Free-run electromyography assisted interlaminar endoscopic lumbar disckectomy at L4L5 and L5S1 under general anesthesia

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A R T I C L E I N F O

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A B S T R A C T

Introduction: Interlaminar Endoscopic Lumbar Disckectomy has been found to offer symptomatic alleviation comparable to open disckectomy while reducing blood loss, postoperative discomfort, complications, hospital stay, and narcotic use. General anesthesia decreases intraoperative stress, but surgeons may not be sure whether they injure nerve roots. Free-run electromyography may protect nerve roots that are thought to be in danger from surgery.
Methods: Patients with L4L5 or L5S1 lumbar disc herniation were treated with IELD. EMG was monitored via needle electrodes in lateral vastus lateralis, anterior tibialis, abductor hallucis muscles. Surgeons were asked to halt the surgery and adjust their manipulation right when abnormal EMG appeared on the screen. The severity of signs and symptoms were noted pre- and post-operatively.
Results: In all 26 cases, the median of visual analogue scale (VAS) of low back pain was 4.5. That of radicular pain was 7. Two patients had motor weakness at L4 or S1 muscles. One patient has sensory loss at L5 dermatome. The level of disc herniation was 46% at L4L5 and 56% at L5S1. The complications included only superficial infection in two patients that were effectively managed with antibiotics. During postoperative follow-up, all patients recovered completely without any neurological deficit. f-EMG signal included uneventful (9 patients), burst/ spike (10 patients), A-train (3 patients, and C-train (4 patients)
Conclusion: Free-run EMG is a protective mean in IELD. All surgeons will profit from this technique in the early stages of their learning curve. To examine the outcomes, further comparative research and prospective, randomized, controlled trials should be undertaken.

1. Introduction

IELD has been found to offer symptomatic alleviation comparable to open disckectomy while reducing blood loss, postoperative discomfort, complications, hospital stay, and narcotic use [1,2]. Microendoscopic lumbar disckectomy can be performed safely and efficiently, resulting in a shorter hospital stay and quicker return to work; nevertheless, this surgery has a learning curve [3].

This minimally invasive technique can be done under general or local anesthesia. Because general anesthesia decreases intraoperative stress, a wider number of patients may benefit from this technique. One disadvantage of general anesthesia is that surgeons may not be sure whether they injure nerve roots. However, neurologic symptoms are a common complication [4–7]. Intraoperative Neurophysiological Monitoring (IONM) was applied in such procedure to decrease neurologic complications. In a large dataset, IONM was linked to improved clinical outcomes [8].

Free-run electromyography (EMG) is sensitive to lumbosacral nerve root irritation or damage, but low specificity [9]. There are, however, a number of technical restrictions that might result in false-positive or false-negative findings, which must be identified and avoided wherever feasible [10,11]. Electromyography must be taken from muscles belonging to myotomes that correspond to the nerve roots that are thought to be in danger from surgery. Only with careful monitoring and adjustment of neuromuscular blockers can EMG be successful [12].

A study in the USA showed that surgeons were happier with additional neuromonitoring options and were more likely to utilize neuromonitoring if they had completed a residency [13]. To utilize IONM for decision-making during surgery for safe surgery and a positive surgical result, spinal surgeons need to grasp the idea of monitoring methods and

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interpret monitoring records effectively [14]. The functional integrity of afferent dorsal sensory spinal cord tracts, efferent ventral spinal cord motor tracts, and nerve roots may now be assessed intraoperatively using multimodality monitoring methods [15]. In Viet Nam, IONM is still unpopular. Surgeons are not familiar with its knowledge, technique, and interpretation. There are also no technicians specified in this technique. Hence, the lack of knowledge and technique forced the IONM team to only monitor EMG in ILED. One advantage of spontaneous EMG activity is immediate to neurologic injury [16]. The purpose of this study is to identify the role of EMG during IELD.

2. Materials and methods

2.1. Patient population

The prospective case series was from 1/12/2018 to 30/6/2020. The length of follow-up was 3 months. The study included all patients in the Neurosurgery Department of the University Medical Center at Ho Chi Minh City as follows:

- Patients with lumbar back pain radiating to unilateral L4, L5, or S1 dermatome.
- In line with clinical signs and symptoms, magnetic resonance imaging (MRI) revealed a herniated disc at L4-L5 or L5-S1.
- Types of herniation included paracentral herniation at foramina level, disc level, or pedicle level.
- Patients still suffered unsatisfying symptoms in spite of usual conservative therapy for at least 6 weeks.
- Patients were finally managed with ILED and EMG.

