The Efficacy of Intraoperative Neurophysiological Monitoring to Detect Postoperative Neurological Deficits in Transforaminal Lumbar Interbody Fusion Surgery

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BACKGROUND: Despite the extensive use of intraoperative neurophysiological monitoring (IONM) in spinal procedures, there is no standard guideline for what types of IONM tests should be monitored during lumbar procedures with instrumentation. Moreover, the efficacy of IONM during transforaminal lumbar interbody fusion (TLIF) surgery in detecting postoperative neurological deficits has not been well described.

OBJECTIVE: To analyze waveform changes from individual IONM tests (somatosensory evoked potentials [SSEP], motor evoked potentials [MEP], and electromyography [EMG]) during TLIF and compare the sensitivity and specificity of these tests in order to determine the best combination to detect postoperative neurological deficits.

METHODS: Two hundred seventy-five consecutive TLIF cases with IONM between 2010 and 2014 were reviewed, and new postoperative sensory and motor deficits were documented. Sensitivity and specificity for each IONM test in detecting postoperative sensory and/or motor deficits were analyzed.

RESULTS: SSEP and EMG tests were performed on all 275 patients with 66 patients undergoing additional MEP tests. A total of 7 postoperative deficits have been reported: 2 sensory and 5 motor deficits. MEP test had high sensitivity (80.0%) and specificity (100%) in detecting motor deficits. However, SSEP changes failed to detect sensory deficits and EMG test had high false-positive rates for detecting both sensory (100%) and motor deficits (97.3%).

CONCLUSION: MEP test should be incorporated in monitoring protocols during spinal procedures that involve instrumentations below vertebral level L1 such as TLIF, as it provides high sensitivity and specificity in detecting postoperative motor deficits. In addition, we propose modifying the standard lower extremity SSEP monitoring protocol to correspond to the vertebral levels being operated on.

KEY WORDS: Electromyography, Intraoperative neuromonitoring, Motor evoked potentials, Neurological deficits, Somatosensory evoked potentials, Transforaminal lumbar interbody fusion

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The annual number of spinal surgeries in the USA is rapidly increasing, leading surgical institutions to utilize new modalities to decrease cost and potential surgical complications,[1] especially iatrogenic spinal injury. Iatrogenic injury to the spinal cord is a major concern for surgeons of the spinal column and cord and is known to occur during instrumentation procedures. As there has been an increased implementation of new and innovative instrumentation in spine surgery, the need for intraoperative monitoring to assess the functional integrity of the spinal cord has become more critical.

ABBREVIATIONS: EMG, electromyography; **IONM,** intraoperative neurophysiological monitoring; **MEP,** motor evoked potentials; **PTN,** posterior tibial nerve; **SSEP,** somatosensory evoked potential; **TLIF,** transforaminal lumbar interbody fusion

To monitor the spinal cord integrity and potential iatrogenic injuries, intraoperative neurophysiological monitoring (IONM) of the spinal cord has become an important adjunct to neurosurgical and orthopedic spinal procedures. Starting in the late 1970s, earlier monitoring relied on evoked potentials like the somatosensory evoked potentials (SSEP), but current multimodal IONM includes techniques to assess changes in the motor evoked potentials (MEP) and electromyography (EMG) activity as well.[2] These additional monitoring modalities provide feedback to the surgeon with information of possible spinal cord insults during the procedure.[3,4]

Despite the benefits of IONM to monitor potential neurological injury, the efficacy of IONM evoked potential changes has been inconsistent. SSEP, for example, has proven to be effective in monitoring spinal cord function in cervical and thoracic procedures but not specific to the nerve root level during lumbosacral procedures.[5,6] In addition, dermatomal SSEP is used for evaluating specific nerve roots, but it cannot detect immediate changes from an iatrogenic insult.[5,7] In terms of diagnostic value, SSEP and MEP have shown high sensitivity (92.3%) and specificity (98.5%) in predicting postoperative neurological deficits in spinal deformity procedures[8] but not significant value in cervical disc procedures.[9,10] For transforaminal lumbar interbody fusion (TLIF) procedures, only the benefits of EMG activity monitoring during the pedicle screw placement have been explored,[11] but the use of other evoked potential (EP) changes in monitoring potential postoperative deficits in patients undergoing TLIF procedures has not been well described.

