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Intraoperative Neurophysiological Monitoring for Intradural Extramedullary Spinal Tumors Excision

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Abstract

Background: Spinal neurosurgery often uses intraoperative neurophysiological monitoring (IONM), but its efficacy for IDEM spinal tumors is less established. Technological advancements in imaging, neuromonitoring, and minimally invasive techniques are being used to improve functional results and minimize complications. A comprehensive clinical and radiological evaluation was performed. Somatosensory evoked potentials (SEPs) and motor evoked potentials (MEPs) monitoring were performed during surgery. Postoperative neurological outcome was evaluated immediately after surgery and at 6 months follow-up.

Aim of Study: To evaluate the immediate and six-month outcomes of IDEM spinal tumor surgery using IONM in patients with or without neurological deficits.

Patients and Methods: This prospective study was carried out on 30 patients with IDEM spinal tumors who underwent surgery with IONM.

Results: The study involved 30 IDEM tumor patients who underwent IONM surgery, with the majority being females (63.33%) and most having preoperative grade I Modified McCormick scale (MMS) scores (43.33%). The surgery involved total laminectomy in 20 patients (66.67%), total laminectomy with fixation in 6 (20%), and partial laminectomy in 4 (13.33%) patients. Histopathological findings revealed meningioma in 36.67% of patients, followed by schwannoma in 13.33%, neurofibroma in 23.33%, ependymomas in 16.67%, dermoid cysts in 6.67%, and hemangiopericytoma in 3.33%. In a study of 24 patients without deficit, 79.16% had stable IONM, while 20.83% experienced transient minor changes before recovery and continued surgery. In the deficit group, 66.67% experienced minor changes, followed by deterioration and surgery stops in 33.33% of patients. The study found a correlation between the MMS preoperatively, histopathological findings, and hospital stay for both groups with and without deficitafter a 6-months follow-up. Sensitivity decreased from 66.7% to 33.3% at 6 months, specificity from 92.6% to 91.7%, and Accuracy from 90.0% to 80.0% at 6 months. NPV worsene from 96.2% to 84.6%. Mc Nemar test (1 and 0.687), and Kappa tests 0.687 and 0.286, respectively. The rise in false negatives contributed to the decline in accuracy, indicating a need for improved test reliability.

Conclusion: IONM techniques like SSEPs, MEPs, EMG, and D-waves are increasingly used in spinal procedures to prevent neurological complications. It accurately predicts immediate neurological deficit after IDEM spinal tumor excision, but its predictive value for deficit 6 months post-surgery is lower.

Key Words: *Intradural extramedullary – Neurophysiological – Monitoring – Somatosensory – Motor evoked potentials.*

Introduction

MENINGIOMAS, nerve sheath tumors (neurofibromas and schwannomas), dermoids, teratomas,

Abbreviations:

CSF : Cerebrospinal Fluid.
MRC : Medical Research Council.
CT : Computed Tomography.
MRI : Magnetic Resonance Imaging.
EMG : Electromyography.
NPV : Negative predictive value.
IDEM : Intradural extramedullary.
PPV : Positive predictive value.
IONM : Intraoperative neurophysiological monitoring.
SSEPs : Somatosensory evoked potentials.
MEPs : Motor-evoked potentials.
TES : Transcranial electrical stimulation.
MMS : Modified McCormick scale.
UTI : Urinary tract infection.

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paragangliomas, ependymomas, metastases, and hemangioblastomas are among the intradural extramedullary (IDEM) tumors. When feasible, the goal of surgery for IDEM tumorsis complete excision [1-4]. Spinal neurosurgery frequently employs intraoperative neurophysiological monitoring (IONM) for intramedullary tumors, but its efficacy for IDEM spinal tumors is less well-established [5]. Technological advancements in imaging, neuromonitoring, and minimally invasive techniques are being used to enhance functional results and minimize complications in intradural tumor surgery [2,6,7]. The use of IONM has increased recently to prevent these neurological problems. IONM techniques commonly used for spinal procedures include somatosensory sensory evoked potentials (SSEPs), motor-evoked potentials (MEPs), spontaneous and triggered electromyography (EMG), and whenever possible D-waves [8,9].

Most benign intraspinal neoplasms are IDEM tumors, with 40% of all spinal neoplasms. Neurologic evaluation at preoperative intake determines the preoperative neurologic score. In rare cases, severe neurological decline necessitates immediate surgery. IONM is the most common method. Primary spinal cord tumors make up 10%, with 95% being extramedullary and 5% intramedullary [4,10]. Due to their infrequent incident, there are no established treatment protocols for this condition. However, radical excision surgery is the preferred therapy [11]. Advancements in imaging, IONM, and minimally invasive techniques have been established to enhance the surgical treatment of intradural tumors [6,7].

Spinal intradural tumors are commonly removed using laminectomy or laminotomy; however, these approaches can lead to postoperative pain, discomfort, kyphosis, and instability [12]. Surgeons have major challenges imposed by the anatomical position due to the restricted safe operative space. Thus, the goal is to perform complete surgical resection while maintaining spinal stability and preoperative neurological function to ensure a positive functional outcome [11,13]. While IONM for intramedullary tumors has become a standard in neurosurgical practice, IONM for IDEM tumors is still under debate [3]. The use of IONM during surgery can help eliminate IDEM tumors by monitoring the corticospinal motor pathway using MEPs elicited by transcranial electrical stimulation (TES). This combination of epidurally recorded D-waves and limb muscle MEPs serves as a reliable indicator of postoperative motor outcome. However, the effectiveness of IONM for IDEM tumors remains unclear, so this study aimed to assess its function in IDEM surgery [1,2]. Outcomes were evaluated through neurological examinations conducted by the neurosurgeon at 6-7 weeks post-discharge and again at the one-year follow-up [10].