The exclusion criteria included spinal canal stenosis, central disc herniation, lumbar spondylolisthesis, and/or segmental instability verified by radiography; signs of infection, tumor, or other lesions; and converting to open disckectomy because of endoscopic disckectomy failure.

2.2. Perioperative preparation and surgical technique

Patients were assessed the symptoms included radicular pain, sciatica owing to direct nerve root compression, Medical Research Council Scale for motor weakness, and dermatomal sensory abnormalities.

After a patient was admitted to the operation theater, the surgeons, the anesthesiologist, and the IONM team discussed and decided the method of anesthesia, IONM modalities, and surgical techniques. The purpose of this discussion was that all team members understood their own role and the other's role.

Firstly, the patient was under general anesthesia with fentanyl (1–2 mcg/kg/hr for maintenance), propofol (1–1.5 mg/kg for induction), and sevoflurane (1.7–2.6% in oxygen for maintenance). Rocuronium 0.45–0.6 mg/kg were administered solely for intubation but during operation. TOF monitored every 15 min to ensure the patient twitched at least ¼ before any potential injuries took place. If the patient still did not twitch, the IONM team would ask the anesthesiologist to administered sugammadex (2 mg/kg) or neostigmine (0,03 mg/kg).

After anesthesia, the IONM team inserts pairs of needles into muscles that required monitoring. Those muscles included bilateral vastus lateralis for L4 nerve roots; anterior tibialis for L4, L5 nerve roots; and abductor hallucis for S1-S3 nerve roots. The insertional point for vastus lateralis was one handbreadth above the patella, toward the lateral aspect of the thigh. The one for anterior tibialis was four fingerbreadths below the tibial tuberosity and one fingerbreadth lateral to the tibial crest for anterior tibialis. The one for abductor hallucis was half distance between calcaneus and base of the proximal phalanx of the great toe, one fingerbreadth below the navicular bone [17]. For all ILED cases, a NIM-Eclipse system (manufactured by Medtronic, Minneapolis, MN 55432–5604 USA) was used. Filters were set at 30 Hz to 1500 Hz for recording, and sensitivity was set at 100 µV to 1 mV. The time base ranged from 20 to 500 ms. Loudspeakers continually broadcast EMG signals, which were shown on a monitor screen. Data were constantly examined and saved to a hard drive.

The surgeries were performed with the patients in the prone position. All the surgeries were performed by 3 surgeons, who have at least 2 years of experience in microsurgical disckectomy and microendoscopic disckectomy. Posteroanterior and lateral fluoroscopy were used to locate the interlaminar space at L4-L5 or L5-S1. Soft tissue expanders were applied to separate the muscles via a 7-mm skin incision, to allow the insertion of the working cannula and endoscopic surgical system. All the subsequent procedures were performed under constant irrigation with excellent visualization. The inferior edge of the cranial lamina on the side of the lesion and the ligamentum flavum was exposed under visualization using an endoscopic camera system. Then, a small incision was placed on the ligamentum flavum using a laminectomy rongeur, which enabled access into the spinal canal. The direction-variable drill was used to partially resect the cranial lamina in order to enlarge the narrow interlaminar space.

Then the herniated nucleus pulposus tissue was exposed and removed to ensure sufficient decompression of the nerve root. Before ending the surgery, we ensured there was no significant free disc tissue, dural sac damage, or active bleeding. No drainages were required.

During a surgery, EMG was monitored continuously. Pathological EMG activity was detected in the form of bi- or triphasic potentials with a high peak of up to 2500 µV ("spike") or a complete complex of superimposed spikes ("burst"). Spikes were short-lived and returned to baseline quickly, but bursts were longer-lived and lasted up to 470 ms [18]. The fEMG activity might deteriorate further, resulting in trains with a variety of morphologies, frequencies, and amplitudes. Tonic EMG activation had a rapid onset and a fixed amplitude that ranged between 50 and 300 µV. With a frequency range of 50 to 350 Hz, the mean frequency was 184 Hz. The trains lasted anytime from 200 to 4200 ms. There were three train activities – types A, B, and C [19]. Because the authors' description of trains A, B, and C was based on their experience with cranial nerve monitoring, specifically facial nerve monitoring with EMG, their clinical relevance when monitoring peripheral nerves or roots may differ. Although there was no clear consensus on the specificity of such discharges in predicting pending irreversible injury and, thus, poor postoperative outcome, our approach to interpreting EMG findings was to notify the surgeon whenever such discharges occurred, especially when they were prolonged and correlated with high-risk surgical maneuvers. *2.3. Data analysis strategy*

