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ORIGINAL ARTICLE

Exiting root injury in transforaminal endoscopic discectomy: preoperative image considerations for safety

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Abstract
Purpose To evaluate the clinical and radiological risk factors for exiting root injuries during transforaminal endoscopic discectomy.
Methods We retrospectively examined cohort data from 233 patients who underwent percutaneous endoscopic lumbar discectomy for lumbar disc herniation between January 1st, 2010 and December 31st, 2011. We divided the patients into the two groups: those who presented a postoperative exiting root injury, such as postoperative dysesthesia or motor weakness (Group A, $n = 20$), and those who did not suffer from a root injury (Group B, $n = 213$). We examined the clinical and radiological factors relating exiting root injuries. We measured the active working zone with the exiting root to the upper facet distance (Distance A), the exiting root to disc surface distance at the lower facet line (Distance B) and the exiting root to the lower facet distance (Distance C) in magnetic resonance imaging (MRI).
Results Group A exhibited a shorter Distance C (6.4 ± 1.5 versus 4.4 ± 0.8 mm, $p < 0.001$) and a longer operation time (67.9 ± 21.8 versus 80.3 ± 23.7 min, $p = 0.017$) relative to Group B. The complication rate decreased by 23 % per each 1-mm increase in Distance C ($p = 0.000$). In addition, the complication rate increased 1.027-fold per each 1-min increase in the operation time ($p = 0.027$).
Conclusion We recommend measuring the distance from the exiting root to the facet at the lower disc level according to a preoperative MRI scan. If the distance is narrow, an alternative surgical method, such as micro-discectomy or conventional open discectomy, should be considered.

Keywords Endoscopy · Discectomy · Root injury · Working zone

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Introduction

In 1973, Kambin [1] introduced the concept of achieving decompression of the spinal canal via a posterolateral approach. With advances in instrumentation, including endoscopes and the side-firing Ho:YAG laser, the range of indications for posterolateral endoscopic lumbar discectomy (PELD) has expanded [2–7]. Consequently, since the 1980s, many acceptable and favourable surgical outcomes for PELD have been reported [8–10]. However, perioperative complications, such as neurovascular structure injuries and internal abdominal injuries, hamper a more widespread use of PELD. In particular, postoperative dysesthesia (POD) and motor weakness due to an exiting root injury can reduce the physical function and overall satisfaction of the patient. This injury hinders rapid recovery and delays the return to daily work [11]. POD and motor weakness are closely related to exiting root injuries, which in turn are associated with the needle insertion anatomy of endoscopic discectomy. From the anatomical perspective, the exiting root forms the hypotenuse of the working zone. Two cadaveric studies performed normal morphometric analyses of the working zone [12, 13]. We hypothesise that exiting injuries are closely related to the working zone morphology. However, the working zone has not previously been evaluated using MRI prior to surgery. Our study aimed to evaluate the clinical and radiological risk factors for exiting root injuries during transforaminal endoscopic discectomy.

Materials and methods

Study design

A total of 2,146 patients were admitted to The Armed Forces Capital Hospital for lumbar disc herniation between January 1, 2010 and December 31, 2011. All of these individuals were Korean military servicemen who were seeking treatment for lumbar disc herniation. We treated 1,442 of the 2,146 patients using conservative methods: physical therapy, epidural or selective root block and medication. In 704 patients, surgical treatment was applied. The surgical intervention methods included microdiscectomy (399 patients) and endoscopic discectomy (305 patients). Two approach methods were selected for the endoscopic procedures (interlaminar in 72 cases and transforaminal in 233 cases). Finally, a total of 233 patients who underwent transforaminal endoscopic discectomy were enrolled in the study. We divided these individuals into two groups according to whether they had an exiting root injury after surgery. Group A ($n = 20$) had exiting root injuries, such as dysesthesia or motor weakness and group B ($n = 213$) did not suffer from a root injury.

Patient populations

All of the patients were male and they ranged in age from 18 to 51 years (mean = 23 years). The duration of symptoms ranged from 1 to 124 weeks (mean = 24 weeks). All of the patients presented symptoms and confirmatory signs of lumbar radiculopathy, which matched the symptomatic disc level and findings of the imaging study. The inclusion criteria for PELD were the presence of soft lumbar disc herniations manifesting as radicular leg pain and/or back pain at the lower lumbar level, as demonstrated by MRI imaging. The exclusion criteria included the presence of spinal stenosis, segmental instability, discogenic back pain, calcified disc, cauda equina syndrome and pyogenic discitis

Table 1 Baseline demographic characteristics, following clinical and radiological patient findings

