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CME

Unsuccessful Percutaneous Endoscopic Lumbar Discectomy: A Single-Center Experience of 10 228 Cases

BACKGROUND: Percutaneous endoscopic lumbar discectomy (PELD) has remarkably evolved with successful results. Although PELD has gained popularity for the treatment of herniated disc (HD), the risk of surgical failure may be a major obstacle to performing PELD. We analyzed unsuccessful cases requiring reoperation.

OBJECTIVE: To find common causes of surgical failure and elucidate the limitations of the conventional PELD technique.

METHODS: A retrospective review was performed on all patients who had undergone PELD between January 2001 and December 2012. Unsuccessful PELD was defined as a case requiring reoperation within 6 weeks after primary surgery. Chart review was done, and preoperative, intraoperative, and postoperative radiographic reviews were performed. All unsuccessful PELD cases were classified according to the type of HD, location of herniation, extruded disc migration, working channel position, and intraoperative and postoperative findings.

RESULTS: In 12 years, 10 228 patients had undergone PELD; 436 (4.3%) cases were unsuccessful. The causes were incomplete removal of HDs in 283 patients (2.8%), recurrence in 78 (0.8%), persistent pain even after complete HD removal in 41 (0.4%), and approach-related pain in 21 (0.2%). Incomplete removal of the HD was caused by inappropriate positioning (95 cases; 33.6%) of the working channel and occurred in central HDs (91 cases; 32.2%), migrated HDs (70 cases; 24.7%), and axillary type HDs (63 cases; 22.3%).

CONCLUSION: Proper surgical indications and good working channel position are important for successful PELD. PELD techniques should be specifically designed to remove the disc fragments in various types of HD.

KEY WORDS: Incomplete removal, Percutaneous endoscopic lumbar discectomy, Recurrence, Reoperation

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Percutaneous endoscopic lumbar discectomy (PELD) is a minimally invasive spinal technique that has several advantages over open discectomy, including less paravertebral muscle injury, preservation of bony structure, and rapid recovery. PELD has gained popularity for removal of herniated disc (HD) material over the past few years since Kambin[1] introduced the percutaneous posterolateral approach in 1983. Despite the remarkable evolution of endoscopic techniques and instrumentation leading to successful outcomes comparable to conventional open surgery,[2-4] surgeons still have some difficulty in PELD. Most concerns are about the incomplete removal of disc fragments, a steep learning curve, recurrence, and radiation exposure.[5-7] The risk of surgical failure may be a major obstacle to performing PELD. We analyzed unsuccessful cases requiring reoperation. The purpose of this study was to find the common causes of surgical failure and to elucidate the limitations of the conventional PELD technique. We also discuss techniques to address these limitations.

ABBREVIATIONS: HD, herniated disc; **PELD,** percutaneous endoscopic lumbar discectomy

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METHODS

This study was approved by our institutional review board. A retrospective review was performed on all patients who had undergone PELD between January 2001 and December 2012. This study included patients (1) with lumbar disc herniation at L1-2, L2-3, L3-4, L4-5, and L5-S1; (2) with intracanal and extracanal (foraminal/extraforaminal) disc herniations; (3) undergoing transforaminal PELD alone; and (4) having preoperative and postoperative magnetic resonance image (MRI), computed tomography (CT) scan, and intraoperative radiography before discharge, with postoperative checkup 6 weeks later at an outpatient clinic. Exclusion criteria were as follows: (1) interlaminar PELD, (2) segmental instability, and (3) infection. Clinical outcomes were assessed by the Modified MacNab criteria (Excellent: no pain, no restriction of mobility, return to normal work and level of activity; Good: occasional nonradicular pain, relief of presenting symptoms, able to return to modified work; Fair: some improved functional capacity, still handicapped and/or unemployed; Poor: continued objective symptoms of root involvement, additional operative intervention needed at index level irrespective of length of postoperative follow-up).

Unsuccessful PELD was defined as a case requiring reoperation (open surgery or another PELD attempt) on the same side in the same level within 6 weeks after primary surgery. Recurrence was defined as a reherniation at the same level and side under radiological diagnosis despite a transient symptom-free period of at least 2 weeks, with an immediate postoperative MRI confirming the complete removal of herniated disc fragments. Postoperative analysis was done with a chart review and the evaluation of preoperative and postoperative MRIs and intraoperative radiography. Independent observers (K.-C.C. and L.A.S.) analyzed all unsuccessful cases according to the type of disc herniation; the location of the herniated disc on the axial view (central or paramedian), coronal view (shoulder or axillary), and sagittal view (high-grade or low-grade migration) on MRI; the position of the endoscopic working channel; and intraoperative and postoperative findings.

An inappropriate position of the endoscopic working channel was described as having the bevel-ended opening of the cannula verified below the posterior vertebral line (within the disc space) on lateral intraoperative fluoroscopic radiographs. On confirmation with anteroposterior intraoperative radiographs, it reveals the bevel-ended cannula position to be immediately below the main herniated disc mass (Figure 1). In this situation, removal of the extruded disc was almost impossible.

The location of herniation in relation to the pedicle and spinal canal was described either as central or paramedian. A higher herniation midline split ratio exceeding 60:40 placed the herniation in the paramedian group.[8] In paramedian HD, the herniated disc was classified as a shoulder or axillary type. An axillary type describes the herniated disc fragment location between the traversing nerve root and the thecal sac or nerve root.[9] A shoulder type describes the herniated disc fragment as located