All pain grading, complications, pathological EMG activities, and related surgical manipulation were recorded. Surgical manipulation consisted of endoscope placement and sequestrectomy. All mean values of pain grading were calculated for a variety of EMG categories. The EMG categories consisted of no activity, burst/spike, A-train, and C- train. The mean values were compared between EMG categories.

This study was performed in accordance with the principles of the Helsinki Declaration. The protocol for the study was examined and approved by the Ethics Committee of the University of Medicine and Pharmacy at Ho Chi Minh City (Code: 41/HDDD). Written informed consents were obtained. All reporting data from this study were also reviewed and approved by the Ethics Committee.

3. Results

There were 26 patients who underwent EMG assisted ILED. The range of age was between 21 and 65. The duration of symptoms before surgery was from 6 to 32 weeks. The median of visual analogue scale (VAS) of low back pain was 4.5. That of radicular pain was 7. One patient had thigh extension weakness, another patient had plantar flexion weakness. The grading of motor strength according to the British Medical Research Council was 3/5 for both patients. Another patient had sensory loss at L5 dermatome. The level of disc herniation was 46% at L4L5 and 56% at L5S1. Herniation at infrapedicular level was 54%, at disc level was 42%, and at pedicular level was 4%. The complications included only superficial infection in two patients that were effectively managed with antibiotics. (Table 1)

EMG monitoring was entirely unremarkable in 9 patients. In each case, the corresponding nerve root was seen via endoscope. Pathological EMG activity was detected in the form of bi- or triphasic potentials with a high peak of up to 2500 μV ("spike") or a complete complex of superimposed spikes ("burst") (10 patients). Placing the endoscope through ligamentum flavum resulted in spikes or bursts in 6/10 patients. Five patients among those, the nerve root was visible via the endoscope. The tip of the working channel was in direct touch with the nerve root or with the sequestration, which dislocated or compressed it in five cases. The solution is utilizing a direction-variable drill to partially resect the cranial lamina and using a modified trajectory to insert the endoscope through ligamentum flavum again while monitoring EMG closely. During the removal of the herniated disc, a similar sort of EMG activity was observed in additional 4/10 patients. By stopping the surgical manipulation and repositioning the instruments, EMG activity was restored in all cases.

In a total of 7 patients, train EMG activation was seen. Only A- and C- trains (Figs. 1 and 2) were discovered out of the three train activities defined elsewhere – types A, B, and C [19]. A-trains showed up in 3 patients and C-train in 4 patients. Intermittent spikes and bursts were also seen in the 7 patients with train activity before and after the onset of the trains.

A-train activity was during sequestrectomy in 2 patients and during endoscope placement in 1 patient. In 4 patients with C-train, there was a

Table 1
General information of patients.

