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Application of intraoperative neurophysiological monitoring in unilateral biportal endoscopic lumbar spine surgery

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Abstract

Objective To analyze the value of intraoperative neurophysiological monitoring (IONM) in unilateral biportal endoscopic (UBE) lumbar spine surgery.

Methods A retrospective analysis was performed on 127 patients who underwent UBE lumbar spine surgery at Xicheng Branch of Beijing Friendship Hospital from January 2024 to September 2024. Patients were divided into two groups: the observation group (IONM, 64 cases) and the control group (no IONM, 63 cases). Changes of monitoring indicators included somatosensory evoked potentials (SEP), motor evoked potentials (MEP), and free electromyography (freeEMG) were recorded. Age, sex, body mass index, surgery length, surgical levels, surgery time, intraoperative fluid volume, post anesthesia care unit time, time to first ambulation, length of hospital stay, leg visual analog scale (VAS), preoperative and postoperative fall scores, activities of daily living, and postoperative complication of two groups were collected and compared.

Results In the observation group, 40 cases (62.5%) showed freeEMG stimulation. 10 cases (15.6%) had a significant decrease in MEP amplitudes, with 9 cases showing a decline in MEP amplitudes immediately following freeEMG stimulation. No significant changes in SEP. The postoperative 24-hour leg VAS in the observation group was 1.8 ± 0.4, which was significantly lower than the 2.1 ± 0.2 in the control group ($p < 0.001$). No significant differences were found between the two groups in terms of surgical time and other data ($p > 0.05$).

Conclusion IONM provides timely information of neurological function in UBE lumbar spine surgery, reduces the invasiveness of intraoperative procedures, and reduce early postoperative leg pain.

Keywords Unilateral biportal endoscopic spine surgery, Multimodal intraoperative neurophysiological monitoring, Nerve protection

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Introduction

With the aging population, the prevalence of lumbar degenerative diseases has steadily increased [1]. The symptoms are primarily characterized by low back pain, leg pain, and muscle numbness and weakness. When conservative treatments fail to alleviate symptoms, surgical intervention is often required [2, 3]. In recent years, unilateral biportal endoscopic spine surgery (UBE) has gradually become one of the main surgical approaches for treating lumbar degenerative diseases due to its advantages of minimal trauma, excellent intraoperative visualization, a gentle learning curve, rapid recovery, and fewer complications [4]. However, UBE surgery carries risks of complications such as dural tears, epidural hematomas, and nerve root injuries [5]. Intraoperative neurophysiological monitoring (IONM) can be used to provide real-time feedback on the neural function status during surgery, offering reliable information for early detection of neurological complications, which can help reduce nerve damage to some extent.

Common intraoperative neurophysiological monitoring techniques include somatosensory evoked potentials (SEP), motor evoked potentials (MEP), and free electromyography (freeEMG) [6]. SEP is used to assess the sensory function of the ascending spinal cord pathways [7], MEP monitors the motor function of the descending spinal pathways [8], and freeEMG is commonly used for real-time recording of muscle fiber discharge to reflect the instantaneous changes in nerve root function [9].

Table 1 General information

Variable	Observation group (*n* = 64)	Control group (*n* = 63)	*p* value
Gender	23:41	33:30	0.06
Age (year)	62.0 ± 12.9	60.0 ± 13.5	0.39
BMI (kg/m^2)	25.5(23.5,27.1)	26.7(23.8,29.3)	0.16
Surgery length			0.28
1	58(90.6)	61(96.8)	
2	6(9.4)	2(3.2)	
Surgical levels			0.19
L2-3	1(1.6)	1(1.6)	
L3-4	3(4.7)	9(14.3)	
L4-5	34(53.1)	33(52.4)	
L5-S1	20(31.3)	18(28.5)	
L1-2&L2-3	2(3.1)	0(0.0)	
L3-4&L4-5	2(3.1)	2(3.2)	
L4-5&L5-S1	2(3.1)	0(0.0)	
Surgical procedure			0.07
Decompression	20(31.2)	17(27.0)	
Discectomy	27(42.2)	38(60.3)	
ULBD	17(26.6)	8(12.7)	

Gender are presented as (male: female, n). BMI are presented as M(Q1, Q2). The other values are presented as mean ± standard deviation or number (%).BMI, body mass index; ULBD, unilateral laminotomy for bilateral decompression