Patients and Methods

This prospective cohort study was carried out of 30 patients who underwent microsurgical resection of IDEM spinal tumor using IONM between January 2020 and December 2023. IONM was subdivided into post-induction baseline, intraoperative period, and during closure. SSEPs and MEPs monitoring were performed on all patients. These patients were followed up for six months after surgery.

Inclusion criteria: Patients with a radiologically confirmed IDEM spinal tumor and preoperative motor power grade III or higher according to the Medical Research Council (MRC) grading system were included in this cohort.

Exclusion criteria: Patients with severe preoperative neurological deficits, multiple IDEM tumors, or radiologically verified spinal tumors of various types were excluded.

Patients: Patients underwent medical and surgical history, clinical examination, neurological examination, laboratory investigations, and detailed imaging evaluation using MRI, and CT scan. Motor strength was evaluated using the MRC scale, and patients were categorized according to the Modified McCormick Scale (MMS). MRI spine scans were utilized to identify tumors on various vertebral column sections, determine their size, and characterize them based on margins, composition, enhancement pattern, and calcification presence. CT scans were also used to identify calcification, assess spine-related deformities or instability, and examine spinal canal and neural foramen expansion in cases of extradural extension. The cases underwent microsurgical resection under general anesthesia, considering the need for intraoperative neurophysiological monitoring.

Anaesthetics remarks: The surgical procedure used IONM modalities, avoiding halogenated and muscle relaxants as they block MEP. Short-acting muscle relaxants were used for intubation and muscle dissection. Intravenous anesthesia was maintained with propofol (100-150 ug/kg/min) and fentanyl infusions (1 ug/kg/h) throughout the procedure.

Surgical position: Patients underwent surgery in the prone position, with C-arm fluoroscopy confirmed pathology location and incision planning. Full laminectomy, hemilaminectomy, or laminotomy were performed based on lesion size and extension.

Electrophysiological monitoring: MEPs and SSEPs were used to monitor motor and sensory pathways, while electromyography tracked nerve roots, particularly for conditions like neurofibroma, schwannoma, and filum terminal anomalies.

The use of multiple IONM modalities was tailored to the patient's pathology, lesion site, and clinical presentation. IONM readings and alarms, and post-operative general and neurological complications were also recorded and assessed.

Definitions of IONM results:

True positive: Patients experienced new neurological deterioration positively correlated with IONM findings, or a significant signal deterioration improved after intraoperative corrective actions were initiated.

True negative: The patient reported normal IONM results and no new neurological deficit post-operatively.

False positive: Patients post-surgery remained neurologically intact, but there was a noticeable decrease or elimination of IONM data.

False-negative: After surgery, patients experienced a new neurological deficit, but the IONM findings were found to be normal.

Outcome: Assessment was done immediately and after 6 months using the Modified McCormick Scale.

Statistical analysis: The study used SPSS version 26 for statistical analysis, comparing quantitative and qualitative variables using unpaired Student's *t*-tests and Chi-square or Fisher's exact tests. A two-tailed *p*-value <0.05 was considered statistical significance. Diagnostic characteristics such as sensitivity, specificity, and likelihood ratios were also calculated. The study aimed to understand the relationship between variables.

Results

This study was carried out on 30 patients with IDEM tumors who underwent surgery with IONM. Most were females in 19 (63.33%) patients with a mean age of 36.97±10.88 years. Our patients had Modified McCormick scale preoperative grade I in 13 (43.33%) patients, followed by grade II in 11 (36.67%) patients, and grade III in 6 (20%) patients. The surgery involved total laminectomy in 20 patients (66.67%), total laminectomy with fixation in 6 (20%), and partial laminectomy in 4 (13.33%) patients. Histopathological findings showed meningioma in 11 (36.67%) patients, followed by schwannoma in 4 (13.33%) patients, neurofibroma in 7 (23.33%) patients, Ependymomas in 5 (16.67%) patients, dermoid cysts in 2 (6.67%) patients, and hemangiopericytoma in 1 (3.33%) patient. In no deficit group patients (n=24), 19 (79.16%) patients had stable IONM, and 5 (20.83%) patients had transient minor changes, then recovered and continued surgery. In Deficit group patients (n=6), Transient minor change, then recovery and continued surgery were found in 4 (66.67%) patients, followed by IONM deterioration and stop surgery in 2 (33.33%) patients. There was no Stable IONM in this group. Comparing both groups with and without deficit, we found a correlation between MMS preoperative and both groups (*p* 0.003); between Histopathological findings and both groups (*p*=0.035), and between Hospital stay (days) and both groups (*p* 0.005). According to the 6-month follow-up of patients, we found a correlation between the MMS preoperative and both groups with a statistical difference (*p*=0.001) between Hospital stay (days) and both groups (*p*=0.019) (Table 2). Characteristics of patients presenting significant IONM deficit: The mean age was 41±6.42 years, and 4 (66.67%) patients were females. Modified McCormick scale preoperative was grade II in 2 (33.33%) patients and grade III in 4 (66.67%) patients. Regarding the level of the spine lesion, thoracic level was found in 4 (66.67%) patients; cervical and thoracolumbar levels in 1 (16.67%) patient each. The lesion extended to 1-2 vertebra in 5 (83.33%) patients and more than 2 in 1 (16.67%) patient. According to histopathological findings, meningioma was present in 2 (33.33%) patients, schwannoma in 3 (50%) patients, and dermoid cyst in 1 (16.67%) patient. Stop and then go surgery was implemented in 4 (66.67%) patients, and stop surgery occurred in 2 (33.33%) patients. Regarding intraoperative IONM, transient significant change, then recovery and continued surgery occurred in 4 (66.67%) patients, gross total resection was achieved, and IONM deterioration and stop surgery occurred in 2 (33.33%) patients. These last two parameters coincided with IONM changes.