Patient ID	Age and gender	Localization of herniated disc	Neurological symptoms	VAS of lumbar back pain (LBP)	VAS of radicular pain (RP)	Duration (month) of symptoms before surgery	EMG findings	Causes of EMG activity	Complication	VAS of 3 month postop-LBP	VAS of 24 h postop-RP	VAS of 3 month postop-RP
1	21 M	L4L5 p[a)] f[c)]	None	2	6	6	None	None	infection	0	2	0
2	55 M	L4L5 p f	Motor	10	8	12	C-train	Sp[m)]/ endo[k)]/ seq[l)]	None	3	4	4
3	34 M	L4L5 s[d)] f	None	6	6	6	A-train	Seq/ endo	None	3	5	4
4	56 M	L5S1 p f	None	8	8	6	Burst/ Spike	Sp/Seq/ endo	None	3	4	4
5	54F	L4L5 e[b)] f	None	3	4	6	C-train	Endo	None	3	4	3
6	41F	L5S1 p f	None	4	6	6	Burst/ Spike	Endo	None	2	2	2
7	47F	L4L5 s ped[j)]	None	5	6	6	A-train	Endo	None	2	2	2
8	35 M	L5S1 p f	None	4	6	6	A-train	Endo	None	2	2	2
9	47 M	L5S1 s ped	None	5	8	12	None	None	None	0	0	0
10	33F	L5S1 e f	None	2	6	6	None	None	None	0	0	0
11	46F	L4L5 s ped	None	7	8	6	None	None	None	0	0	0
12	22F	L5S1 p f	None	4	7	6	None	None	None	2	2	2
13	62 M	L4L5 s ped	None	9	7	6	Burst/ Spike	Seq	None	0	2	0
14	47 M	L5S1 p d[i)]	None	3	4	6	None	None	None	0	0	0
15	40F	L4L5 b f	None	1	5	6	None	None	None	0	0	0
16	36 M	L4L5 s f	None	2	5	6	None	None	None	0	0	0
17	55 M	L4L5 s ped	Sensory	5	7	8	None	None	None	0	1	0
18	42 M	L5S1 s f	None	6	5	6	Burst/ Spike	Seq/ endo	None	1	2	1
19	45F	L5S1 s ped	Motor	4	7	6	Burst/ Spike	Seq	None	1	3	1
20	35 M	L4L5 p f	None	3	8	12	Burst/ Spike	Seq/ endo	infection	0	1	0
21	30 M	L5S1 p f	None	2	5	6	C-train	Seq	None	1	2	1
22	40 M	L5S1 s ped	None	8	9	12	Burst/ Spike	Seq/ endo	None	1	3	1
23	56 M	L5S1 s ped	None	7	7	32	Burst/ Spike	Sp/Seq/ endo	None	2	2	2
24	42 M	L5S1 s ped	None	6	9	12	Burst/ Spike	Seq/ endo	None	3	3	3
25	47 M	L5S1 s ped	None	3	7	6	Burst/ Spike	Seq/ endo	None	1	2	1
26	65 M	L4L5 s ped	None	7	9	6	C-train	Sp/Seq/ endo	None	2	3	2

a) p: protrusion
b) e: extrusion
c) s: sequestration
d) f: foraminal level
e) d: disc level
f) ped: pedicular level
g) endo: EMG activities caused by endoscope placement
h) seq: EMG activities caused by sequestrectomy
i) sp, spontaneous EMG activities

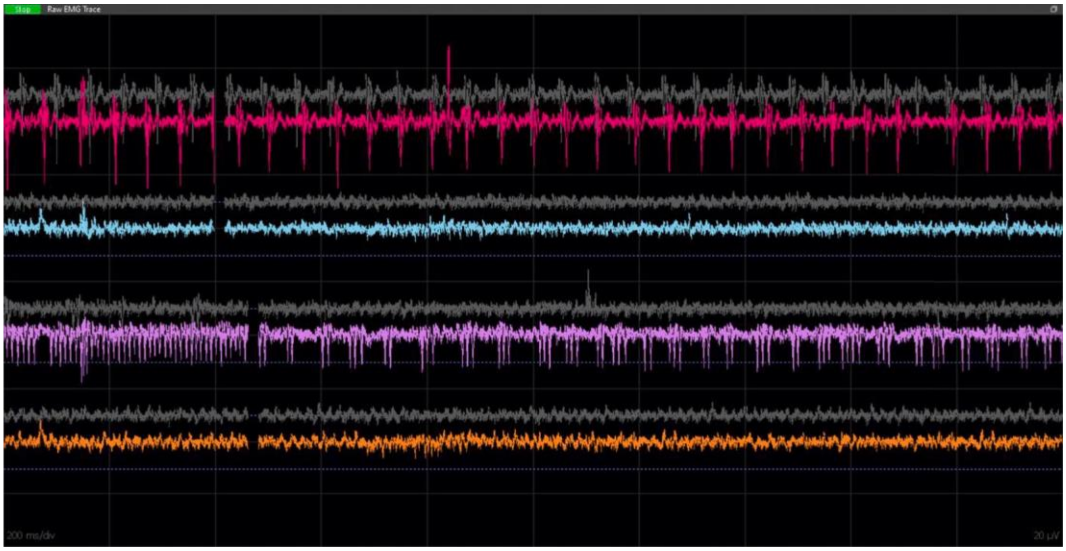

Fig. 1. A-train in the first 400 ms at purple trace.