The application of IONM can monitor the function of the spinal cord and nerve roots during spinal surgery, providing higher accuracy, with monitoring effects far superior to those of single-method monitoring. Surgeons can take timely measures based on the neurophysiological feedback provided by IONM, reducing irreversible damage and effectively lowering the risk of nerve injury [10]. However, IONM technology is primarily applied in open surgeries for spinal deformities, spinal tumors, and degenerative conditions of the cervical and lumbar spine, with limited reports on its use in UBE surgery. This study is the first to report on the application of IONM in UBE lumbar spine surgery, retrospectively analyzing the results of 64 patients who underwent UBE lumbar surgery with IONM and comparing their postoperative outcomes with those of 63 patients who did not receive IONM, in order to explore the value of IONM in UBE lumbar spine surgery.

Materials and methods

General data

1) Inclusion Criteria: (1) Diagnosed with lumbar degenerative diseases, including lumbar spinal stenosis, lumbar disc herniation, or lumbar degenerative spondylolisthesis. (2) Clinical presentation of low back and leg pain, intermittent claudication, with complete X-ray, CT, and MRI data, and symptoms and signs consistent with imaging findings. (3) Underwent UBE lumbar surgery. (4) Preoperative lumbar pain visual analogue scale (VAS) ≤ 3 points, leg VAS ≥ 5 points.

2) Exclusion Criteria: (1) Patients with severe cardiopulmonary dysfunction. (2) Patients with cranial defects. (3) Patients with a history of epilepsy, intracranial hypertension, or pacemaker implantation. (4) Patients who voluntarily declined monitoring. (5) Preoperative imaging examination suggests lumbar instability. (6) Patients with incomplete clinical data. (7) Patients who did not provide informed consent.

3) This study retrospectively analyzed the data of 127 patients who underwent UBE lumbar surgery for lumbar degenerative diseases at Beijing Friendship Hospital (BFH) from January 2024 to September 2024. There were 56 male and 71 female patients, with a mean age of 61.0 ± 13.2 years (range 19–84 years). The patients were divided into two groups: the IONM group (64 patients) and the non-IONM group (63 patients). The general data of both groups were comparable with no statistical differences (Table 1).

Anesthesia and surgical methods

1) Anesthesia: All patients received general anesthesia. Induction was achieved with an intravenous injection of sufentanil (4–5 μg/kg), propofol (2–3 mg/kg), and rocuronium bromide (2–3 mg/kg). Maintenance was

provided with continuous intravenous infusion of remifentanil (0.05–0.50 μg/(kg·min)) and propofol (3–9 mg/(kg·h)). No additional muscle relaxants were administered after endotracheal intubation.

2) Main steps of the surgery: (1) After general anesthesia, the patient is placed prone on the spinal bed, with the abdomen suspended and a protective pad placed on the compressed area. The C-arm X-ray machine is used to determine the responsible segment and mark the surgical incision (a horizontal line is drawn on the upper endplate of the lower vertebral body of the responsible segment, and a vertical line is drawn on the inner edge of the projection of the operating side pedicle. The intersection point of the two is the center, and a 1.0 cm long horizontal incision marking line is drawn 1.5 cm from both ends of the head and tail); (2) Routine disinfection preparation and exposure of the surgical area, sequentially incising the skin, subcutaneous tissue, and deep fascia (operating channel deep fascia incision with a "cross" shape), inserting a positioning needle and reexamining to confirm the target gap, then gradually inserting an expansion sleeve, bluntly peeling off the muscle tissue at the root of the spinous process and the vertebral lamina, establishing the channel, and placing endoscopes and Ablation electrode respectively to maintain smooth water flow in and out of the channel; (3) Remove the soft tissue around the gap and fully expose the inner side of the upper and lower vertebral plates and articular processes. Using high-speed drills, vertebral lamina bone biting forceps, and other instruments, remove the lower half of the upper vertebral lamina, the inner part of the articular process, and the upper edge of the lower vertebral lamina through the operating channel. After exposing the various insertion points of the ligamentum flavum, remove the ligamentum flavum. Depending on the patient's condition, perform intervertebral disc removal or perform vertebral lamina decompression on the opposite side; (4) Using a radiofrequency blade to decompression and hemostasis, followed by the placement of a drainage tube and suturing of the incision.