Table (1): Modified McCormick grading scale (MMS) **[12, 14,21]**.

Grade	Modified McCormick Scale
I	Intact neurologically, normal ambulation, minimal dysesthesia
II	Mild motor or sensory deficit, functional independence
III	Moderate deficit, limitation of function, independent with external aid
IV	Severe motor or sensory deficit, limited function, dependent
V	Paraplegia or quadriplegia, even with flickering movement

Table (2): Demographic and surgical data of the studied patients.

Findings	(n=30)
Age (years)	36.97±10.88
Sex:	
Male	11 (36.67%)
Female	19 (63.33%)
Modified McCormick scale preoperative:	
Grade 1	13 (43.33%)
Grade 2	11 (36.67%)
Grade 3	6 (20%)
Histopathological finding:	
Meningioma	11 (36.67%)
Schwannoma	4 (13.33%)
Neurofibroma	7 (23.33%)
Ependymoma	5 (16.67%)
Dermoid cyst	2 (6.67%)
Hemangiopericytoma	1 (3.33%)
Surgical access:	
Total laminectomy	20 (66.67%)
Total laminectomy with fixation	6 (20%)
Partial laminectomy	4 (13.33%)
No deficit group	(n=24)
Intraoperative IONM:	
Stable IONM	19 (79.16%)
Transient minor change then recovery and continued surgery	5 (20.83%)

Data are presented as mean ± SD or frequency (%).
IONM: Intraoperative monitoring.

Table (3): Characteristics of patients presenting intraoperative neurophysiological monitoring deficit.

Deficit group	(n=6)
Age (years)	41±6.42
Sex:	
Male	2 (33.33%)
Female	4 (66.67%)
Modified McCormick scale preoperative:	
Grade 1	0 (0%)
Grade 2	2 (33.33%)
Grade 3	4 (66.67%)
MRI findings before surgery:	
Craniocervical	0 (0%)
Cervical	1 (16.67%)
Thoracic	4 (66.67%)
Thoracolumbar	1 (16.67%)
Lumbar	0 (0%)
Lesion extent:	
1-2 vertebra	5 (83.33%)
More than 2	1 (16.67%)
Histopathological finding:	
Meningioma	2 (33.33%)
Schwannoma	3 (50%)
Neurofibroma	0 (0%)
Ependymoma	0 (0%)
Dermoid cyst	1 (16.67%)
Hemangiopericytoma	0 (0%)
Surgical access:	
Total laminectomy	4 (66.67%)
Total laminectomy with fixation	2 (33.33%)
Intraoperative IONM:	
Stable IONM	0 (0%)
Transient significant change then recovery and continued surgery	4 (66.67%)
IONM deterioration and stop surgery	2 (33.33%)

Data are presented as mean ± SD or frequency (%).
IONM: Intraoperative monitoring.
UTI : Urinary tract infection.
CSF : Cerebrospinal fluid.

Immediately after the surgery:

Age, sex, MRC grade, MRI finding before surgery, and lesion extent were insignificantly different between no deficit and deficit groups. MMS grade 1 was significantly greater in no-deficit patients than in deficit patients (p=0.003). Surgical duration, pneumonia, urinary tract infection (UTI), surgical site infection, paralytic ileus, CSF fistula, and hematoma were insignificantly different between both groups. Regarding histopathological findings, schwannoma was significantly lower in no deficit than in deficit patients (p=0.035). Hospital stays were significantly shorter in non-deficit patients than in deficit patients (p=0.005) (Table 3). The diagnostic value of IONM to predict neurological deficit immediately after surgery was true negative in 25 (83.33%) patients, followed by true and false positive in 2 (6.67%) patients each. False negative was found in 1 (3.33%) patient (Table 5).

At the 6-month follow-up, Age, sex, MRC grade, MRI finding before surgery, and lesion extent were insignificantly different between the no deficit and deficit groups. MMS Grade 3 was significantly lower in the no-deficit group than in the deficit group (p=0.001). Histopathological findings, surgical duration, pneumonia, UTI, paralytic ileus, surgical site infection, CSF fistula, and hematoma were insignificantly different between both groups. Hospital stay was significantly shorter in no deficit than deficit (p=0.019) Table (4). In the follow-up at six months after surgery, 22 (73.33%) patients were truly negative, followed by false negative in 4 (13.33%) patients. True and false positives didn’t change even after 6 months of follow-up (Table 5).

Table (4): Comparison between no deficit and deficit groups immediately postoperative.

Findings	No deficit (n=24)	Deficit (n=6)	*p*-value
Age (years)	35.96±11.62	41±6.42	0.318
Sex:			
Male	9 (37.5%)	2 (33.33%)	1
Female	15 (62.5%)	4 (66.67%)	
Medical research council:			
Grade 3	6 (25%)	2 (33.33%)	0.138
Grade 4	8 (33.33%)	4 (66.67%)	
Grade 5	10 (41.67%)	0 (0%)	
Modified McCormick scale preoperative:			
Grade 1	13 (54.17%)	0 (0%)	0.003*
Grade 2	9 (37.5%)	2 (33.33%)	
Grade 3	2 (8.33%)	4 (66.67%)	
MRI findings before surgery:			
Craniocervical	2 (8.33%)	0 (0%)	0.530
Cervical	6 (25%)	1 (16.67%)	
Thoracic	9 (37.5%)	4 (66.67%)	
Thoracolumbar	2 (8.33%)	1 (16.67%)	
Lumbar	5 (20.83%)	0 (0%)	
Lesion extent:			
1-2 vertebra	14 (58.33%)	5 (83.33%)	0.372
More than 2	10 (41.67%)	1 (16.67%)	
Histopathological finding:			
Meningioma	9 (37.5%)	2 (33.33%)	0.035*
Schwannoma	1 (4.17%)	3 (50%)	
Neurofibroma	7 (29.17%)	0 (0%)	
Ependymoma	5 (20.83%)	0 (0%)	
Dermoid cyst	1 (4.17%)	1 (16.67%)	
Hemangiopericytoma	1 (4.17%)	0 (0%)	
Surgical duration (hours)	3.96±0.81	4.17±0.98	0.591
Hospital stays (days):	6.25±3.35	10.67±2.34	0.005*
Complications:			
Pneumonia	4 (16.67%)	0 (0%)	0.557
UTI	4 (16.67%)	0 (0%)	0.557
Paralytic ileus	2 (8.33%)	0 (0%)	1
Surgical site infection	4 (16.67%)	0 (0%)	0.577
CSF fistula	4 (16.67%)	1 (16.67%)	1
Hematoma	1 (4.17%)	0 (0%)	1

