesthesia, which facilitates continuous patient communication and minimizes nerve root damage [39].

The limitations of this study are as follows. (1) The retrospective study design and small sample size may introduce statistical bias, indicating a need for prospective studies with increased sample sizes for validation in the future. (2) Risk factors affecting the prognosis were not analyzed, so a follow-up analysis is needed in future studies to verify the potential impact of PTED on the prognosis of LDH patients. (3) PTED combined with comprehensive nursing was not considered to prevent related postoperative complications. Further studies can implement relevant nursing interventions to optimize the management of LDH patients.

In summary, PTED for LDH demonstrates remarkable clinical efficacy, contributing to an improved response rate, favorable surgical metrics, and low incidence of postoperative complications. In addition, it facilitates rapid recovery of patients while effectively relieving postoperative pain and improving lumbar function. Our findings provide clinical evidence for the selection of surgical strategy in patients with LDH.

Disclosure of conflict of interest

None.

Address correspondence to: Xile Wen, Department of Orthopedics, The People's Hospital of Pingyang, Pingyang County, Wenzhou 325400, Zhejiang, China. Tel: +86-13758809727; E-mail: a4969wen@163.com

References

[1] Wang Y, Xu Y, Tian G and Dai G. Pediatric lumbar disc herniation: a report of two cases and review of the literature. Eur J Med Res 2022; 27: 82.

[2] Kreiner DS, Hwang SW, Easa JE, Resnick DK, Baisden JL, Bess S, Cho CH, DePalma MJ, Dougherty P 2nd, Fernand R, Ghiselli G, Hanna AS, Lamer T, Lisi AJ, Mazanec DJ, Meagher RJ, Nucci RC, Patel RD, Sembrano JN, Sharma AK, Summers JT, Taleghani CK, Tontz WL Jr and Toton JF; North American Spine Society. An evidence-based clinical guideline for the diagnosis and treatment of lumbar disc herniation with radiculopathy. Spine J 2014; 14: 180-191.

[3] Cunha C, Silva AJ, Pereira P, Vaz R, Goncalves RM and Barbosa MA. The inflammatory response in the regression of lumbar disc herniation. Arthritis Res Ther 2018; 20: 251.

[4] Corniola MV, Tessitore E, Schaller K and Gautschi OP. Lumbar disc herniation--diagnosis and treatment. Rev Med Suisse 2014; 10: 2376-2382.

[5] Balafif F, Faris M, Subagio EA, Bajamal AH and Kusumadewi A. Lumbar disc herniation in a 15-year-old girl: a case report. Int J Surg Case Rep 2022; 98: 107560.

[6] Li H, Du W, Ivanov K, Yang Y, Zhan Y and Wang L. The EEG analysis of actual left/right lateral bending movements in patient of lumbar disc herniation. Annu Int Conf IEEE Eng Med Biol Soc 2019; 2019: 4707-4711.

[7] Sarkar S, Hossen MK, Mazumder U and Dey A. Surgical outcome of cauda equina syndrome secondary to disc herniation presenting late in developing countries. Mymensingh Med J 2022; 31: 1121-1127.