In this study, we analyzed waveform changes from individual IONM tests such as SSEP, MEP, and EMG during the TLIF procedures and compared the sensitivity and specificity of these tests in order to determine the best combination that could be used intraoperatively to detect postoperative neurological deficits.

METHODS

Patient Population and Postoperative Neurological Evaluation

We retrospectively reviewed 275 consecutive TLIF patients operated on by trained full-time neurosurgery and orthopedic attending surgeons at a single center between January 2010 and December 2014. The Institutional Review Board at the hospital institution granted approval for the review of the medical records and conduction of this study. The study was exempt from patient consent as it was classified as minimal risk.

Patients younger than 18 yr of age and surgeries performed without IONM were excluded from the study. All demographic/surgical information was collected from hospital electronic medical records. Postoperative exacerbations of pre-existing neurological deficits and new postoperative neurological deficits were identified from postoperative progress and discharge reports. Neurological deficits were defined as sensory or motor deficits that included but were not limited to decreased proprioception, vibratory sensation, coordination, muscle strength, and range of motion. Patients were evaluated by the surgeons upon waking from the procedure and for at least 48 h until discharge. Deficits were documented in the patient electronic medical records, and deficits were considered as true neurological deficits when still present at 1-yr follow-up.

IONM Data—Intraoperative cortical SSEP

All monitoring was performed using the NeuroNet-VI system (Computational Diagnostics, Inc, Pittsburgh, Pennsylvania). We recorded baseline traces of the cortical (P37) component of lower limb SSEPs elicited by stimulating each posterior tibial nerve (PTN) at the ankle. SSEP monitoring was considered feasible when reproducible signals (amplitude 0.2 mV for P37) were obtained on at least 1 side. Throughout the procedure, SSEP responses were recorded continuously. Stimulation intensity ranged from 35 to 45mA, the stimulation rate was 2 Hz, and 160 to 300 trials were averaged for each trace. Responses were recorded in a referential fashion from multiple electrodes fixed Cz, Fz, C'1, and C'2 scalp points (International 10-20 System). SSEP amplitude was defined as peak-to-peak amplitude. The continuous recording was compared with the baseline trace, and at least 50% decrease in amplitude or 10% increase in latency was taken as alarm criteria and considered to be a change in the SSEP test.

IONM Data—Intraoperative Transcranial Electrical Stimulation-MEPs (MEP)

Intraoperative MEPs were elicited by transcranial electrical stimulation, using a NeuroNet-VI system (Computational Diagnostics, Inc) with constant current output, and recorded from the tibialis anterior and abductor hallucis muscles bilaterally. Transcranial pulse-train stimulation was delivered to the motor cortex via 2 corkscrew electrodes inserted subcutaneously over C3-C4 (International 10-20 System). Stimulation parameter values (ie, number of pulses, interstimulus interval, and voltage) were optimized to elicit the maximal baseline response amplitude in each patient (trains of 5-7 pulses with an interstimulus interval of 2-4 ms, and a constant current of 100-200 mA). We defined a response to be monitorable when its amplitude was of at least 25 mV, as lower amplitudes can be difficult to distinguish from background noise. Throughout the surgery, an amplitude attenuation (exceeding 50%-80% of baseline) or any abrupt abolition of the response was taken as an alarm criterion or considered to be a change in the MEP test.

IONM Data—Intraoperative Spontaneous EMG

Spontaneous EMG can be used intraoperatively to localize nerve irritation. We measured spontaneous EMG activity with recording electrodes placed into the lower extremities muscles bilaterally. Muscle selection was made to maximize nerve root coverage based on the spinal level surgeons were working on. Although stimulation is not performed for in this test, surgical manipulation such as pulling, stretching, or compressing nerve roots/nerves can produce neurotonic discharges resulting in activity in the corresponding innervated muscles. During surgery, spontaneous EMG trains are of clinical significance and they are continuous, repetitive EMG firing caused by force applied to the nerve root. Surgeons were notified if these occurred.