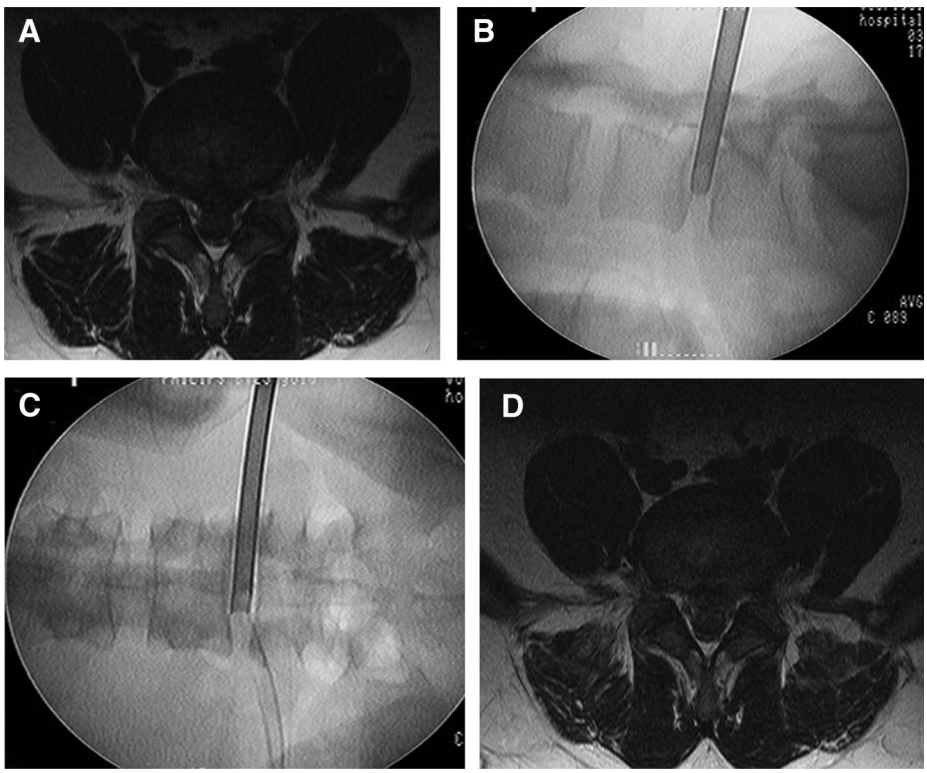

FIGURE 1. *Inappropriate working channel position. Central disc compressing nerve root (**A**), intraoperative fluoroscopy showing working channel within disc space (**B**) and anteroposterior fluoroscopy showing the bevel opening at the midline (**C**), and after PELD, the central disc still remained (**D**). PELD, percutaneous endoscopic lumbar discectomy.*

TABLE 1. Causes of Unsuccessful PELD[a]

Cause of Unsuccessful PELD	No. of Patients	Percentage of Unsuccessful PELD	Percentage of All PELD
Incomplete removal of HD	283	64.9	2.8
Recurrence	78	17.9	0.8
Persistent pain regardless of complete removal of HD	41	9.4	0.4
Approach-related pain	21	4.8	0.2
Postoperative hematoma	6	1.4	0.1
Neural injury	3	0.7	0
Miscellaneous	4	0.9	0
Total	436	100.0	4.3

[a]HD, herniated disc; PELD, percutaneous endoscopic lumbar discectomy.

lateral to traversing nerve root or underneath the medial to lateral part of a nerve root with a broad base. Herniated disc migration was described as a high-grade migration if the extent of migration was larger than the measured height of the posterior marginal disc space. On the other hand, migration of less than the measured height of the posterior marginal disc space was described as a low-grade migration.[10,11] Lateral recess stenosis was defined as lateral recess measurement of less than 3 mm on CT scan.[12] The Pfirrmann grading system of nerve root compromise due to disc herniation was used: grade 0 (normal), no compromise of the nerve root; grade 1 (contact), visible contact of disc with the nerve root; grade 2 (deviation), dorsal displacement of the nerve root by disc material; grade 3 (compression), compress nerve root by disc.[13] An incomplete removal of HD was defined as the deviation or compression of the nerve root after the initial PELD.

We compared all PELD cases with the cases of 3 surgeons (K.-C.C., J.-H.L., and J.-S.K.) having experienced more than 250 cases with teaching PELD in Korea Minimal Invasive Surgery Society. We performed statistical analyses using SPSS for Windows (version 12.0; SPSS, Inc, Chicago, IL). We used the χ^2 test for comparing the data of the 2 groups. The result was considered statistically significant if the *P* value was less than .05.

TABLE 2. Causes of Incomplete Disc Removal[a]

Causes of Incomplete Disc Removal	No. of Patients	Percentage
Incomplete disc removal	283	
Inappropriate working channel location	95	33.6
Central HD	91	32.2
Migrated HD	70	24.7
Low-grade cranial	3	1.1
Low-grade caudal	56	19.8
High-grade cranial	4	1.4
High-grade caudal	7	2.5
Axillary type HD	63	22.3
Shoulder type HD	18	6.4
Foraminal/extraforaminal HD	12	4.2

[a]HD, herniated disc.

Surgical Techniques

In all of the patients, the PELD procedure was performed under local anesthesia in the prone position. The patients communicated with the surgeon during the entire procedure. Skin entry point was usually about 8 to 13 cm from the midline. The point depends on the patient's body size, location of the herniated disc, and foraminal dimension. After infiltration of the entry point with local anesthetics, an 18-gauge spinal needle was introduced under fluoroscopic guidance. The needle tip was positioned at 1 point of the medial-to-lateral pedicular line on the anteroposterior fluoroscopic projection and at the posterior vertebral line on the lateral projection. Next, an epidurogram was performed by using contrast media to confirm the location of the exiting root and the traversing root. After inserting the spinal needle into the disc, the nucleus pulposus was stained blue with a 1-mL mixture of contrast media and indigo carmine for discography. Then the following steps were performed: (1) a guide wire was inserted through the spinal needle, (2) the spinal needle was removed, (3) a small incision was made in the skin at the entry site, (4) a tapered cannulated obturator was inserted along the guide wire, (5) after touching the annulus, the obturator was inserted into the disc by hammering, and, last (6), a bevel-ended, oval-shaped working cannula was inserted into the disc along the obturator after which the obturator was removed. Next, an endoscope was inserted through the cannula. The pathological nucleus was stained for easy discrimination. The blue-stained disc was removed using endoscopic forceps and a side firing, holmium:yttrium-aluminum-garnet laser using the "in and out" technique by working from the central portion to the lateral portion of the disc space on the anteroposterior image. The inflamed nucleus was observed as being anchored by the annular fissure. The herniated disc and fibrotic scar tissues were released and removed by the use of endoscopic forceps and a side-firing the holmium:yttrium-aluminum-garnet laser. After the herniated fragment was completely removed, the endoscope was removed (See **Video**, **Supplemental Digital Content**, http://links.lww.com/NEU/A707).