Data are presented as mean ± SD or frequency (%).
*: Significantly different as *p*-value ≤0.05.
IONM: Intraoperative monitoring.
UTI : Urinary tract infection.
CSF : Cerebrospinal fluid.

Statistically significant differences are observed in the Modified McCormick scale preoperative grades, histopathological findings, and hospital stay duration. These differences suggest that patients with deficits tend to have worse preoperative grades, different histopathological findings, and longer hospital stays.

Diagnostic value of IONM to predict immediate postoperative neurological deficit:

Sensitivity decreased from 66.7% at immediate postoperative to 33.3% at 6 months follow-up. Specificity slightly decreased from 92.6% at immediate postoperative to 91.7% at 6 months follow-up. The PPV was stable from immediate to follow-up at 6 months. The NPV and accuracy ere respectively decreased from 96.2% to 84.6% and from 90.0% to 80.0%. The McNemar tests were 1 and 0.687, Kappa test were 0.687 and 0.286 respectively from postoperative immediate to the 6 months follow-up (Table 5).

Table (5): Diagnostic value of IONM to predict neurological deficit immediately postoperative and 6-month follow-up.

	Immediate postoperative		At 6 months follow-up	
	N	%	N	%
True Positive	2	6.67	2	6.67
True Negative	25	83.33	22	73.33
False Positive	2	6.67	2	6.67
False Negative	1	3.33	4	13.33
Statistical tests:				
McNemar test	1		0.687	
Kappa	0.516		0.286	
Sensitivity	66.7%		33.3%	
Specificity	92.6%		91.7%	
PPV	50.0%		50.0%	
NPV	96.2%		84.6%	
Accuracy	90.0%		80.0%	

Data are presented as frequency (%).
PPV: Positive predictive value.
NPV: Negative predictive value.

Case (1)

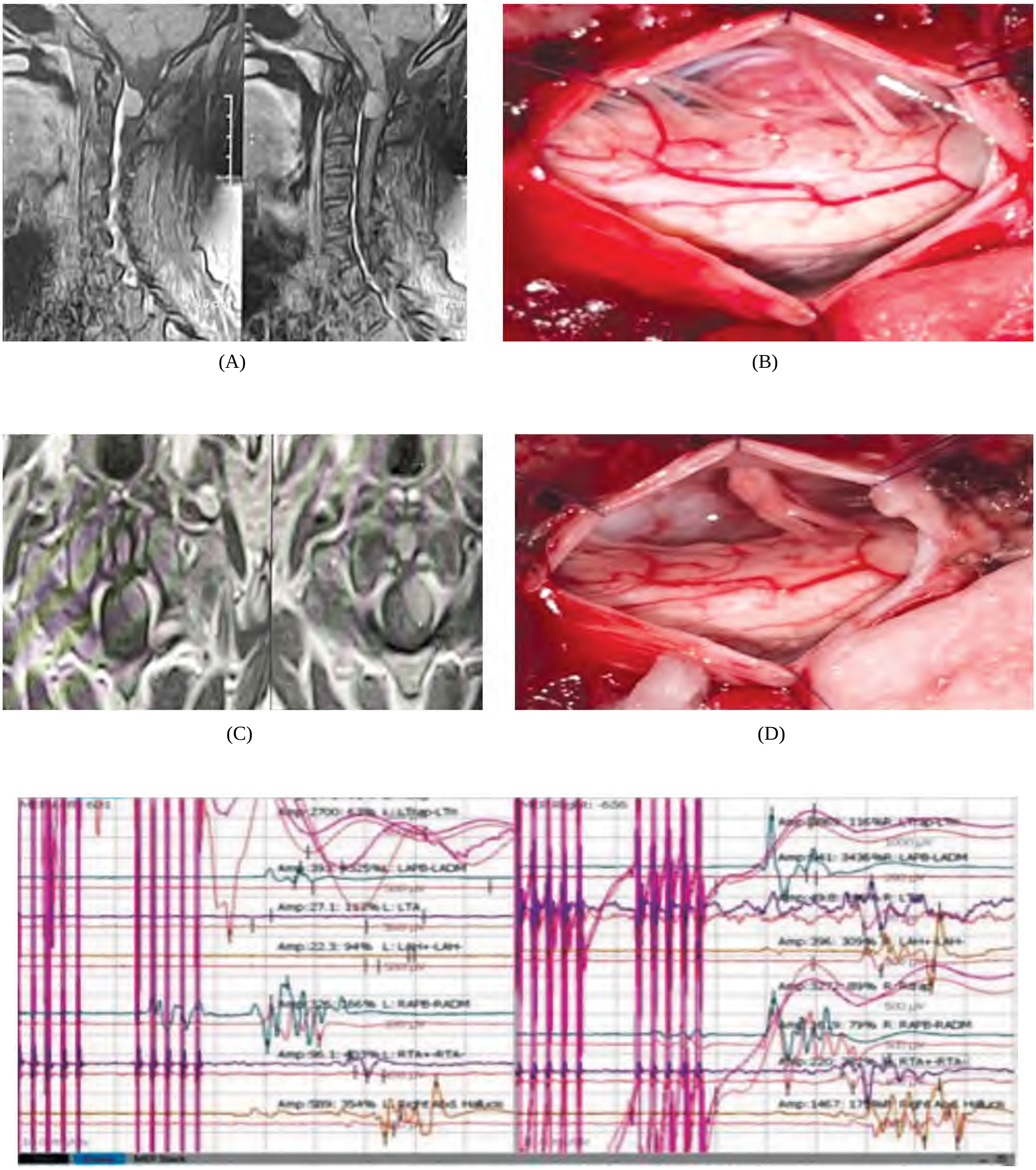
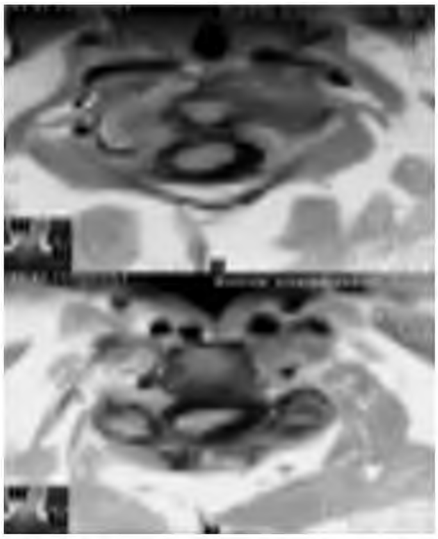
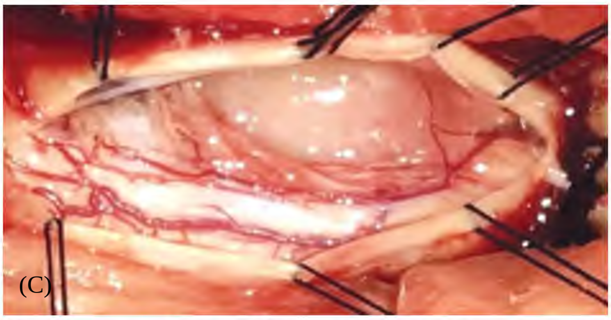


