INTERNATIONAL JOURNAL of SPINE SURGERY

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Int J Spine Surg 2022, 16 (3) 548-553
doi: https://doi.org/10.14444/8247
https://www.ijssurgery.com/content/16/3/548

The International Journal of Spine Surgery
2397 Waterbury Circle, Suite 1,
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International Journal of Spine Surgery, Vol. 16, No. 3, 2022, pp. 548–553
https://doi.org/10.14444/8247

Review of the Role of Intraoperative Neurophysiological Monitoring in Spinal Surgery With a Focus on the True and False Positives and a Clinical Correlation

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ABSTRACT

Background: Spinal surgery is a technically challenging endeavor with potentially devastating complications. Intraoperative neurophysiological monitoring (IONM) is a method of preventing and identifying damage to the spinal cord.

Objective: The aim of our study was to examine the clinical utility of IONM in spinal surgeries performed at our institution and what effect, if any, subsequent interventions had on postoperative patient outcomes.

Methods: This is a retrospective cohort study of 169 patients who underwent spinal surgery with IONM at 2 institutions between 2013 and 2018. Signal changes detected were recorded as well as the surgeon's response to these changes. Neurological status was recorded using a standard neurological examination and characterized as per the McCormick Neurological Scale. Patients were followed up for 12 months after surgery.

Results: A total of 169 spinal surgery cases with concurrent use of spinal cord monitoring were carried out in our institution between 2013 and 2018. The youngest patient was 14 years old, and the oldest was 92 years old (mean, 51.9 ± 19.6 years). There were 100 female patients and 69 male patients. Most patients (n = 124) had no signal changes. Signal changes were observed in 26.6% of the cases (n = 45). Most of these signal changes were rectified through repositioning of the patient (n = 24). The other 21 patients saw no improvement in their signals before the end of their procedures; however, these 21 patients had no postoperative deficits (grade I). This brought the false positive rate to 38% (21/55); the false negative rate was 1.8% (3/169).

Conclusion: This study showed similar outcomes in patients whether IONM signals were recovered or not. The false positive and false negative rates were high. Our study helps to raise awareness about IONM's strengths and weaknesses to inform future clinical practice. We recommend prioritizing clinical judgment in spinal surgery cases and using IONM with caution.

Level of Evidence: 3.

New Technology

Keywords: spinal cord monitoring, intraoperative neurophysiological monitoring, somatosensory-evoked potentials, motor-evoked potentials, spinal surgery, spine

INTRODUCTION

Spinal surgery is a high-risk endeavor with little margin for error.[1] As advancements in patient treatments are developing at a rapid pace and patient expectations are higher than ever, appropriate care must be taken to minimize risk to patients. Intraoperative neurophysiological monitoring (IONM) is a common tool (introduced in 1975 by Tamaki and Yamane[2]) used by spine surgeons to mitigate the risk of spinal cord injury during spinal surgery. Its goals are to identify impending damage or injury to the neural structures and allow the surgeon to complete the procedure safely.[3] It has shown its reliability in several studies, with a sensitivity and specificity rate of 89% and 99%, respectively.[4,5] In the United States and most other developed countries, multimodal IONM is compulsory, particularly in spinal deformity surgeries, and forms the standard of care.[6]

Current evidence states that multimodal IONM allows for the best interpretation of the condition of the spinal cord during surgery.[7,8] The purported value of its use is the ability to intervene promptly in the case of an intraoperative signal change. This can theoretically allow the surgeon to prevent neurologic injury, which may have otherwise gone undetected.[9] Its role in both adult and pediatric deformity surgeries is well documented.[10,11] However, the true ability of IONM to prevent postoperative neurological deficits in other procedures is still contested. The most benefit appears to be seen in procedures with more direct manipulation of the cord,[12] whereas other "low-risk" procedures (eg, instrumented lumbar procedures) see little benefit.[13]

There is a paucity of research in the published literature regarding the clear benefit of IONM during spinal surgery. Numerous studies have attempted to assess its clinical role in various spinal procedures including tumor surgery,[14] discectomies,[15] cervical procedures,[16] and deformity correction.[17] To our knowledge, this is the first study examining the use of IONM in spinal surgeries for multiple indications. The aim of our study was to examine the clinical utility of IONM in spinal surgeries performed at our institution and what effect, if any, subsequent interventions had on postoperative patient outcomes.