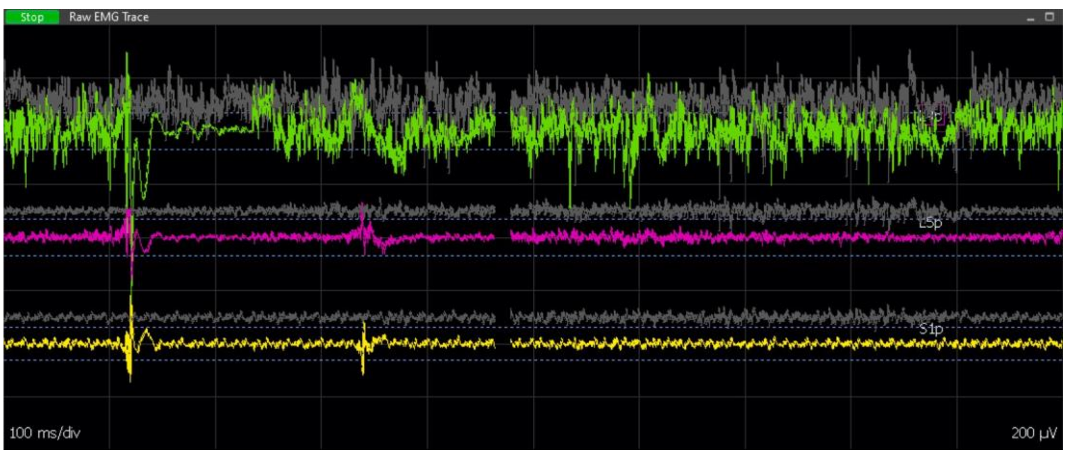

Fig. 2. C-train at light green trace.

significant volume of herniated disc and nerve root dislocation. In 4 cases, sequestrectomy which caused C-train was complicated by an adhesive intraspinal component.

When train activity was detected, the operation was promptly halted. The instrument was taken out of the affected point and repositioned. Train activity came to a halt in 3 of 7 cases after a brief retreat and repositioning in front of the interlaminar space through a slightly altered trajectory. After relocating the endoscope in the other three patients, tonic EMG activity recurred during sequestrectomy. The EMG activity generated by these manipulations was interpreted as a warning signal, and the grasping forceps manipulation was instantly stopped and resumed in a different location. The surgeon next tried to find a different part of the interlaminar space where the herniated disc could be deployed without causing abnormal EMG activity. After the sequestrectomy was completed or the endoscope and working channel were withdrawn, train activity continued 1–2 min after that.

Preoperative lumbar back pain was lowest in patients whose intraoperative monitoring was uneventful, with a score of 3.4, compared to 5.8 in the spike/burst activity group, 5 in those with A-train activity, and 5.5 in those with C-trains. The scores of radicular pain were similar among those groups. In the uneventful monitoring groups, the ratings for 3-month-post-op-lumbar back pain, 24-hour-post-op-radicular pain, and 3-month-post-op-radicular pain were slightly below the score of eventful monitoring groups. This is a definite trend, but owing to the limited number of patients, meaningful significances cannot be determined. Although the average scores of pain were lower postoperatively, one patient (number 5) still suffered the same lumbar back pain and 24- hour-post-op-radicular pain. Medicines helped to alleviate the symptoms. Then, 3-month-radicular pain was lower than that at 24 h post-op. (Table 2)

Postoperatively, two patients with motor deficits improved clinically from motor power 3 to 4. During their intraoperative EMG monitoring, burst/spike activity was noted in one patient, C-Train activity was noted in another patient. Another patient with sensory impairment, recovered from it completely.

Table 2
Pre- and postoperative average VAS pain grading by EMG findings.

EMG findings	Lumbar back pain	Radicular pain	3 month postop lumbar back pain	24 h postop-radicular pain	3 month postop-radicular pain
None	3.4	6.2	0.2	0,6	0.2
Burst/ spike	5.8	7.3	1.4	2.4	1.5
A-train	5	6	2.3	3	2.7
C-train	5.5	6.5	2.3	3.3	2.5

4. Discussion

ILED with EMG appears to be safe and effective. It improves symptoms such as lumbar back pain, radicular pain, motor deficit, and sensory deficit. EMG helps to warn before any aggressive manipulations proceed. In this study, we do not recognize any neurologic complications. The signs and symptoms were all relieved postoperatively.