	Group A ($n = 20$)	Group B ($n = 213$)	p value
Age (mean of year)	23.2 ± 5.9	23.3 ± 5.1	0.928
Body mass index (kg/m^2)	24.0 ± 2.9	23.6 ± 3.0	0.595
Preoperative symptom (%)			
Back pain dominant	9 (45)	75 (35.4)	0.392
Radiating pain dominant	11 (55)	137 (64)	
Symptom duration (weeks)	28.1 ± 24.2	27.6 ± 19.4	0.919
Herniation location (%)			
Central	7 (35)	59 (27.7)	
Paracentral	10 (50)	119 (55.9)	0.786
Foraminal	3 (15)	35 (16.4)	
Herniation type (%)			
Contained	11 (55)	120 (56.3)	0.908
Non contained	9 (45)	93 (43.7)	
Herniation direction (%)			
Upward	0 (0)	6 (2.8)	0.734
Middle	15 (75)	151 (70.9)	
Downward	5 (25)	56 (26.3)	
Distance A (mm)	1.4 ± 0.8	1.8 ± 0.9	0.043*
Distance B (mm)	1.4 ± 0.6	1.6 ± 0.7	0.228
Distance C (mm)	4.4 ± 0.8	6.4 ± 1.5	<0.001*
Approach side (%)			
Right	12 (60)	101 (47.4)	0.282
Operative time (min)	80.3 ± 23.7	67.9 ± 21.8	0.017*

Group A had exiting root injury. Group B was free from exiting root injury

Distance A = the shortest distance between the root and facet surface at the upper disc margin level

Distance B = the shortest distance between the root and disc surface at the lower disc margin level

Distance C = the shortest distance between the root and facet surface at the lower disc margin level

Mean ± standard deviation or proportions of subjects are presented. Statistics were analysed by t test and Chi square test. * Significant ($p < 0.05$)

(Table 1). Two neurosurgeons reviewed the clinical charts, operative notes, neurophysiological data and neuroimaging studies.

Assessment of clinical and radiological findings

We examined the clinical and radiological factors. The clinical factors included age, preoperative symptoms, symptom duration, body height, weight, BMI and operative time. The radiological factors were determined using a preoperative MRI and included the symptomatic disc level, herniated disc location, herniated disc type and disc migration type. We also accessed the active working zone by measuring exiting root to upper facet distance, the exiting root to disc surface distance at the lower facet line and the exiting root to lower facet distance.

The radiological variables related to the working zone were defined as follows (Figs. 1, 2):

1. The exiting root to the upper facet distance (Distance A): the shortest distance between the root and facet surface at the upper disc margin level.
2. The exiting root to the disc surface distance at the lower facet line (Distance B): the shortest distance between the root and disc surface at the lower disc margin level.
3. The exiting root to the lower facet distance (Distance C): the shortest distance between the root and facet surface at the lower disc margin level.
4. A contained disc includes bulging or protrusion, and a non-contained disc includes extrusion or sequestration.

All of these radiological measurements were obtained twice by different observers.

Surgical techniques

The surgery was mainly a standard transforaminal endoscopic discectomy [14].The needle entry point was modified for the insertion angle. The rod-lens optics diameter was either 6.9 or 8.0 mm. The angle of vision was 25°. In addition, we used a side-firing, Holmium yttrium–aluminium-garnet (Ho:YAG) laser. We confirmed the complete decompression of the transverse nerve root and sac.