METHODS

We conducted a retrospective review of 169 consecutive patients who underwent spinal surgery with concurrent use of IONM at our institution. Operations were performed across 2 clinical sites. One site dealt with trauma and high-risk elective patients. The other site dealt with low-risk elective work. All procedures were carried out by 1 of 3 fellowship-trained consultant orthopedic spinal surgeons. Ethical approval for the study was granted by the Clinical Research Ethics Committee at our institution.

Inclusion criteria consisted of patients older than 14 years who had surgery with IONM. Indications in this unit for IONM included anterior neck surgery with myelopathy, multilevel stenosis requiring decompression, major deformity correction, or patients with pre-existing neurology. Exclusion criteria consisted of patients who underwent spinal procedures not requiring IONM as per institutional guidelines.

Neurological status was recorded using a standard neurological examination, and patients' neurological status was characterized as per the McCormick Neurological Scale. This has been validated in the literature and is growing in clinical use to trend neurofunctional outcomes.[18] Neurological function was graded from I (neurologically intact) to V (paraplegic or quadriplegic)[19] (Table 1). Adverse outcomes such as neurological injury and surgical revisions were also recorded. A consultant orthopedic spinal surgeon performed the neurological examinations. Patients were followed up for a total of 12 months postsurgery.

Data were collected by liaising with the chief technician in charge of the IONM. Anonymous patient data were then checked against theater logbooks. Patient follow-up was achieved using our integrated electronic document management system. Importantly, this allowed us to access outpatient correspondence, which contained the standardized neurological proforma and relevant McCormick Neurological Scale grade.

Table 1. McCormick Neurologic Scale used to characterize neurological status.

Grade	Description
I	Neurological status intact, ambulating normally, minimal dysesthesia
II	Mild sensory of motor deficit, functioning independently
III	Moderate deficit, some limitation of function, maintains independence with external aid
IV	Severe sensory or motor deficit, function very limited, dependent on others
V	Paraplegia or quadriplegia, even in presence of flickering movement

All patients who underwent IONM were entered into a database. Indication for surgery, patient demographics, preoperative neurological status, intraoperative monitoring, and postoperative neurological status were recorded. The IONM was conducted by a technician and overseen by a neurophysiologist using somatosensory-evoked potentials (SSEPs), motor-evoked potentials (MEPs), and free-running electromyography (EMG) measured by subdermal probes. Baseline amplitude was established after positioning and prior to skin incision. Any deviation from baseline was recorded and quantified into percentages with respect to baseline. If the surgeon acted upon the altered IONM in any manner, this was documented. These IONM changes were correlated with postoperative neurological status and neurological outcomes at 1-year postsurgery.

For SSEPs, a change constituted a reduction in amplitude by 50% or greater or an increase in latency over 10%. These would only be in the absence of any other physiological explanation (eg, anesthetic agents, temperature, blood pressure changes, etc). For MEPs, a change constituted a significant reduction in amplitude in either an isolated muscle or group of muscles at or below the surgical level, again in the absence of any other physiological explanations. For free-running EMG, a significant reportable change would be a period of spontaneous EMG activity in an individual muscle or group of muscles that lasts for greater than 30 seconds.

In terms of *duration* elapsed before defining a signal change, this can be instant in the case of MEPs. Clinically significant EMG activity must persist for more than 30 seconds, as mentioned. SSEP changes must be proven to be reproducible, and this may take 2 to 3 minutes to establish.