The limitations of this study are small patient number, short follow- up duration, procedures carried out by 3 surgeons, EMG monitored by 2

neurophysiologists, and single EMG monitored. Continuous study on this topic with long-term follow-up may give a more valuable conclusion about the benefits and limitations of this procedure. Comparative multicentral studies also contribute to consistent recommendations in the future.

The efficacy and complications can be influenced by the experience of surgeons and IONM team. However, those staff had more than 2 years of expertise. Three surgeons had operated on more than 50 lumbar endoscopic disckectomy patients before this study. IONM team in our hospital in fact are neurosurgeons who experienced spinal surgery and dedicated to IONM more than 1 year before this study.

EMG only shows abnormal activities due to nerve root irritation or damage, but not the functional integrity of afferent dorsal sensory spinal cord tracts, efferent ventral spinal cord motor tracts [9]. EMG was used because nerve root irritation is the most frequent injury. It also has high sensitivity and real-time responses for detecting a new postoperative neurologic impairment. Theoretically, all severe injuries to nerve roots were prevented right when abnormal activities appear on the screen.

Effective EMG monitoring requires some factors. EMG is sensitive to lumbosacral nerve root irritation or damage, although sharp nerve root transection may give no alarm activities. Thus, surgeons should not rely absolutely on IONM team's warning but be careful in each step during surgery. EMG from muscles belonging to myotomes appropriate for the nerve roots at risk from operation must be recorded. Due to the high cost of IONM disposable material in Viet Nam, we may decrease the number of monitored muscles. Monitoring may focus on the most vulnerable nerve roots in an individual patient. Those nerve roots can be identified by lumbar MRI, signs, and symptoms.

EMG is only useful when neuromuscular blockers are carefully monitored and titrated. Anesthesiologists and neurophysiologists should understand this to achieve enough analgesia, sedation, and the level of muscle blockage. In this study, anesthesiologists did not administer neuromuscular blockers during surgery. Train-of-four was also monitored until it obtained at least ¼ before any potential nerve root injuries. In 5 patients, IONM team had to ask anesthesiologists to administer sugammadex which forms a compound with the neuromuscular blockers rocuronium, reducing the quantity of neuromuscular blockers available to bind to nicotinic cholinergic receptors in the neuromuscular junction.

The presence of A trains has been shown to be a very accurate predictor of postoperative facial palsy in cerebellopontine angle (CPA) surgery [19]. The results of spinal EMG monitoring in our study do not support these findings, possibly because of the small number of patients exhibiting train activity. In all cases, the surgeons repositioned the instrument quickly in response to these abnormal activities, and no postoperative motor function impairment was noted. It is possible that the dural layer that covers the spinal nerve roots provides some mechanical protection and, unlike CPA surgery, prevents immediate motor impairments if the traumatic impact during surgery is minor and brief.

The endoscopic approach was shown to be superior to the open surgical technique in terms of causing nerve root discomfort on EMG. Microendoscopic disckectomy, provides for a smaller incision and less tissue stress while providing equivalent nerve structure visibility to open surgery [20]. However, endoscopic surgery comes with a high learning curve [7,20]. Hence, it is important to do endoscopic disckectomy for several first times together with EMG. In this study, we do not have any technique-related complications. This may result from surgeons' experience in endoscopic spinal surgery and early warning from IONM team.

5. Conclusion

Although ILED is an advanced technique, it still has potential risks for nerve root injuries. Our studies found that pathological EMG activities appeared in more than half of the cases. Those activities were caused by endoscope placement and sequestrectomy. The activities included spikes, bursts, A-trains, and C-trains. Those activities were the signs for modifying ILED technique. The modifications included partial resection of cranial lamina, reposition of endoscope and instruments, finding a different part of the interlaminar space where the herniated disc could be deployed. ILED should be carefully taken in patients with VAS of LBP more than 3 because of a high frequency of pathological EMG findings.

Because microendoscopic lumbar disckectomy has a learning curve, pathological EMG activities may appear more frequently than this study if ILED was performed by inexperienced surgeons. Hence, intraoperative free-run EMG may play an important role in the early stages of their learning curve.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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