Intraoperative neurophysiological monitoring methods

In this study, IONM was performed using the NIM-ECLIPSE system (USA). Needle electrodes were used to record signals from the quadriceps femoris, tibialis anterior, abductor hallucis and anal sphincter. The thenar muscle were used as reference electrodes. According to the international EEG 10–20 system, transcranial recording electrodes were placed at Cz, C3, and C4 locations, with Fz as the reference. Surface electrodes were used for peripheral nerve stimulation, placed on the ulnar nerve at the wrist, and transcranial stimulation electrodes were placed at C1 and C2. The SEP stimulus intensity was set at 20–30 mA, with a frequency of 2.1–4.7 Hz, and the number of stimulations was 100. MEP electrical stimulation consisted of 8 sets of square wave stimuli, each lasting 200–400 μs, with a stimulation voltage of 200–400 V. The alarm thresholds for SEP were: latency delay > 10% or amplitude decrease > 50% [11]. The alarm threshold for MEP was set at an amplitude decrease of > 80% [12]. The alarm threshold for freeEMG was set for continuous burst-like muscle activity.

Perioperative management

Both the observation group and the control group patients underwent the enhanced recovery after surgery (ERAS) clinical pathway for UBE surgery at BFH. The core points include patient education sessions, pain management, preoperative application of oral carbohydrate, rehabilitation department participation in guiding perioperative functional exercise, and early out-of-bed activities (6 h after surgery).

Outcome measures

The observation group was monitored for the metabolism of muscle relaxants using TOF (train-of-four) monitoring during the surgery. Once muscle relaxation was fully reversed, changes in the amplitudes of freeEMG, SEP, and MEP were recorded. The following data were compared between the observation group and control group: gender, age, body mass index (BMI), surgery length, surgical levels, surgery procedure, surgery time, intraoperative fluid volume, post anesthesia care unit (PACU) recovery time, first ambulation time post-surgery, length of hospital stay, VAS scores at different time points, preoperative and postoperative fall scores, activities of daily living (ADL) scores, and incidence of postoperative complications.

Statistical analysis

Data were processed and analyzed using SPSS software. Continuous data were presented as mean ± SD or M(Q1, Q3) and the *t*-test or Mann-Whitney *U* test was used for inter group comparison. Categorical data were presented as the number of cases and percentages (n, %) and were compared between groups using the χ^2 test. A p-value < 0.05 was considered statistically significant.

Results

Intraoperative nerve root stimulation

In the observation group, 40 patients (62.5%) experienced freeEMG signal stimulation. Among these, 35 patients had freeEMG signal stimulation from muscles innervated by the surgical segment, which showed a reasonable correlation with specific surgical steps such as grinding off the lamina (Fig. 1A, B), ligamentum flavum dissection (Fig. 1C, D), decompression, and disc exploration (Fig. 1E, F). One patient experienced freeEMG stimulation due to insufficient anesthesia (Fig. 1G), and one occurred during the insertion of the hammer the positioning pin (Fig. 1H). 3 patients developed freeEMG stimulation without any manipulation of the nerve roots or surrounding tissues. According to the pattern of muscle contraction responses observed in the freeEMG, 22 cases showed continuous bursts of muscle contraction, while 18 cases exhibited a single burst of muscle contraction. A dural tear led to bilateral multiple continuous bursts of muscle contractions (Fig. 1I).

Intraoperative changes in MEP and SEP

A significant decrease in MEP amplitude was observed in 10 patients (15.6%), of whom 1 patients experienced a decrease in MEP amplitude in muscles innervated by the surgical segment without significant freeEMG stimulation, while 9 patients showed a decrease in MEP amplitude immediately following freeEMG stimulation. Taking the example of bilateral L4-5 decompression and disc exploration, during the right-sided nerve root decompression and disc exploration, continuous freeEMG stimulation was observed in the right foot. At this point, MEP amplitude in the upper limb remained stable, and no significant changes were seen in the right hand MEP, while the right foot MEP amplitude decreased from an initial value of 4485 μV to 1317 μV, a reduction of about 71%. Although the decrease did not reach the threshold of 80%, the presence of continuous freeEMG stimulation and the subsequent MEP amplitude decrease prompted the surgeon to adjust the surgical procedure. After several minutes, once the freeEMG signal returned to baseline, decompression was continued, and no further freeEMG stimulation was observed. At this point, the right foot MEP amplitude increased to 10,904 μV (Fig. 1J, K, L). No significant changes in SEP signals were observed during the procedure.