RESULTS

In the span of 12 years, 11 118 patients had undergone PELD. This study included 10 228 patients who had undergone transforaminal PELD. The remaining 890 patients excluded from this study were 733 patients who had undergone interlaminar PELD and 157 patients who were not checked up postoperatively or whose postoperative MRI was not verified or available. According to their levels, there were 31 cases at L1-2, 171 cases at L2-3, 602 cases at L3-4, 7499 cases at L4-5, and 1925 cases at L5-S1. There were 6451 men and 3777 women with a mean age of 39.9 years (range, 20-59). The mean operation was 50 minutes, ranging from 30 minutes to 90 minutes. The mean hospital stay was within 1 day. Forty-two different endoscopic surgeons treated the patients. Based on modified MacNab criteria, the outcomes were rated as excellent 48% (4910), good 42% (4295), fair 5.2% (532), and poor 4.8% (491). Four hundred thirty-six patients (4.3%)

TABLE 3. Comparison of Revisional Operation in All Cases and 3 Teaching Surgeons[a]

	42 Surgeons		3 Teaching Surgeons		*P* Value
	n	%	n	%	
No. of operations	10 228		1009		
Revision	436	4.3	29	2.9	.04
Incomplete removal of HD	283	2.8	17	1.9	.04
Recurrence	78	0.8	9	0.9	.66
Persistent pain regardless of complete removal of HD	41	0.4	2	0.2	.43
Approach-related pain	21	0.2	1	0.1	.72
Cause of incomplete removal of HD	283		17		
Inappropriate working channel location	95	33.6	3	17.6	.17
Central disc herniation	91	32.2	4	23.5	.46
Migrated HD	70	24.7	7	41.2	.15
Axillary type HD	63	22.3	2	11.8	.54
Shoulder type HD	18	6.4	2	11.8	.32
Foraminal/extraforaminal HD	12	4.2	1	5.9	.54
Recurrent HD	11	3.9	1	5.9	.51

[a]HD, herniated disc.

underwent reoperation within 6 weeks after surgery. After initial PELD for lumbar disc herniation, the patients required revision surgery for the following reasons: persistent preoperative symptoms, aggravated pain, or development of neurological deficit. Open discectomy was done in 326 (74.8%) patients, fusion in 2 (0.5%) patients, and repeat PELD in 108 (24.8%) patients. According to the revised levels, there were 5 patients at L1-2, 10 patients at L2-3, 34 patients at L3-4, 313 patients at L4-5, and 74 patients at L5-S1. The mean period of revision was 9.3 days (range, 0-42 days). There were 283 (2.8%) cases with incomplete removal of herniated disc material, 78 (0.8%) with recurrence, 41 (0.4%) with persistent pain regardless of the complete removal of HD, 21 (0.2%) with conversion to open surgery because of approach-related pain, 6 (0.1%) with postoperative epidural hematoma, and 3 with neural injuries (Table 1). Of the patients with persistent pain, 26 (63.4%) had radiographically verified complete herniated disc removal with concomitant lateral recess stenosis. Among the 283 cases with incomplete removal of HD, technically inappropriate positioning of the working channel was the main reason (95 cases; 33.6%) for the incomplete removal. The herniated disc materials in these cases were classified as central disc herniations (91 cases, 32.2%), migrated discs (70 cases, 24.7%), axillary type HDs (63 cases, 22.3%), shoulder type HDs (18 cases, 6.4%), and foraminal/extraforaminal HDs (12 cases, 4.2%). The migrated discs include low-grade cranially migrated (3 cases, 1.1%), low-grade caudally migrated (56 cases, 19.8%), high-grade cranially migrated (4 cases, 1.4%), and high-grade caudally migrated (7 cases, 2.5%; Table 2).

Comparing all cases with the 3 teaching surgeons, the rates of early revision surgery and incomplete removal of HD were lower in the 3 teaching surgeons (P = .04, Table 3).

DISCUSSION

Reoperation rates of PELD have been reported from 2.3% to 15%.[14-18] According to a nationwide cohort study, there is no significant difference in the reoperation rates between open discectomy (13.7%) and endoscopic discectomy (12.4%).[19] The authors have also reported that early reoperation rates (<3 months) were similar between the 2 groups. However, some authors reported that endoscopic discectomy has a shorter reoperation interval than open discectomy.[5]

Our experience of 10 228 cases done in a single center shows that the unsuccessful surgical rate of PELD was 4.3%. The common causes were incomplete removal of herniated disc material (2.8%) and early recurrence (0.8%). Inappropriate positioning of the working channel, herniated disc type, and migration characteristics of herniated discs influenced surgical outcomes.

The key step of PELD is to position the working channel near the herniated mass. If the working cannula is located inside the nucleus pulposus with a steep trajectory angle, the ruptured disc in the epidural space is not accessible and cannot be removed (Figure 1). This problem happens frequently to the neophyte practitioners of PELD and can be reduced with acquiring experience. In the case of foraminal narrowing due to facet hypertrophy and L5-S1 intracanal disc herniation, there is a high possibility of the occurrence. The location of the fixed working cannula, which is far from hernia mass, due to the narrow foramen and disc space, and overlying iliac bone, makes it difficult to remove the herniated disc material. In intracanal disc herniation, during the needling step, the final target point of the spinal needle is the medial pedicular line on the anteroposterior image and the posterior vertebral line on the lateral image. However, if the

spinal needle is on the medial pedicular line on anteroposterior view and the needle tip is located within disc space on lateral view, foraminal widening technique may be needed if blocked by the iliac crest or by hypertrophy of the facet joints.[20] The superior facet is undercut a little by a bone reamer or bone cutter.[21] Choi et al[20] reported that 40% of transforaminal PELD at the L5-S1 level required a foraminoplasty to gain access in the level of the disc herniation.