Additional IONM Criteria

Systemic and other potential factors such as anesthetic changes, level of neuromuscular blockade, and IONM technical problems were ruled out and discussed in real time with the surgeon as they were informed about EP changes.

IONM Reports and Archived Waveforms Traces

SSEP and MEP signal changes and EMG activity were documented in the patients' neurophysiology reports, which were completed by

TABLE 1. List of Patients' IONM Tests With Evoked Potential Changes and Postoperative Deficits

Patient No.	Sex	Age (yr)	Operated Vertebral Levels	IONM Test With Evoked Potential Changes	Description of Postoperative Deficits
1	M	68	L2-L5	SSEP, EMG	*No Deficit*
2	M	62	L5-S1	SSEP, EMG	*No Deficit*
3	M	71	L4-L5	SSEP	*No Deficit*
4	M	35	L3-S1	*No Change*	Sensory—Anterior thigh pain with numbness and tingling
5	M	60	L5-S1	*No Change*	Sensory—Numbness of right thigh and hip
6	F	58	L2-S1	MEP, EMG	Motor—Bilateral muscle weakness (3/5) with no dorsiflexion or plantar flexion
7	M	29	L5-S1	MEP, EMG	Motor—Bilateral muscle weakness (3/5) with decreased range of motion
8	F	49	L5-S1	MEP, EMG	Motor—Right lower extremity weakness (3/5)
9	M	81	L2-S1	MEP	Motor-Bilateral muscle weakness (3/5)
10	F	54	L3-L4	*No Change*	Motor—Bilateral muscle weakness (3/5)

trained neurologists after the procedures. Final reports were reviewed by neurology attending and the institution's intraoperative neuromonitoring attending. IONM test selection for each case was based on the surgeons' request with the guidance of a neurologist's consult.

Analysis and Calculations

Sensitivity was defined as the proportion of patients with EP changes and postoperative deficits (true positive) to the total number of patients who experienced postoperative deficits. Specificity was defined as the proportion of patients with no EP change or postoperative deficits (true negative) to the total number of patients who did not experience postoperative deficits. False positive was defined as patients with EP changes but with no postoperative deficits while false negative was defined as patients with no EP change but had postoperative deficits. Positive predictive value was defined as the proportion of patients with EP changes and postoperative deficits (true positive) to the total number of patients who had EP changes. Negative predictive value was defined as the proportion of patients with no EP change or postoperative deficits (true negative) to the total number of patients who had no EP change.

RESULTS

A total of 275 patients (age range: 21-84 yr, 149 male and 126 female) who underwent TLIF were identified. Mean age was 54.2 yr with a standard deviation of 13.6 and an average of 1.4 vertebral levels was operated on per patient. SSEP and EMG tests were performed on all 275 patients with 66 patients undergoing additional MEP tests. A total of 7 postoperative deficits have been reported, of which 2 were sensory deficits and 5 motor deficits. Both sensory deficits were described as decreased sensation, numbness, and tingling in the lower extremities including the thighs. All patients with motor deficits had decreased lower extremity muscle strength ($\leq$3/5) and 1 patient had an additional decreased range of motion of the hip, knee, and ankle (Table 1).

Out of 275 patients with SSEP monitoring, 3 patients (Pt no. 1, 2, 3) had intraoperative SSEP change without new postoperative neurological deficits. Out of these 3 patients, 0 had MEP changes but 2 patients (Pt no. 1, 2) had EMG activity.

In contrast, out of 275 patients with SSEP monitoring, 2 patients (Pt no. 4, 5) developed postoperative sensory deficits. In these patients, there was no reported change in SSEPs waveforms and no changes in MEP and EMG tests.

Of the 66 patients who had MEP monitoring in addition to SSEP and EMG tests, 4 patients (Pt no. 6, 7, 8, 9) had intraoperative MEP changes. MEP changes for Pt no. 6 and 7 occurred during the cage placement and trial, while changes for Pt no. 8 and 9 occurred during the disc distraction and screw insertion. After screw readjustment or rod correction, MEP changes returned to baseline for all patients. All 4 patients suffered postoperative motor deficits. Out of these 4 patients, none had intraoperative SSEPs changes and 3 patients (Pt no. 6, 7, 8) had EMG activity.