Table 2 Postoperative information

Variable	Observation group ($n=64$)	Control group ($n=63$)	p value
Surgical time(min)	124.3 ± 52.6	118.2 ± 51.7	0.51
Intraoperative fluid volume (ml)	1175.9 ± 404.0	1117.5 ± 375.7	0.40
PACU recovery time (min)	22.8 ± 7.8	21.5 ± 8.5	0.37
First ambulation time postoperative(h)	8.5 ± 3.9	7.4 ± 3.0	0.09
LOS (d)	5.0(4.0,6.0)	5.0(4.0,6.0)	0.95
Leg VAS			
Preoperative	6.0 ± 1.1	5.9 ± 1.0	0.60
24 h postoperative	1.8 ± 0.4	2.1 ± 0.2	<0.001
Discharge	2.0 ± 0.3	2.0 ± 0.3	0.57
Fall scores			
Admission	34.7 ± 22.0	31.8 ± 20.6	0.46
Postoperative	40.5 ± 16.4	39.3 ± 12.1	0.65
ADL scores			
Admission	85.6 ± 12.4	88.7 ± 13.2	0.16
Postoperative	47.1 ± 11.1	49.4 ± 13.3	0.30

LOS are presented as M(Q1, Q2) and the other values are presented as mean ± standard deviation or number (%). PACU, post anesthesia care unit; LOS, length of hospital stay; VAS, visual analog scale; ADL, activities of daily living

Comparison of postoperative data

The observation group had a significantly lower postoperative 24-hour leg VAS score (1.8 ± 0.4) compared to the control group (2.1 ± 0.2), with a statistically significant difference ($p < 0.001$) (Table 2). No statistical differences were observed between the two groups in terms of operative time, intraoperative fluid volume, PACU stay time, time to first ambulation, length of hospital stay, preoperative and discharge VAS scores, preoperative and postoperative fall scores, or ADL scores ($p > 0.05$) (Table 2). Both groups had no severe postoperative complications.

Discussion

UBE has gained widespread use as a minimally invasive technique for the treatment of lumbar degenerative diseases, showing good clinical outcomes for conditions like lumbar disc herniation and lumbar spinal stenosis [13, 14]. However, during the surgery, nerve root stimulation, compression, dura tear, local hematoma, and myelopathy may occur due to the unique neuroanatomy of patients, limitations of the endoscopic field of view, and pressure effects of the water medium. The overall complication rate is about 10.3% [15]. In such cases, IONM becomes crucial for ensuring patient safety. During open cervical, thoracic, and lumbar spine surgeries, SEP is commonly used for continuous monitoring of spinal sensory pathways. SEP is unaffected by muscle relaxants and does not interfere with the surgical process, reflecting the integrity of the ascending sensory pathways of the spinal cord. To reduce noise, multiple stimuli are averaged during SEP recordings, but the process has inherent time lag, limiting its ability to provide real-time spinal cord functional information. Therefore, by the time SEP abnormalities appear, spinal cord damage may have become irreversible [16]. MEP and freeEMG provide real-time feedback and do not require multiple stimuli for averaging. MEP can directly reflect changes in spinal cord motor function due to ischemia, compression, or stretching during surgery, but it is significantly affected by muscle relaxants, and stimulation can cause noticeable patient movement, potentially interfering with the surgical process. FreeEMG, on the other hand, records muscle fiber contractions caused by direct or indirect stimulation of the nerve roots and is sensitive to the surgeon's manipulation of the nerve roots [9]. However, freeEMG recordings can also be influenced by muscle relaxants and may be susceptible to electrical interference from surgical tools such