[8] Faur C, Patrascu JM, Haragus H and Anglitoiu B. Correlation between multifidus fatty atrophy and lumbar disc degeneration in low back pain. BMC Musculoskelet Disord 2019; 20: 414.
[9] Chen BL, Guo JB, Zhang HW, Zhang YJ, Zhu Y, Zhang J, Hu HY, Zheng YL and Wang XQ. Surgical versus non-operative treatment for lumbar disc herniation: a systematic review and meta-analysis. Clin Rehabil 2018; 32: 146-160.
[10] Maayan O, Pajak A, Shahi P, Asada T, Subramanian T, Araghi K, Singh N, Korsun MK, Singh S, Tuma OC, Sheha ED, Dowdell JE, Qureshi SA and Iyer S. Percutaneous transforaminal endoscopic discectomy learning curve: a CuSum analysis. Spine (Phila Pa 1976) 2023; 48: 1508-1516.
[11] Ahn Y. Percutaneous endoscopic decompression for lumbar spinal stenosis. Expert Rev Med Devices 2014; 11: 605-616.
[12] Zhong-Sheng Z, Rui F, Yan-Long K, Hai-Jun X, Ya-Dong Z and Feng X. Percutaneous transforaminal endoscopic diskectomy for lumbar disk herniation: young (age <60 years) versus older (age ≥60 years) patients. J Neurol Surg A Cent Eur Neurosurg 2023; 84: 103-108.
[13] Wang YB, Chen SL, Cao C, Zhang K, Liu LM and Gao YZ. Percutaneous transforaminal endoscopic discectomy and fenestration discectomy to treat posterior ring apophyseal fractures: a retrospective cohort study. Orthop Surg 2020; 12: 1092-1099.
[14] Jin LY, Wang K, Lv ZD, Su XJ, Liu HY, Shen HX and Li XF. Therapeutic strategy of percutaneous transforaminal endoscopic decompression for stenosis associated with adult degenerative scoliosis. Global Spine J 2022; 12: 579-587.
[15] Gadjradj PS, Harhangi BS, Amelink J, van Susante J, Kamper S, van Tulder M, Peul WC, Vleggeert-Lankamp C and Rubinstein SM. Percutaneous transforaminal endoscopic discectomy versus open microdiscectomy for lumbar disc herniation: a systematic review and meta-analysis. Spine (Phila Pa 1976) 2021; 46: 538-549.
[16] Zhang J, Gao Y, Zhao B, Li H, Hou X and Yin L. Comparison of percutaneous transforaminal endoscopic discectomy and open lumbar discectomy for lumbar disc herniations: a systematic review and meta-analysis. Front Surg 2022; 9: 984868.
[17] Wang K, Hong X, Zhou BY, Bao JP, Xie XH, Wang F and Wu XT. Evaluation of transforaminal endoscopic lumbar discectomy in the treatment of lumbar disc herniation. Int Orthop 2015; 39: 1599-1604.
[18] Jiang HW, Chen CD, Zhan BS, Wang YL, Tang P and Jiang XS. Unilateral biportal endoscopic discectomy versus percutaneous endoscopic lumbar discectomy in the treatment of lumbar disc herniation: a retrospective study. J Orthop Surg Res 2022; 17: 30.
[19] Kim SK, Kang SS, Hong YH, Park SW and Lee SC. Clinical comparison of unilateral biportal endoscopic technique versus open microdiscectomy for single-level lumbar discectomy: a multicenter, retrospective analysis. J Orthop Surg Res 2018; 13: 22.
[20] Chen Z, Huang L, Wang Z, Liu Z, Xie P, Liu B, Zhang L, Chen R, Dong J and Rong L. Determination of patient acceptable symptom state for the oswestry disability index score in patients who underwent minimally invasive discectomy for lumbar disc herniation: 2-year follow-up data from a randomized controlled trial. World Neurosurg 2022; 167: e53-e60.
[21] Mobbs RJ, Phan K, Malham G, Seex K and Rao PJ. Lumbar interbody fusion: techniques, indications and comparison of interbody fusion options including PLIF, TLIF, MI-TLIF, OLIF/ATP, LLIF and ALIF. J Spine Surg 2015; 1: 2-18.
[22] Arts MP, Brand R, van den Akker ME, Koes BW, Bartels RH, Tan WF and Peul WC. Tubular diskectomy vs conventional microdiskectomy for the treatment of lumbar disk herniation: 2-year results of a double-blind randomized controlled trial. Neurosurgery 2011; 69: 135-144; discussion 144.
[23] Ran J, Hu Y, Zheng Z, Zhu T, Zheng H, Jing Y and Xu K. Comparison of discectomy versus sequestrectomy in lumbar disc herniation: a meta-analysis of comparative studies. PLoS One 2015; 10: e0121816.
[24] Huang W, Han Z, Liu J, Yu L and Yu X. Risk factors for recurrent lumbar disc herniation: a systematic review and meta-analysis. Medicine (Baltimore) 2016; 95: e2378.
[25] Zhou YL, Chen G, Bi DC and Chen X. Short-term clinical efficacy of percutaneous transforaminal endoscopic discectomy in treating young patients with lumbar disc herniation. J Orthop Surg Res 2018; 13: 61.
[26] Li X, Hu Z, Cui J, Han Y, Pan J, Yang M, Tan J, Sun G and Li L. Percutaneous endoscopic lumbar discectomy for recurrent lumbar disc herniation. Int J Surg 2016; 27: 8-16.
[27] Ding W, Yin J, Yan T, Nong L and Xu N. Meta-analysis of percutaneous transforaminal endoscopic discectomy vs. fenestration discectomy in the treatment of lumbar disc herniation. Orthopade 2018; 47: 574-584.
[28] Kong L, Shang XF, Zhang WZ, Duan LQ, Yu Y, Ni WJ and Huang Y. Percutaneous endoscopic lumbar discectomy and microsurgical laminotomy: a prospective, randomized controlled trial of patients with lumbar disc herniation and lateral recess stenosis. Orthopade 2019; 48: 157-164.