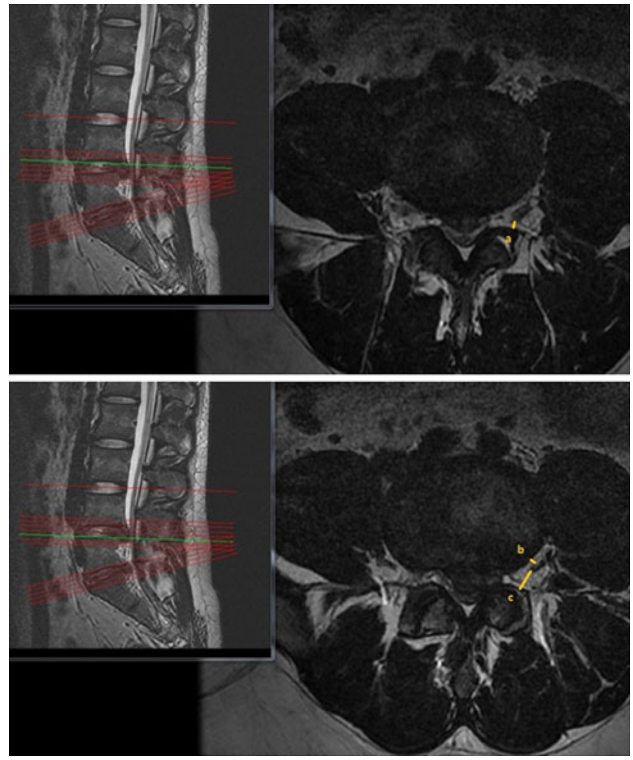

Fig. 2 The MRI showing working zone at the L4–5 disc level *a* the exiting root to the upper facet distance (Distance A): the shortest distance between the root and facet surface at the upper disc margin level, *b* the exiting root to disc surface distance at the lower facet line (Distance B): the shortest distance between the root and disc surface at the lower disc margin level and *c* the exiting root to the lower facet distance (Distance C): the shortest distance between the root and facet surface at lower disc margin level

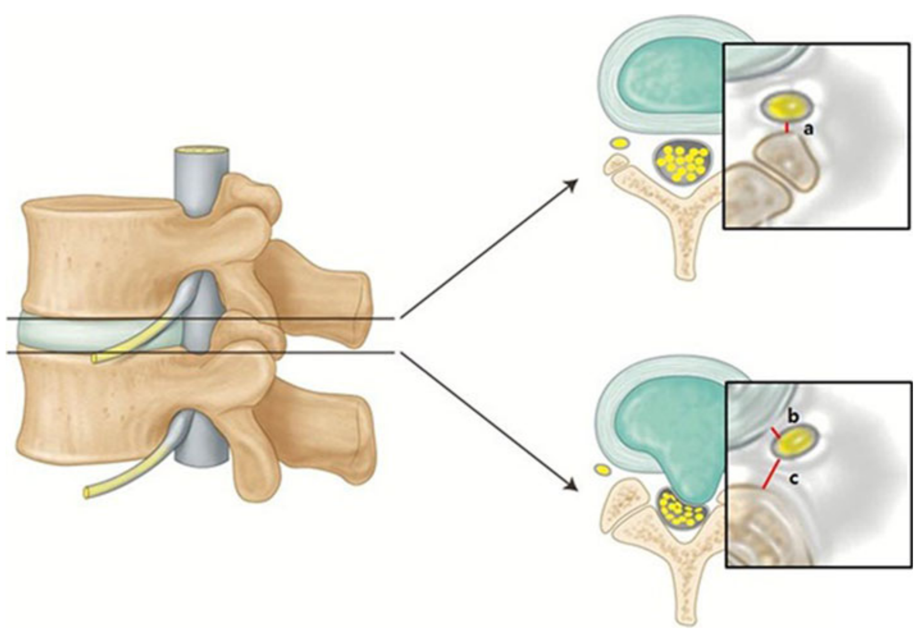

Fig. 1 A schematic illustration of structures in the photograph showing working zone; *a* the exiting root to the upper facet distance (Distance A): the shortest distance between the root and facet surface at the upper disc margin level, *b* the exiting root to disc surface distance at the lower facet line (Distance B): the shortest distance between the root and disc surface at the lower disc margin level and *c* the exiting root to the lower facet distance (Distance C): the shortest distance between the root and facet surface at lower disc margin level

Statistical analysis of the data

The data were imported into SPSS (version 12.0.1; SPSS Inc., Chicago, IL, USA) for analysis. Unpaired student's *t* tests and Chi square tests were used to examine the differences in age, BMI, preoperative symptom, symptom duration, herniation location, herniation type, herniation direction, Distances (A, B and C), approach side and operation time.

Analysis of variance (ANOVA) was used to compare the differences in Distances A and C, as well as the operation time. Univariate regression analysis was performed to assess the individual effects on exiting root injury of age, BMI, preoperative symptom, symptom duration, herniation location, herniation type, and herniation direction, Distance A, Distance B and Distance C. A stepwise multiple linear regression was then performed using a backward elimination to select an appropriate model, and a p value >0.05 was used for removal.