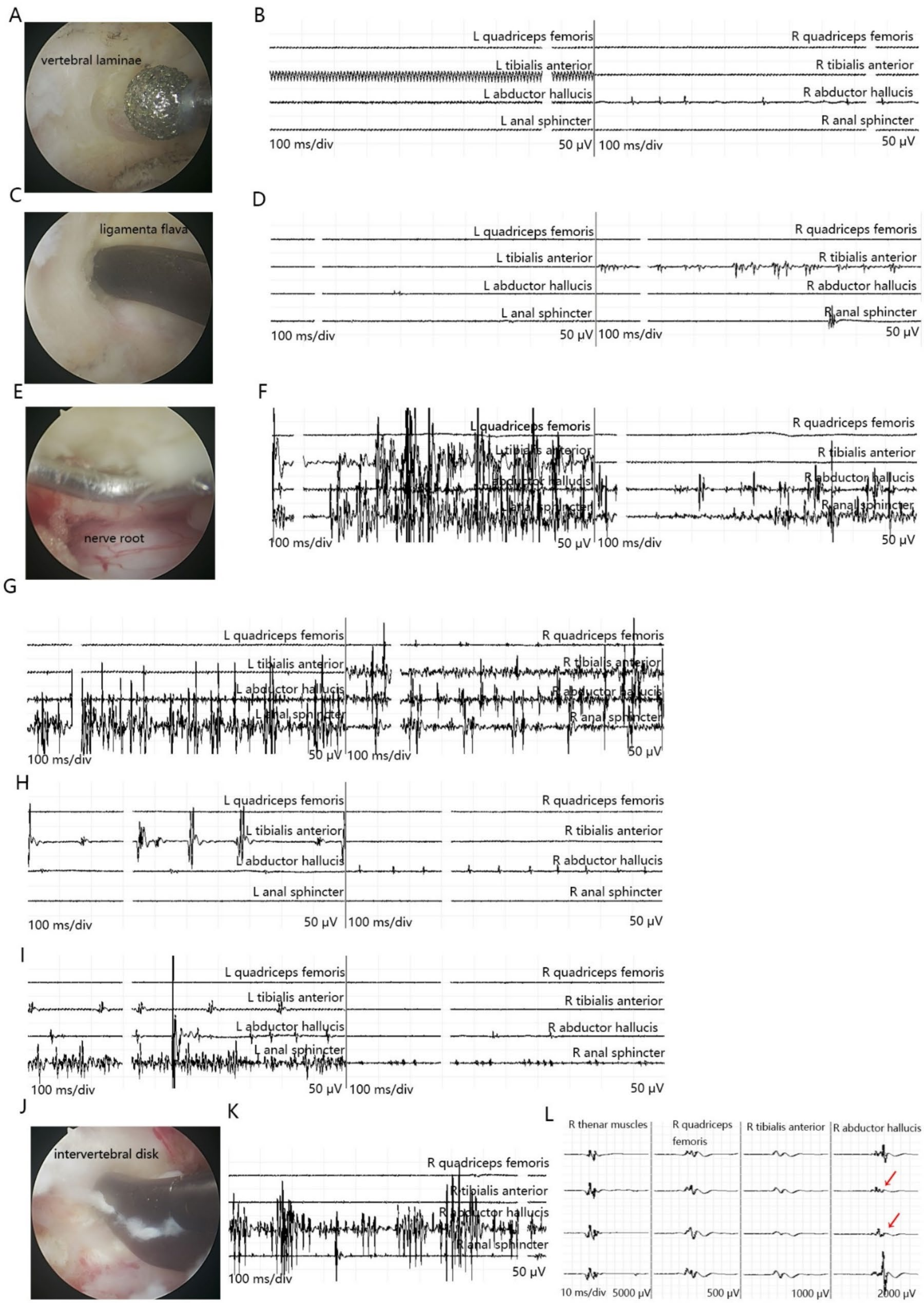

Fig. 1 (See legend on next page.)

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Fig. 1 Changes in IONM signals. **(A)** Using a burr to remove the lamina; **(B)** Vibration stimulation near the nerve root adjacent to the lamina; **(C)** Dissection of the superficial yellow ligament; **(D)** Traction on the adjacent nerve root during the dissection of the superficial yellow ligament; **(E)** Right side approach, decompression of L4-5 left nerve root; **F** Inducing contraction response of muscles innervated by adjacent nerve roots on both sides; **G**. freeEMG response due to shallow anesthesia; **H**. Vibration of the adjacent nerve root during the insertion of the location pin; **I**. Bilateral free EMG stimulation caused by dura mater tear during decompression; **J**. Decompression of the L4-5 nerve root and exploration of the intervertebral disc; **K**. Contraction response of the right abductor hallucis; **L**. Decreased MEP amplitude of the right abductor hallucis

as cold saline, ultrasonic bone scalpel, and bipolar radiofrequency devices. Given that each monitoring technique has distinct roles and advantages, combining multiple neurophysiological monitoring methods enhances the ability to predict and detect intraoperative nerve injury during UBE surgery.