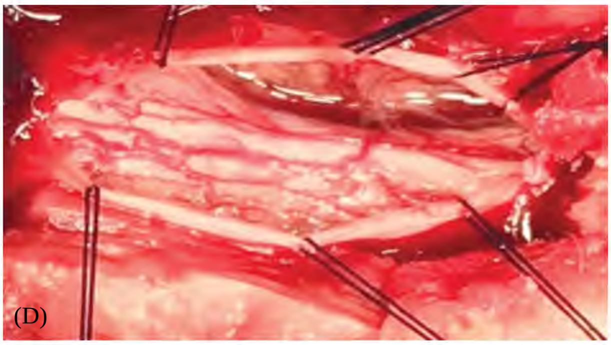
Fig. (1): A case of cervical meningioma, gross total resection was achieved using IONM techniques without any intraoperative MEP or SSEP alarming changes, patient recovered well without post-operative deficit. (A, C) Cervical spine MRI with contrast showed well defined homogeneously IDEMlesion at the level of C1 - C2 located left anterolaterally pushing the cord to the right. (B) A screenshot during intraoperative IONM. (D, E) Pre and post resection photos which revealed gross total resection.

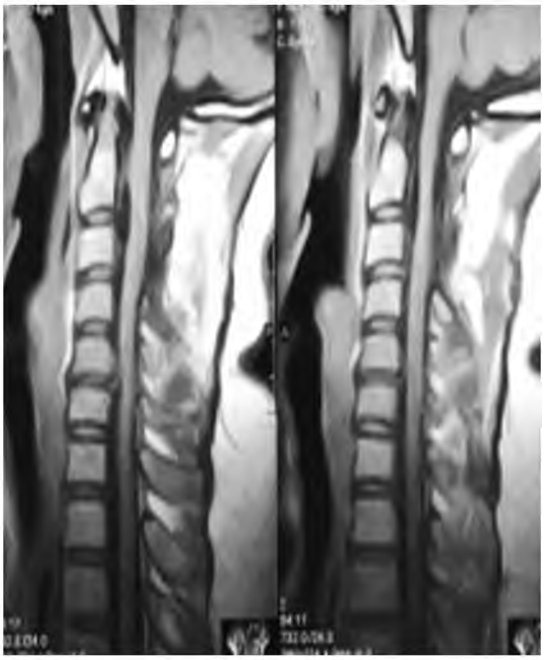
Case (2): A 50 years old female patient, known diabetic, presented with neck pain and progressive weakness of both upper and lower limbs more on the left UL 1 month ago, on examination motor power was gradeIV +ve in both LLs while right UL was grade IV -ve and left UL was grade III. Hypothesia of both ULs and LLs, spastic gait and hyperreflexia were also associated. Modified McCormick scale was grade III.

(A)


(B)


(C)


(D)


(E)


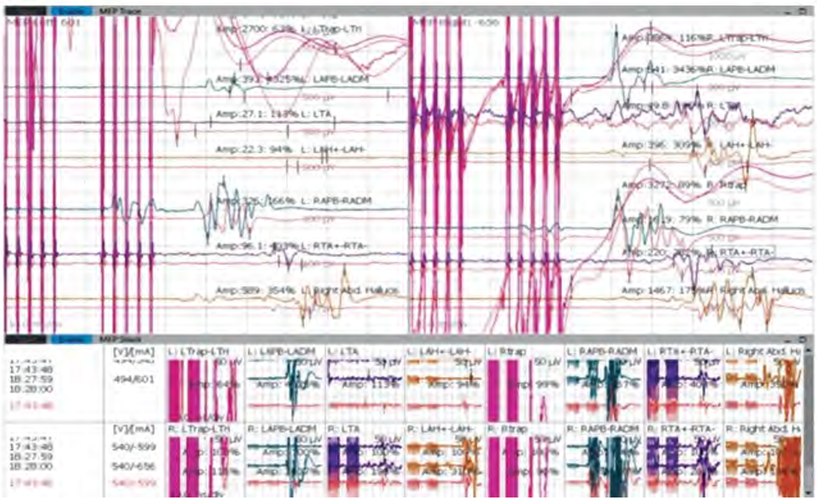
(F)