Additionally, out of the 66 MEP monitored patients, 1 patient (Pt no. 10) had postoperative motor deficits but had no changes in SSEP, MEP, or EMG tests.

Analysis of EMG monitoring showed that out of all 275 patients, 110 had EMG activity. Three patients (Pt no. 6, 7, 8) with reported EMG activity had postoperative motor deficits but no sensory deficits. For postoperative motor deficits, EMG test had a false-positive rate of 39.6%, while a false-negative rate of 40%. For postoperative sensory deficits, EMG test had a false-positive rate of 40.3% while a false-negative rate of 100%.

The sensitivity and specificity of each modality of monitoring for postoperative sensory deficits are the following: SSEP only (sensitivity = 0.0%, specificity = 98.9%); MEP only (0.0%, 93.8%); EMG only (0.0%, 59.7%); SSEP and MEP (0.0%, 89.1%); MEP and EMG (0.0%, 51.6%); SSEP and EMG (0.0%, 59.7%); SSEP, MEP, and EMG (0.0%, 59.3%; Table 2). The positive predictive values for postoperative sensory deficits are 0.0% for all the following tests: SSEP only; MEP only; EMG

TABLE 2. Distribution of Changes in IONM Test and Postoperative Sensory Deficits

	Sensory Deficits	No Sensory Deficit	*Total*
SSEP Test *only*			
SSEP Change	0	3	3
No SSEP Change	2	270	272
Total	2	273	*275*
		Sensitivity: 0.0% Specificity: 98.9%	
MEP Test *only*			
MEP Change	0	4	4
No MEP Change	2	60	62
Total	2	64	*66*
		Sensitivity: 0.0% Specificity: 93.8%	
EMG Test *only*			
EMG Change	0	110	110
No EMG Change	2	163	165
Total	2	273	*275*
		Sensitivity: 0.0% Specificity: 59.7%	
SSEP and MEP Tests			
Evoked Potential Change	0	7	7
No Change	2	57	59
Total	2	64	*66*
		Sensitivity: 0.0% Specificity: 89.1%	
MEP and EMG Tests			
Evoked Potential Change	0	31	31
No Change	2	33	35
Total	2	64	*66*
		Sensitivity: 0.0% Specificity: 51.6%	
SSEP and EMG Tests			
Evoked Potential Change	0	110	110
No Change	2	163	165
Total	2	273	*275*
		Sensitivity: 0.0% Specificity: 59.7%	
SSEP, MEP, and EMG Tests			
Evoked Potential Change	0	111	111
No Change	2	162	164
Total	2	273	*275*
		Sensitivity: 0.0% Specificity: 59.3%	

only; SSEP and MEP; MEP and EMG; SSEP and EMG; SSEP, MEP, and EMG. The negative predictive values for postoperative sensory deficits are the following: SSEP only (99.3%); MEP only (96.8%); EMG only (98.8%); SSEP and MEP (96.6%); MEP and EMG (94.3%); SSEP and EMG (98.8%); SSEP, MEP, and EMG (98.8%).

The sensitivity and specificity of each modality of monitoring for postoperative motor deficits are the following: SSEP only (sensitivity = 0.0%, specificity = 98.9%); MEP only (80.0%, 100%); EMG only (60.0%, 60.4%); SSEP and MEP (80.0%, 95.1%); MEP and EMG (80.0%, 55.7%); SSEP and EMG (60.0%, 60.4%); SSEP, MEP, and EMG (80.0%, 60.4%; Table 3). The positive predictive value for postoperative motor deficits are the following: SSEP only (0.0%); MEP only (100%); EMG only (2.7%); SSEP and MEP (57.1%); MEP and EMG (12.9%); SSEP and EMG (2.7%); SSEP, MEP, and EMG (3.6%).The negative predictive value for postoperative motor deficits are the following: SSEP only (98.2%); MEP only (98.4%); EMG only (98.8%); SSEP and MEP (98.3%); MEP and EMG (97.1%); SSEP and EMG (98.8%); SSEP, MEP, and EMG (99.4%).