Results

The patients in Group A were further subdivided into those with POD and those with motor weakness. Among the 20 patients in Group A, 15 patients showed symptoms of POD. After 3–180 days (mean 54 days), the POD symptoms had fully dissipated. A further five patients in Group A displayed motor weakness grade 2–4. Although one patient was lost during the follow-up period, the remaining four patients showed full recoveries between day 4 and 240. Between Groups A and B, no significant differences were observed in the preoperative symptoms, symptom duration, body height, weight, BMI, herniated location, herniated disc type or disc migration. However, Group A had a significantly smaller Distance A (1.8 ± 0.9 versus 1.4 ± 0.8, $p = 0.043$) and Distance C (6.4 ± 1.5 versus

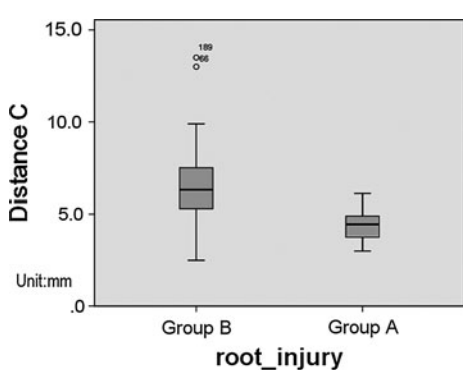

Fig. 3 The distribution of mean (±SE) Distance C according to the exiting nerve injury. Group A had exiting root injury. Group B was free from exiting root injury. *Distance C* the shortest distance between the root and facet surface at the lower disc margin level

4.4 ± 0.8, $p < 0.001$) (Fig. 3) and a longer operation time (67.9 ± 21.8 versus 80.3 ± 23.7, $p = 0.017$) relative to Group B (Table 1).

Group A was further subdivided into those with POD and those with motor weakness, such as foot drop. Among the POD and motor weakness groups of Group A, the operation time (67 ± 21 versus 76 ± 22 versus 92 ± 24, $p = 0.021$) and Distance C (6.4 ± 1.5 versus 4.5 ± 0.8 versus 4.1 ± 0.8, $p < 0.001$) were significantly different (Table 2). Finally, the complication rates were reduced by 23 % per each 1-mm increase in Distance C ($p = 0.000$). Furthermore, the complication rate increased 1.027-fold per each 1-min increase in the operation time ($p = 0.027$; Table 3).

Discussion

Microdiscectomy (MD) provides rapid relief from acute attacks and better outcomes up to a few years after surgery compared to conservative management for selected patients with sciatica due to lumbar nucleus prolapse [15–19]. The outcomes of endoscopic discectomy (ED) are comparable to those of MD [8, 10]. ED offers the significant advantage of being a minimally invasive surgery that can reduce tissue damage and hasten the return to daily life [20].

Two approach methods were used for endoscopic discectomy: the transforaminal and interlaminar approaches. These two methods have a complementary relationship. With the transforaminal approach, all of the lumbar spinal canals can be reached, but the osseous barrier of the foramen and the exiting nerve can limit the working mobility and the excision of herniated material [21, 22]. Moreover, the pelvis and the abdominal structures at the L5/S1 level may block access [23].The interlaminar approach was developed to enable the extirpation of pathological entities that were not successfully achieved using the transforaminal approach. However, a narrow interlaminar window and relatively low interlaminar windows compared with the disc space have limited the interlaminar approach. The interlaminar approach is only clearly preferable at the L5/S1 level. At all levels except L5/S1, the transforaminal approach is favoured [9].

Transforaminal ED suffers from several complications that preclude its widespread adoption among surgeons. These include the intraoperative injury to neural and vascular structures, perforation of the peritoneal sac and abdominal contents and failure of the surgery. In particular, POD and motor weakness (foot drop) are found in association with exiting root injuries. These exiting root injuries have been reported by <5 % of patients in published case series. The incidence of exiting root injury has been

Table 2 Comparison of variables having statically difference among three groups

	Normal ($n = 213$)	POD ($n = 15$)	Motor weakness ($n = 5$)	p value
Distance A (mm)	1.8 ± 0.9	1.3 ± 0.8	1.7 ± 0.7	0.094
Distance C (mm)	6.4 ± 1.5[a]	4.5 ± 0.8[a]	4.1 ± 0.8[b]	<0.001*
Operative time (min)	67 ± 21[a]	76 ± 22a[b]	92 ± 24[b]	0.021*

Distance A = the shortest distance between the root and facet surface at the upper disc margin level

Distance C = the shortest distance between the root and facet surface at the lower disc margin level

POD Postoperative dysesthesia

Statistical significances were tested by one-way analysis of variances among groups and Chi square test. The same letters indicate non-significant difference between groups based on Scheffe multiple comparison tests. * Significant ($p < 0.05$)

Table 3 Multivariate logistic regression results for predicting exiting root injury

	B	OR	p value	95 % CI
Distance A (mm)	0.231	1.259	0.542	0.601–2.641
Distance C (mm)	−1.468	0.230	0.000	0.123–0.432
Operative time (min)	0.027	1.027	0.027	1.003–1.051

Distance A = the shortest distance between the root and facet surface at the upper disc margin level

Distance C = the shortest distance between the root and facet surface at the lower disc margin level

OR odds ratio, *CI* confidence interval

Logistic regression model (backward elimination, if p value was above 0.05)

variably reported from 1.0 to 6.7 % [6, 9, 10, 13, 14, 24–26]. It is not a life-threatening complication. However, it is a complication that is related to the PELD itself. It prevents the patient from returning to his/her daily life early. Consequently, the prevention of exiting root injury is important for achieving successful and widespread use of PELD.