Fig. (1): (A, B) MRI cervical spine with contrast showed well defined homogenously enhanced IDEM lesion at the level of C2-C3, located left anterolaterally pushing the cord to the right.(C, D, E) total resection was done using IONM techniques. During resection and at closure, non-alarming MEP or SSEP changes were present. (F) The patient recovered well with immediate postoperative improvement of left UL to motor power gradeIV. Postoperative MRI with contrast showed total resection of the tumor with no residual. Histopathological examination reported Meningioma gradeI.At 6 months follow-up after intense physiotherapy and rehabilitation, the patient was completely independent and full power with Modified McCormick scale grade I.

Discussion

Intradural extramedullary (IDEM) tumors include meningiomas, nerve sheath tumors, metastases, dermoids, teratomas, paragangliomas, ependymomas, and hemangioblastomas. Spinal neurosurgery uses IONM, but efficacy is less established. Advancements in imaging and neuromonitoring improve results [1,5]. Surgeons face challenges in tumor surgery due to their anatomical positioning and limited maneuverability. To achieve gross total resection and functional outcomes while maintaining spinal stability, advancements in imaging, IONM, and minimally invasive techniques have been developed for intradural tumor surgeries [14]. Research indicates high success rates for IDEM tumors, with 90% complete removal success, less than 20% surgical complications, and over 80% postoperative neurological improvement in over 80% of patients [15-18]. IONM is a useful tool for finding neurological injuries quickly during surgery. It can potentially recommend corrective actions to surgeons and predict both short-term and long-term clinical outcomes. Identifying a neurological early enough will allow the neurosurgeon to take remedial action before permanent damage develops [1,14]. Several studies have demonstrated that the loss of muscular MEPs would only cause temporary motor impairments when the D-wave retains a maximum of 50% of its initial amplitude [19]. The majority of our patients who underwent surgery with IONMwere females (63.33%), with a mean age of 36.97±10.88 years. This result corroborates with Cofano F et al.'s study, which reported 64.7% of female patients [14]. The IONM value and reliability have been significantly increased by adding MEPs induced by transcranial electrical stimulation (TES) to monitor the corticospinal motor pathway [20].

There is a significant difference in the preoperative MMS preoperative grades. Grade I is more common in the no deficit group (54.17%) and absent in the deficit group. However, the MMS preoperative Grade III is more common in the deficit group (66.67%) than in the no-deficit group (8.33%). This difference is statistically significant (p 0.003*). There is a significant difference in histopathological findings. Schwannoma is more common in the deficit group (50%) compared to the no-deficit group (4.17%). Meningioma is more common in the no-deficit group (37.5%) compared to the deficit group (33.33%). This difference is statistically significant (p 0.035*). The hospital stay is significantly longer in the deficit group (10.67 days) compared to the no-deficit group (6.25 days). This difference is statistically significant (p 0.005*). Our patients had MMS preoperative grade I in 13 (43.33%) patients, followed by grade II in 11 (36.67%), and grade III in 6 (20%). In Characteristics of patients presenting significant IONM, the MMS preoperative was grade II in 2 (33.33%) patients and grade III in 4 (66.67%) patients. Immediately after surgery, MMS grade I was significantly greater in no-deficit patients than in deficit patients (p 0.003). At the 6-month follow-up, MMS Grade III was significantly less common in the no-deficit group compared to the deficit group (p 0.001). Additionally, the benefits of IONM were more pronounced in patients with better preoperative neurological conditions (MMS Grades I and II) than in those with severe deficits (MMS Grades III and IV). D-waves were recorded in 83% of all patients [14].

Histopathological findings showed meningioma in 11 (36.67%) patients, followed by schwannoma in 4 (13.33%) patients, neurofibroma in 7 (23.33%) patients, Ependymomas in 5 (16.67%) patients, dermoid cysts in 2 (6.67%) patients, and hemangiopericytoma in 1 (3.33%) patient. Cofano et al. found Schwannomas in 43.7% of patients, followed by Meningiomas in 37.7%. Other tumors included filum terminale ependymomas, paragangliomas, neurofibromas, hemangioteliomas, and hemangiopericytomas [14]. Meningiomas were the most frequently observed tumors in both groups, making up 35.6% of all cases. Ependymomas and schwannomas comprised 14.1% and 30.1% of the tumors, respectively. Tumors were classified as World Health Organization (WHO) grade I in 77.9% of cases, grade II in 6.7%, and grade III in 1.8%, while the remaining 13.5% were unclassifiable. No significant difference was found between the two groups for any grade (p 0.156) [5]. Regarding the level of the spine lesion, thoracic level was found in 4 (66.67%) patients; cervical and thoracolumbar levels in 1 (16.67%) patient each. The lesion extended to 1-2 vertebra in 5 (83.33%) patients and more than 2 in 1 (16.67%) patient. According to histopathological findings, meningioma was present in 2 (33.33%) patients, schwannoma in 3 (50%) patients, and dermoid cyst in 1 (16.67%) patient. According to Cofano et al., tumor localization, in the thoracic spine was affected in 43.8% of cases, lumbar lesions were found in 38.5% of patients, and cervical lesions occurred in 17.7% of patients [14].