A conventional "inside-out technique" has more than 25° approach angle. The technique involves an intradiscal working channel that utilizes a cavity through annulotomy opening with the use of biting forceps, but this technique has a limited removal of the epidural disc fragment in the central portion of the herniated disc (Figure 2). In cases of centrally located disc herniations, the bevel-ended cannula should be located in the midline on anteroposterior view as well as in between the epidural space and intra-annular portion on the lateral view in intra-operative fluoroscopic guidance resulting in a relatively shallow angle.[22] This approach provides direct access to the annular defect site where the pathological disc fragment can be readily found.

An axillary type of disc herniation is a common cause of incomplete removal of herniated disc material. Although axillary type disc herniations may seem to be removed easily by conventional PELD, there are actually remaining herniated disc fragments located in the epidural space compressing the traversing nerve root in our cases. What is usually removed are the subannular disc protrusions within the disc space (Figure 3). There are 3 important points to remember. First, it is necessary to do adequate release of the entire disc fragment from the annulus

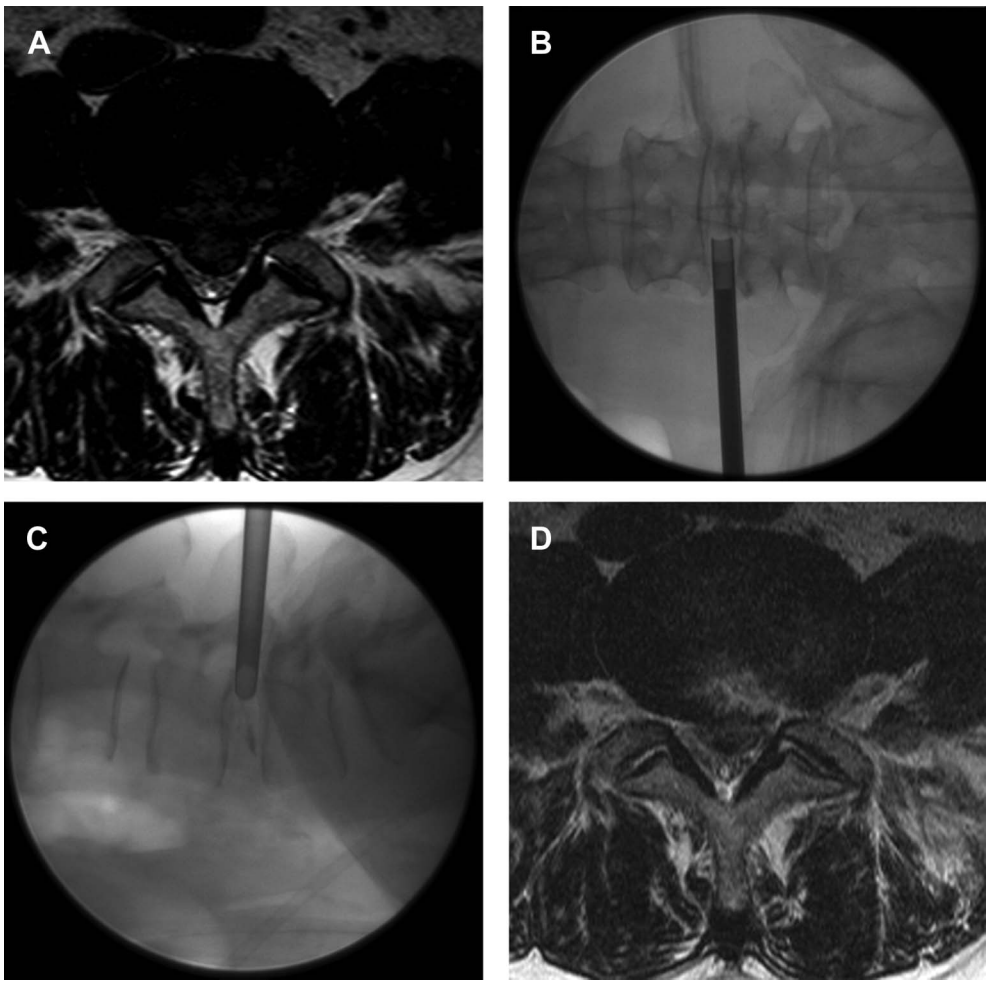

FIGURE 2. *Central disc herniation. Central disc herniation compressing the thecal sac and nerve root (A), bevel opening is located between medial pedicle and midline (B), as well as between epidural space and disc space (C), and the epidural extruded disc still remained with removal of the subannular disc (D).*