During UBE decompression, direct stimulation from the UBE instruments, heat stimulation from electrocautery and radiofrequency ablation, and improper handling may damage the nerve roots [17]. Even during preoperative fluoroscopy and the insertion of guidewires and cannulas, mechanical nerve root injury may occur [18]. According to neurophysiological monitoring guidelines, freeEMG records show a single muscle contraction burst in response to direct nerve stimulation, while continuous bursts of muscle contraction typically correspond to sustained stretching or compression. When either of these responses occurs intraoperatively, especially continuous bursts, the surgeon should be alerted and investigate the cause.

In this study, we found that when direct touch, traction, or compression of the nerve root occurred during surgery, freeEMG showed low-frequency responses, indicating true positive reactions. These responses were highly sensitive to time and location, alerting the surgeon to take caution, while MEP amplitude and latency remained stable. Postoperatively, patients did not develop new nerve root symptoms. When freeEMG displayed high-frequency, sustained bursts of electrical activity for several seconds, the surgeon paused, and after the freeEMG signal returned to baseline, the operation continued. During this period, both MEP amplitude and latency transiently decreased. Although postoperative muscle strength was not affected, patients reported pain, likely related to nerve edema induced by intraoperative stimulation. In the group with IONM, VAS scores 24 h postoperatively were significantly lower than those in the control group, suggesting that intraoperative monitoring during UBE decompression helped the surgeon detect nerve damage, take timely corrective actions, and reduce postoperative pain.

Dural tear is the most common complication during UBE surgery, with an incidence of 1.9–5.8% [19]. Dural tear often occurs during the excision of the yellow ligament, and freeEMG can first detect continuous electrical activity, alerting the surgeon to the risk of nerve damage. When the operation is paused, the burst activity tends to diminish. Intraoperative MEP, recorded from the leg muscles, shows a significant decrease in amplitude, indicating that nerve root stimulation is occurring. Most patients' MEP amplitude returned to baseline by the end of the surgery, and muscle strength was preserved without adverse effects. Only one patient exhibited a persistent decrease in MEP amplitude without recovery by the end of the surgery, although muscle strength remained unaffected. However, the muscle innervated by the stimulated nerve root showed noticeable pain postoperatively.

In this study, 40 patients exhibited freeEMG responses, with one occurring during the insertion of the hammering positioning pin, one due to shallow anesthesia, and 3 with no operative manipulation of the nerve roots or surrounding tissues. The remaining 35 freeEMG responses were directly or indirectly related to nerve root stimulation or dural tears, suggesting some potential for false positives. In addition, 24 patients showed no freeEMG activity throughout the surgery, which could be attributed to the surgeon's skilled technique or the prolonged disease course, leading to insensitivity in the nerve root response. None of these patients developed new nerve root symptoms postoperatively. During the surgery, there was no change in SEP when freeEMG stimulation occurred, but MEP amplitude decreased following freeEMG stimulation in 9 patients. 1 patients showed MEP amplitude reductions without obvious freeEMG stimulation. These findings suggest that freeEMG monitoring can effectively help the surgeon identify nerve roots during UBE surgery, while the combined use of SEP and MEP provides a comprehensive assessment of spinal cord and nerve root function, helping to identify and correct potential nerve damage promptly, preventing new postoperative neurological deficits.

This study is a single-center retrospective clinical investigation primarily focusing on perioperative clinical data. It has limitations in terms of long-term postoperative follow-up. Further multi-center, prospective clinical studies are needed to explore the full potential of IONM in UBE treatment of lumbar degenerative diseases.

Conclusion

The use of IONM in UBE lumbar decompression surgery can assist the surgeon in accurately assessing the impact of surgical manipulation on nerve function, providing critical real-time feedback for intraoperative decision-making. This can reduce the risk of nerve damage and improve patient outcomes.

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Author contributions
Q.F., T.B., and H.M. made substantial contributions to the conception and design of the work; T.B. and H.M. made the acquisition and analysis of data; J.L. and Z.F made the analysis and interpretation of data; T.B. and H.M. drafted the work; Q.F. revised the work critically for important intellectual content and approved the version to be published; Q.F. agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy and integrity of any part of the work are appropriately investigated and resolved.

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Data availability
The data and materials used can be available from the corresponding author upon motivated request.

Declarations

Ethics approval and consent to participate
The study was performed according to the Helsinki Declaration and approved by the Research Ethics Committee of Beijing Friendship Hospital (No. BFH20250117001).

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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