The surgery involved total laminectomy in 20 (66.67%) patients, total laminectomy with fixation in 6 (20%), and partial laminectomy in 4 (13.33%) patients. Unilateral laminectomy 31.3%; bilateral laminectomy 59.5% of patients. Laminectomy, a successful and common procedure in intradural surgery, is believed to reduce treatment effects and instability risk, accounting for 97% of IONM cases [5,14]. Mohamed et al., reported that using IONM for IDEM tumors allowed for safer manipulation of tumors in difficult cases. This included lesions at the craniovertebral junction, antero/anterolateral locations, and tumors closely attached to the spinal cord without a clear separation boundary [1]. Regarding IONM, transient significant change, then recovery and continued surgery occurred in 4 (66.67%) patients, gross total resection was achieved, and

IONM deterioration and stop surgery occurred in 2 (33.33%) patients. These last two parameters coincided with IONM changes. Yu et al.'s study revealed that IONM significantly changed in six patients (2SEPs, 3MEPs, 1EMG event), with all experiencing immediate postoperative deterioration. Two patients fully recovered by discharge, while four had lingering impairments, with two showing complete recovery by the 3-month follow-up *[21]*. The minimally invasive techniques, such as monolateral laminectomy, were equally successful for tumor resection as bilateral laminectomy or laminoplasty, but the surgeon's experience and confidence may have influenced the choice of the surgical corridor *[14]*.

The study found no significant differences in age, sex, MRC grade, MRI findings before surgery, and lesion extent between no-deficit and deficit groups immediately after surgery, and no significant differences in length of surgery, surgical site infection, pneumonia, paralytic ileus, UTI, CSF fistula, and hematoma. Hospital stays were significantly shorter in non-deficit patients than in deficit patients (*p* 0.005). At the 6-month follow-up, there were no significant differences between the no deficit and deficit groups in terms of age, sex, MRC grade, pre-surgery MRI findings, or lesion extent. Additionally, factors such as surgical duration, pneumonia, UTI, paralytic ileus, surgical site infection, CSF fistula, and hematoma were similar between the groups. We evaluated IONM in IDEM tumor excision to predict neurological deficits.

In our results, Sensitivity decreased from 66.7% at immediate postoperative to 33.3% at 6 months follow-up, and NPV dropped. This means the test became less effective at detecting true positives over time. Specificity slightly decreased from 92.6% at immediate postoperative to 91.7% at 6 months follow-up. High specificity (92.6%) and stable PPV (50%) suggest reliability in ruling out the condition and confirming positives when tests are positive. Accuracy dropped from 90.0% immediately postoperative to 80.0% at 6 months follow-up. While specificity and PPV stayed relatively consistent, sensitivity, Kappa, and NPV worsened significantly from 96.2% to 84.6% at 6 months, reducing the test's overall reliability in detecting true positives during follow-up. The rise in false negatives contributed to the decline in accuracy. In line with our results, Wal et al., stated that 14.10% of patients had a worsening neurologic status six weeks postoperatively; this decreased to 9.84% one year postoperatively. They also noted that a high sensitivity (73%) and specificity (78%) were achieved by IONM for IDEM in predicting postoperative neurologic outcomes at six weeks *[10]*.Also, Ishida et al., noted that 16.50% of cases developed a new deficit at baseline. They exhibited that IONM demonstrated remarkable diagnostic value in predicting newly developed neurological deficits after six months, as evidenced by its AUC = 0.893, sensitivity (82.4%), specificity (90.7%), PPV (63.6%), and NPV (96.3%) *[22]*. IONM demonstrated perfect sensitivity (100%) and high specificity (98%) with a 100% negative predictive value but lower positive predictive value (67%). Transient changes occurred in 3.4% of procedures (2 MEPs alerts, 1 EMG event), and MEP waveform reductions in two cases were associated with hypotension *[21]*. Functional outcomes were not linked to the surgical approach in either the chi-square test or multivariate analysis. Additionally, there was no correlation between the surgical approach and the incidence of incidental durotomy or the degree of resection. The study found no association between the use of IONM and clinical outcomes at discharge. However, both the chi-square test and multivariate analysis showed significant results at follow-up *[14]*. The discussion often focuses on the effectiveness of using IONM in surgeries for IDEM tumors, compared to its well-known success in treating intramedullary tumors *[5]*. IONM is a crucial surgical tool that monitors neural pathways to detect and prevent nerve damage. It assists surgeons in identifying and mapping critical neural structures, ensuring precise interventions. Early detection of changes in brain, spinal cord, and peripheral nerve function allows for immediate corrective actions, preventing permanent deficits. IONM reduces complications such as paralysis, muscle weakness, and chronic pain, enhancing both safety and effectiveness. The use of IONM has significantly increased in recent years to prevent neurological complications during surgery. The three most used IONM methods for spinal surgeries are MEPs, spontaneous and triggered EMG, and SSEPs. It seeks to alert the surgeon of impending neurological injury before permanent deficits are inflicted *[5,8]*. Various methods were used to assess IONM. For cervical lesions, MEPs were recorded from muscles such as the biceps, deltoid, extensor, and abductor pollicis brevis; quadriceps; tibialis anterior; abductor digiti minimi; gastrocnemius; and abductor hallucis. For thoracic and lumbar lesions, the same muscles were used except for the deltoid and biceps. The bulbocavernosus reflex was assessed by stimulating the dorsum of the clitoris or penis and recording the response from the anal sphincter *[5]*.

Electrophysiological monitoring is recommended during spinal cord surgeries to assess the spinal cord's functional integrity. It's used in procedures like spinal cord decompression, spinal column deformity correction, intramedullary tumor resection, and stabilization of cervical and thoracic spinal injuries. This monitoring serves as a valuable diagnostic tool during these surgeries *[23]*. The synergy between IONM and anesthetic drugs is crucial for modern surgical safety. IONM provides a detailed view of the nervous system, while anesthetics ensure the physiological conditions necessary for precise monitoring and patient stability. Together, they minimize neurological complications and enhance outcomes in high-risk surgeries. Anesthetics create stable physiological conditions for accurate monitoring and patient safety. Their interdependence minimizes risks of paralysis, improves surgical accuracy, and enhances patient outcomes.