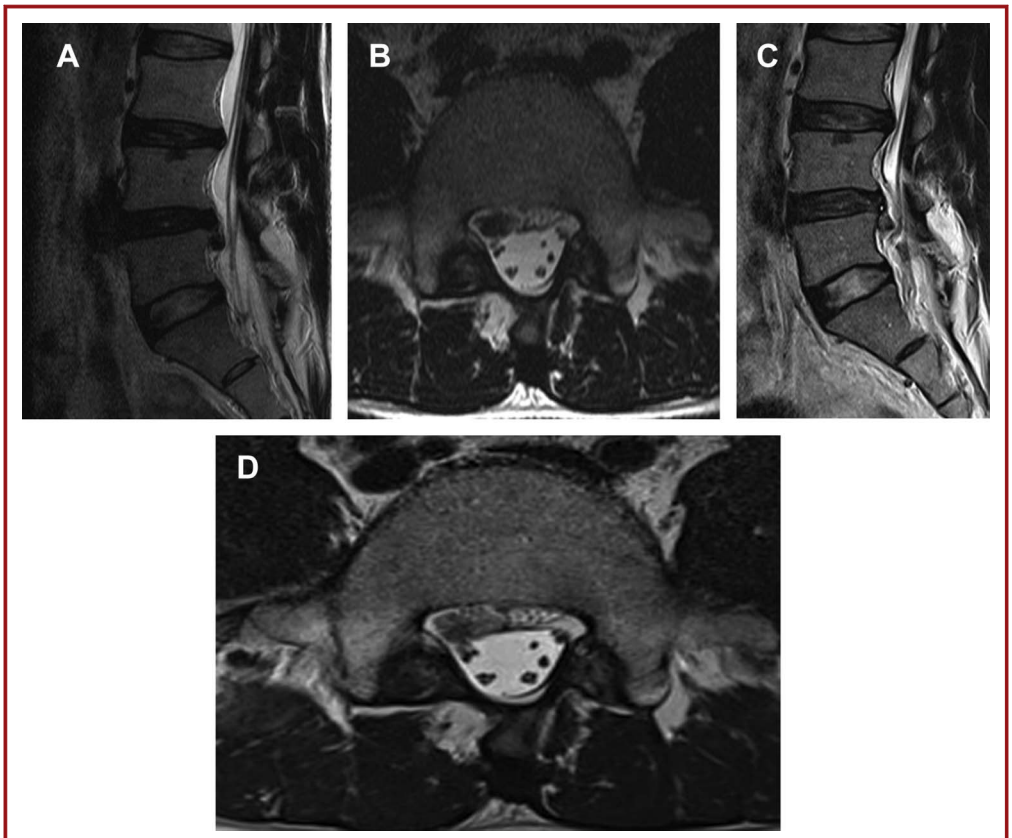

FIGURE 3. *Axillary type disc herniation. Axillary type disc fragment compressing the nerve root with low-grade caudal migration (**A**, **B**); postoperative MR showing axillary disc fragment still remaining with the removal of the subannular disc (**C**, **D**).*

before grasping the tail or tip of the herniated disc and pulling it out. If this is not done, an epidural disc fragment remnant will remain when the intradiscal portion of the herniation is pulled out. Second, the herniated disc removal is to be done at the level of the bevel cannula opening. For example, in the case of an axillary-located disc with a downward migrated fragment, the fragment can be covered by the working cannula bevel. When the working cannula bevel is rotated and opens caudally, we should carefully search for the herniated disc fragment in the epidural space. Third, it is not uncommon to have multiple disc fragments in a disc herniation. It may be possible to have some retained fragments while some have been removed.

In cases of a high-grade migrated HD, the use of the conventional PELD technique may result in the difficulty of the removal of a migrated HD (Figure 4).[11] Migrated discs are considered inaccessible by conventional PELD techniques because of rigid instrumentation, poor visualization, and the inability to reach and grasp herniated fragments. Occasionally, it is possible for conventional PELD to remove the whole migrated disc by grasping the tip of the disc fragment. However, this technique does not guarantee complete removal in high-grade disc migration. In caudally migrated discs, foraminal widening through removal of the superior part of facet is needed to expose the anterior epidural space.[23] For cranially migrated discs, the working channel can directly access the target lesion in the epidural space without annulus penetration. Choi et al[24] described a procedure in which the cannula was initially positioned at the lower part of the disc and gradually shifted upward. Percutaneous endoscopic technique for migrated disc is technically demanding and can be affected by the surgeon's experience. Yeung and Tsou[25] suggested that 70° wide angle endoscope makes it possible to find hidden epidural migrated disc fragments. Choi et al[26] introduced the MRI-equipped operative suite-assisted PELD for concerns about surgical failure, especially highly migrated disc. They could confirm complete decompression in the operating room immediately after PELD.

Concomitant persistent pain was commonly caused by surgically unappreciated disc fragments, concurrent lateral recess stenosis, nerve root injury, epidural hematoma, and nerve root edema regardless of the complete removal of the herniated disc in the postoperative MR. Concurrent lateral recess stenosis is associated with poor prognosis.[14] Lateral recess bony stenosis

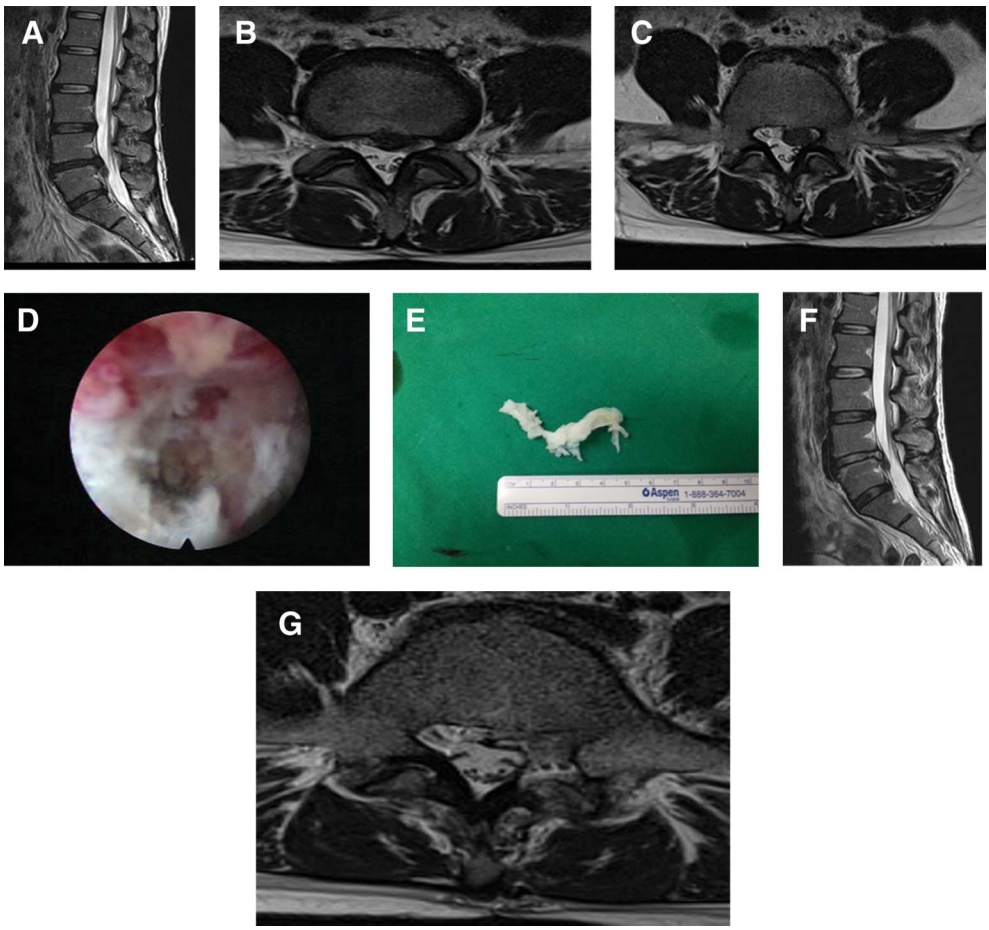

FIGURE 4. *Migrated disc herniation. Ruptured disc migrating downward (**A**, **B**, **C**), intraoperative endoscopic view (**D**) showing removal of the subannular disc and decompression of neural tissue, removed disc fragment (**E**) during the PELD, postoperative MR (**F**) showing migrated disc still remaining, and remnant disc was removed by revision open surgery (**G**). PELD, percutaneous endoscopic lumbar discectomy.*