The sensitivity and specificity of each modality of monitoring for any postoperative deficits, sensory or motor, are shown in Table 4.

DISCUSSION

Before the applications of IONM, assessment of the spinal cord integrity required the Stagnara wake-up test, where general anesthesia was reversed and neurological assessment of the lower extremity motor function was undertaken.[2] Currently, with increasing implementation of newer instrumentation in spine surgery and the demand for reducing neurological injury, multimodal IONM has become the standard of care for

TABLE 3. Distribution of Changes in IONM Test and Postoperative Motor Deficits

	Motor Deficits	No Motor Deficit	*Total*
SSEP Test *only*			
SSEP Change	0	3	3
No SSEP Change	5	267	272
Total	5	270	*275*
		Sensitivity: 0.0% Specificity: 98.9%	
MEP Test *only*			
MEP Change	4	0	4
No MEP Change	1	61	62
Total	5	61	*66*
		Sensitivity: 80.0% Specificity: 100%	
EMG Test *only*			
EMG Change	3	107	110
No EMG Change	2	163	165
Total	5	270	*275*
		Sensitivity: 60.0% Specificity: 60.4%	
SSEP and MEP Tests			
Evoked Potential Change	4	3	7
No Change	1	58	59
Total	5	61	*66*
		Sensitivity: 80.0% Specificity: 95.1%	
MEP and EMG Tests			
Evoked Potential Change	4	27	31
No Change	1	34	35
Total	5	61	*66*
		Sensitivity: 80.0% Specificity: 55.7%	
SSEP and EMG Tests			
Evoked Potential Change	3	107	110
No Change	2	163	165
Total	5	270	*275*
		Sensitivity: 60.0% Specificity: 60.4%	
SSEP, MEP, and EMG Tests			
Evoked Potential Change	4	107	111
No Change	1	163	164
Total	5	270	*275*
		Sensitivity: 80% Specificity: 60.4%	

monitoring spinal cord integrity.[2-4] Despite the extensive use of IONM to assess spinal cord integrity, the efficacy of IONM-evoked potential changes in different types of spine surgery is inconsistent and has not been well explored, especially in TLIF procedures that involve the lumbar nerve root level below the conus medullaris.[5-9] Thus, in the present study, we reviewed evoked potential changes in SSEP, MEP, and EMG tests and evaluated which combination of these modalities was more precise in detecting postoperative sensory and/or motor deficits during TLIF.

TLIF is indicated in cases of degenerative disc disease, low-grade spondylolisthesis, and reoperation for disc herniation.[12] TLIF arose as an improvement of the posterior lumbar interbody fusion procedure by accessing the intervertebral disc through the lateral portion of the vertebral foramen, which lowered risk for neurological injuries and improved lordosis alignment with graft placements.[12]

In our study, 7 postoperative deficits (2.5%) were reported from 275 TLIF patients. Two of these 7 permanent postoperative deficits were sensory deficits with the other 5 being motor deficits. While sensitivities of SSEP and EMG tests were poor, MEP test had high sensitivity and specificity for postoperative motor deficits.

SSEP tests are used to assess the spinal cord integrity of the dorsal column pathway. A change in the EP could indicate an insult to the sensory pathway and result in a postoperative sensory deficit, but based on our data, the sensitivity of SSEP changes was very poor (0.0%). As surgeons rely on evoked potential changes to detect iatrogenic insults to the neural structures, SSEP test in TLIF procedures was not useful in indicating significant postoperative sensory deficits. Furthermore, not even the combinations of different types of IONM tests were adequate to have high sensitivity and specificity to detect a postoperative sensory deficit (Table 2).