Conclusion:

Intradural extramedullary tumors (IDEM) include meningiomas, nerve sheath tumors, metastases, dermoids, teratomas, paragangliomas, ependymomas, and hemangioblastomas. Surgery aims for complete excision. Techniques like SSEPs, MEPs, EMG, and D-waves are employed in spinal procedures to prevent neurological complications. Techniques for predicting neurological deficits after IDEM tumor excision are accurate, but their predictive value for deficits six months following surgery is reduced. IONM is a crucial tool in modern surgery, combining safety, precision, and preventive care to protect neurological function and optimize outcomes in neurosurgical procedures. It reduces complications such as paralysis, muscle weakness, and chronic pain, enhancing both safety and effectiveness.

Declarations:

Consent for publication: Images used are anonymized without any patient details or identifiable factors.

Ethics approval and consent to participate: This study was approved by the institutional review board (Approval Code: KFSIRB200-172).

Availability of data and material: All data generated during this study are included in this published article.

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المراقبة الفسيولوجية العصبية أثناء الجراحة لاستئصال الأورام الشوكية داخل الأم الجافية وخارج النخاع الشوكى

الخلفيـة: تُستخدم المراقبة الفسيولوجية العصبية أثناء الجراحة (IONM) كثيرًا فى جراحة الأعصاب الشوكية، ولكن فاعليتها فـي أورام النخاع الشوكي داخل الأم الجافية وخارج النخاع الشوكى (IDEM) لا تزال غير مثبتة بشكل كافٍ. تُستخدم التطورات التكنولوجية فى التصوير، والمراقبة العصبية، والتقنيات الجراحية طفيفة التوغل لتحسين النتائج الوظيفية وتقليل المضاعفات. تم إجراء تقييم سريرى وإشعاعى شامل، كما تم إجراء مراقبة للجهود الحسية المستثارة (SEPs) والجهود الحركية المستثارة (MEPs) أثناء الجراحة. تم تقييم الحالة العصبية بعد العملية مباشرةً وبعد ستة أشهر من المتابعة.

هدف الدراسة: تقييم النتائج العصبية الفورية وبعد ستة أشهر من استئصال أورام IDEM باستخدام IONM فى مرضى يعانون أو لا يعانون من أعراض عصبية.

المرضى والطُرق: أُجريت هذه الدراسة المستقبلية على ٣٠ مريضًا مصابًا بأورام IDEM خضعوا للجراحة باستخدام IONM.

النتائج: شملت الدراسة ٣٠ مريضًا بأورام IDEM خضعوا لجراحة باستخدام IONM، وكانت الغالبية من الإناث (٦٣,٣٣٪)، وكان أغلب المرضى لديهم درجة أولى (I) على مقياس ماكوريك المعدل (MMS) قبل الجراحة (٤٣,٣٣٪). شملت الجراحة إزالة كاملة للقوس الفقرى الخلفى (لامينكتومى) فى ٢٠ مريضًا (٦٦,٦٧٪)، ولامينكتومى كامل مع تثبيت فى ٦ مرضى (٢٠٪)، ولامينكتومى جزئى فى ٤ مرضى (١٣,٣٣٪). أظهرت النتائج الباثولوجية أن ٣٦,٦٧٪ من المرضى لديهم ورم سحائى، و١٣,٣٣٪ لديهم ورم شفانى، و٢٣,٣٣٪ ورم ليفى عصبى، و١٦,٦٧٪ ورم بطانى عصبى، و٦,٦٧٪ كيسة جلدية، و٣,٣٣٪ ورم وعائى حول الخلايا.

فى مجموعة المرضى الذين لم يعانوا من أعراض عصبية (٢٤ مريضًا)، كان IONM مستقرًا فى ٧٩,١٦٪، بينما ظهر تغير مؤقت بسيط فى ٢٠,٨٣٪ من المرضى قبل أن يتعافى ويستمر الجراح فى العملية. فى المجموعة التى كانت تعانى من أعراض، ظهر تغير بسيط في ٦٦,٦٧٪ من المرضى، وتدهور أدى إلى إيقاف الجراحة فى ٣٣,٣٣٪ منهم. أظهرت الدراسة وجود علاقة بين MMS قبل الجراحة، والنتائج الباثولوجية، ومدة البقاء فى المستشفى فى كلا المجموعتين بعد المتابعة لمدة ستة أشهر. انخفضت الحساسية من ٦٦,٧٪ إلى ٣٣,٣٪، وتراجعت النوعية من ٩٢,٦٪ إلى ٩١,٧٪، بينما انخفضت الدقة من ٩٠,٠٪ إلى ٨٠,٠٪. كما تراجعت القيمة التنبؤية السلبية (NPV) من ٩٦,٢٪ إلى ٨٤,٦٪. بلغت نتائج اختبار McNemar (١ و٠,٦٨٧)، واختبار كابا ٠,٦٨٧ و٠,٢٨٦ على التوالى. ساهمت الزيادة فى النتائج السلبية الكاذبة فى انخفاض الدقة، مما يشير إلى الحاجة لتحسين موثوقية الاختبار.

الاستنتاج: تُستخدم تقنيات IONM مثل EMG، MEPs، SSEPs، وD–waves بشكل متزايد فى الجراحات الشوكية لتقليل المضاعفات العصبية. تُعد هذه التقنية دقيقة فى التنبؤ بالضرر العصبى الفورى بعد استئصال أورام IDEM، لكن قدرتها التنبؤية بعد ٦ أشهر تكون أقل.