can be addressed with a separate decompression procedure. These problems can be solved by open surgery. In our study, 63.4% of patients with persistent pain were associated with lateral recess stenosis.

PELD under local anesthesia potentially limits neural injury, although some authors perform PELD safely under general anesthesia.[2,17] Sometimes PELD can be converted to open surgery owing to approach-related pain. Irritation of the exiting nerve root and dorsal root ganglion can cause severe leg pain. In this situation, if the irritation symptom occurs, the surgeons try to adjust the entry point and trajectory, and then stop the procedure if the pain persists. Postoperative dysesthesia is one of the significant sequelae and affects the patient's daily life negatively. Some authors suggest that the technique of not penetrating the annulus can minimize the exiting nerve irritation.[27] Measurement of the preoperative distance from exiting nerve root to facet at the lower disc level helps to avoid exiting nerve root injury.[28] In performing the discogram or the working cannula insertion, when the needle touches or penetrates into the annulus, severe pain may occur. If there is poor patient pain tolerance, the procedure should be discontinued, otherwise the use of serial dilation or a preemptive epidural block to diminish the pain can be done.

The early recurrence rate was 0.8% in our study (Figure 5). PELD recurrence rates are reported to range from 0% to 7.4%.[2,18,23,29-31] Recurrence rates after open discectomy have been reported to range from 1% to 21%.[32,33] Several studies showed no difference in recurrence rates between PELD and open discectomy.[5,19] Some authors reported that real recurrent herniation requiring reoperation is higher after PELD than after open discectomy. In 1 study, the early recurrence (<6 months) rates have been shown to be more than 50% in PELD.[5] Surgically

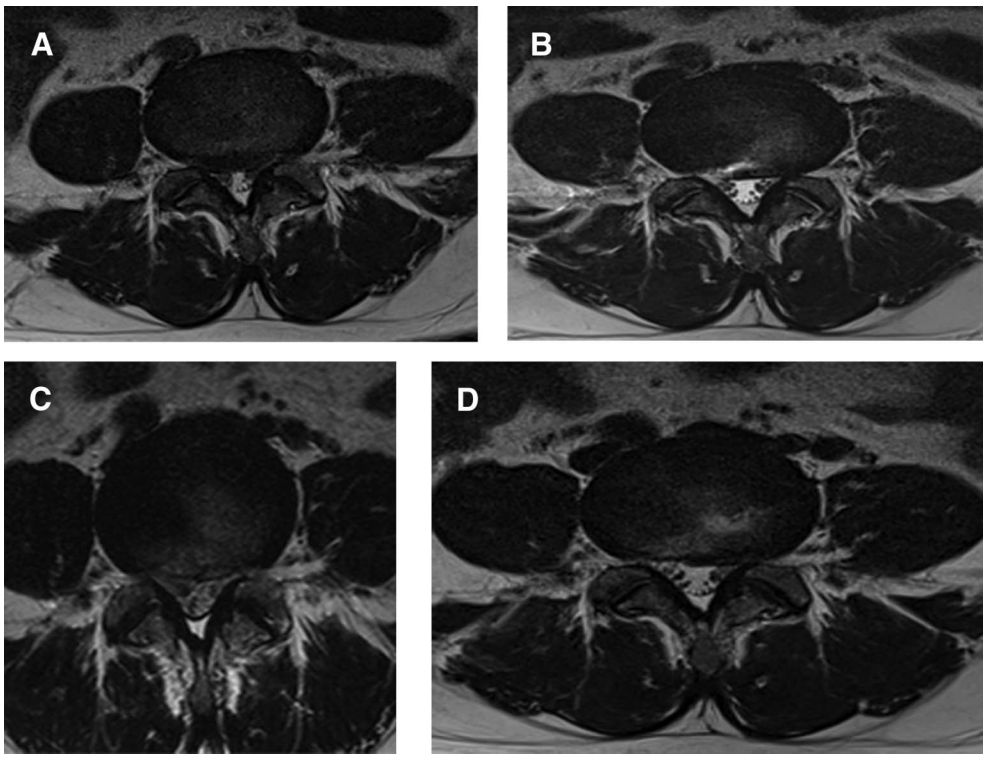

FIGURE 5. *Recurrence. Paramedian disc compressing L5 nerve root (A), after PELD, complete removal of disc (B), 3 weeks later, MR showing reherniation at the same site (C), after revision PELD, showing complete removal of the disc fragment (D). PELD, percutaneous endoscopic lumbar discectomy.*

unappreciated disc fragment remnants and incomplete decompression by piecemeal removal may lead to a higher early recurrence. To reduce recurrence rates, complete removal of herniated mass is required including the basal and extruded parts.[34]

PELD technique and experience can affect success of PELD. During the steep learning curve phase, longer operation times are required and the incidence of complication may be higher than those by experienced surgeons.[35,36] Experienced surgeons can also expand the indications of PELD for applications in various strategic indications.[20-24]

Ahn et al[7] reported that radiation exposure time was 2.5 minutes during the PELD in the author's institute. They suggested that 5000 PELD cases can be performed per year using radiation shielding clothes and 291 PELD cases can be performed without shielding clothes.

Limitations

This study has some limitations. First, it was a retrospective review. Second, there was no control group. If this study had a control group, a comparative study would have provided a clearer elucidation of the answers.