[29] Jiang X, Zhou X and Xu N. Clinical effects of transforaminal and interlaminar percutaneous endoscopic discectomy for lumbar disc herniation: a retrospective study. Medicine (Baltimore) 2018; 97: e13417.
[30] Pan M, Li Q, Li S, Mao H, Meng B, Zhou F and Yang H. Percutaneous endoscopic lumbar discectomy: indications and complications. Pain Physician 2020; 23: 49-56.
[31] Xie P, Feng F, Chen Z, He L, Yang B, Chen R, Wu W, Liu B, Dong J, Shu T, Zhang L, Chen CM and Rong L. Percutaneous transforaminal full endoscopic decompression for the treatment of lumbar spinal stenosis. BMC Musculoskelet Disord 2020; 21: 546.
[32] Li H, Wang S, Tang J, Wu J and Liu Y. Computed tomography- (CT-) based virtual surgery planning for spinal intervertebral foraminal assisted clinical treatment. J Healthc Eng 2021; 2021: 5521916.
[33] Jarebi M, Awaf A, Lefranc M and Peltier J. A matched comparison of outcomes between percutaneous endoscopic lumbar discectomy and open lumbar microdiscectomy for the treatment of lumbar disc herniation: a 2-year retrospective cohort study. Spine J 2021; 21: 114-121.
[34] Uchikado H, Nishimura Y, Hattori G and Ohara Y. Micro-anatomical structures of the lumbar intervertebral foramen for full-endoscopic spine surgery: review of the literatures. J Spine Surg 2020; 6: 405-414.
[35] Quan GM, Vital JM, Aurouer N, Obeid I, Palussiere J, Diallo A and Pointillart V. Surgery improves pain, function and quality of life in patients with spinal metastases: a prospective study on 118 patients. Eur Spine J 2011; 20: 1970-1978.
[36] Ahn Y, Jang IT and Kim WK. Transforaminal percutaneous endoscopic lumbar discectomy for very high-grade migrated disc herniation. Clin Neurol Neurosurg 2016; 147: 11-17.
[37] Kapetanakis S, Chaniotakis C, Kazakos C and Papathanasiou JV. Cauda equina syndrome due to lumbar disc herniation: a review of literature. Folia Med (Plovdiv) 2017; 59: 377-386.
[38] Kapetanakis S, Floros E and Gkantsinikoudis N. Extreme cases in percutaneous transforaminal endoscopic surgery: case series and brief review of the literature. Br J Neurosurg 2024; 38: 94-98.
[39] Sairyo K, Chikawa T and Nagamachi A. State-of-the-art transforaminal percutaneous endoscopic lumbar surgery under local anesthesia: discectomy, foraminoplasty, and ventral facetectomy. J Orthop Sci 2018; 23: 229-236.