TABLE 4. **Distribution of Changes in IONM Test and Postoperative Sensory and/or Motor (Any) Deficits**

	Any Deficits	No Deficit	*Total*
SSEP Test *only*			
SSEP Change	0	3	3
No SSEP Change	7	265	272
Total	7	268	*275*
		Sensitivity: 0.0% Specificity: 98.9%	
MEP Test *only*			
MEP Change	4	0	4
No MEP Change	3	59	62
Total	7	59	*66*
		Sensitivity: 57.1% Specificity: 100%	
EMG Test *only*			
EMG Change	3	107	110
No EMG Change	4	161	165
Total	7	268	*275*
		Sensitivity: 42.9% Specificity: 60.1%	
SSEP and MEP Tests			
Evoked Potential Change	4	3	7
No Change	3	56	59
Total	7	59	*66*
		Sensitivity: 57.1% Specificity: 94.9%	
MEP and EMG Tests			
Evoked Potential Change	4	27	31
No Change	3	32	35
Total	7	59	*66*
		Sensitivity: 57.1% Specificity: 54.2%	
SSEP and EMG Tests			
Evoked Potential Change	3	107	110
No Change	4	161	265
Total	7	268	*275*
		Sensitivity: 42.9% Specificity: 60.1%	
SSEP, MEP, and EMG Tests			
Evoked Potential Change	4	107	111
No Change	3	161	164
Total	7	268	*275*
		Sensitivity: 57.1% Specificity: 59.0%	

On the other hand, for identifying postoperative motor deficits, MEP change had high sensitivity (80.0%) and specificity (100%). MEP assesses the integrity of the corticospinal pathway. Our data showed MEP changes to be significantly reliable in detecting motor deficits, which is consistent with studies in spinal deformity surgeries where an 80% decrease in amplitude served as a warning criterion for neurological damage.[13] When MEP test was combined with other IONM tests, however, the sensitivity and specificity were lowered.

For EMG activity, EMG test had high false-positive rates for both sensory deficits (110/110, 100%) and motor deficits (107/110, 97.3%). In addition, EMG test with combinations of other IONM tests could not detect postoperative sensory and/or motor deficits with a high degree of sensitivity or specificity. Previous literature cites EMG activity as a useful tool during pedicle screw placement;[11] however, a distinction needs to be made as this EMG activity is a triggered EMG where a change results from a direct electrical stimulation of instrumented hardware. In this study, we analyzed the usefulness of the continuous EMG monitoring during the entire TLIF procedure. Based on our data, we concluded that continuous EMG is not helpful for monitoring postoperative neurological deficits, which is consistent with parotidectomy procedures where continuous EMG also failed to detect facial nerve injury and facial paralysis.[14]

In our study, even after a change in MEP and a subsequent return to baseline, patients still experienced postoperative motor deficits. However, for patients with postoperative sensory deficits, SSEP test was not able to detect these deficits as there was no reported change in SSEP waveforms intraoperatively. We propose that this failure of SSEP test could be explained by the limitations of the current SSEP monitoring protocol. We followed the widely accepted standard protocol for lower extremity SSEP monitoring

TABLE 5. Characteristics of Patients with Motor Evoked Potential (MEP) Monitoring vs no MEP Monitoring

	MEP Monitoring		No MEP Monitoring		
Patient Characteristics	*n*	%	*n*	%	*P*-value
Sex					.23
Male	40	60.6	109	52.2	
Female	26	39.4	100	47.8	
Age (yr)					.25
>50	35	54.5	129	61.7	
Ethnicity					.19
White	30	45.5	111	53.1	
Black	8	12.1	23	11.0	
Hispanic	26	39.4	58	27.8	
Other	2	3.0	17	8.1	
ASA Class[a] > II	37	56.1	95	45.5	.16
Operated Vertebral Levels > 1	23	34.8	92	44.0	.20

[a] American Society of Anesthesiologists physical status classification.

which consists of recording SSEPs from the stimulation of the PTN.[15-17] The PTN consists of fibers arising from the L4 to S3 nerve roots and has corresponding sensory dermatome below the knee.[16] However, in our study, 2 patients (Pt no. 4, 5) had postoperative sensory deficits that corresponded to sensory loss at the L2-L3 dermatome region, which is innervated by the femoral nerve.[16] Patient no. 4 was operated on vertebral levels L2-L5 and developed numbness and tingling in the anterior thighs, corresponding to the L2-L3 sensory dermatome region. Patient no. 5 was operated on vertebral levels L3-S1 and reported numbness of the right hip and thigh, which also corresponded to the L2-L3 sensory dermatome region. Therefore, the sensory deficits of these patients could be due to iatrogenic insults to the neural pathways or more likely prolonged pressure on a peripheral sensory nerve that were not included in standard SSEP monitoring protocol.