CONCLUSION

Although the PELD technique has evolved remarkably, successful PELD requires techniques tailor-made to remove the herniated disc fragments in various types of disc herniations such as central, axillary, or migrated disc herniations. Accurate positioning of the working channel should be considered depending on the location of the disc and its fragments. Experienced surgeons have fewer revisions.

Disclosures

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REFERENCES

1. Kambin P, Gellman H. Percutaneous lateral discectomy of the lumbar spine: a preliminary report. *Clin Orthop.* 1983;174:127-132.
2. Ruetten S, Komp M, Merk H, Godolias G. Full-endoscopic interlaminar and transforaminal lumbar discectomy versus conventional microsurgical technique: a prospective, randomized, controlled study. *Spine (Phila Pa 1976).* 2008;33(9):931-939.
3. Lee DY, Shim CS, Ahn Y, Choi YG, Kim HJ, Lee SH. Comparison of percutaneous endoscopic lumbar discectomy and open lumbar microdiscectomy for recurrent disc herniation. *J Korean Neurosurg Soc.* 2009;46(6):515-521.

4. Lee SH, Chung SE, Ahn Y, Kim TH, Park JY, Shin SW. Comparative radiologic evaluation of percutaneous endoscopic lumbar discectomy and open microdiscectomy: a matched cohort analysis. *Mt Sinai J Med.* 2006;73(5):795-801.
5. Cheng J, Wang H, Zheng W, et al. Reoperation after lumbar disc surgery in two hundred and seven patients. *Int Orthop.* 2013;37(8):1511-1517.
6. Wang H, Huang B, Li C, et al. Learning curve for percutaneous endoscopic lumbar discectomy depending on the surgeon's training level of minimally invasive spine surgery. *Clin Neurol Neurosurg.* 2013;115(10):1987-1991.
7. Ahn Y, Kim CH, Lee JH, Lee SH, Kim JS. Radiation exposure to the surgeon during percutaneous endoscopic lumbar discectomy: a prospective study. *Spine (Phila Pa 1976).* 2013;38(7):617-625.
8. Yeung AT, Tsou PM. Posterolateral endoscopic excision for lumbar disc herniation: surgical technique, outcome, and complications in 307 consecutive cases. *Spine (Phila Pa 1976).* 2002;27(7):722-731.
9. McCulloch JA, Young PH. Musculoskeletal and neuroanatomy of the lumbar spine. In: McCulloch JA, Young PH, eds. *Essentials of Spinal Microsurgery*. Philadelphia, PA: Lippincott-Raven; 1998:249-292.
10. Fardon DF, Milette PC. Nomenclature and classification of lumbar disc pathology. Recommendations of the Combined task Forces of the North American spine Society, American Society of spine Radiology, and American Society of Neuroradiology. *Spine (Phila Pa 1976).* 2001;26(5):E93-E113.
11. Lee SH, Kang BU, Ahn Y, et al. Operative failure of percutaneous endoscopic lumbar discectomy: a radiologic analysis of 55 cases. *Spine (Phila Pa 1976).* 2006; 31(10):E285-E290.
12. Ciric I, Mikhael MA. Lumbar spinal-lateral recess stenosis. *Neurol Clin.* 1985;3(2): 417-423.
13. Pfirrmann CW, Dora C, Schmid MR, Zanetti M, Hodler J, Boos N. MR image-based grading of lumbar nerve root compromise due to disk herniation: reliability study with surgical correlation. *Radiology*. 2004;230(2):583-588.
14. Ahn Y, Lee SH, Park WM, Lee HY, Shin SW, Kang HY. Percutaneous endoscopic lumbar discectomy for recurrent disc herniation: surgical technique, outcome, and prognostic factors of 43 consecutive cases. *Spine (Phila Pa 1976).* 2004;29(16): E326-E332.
15. Hoogland T, van den Brekel-Dijkstra K, Schubert M, Miklitz B. Endoscopic transforaminal discectomy for recurrent lumbar disc herniation: a prospective, cohort evaluation of 262 consecutive cases. *Spine (Phila Pa 1976).* 2008;33(9): 973-978.
16. Kambin P. Arthroscopic microdiscectomy. *Arthroscopy*. 1992;8(3):287-295.
17. Ruetten S, Komp M, Godolias G. An extreme lateral access for the surgery of lumbar disc herniations inside the spinal canal using the full-endoscopic uniportal transforaminal approach-technique and prospective results of 463 patients. *Spine (Phila Pa 1976).* 2005;30(22):2570-2578.
18. Mayer HM, Brock M. Percutaneous endoscopic discectomy: surgical technique and preliminary results compared to microsurgical discectomy. *J Neurosurg.* 1993; 78(2):216-225.
19. Kim CH, Chung CK, Park CS, Choi B, Kim MJ, Park BJ. Reoperation rate after surgery for lumbar herniated intervertebral disc disease: nationwide cohort study. *Spine (Phila Pa 1976).* 2013;38(7):581-590.
20. Choi KC, Kim JS, Ryu KS, Kang BU, Ahn Y, Lee SH. Percutaneous endoscopic lumbar discectomy for L5-S1 disc herniation: transforaminal versus interlaminar approach. *Pain Physician.* 2013;16(6):547-556.
21. Lee SH, Kang HS, Choi G, et al. Foraminoplastic ventral epidural approach for removal of extruded herniated fragment at the L5-S1 level. *Neurol Med Chir (Tokyo).* 2010;50(12):1074-1078.
22. Lee SH, Choi KC, Baek OK, Kim HJ, Yoo SH. Percutaneous endoscopic intra-annular subligamentous herniotomy for large central disc herniation: a technical case report. *Spine (Phila Pa 1976).* 2014;39(7):E473-E479.
23. Lee S, Kim SK, Lee SH, et al. Percutaneous endoscopic lumbar discectomy for migrated disc herniation: classification of disc migration and surgical approaches. *Eur Spine J.* 2007;16(3):431-437.
24. Choi G, Lee SH, Lokhande P, et al. Percutaneous endoscopic approach for highly migrated intracanal disc herniations by foraminoplastic technique using rigid working channel endoscope. *Spine (Phila Pa 1976).* 2008;33(15):E508-E515.
25. Yeung AT, Tsou PM. Posterolateralendoscopicexcision for lumbar disc herniation: surgical technique, outcome, and complications in 307 consecutive cases. *Spine (Phila Pa 1976).* 2002;27(7):722-731.
26. Choi G, Modi HN, Prada N, et al. Clinical results of XMR-assisted percutaneous transforaminal endoscopic lumbar discectomy. *J Orthop Surg Res.* 2013;8:14.
27. Cho JY, Lee SH, Lee HY. Prevention of development of postoperative dysesthesia in transforaminal percutaneous endoscopic lumbar discectomy for intracanalicular lumbar disc herniation: floating retraction technique. *Minim Invasive Neurosurg.* 2011;54(5-6):214-218.
28. Choi I, Ahn JO, So WS, Lee SJ, Choi IJ, Kim H. Exiting root injury in transforaminal endoscopic discectomy: preoperative image considerations for safety. *Eur Spine J.* 2013;22(11):2481-2487.
29. Hoogland T, Schubert M, Miklitz B, Ramirez A. Transforaminal posterolateral endoscopic discectomy with or without the combination of a low-dose chymopapain: a prospective randomized study in 280 consecutive cases. *Spine (Phila Pa 1976).* 2006;31(24):E890-E897.
30. Choi KC, Kim JS, Kang BU, Lee CD, Lee SH. Changes in back pain after percutaneous endoscopic lumbar discectomy and annuloplasty for lumbar disc herniation: a prospective study. *Pain Med.* 2011;12(11):1615-1621.
31. Jang JS, An SH, Lee SH. Transforaminal percutaneous endoscopic discectomy in the treatment of foraminal and extraforaminal lumbar disc herniations. *J Spinal Disord Tech.* 2006;19(5):338-343.
32. Rogers LA. Experience with limited versus extensive disc removal in patients undergoing microsurgical operations for ruptured lumbar discs. *Neurosurgery*. 1988;22(1 pt 1):82-85.
33. Wera GD, Marcus RE, Ghanayem AJ, Bohlman HH. Failure within one year following subtotal lumbar discectomy. *J Bone Joint Surg Am.* 2008;90(1):10-15.
34. Ahn Y. Transforaminal percutaneous endoscopic lumbar discectomy: technical tips to prevent complications. *Expert Rev Med Devices.* 2012;9(4):361-366.
35. Wang H, Huang B, Li C, Zhang Z, Wang J, Zheng W. Learning curve for percutaneous endoscopic lumbar discectomy depending on the surgeon's training level of minimally invasive spine surgery. *Clin Neurol Neurosurg.* 2013;115(10): 1987-1991.
36. Lee DY, Lee SH. Learning curve for percutaneous endoscopic lumbar discectomy. *Neurol Med Chir (Tokyo).* 2008;48(9):383-388.