In our study, the incidence of exiting root injury was 8.9 % (20/223). This rate was relatively higher than that observed in previous reports. There are several factors that may have contributed to this relatively high incidence rate.

It may be due to the retrospective study. During the early phase of this study, we neglected to measure the working zone at the preoperative stage. We did not know how to anticipate an exiting root injury. During the course of the study, our decisions changed regarding exiting root injuries. In the cases in which the MRI of a patient revealed a small working zone, we performed alternative conventional microdiscectomy.

An exiting root injury occurs relative to the anatomy of the safety working zone. The "safety working zone" is the so-called Kambin's point, with an inferior border formed by the rim of the vertebral plate inferior to the target disc, a posterior border formed by the lateral edge of the superior articular process of the inferior vertebra and a hypotenuse provided by the medial border of the associated spinal nerve as it exits from the vertebra [27]. Therefore, to prevent exiting root injuries, great care must be taken along the hypotenuse of this triangle during procedures. Two studies described the dimensions of the working zone. However, the dimensions of the working zone in these studies were verified using cadavers with or without facetectomy of the lumbar region [12, 13]. In a practical sense, the working zone anatomy without facetectomy was more important. We think that, for safety, recognition of the working zone should be delineated before surgery. However, there had not yet been a study that evaluated the working zone before surgery. Our study analysed the clinical and radiological risk factors for exiting root injury. In our study, only two variables were significantly different between the two groups. These were the distance from the nerve to the facet at the lower disc level (Distance C) and the operation time.

Short distance from nerve root to facet at lower disc level

ED has two stages. The first is from the needle insertion to the scope insertion. The second is from the scope insertion to the fragmented disc excision. Generally, the former stage is performed blind under the guidance of the C-arm. Given the lack of visual control, it is possible to injure the exiting root. The working cannula should be inserted into the foramen as closely as possible to the facet joint, but not directly target the disc to avoid an exiting root injury [28]. Even with careful insertion, the limited distance from the nerve root to the facet at the lower disc level increases the risk of damaging the exiting root. To avoid this risk, it is important that the surgeon communicate with the patient intraoperatively under local anaesthesia. In addition, a foraminoplasty technique and floating retraction technique were introduced to help avoid an exit root injury [11]. However, these techniques are time-consuming and require a great deal of skill and experience. The distance from the nerve root to the facet at the lower disc level can be calculated from a preoperative MRI scan. Therefore, if the distance is too narrow to insert a working cannula (6.9 or 8.0 mm, YESS discoscope), an alternative surgical method, such as microdiscectomy or conventional open discectomy, should be considered.

Prolonged operation time

We believe that a prolonged operation time can be attributed to one of two primary causative events. The first cause of prolonged surgery occurs when the needle is inserted in the cannula. If the patient complains of pain during this process, the operation time will inevitably be prolonged. Patients frequently experience root irritation due to a short distance from the nerve root to the facet at the lower disc level. The second event that may prolong surgery occurs during the insertion of the scope into the fragmented disc that is to be excised. The working cannula may compress the exiting root during this procedure. Therefore, a prolonged operation time may increase the nerve compression time. The compression pressure is closely related to the distance from the nerve root to the facet. The shorter the distance, the higher the compression pressure is likely to be. An in vivo study showed that high compression pressures induced a total conduction block with varying degrees of recovery after the compression release. The sensory fibres are slightly more susceptible to compression than are the motor fibres [29, 30], and a rapid onset of compression pressure induces a more pronounced nerve dysfunction [31].

Limitations

It is important to note that the present study is limited by the retrospective nature of the study design and the small sample size, particularly in the exiting root injury group (20 patients).

Conclusion

The risk of exiting root injuries in transforaminal endoscopic discectomy increases when the distance from the nerve root to the facet at the lower disc margin level is small and the operation time is prolonged. We recommend measuring the distance from the exiting root to the facet at the lower disc level based on preoperative MRI scans. If the distance is small, alternative surgical methods, such as microdiscectomy or conventional open discectomy, should be considered.

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Conflict of interest None.

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