Of note, out of all 275 patients, only 66 had MEP monitoring in addition to SSEP and EMG monitoring. This low number of MEP utilization was because in lumbar spine surgical procedure with instrumentation, such as TLIF, there is no standard guideline in what types of IONM tests should be monitored.[15,17] In the study, IONM test selection for each case was based on the surgeons' request with the guidance of neurophysiologists' consult, type of anesthetic agents used, and the ability to obtain a baseline MEP reading. There was no standardized institution guideline for IONM test modalities for TLIF procedures at the time of the study. Post hoc analysis showed no statistically significant difference between the 66 patients who had additional MEP testing and patients with no MEP testing in terms of number of vertebrae levels operated and other patient demographics (Table 5). Overall, without set guidelines, in many institutions, MEP monitoring is performed at the surgeon's discretion. However, based on our findings, MEP test was shown to be a useful tool in detecting postoperative motor deficits in TLIF procedures.

CONCLUSION

In TLIF procedures, intraoperative SSEP change was not effective in detecting postoperative sensory deficits, while spontaneous EMG had high false-positive rates for sensory and motor deficits. Intraoperative MEP change, on the other hand, was effective in detecting postoperative motor deficits with high sensitivity and specificity.

Based on the results of our analysis, we propose that MEP test should be included in monitoring protocols during spinal procedures that involve instrumentations below vertebral level L1, such as TLIF. This conclusion was based on the MEP test's high sensitivity (80.0%) and specificity (100%) to detect postoperative motor deficits. Further, in order to improve the detection of sensory deficits, we propose modifying the standard SSEP monitoring protocol for lower extremities to correspond to the vertebral levels being operated on. By including the stimulation of the femoral and common peroneal nerves, the modification will allow monitoring of nerve roots that are not monitored by the PTN in the standard SSEP monitoring protocol. As this modification can have cost implications as well as resource utilization implications, future studies regarding cost effectiveness of IONM in TLIF surgery should be considered. Future studies could also focus on establishing normative data and elucidating how intraoperative changes in amplitudes and latencies of the femoral nerve correlate with postoperative clinical outcomes.

Disclosure

The authors have no personal, financial, or institutional interest in any of the drugs, materials, or devices described in this article.

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COMMENT

This is a very good study that validates current "expert opinion" and slow changes in the paradigm of neuromonitoring. Certainly, for lateral surgery, MEPs are advocated over simple EMGs because of the lack of ability to EMGs to detect neural changes and potential injury. Thus, it stands to reason that such a paradigm shift also would translate to posterior lumbar surgeries. This manuscript provides data to support the superiority of MEPs over EMGs even in posterior lumbar surgeries. The manuscript is well-written and well organized, and it will be an important contribution to the future management of our patients.

Dean Chou
San Francisco, California

This painting depicts Martin Rutkowski, MD, during his residency at the University of California, San Francisco performing a craniotomy for aneurysm clipping. Dr Rutkowski's interest in neurosurgery developed in Medical School, where he studied the complete cascade's promotion of development and growth of glioblastoma under Dr Andy Parsa. While in residency at UCSF, he maintained a strong interest in brain tumors, endocrinology, and skull base neurosurgery. He developed a particular interest in pituitary disease and neuroendocrine disorders, and spent his research year in the Brain Tumor Research Center working with Dr Manish Aghi examining how tumor-associated macrophages contribute to the proliferative and invasive characteristics of pituitary adenoma. Currently, Dr Rutkoswki is a fellow in open and minimally invasive endoscopic skull base neurosurgery at the University of Southern California with Dr Gabriel Zada and Dr Steven Giannotta. © Lewis Blevins of Medical Portraiture. Used with permission, all rights reserved.