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COMMENTS

This is a very large retrospective study of over 10 000 patients who underwent percutaneous endoscopic lumbar discectomy (PELD) for symptomatic lumbar disc herniation. The primary purpose of the investigation was to determine causes for failure and discuss limitations of the PELD approach with a subsequent discussion on techniques to mitigate the common reasons for failure. Overall rate of failure was 4.3%; however, this was based on their specific criteria encompassing the need for re-operation within 6 weeks of the index surgery. An anticipated and unsurprising finding was that experienced surgeons had significantly less failures mostly due to more complete disc removals. The authors' recommendations on methods to minimize incomplete disc resections based on location of the disc herniation are insightful and reflective of their extensive experience.

Paul Park
Ann Arbor, Michigan

The authors analyze the outcome after PELD surgery in 10 228 patients at a single institution over 12 years. They review the results of 42 surgeons performing the technique. In their study, they observe a 4.3% reoperation rate which was defined as the need for revision surgery within 6 weeks after the initial surgery. The main indications for revision surgery were incomplete removal of the herniated disk and technique related issues. Reoperated disks were treated with repeat PELD in about 3/4 of the cases, with an additional 1/4 revised as an open diskectomy. They spend a considerable

time identifying the anatomy and location of disk herniations and the optimal techniques using PELD to achieve success. Their study demonstrates that PELD can be performed successfully but that experience matters.

Daniel Refai
Atlanta, Georgia

This is a very large and comprehensive study of 10 228 patients from a single institution that underwent percutaneous endoscopic lumbar discectomy (PELD) over a 12 year period. The authors review the relevant anatomy of the procedure and add in insights from their vast experience. They define failure of the primary procedure (4.3%) if repeat surgery was necessary within 6 weeks of the first operation. They indicate that such patients could still undergo successful repeat PELD (75%) and conversion to open surgery (25%). It is evident from their discussion and personal experience that appreciation for anatomic variations and the completeness of disc removal in the primary operation are important to prevent recurrences. The experience of the operating surgeon is paramount in this regard. Their insights to the reader in techniques to reduce recurrences are thoughtful and practical. They are to be commended on their excellent work.

Shekar N. Kurpad
Milwaukee, Wisconsin

CME QUESTIONS:

1. What factor is associated with increased re-operation rates after percutaneous endoscopic lumbar discectomy (PELD)?
   A. Performing surgery using only local anesthesia
   B. Decompressing the annulus prior to the herniated mass.
   C. High-grade whole migrated discs
   D. Positioning the working channel near the herniated mass.
   E. Central disc herniation
2. Following percutaneous endoscopic lumbar discectomy procedure (PLED), what factor is correlated with approach-related nerve injury and pain?
   A. Completely penetrating the annulus with the working channel
   B. Central disc herniation
   C. Lateral recess stenosis
   D. Partially penetrating the annulus with the working channel
   E. Multiple disc fragments
3. During a percutaneous lumbar discectomy procedure (PLED) under local anesthesia, a patient experiences a persistent severe leg pain. What is the most appropriate next action?
   A. Abort the procedure
   B. Convert PLED to open discectomy
   C. Administer more analgesics
   D. Adjust the entry point and trajectory
   E. Convert to general anesthesia