Table 2. Types of operations monitored (*N* = 169).

Operations	No. (%) of Cases
Anterior cervical discectomy and fusion	72 (42.6%)
Anterior cervical discectom and fusion (revision)	1 (0.6%)
Posterior cervical discectomy and fusion	25 (14.8%)
Posterior occipital cervical fusion	5 (3%)
Cervical corpectomy	3 (1.8%)
Cervical discectomy	4 (2.4%)
Thoracic corpectomy	3 (1.8%)
Thoracic fusion (revision)	4 (2.4%)
Thoracolumbar decompression and fusion	17 (10%)
Lumbar discectomy and fusion	1 (0.6%)
Lumbar fusion (revision)	4 (2.4%)
Posterior thoracolumbar instrumented fusion (scoliosis correction)	29 (17.2%)
Scoliosis correction (revision)	1 (0.6%)
Removal of intervertebral disc prosthesis	1 (0.6%)

Table 3. Indications for neuromonitoring.

Indications	No. (%) of Cases
Cervical stenosis	70 (41.4%)
Cervical stenosis w/ disc prolapse	2 (1.2%)
Cervical disc prolapse	24 (14.2%)
Cervical osteomyelitis	1 (0.6%
Central cord syndrome	1 (0.6%)
Degenerative joint disease	5 (3%)
Thoracic stenosis	1 (0.6%)
Thoracic no. (fracture)	3 (1.8%)
Thoracic discitis and osteomyelitis	1 (0.6%)
Thoracic lesion	1 (0.6%)
Thoracolumbar scoliosis	28 (16.6%)
Lumbar stenosis	3 (1.8%)
Lumbar no. (fracture)	3 (1.8%)
Lumbar disc prolapse	1 (0.6%)
Metastases	
Lung	4 (2.4%)
Breast	3 (1.8%)
Renal	2 (1.18%)
Prostate	1 (0.6%)
Bowel	1 (0.6%)
Thyroid (papillary)	1 (0.6%)
Thymus	1 (0.6%)
Ankylosing spondylitis	1 (0.6%)
Rheumatoid arthritis (C1-C2 subluxation)	1 (0.6%)
Other	1 (0.6%)

RESULTS

There were 169 spinal surgery cases carried out in the 5-year period between 2013 and 2018 in our institution with the concurrent use of spinal cord monitoring. The youngest patient in this study was 14 years old, and the oldest was 92 years old (mean age, 51.9 ± 19.6 years). There were 100 female patients and 69 male patients.

Cervical spine procedures accounted for 66% (*n* = 110) of all procedures. The 2 most common cervical procedures were anterior cervical discectomy and fusion (ACDF) (*n* = 72) and posterior cervical discectomy and fusion (*n* = 25). There was one revision ACDF. Surgery involving the thoracic and lumbar spine accounted for the second largest cohort of patients. This included scoliosis correction (*n* = 29) and thoracolumbar decompression and fixation (*n* = 17) for a variety of indications (Table 2).

The top indication for surgery was cervical stenosis (*n* = 70). Thoracolumbar scoliosis was the next most common (*n* = 28). Of that, 7% of all operations involved malignancy, all of which were metastatic. These involved a spine stabilizing procedure due to vertebral invasion. Lung cancer metastasis was the most common (*n* = 4); metastasis to the bowel (*n* = 1), breast (*n* = 3), renal (*n* = 2), and prostate (*n* = 1) also occurred. There was also a single case of thymic cancer metastasis (Table 3).

There were 24 patients with cervical disc prolapse and myelopathic symptoms. There was a single case of cervical osteomyelitis. Five patients underwent surgery for degenerative joint disease in the cervical spine. We also had 1 patient with severe ankylosing spondylitis and 1 patient with rheumatoid arthritis and subsequent C1-C2 subluxation. In terms of trauma cases, there were 3 thoracic spine fractures and 3 lumbar spine fractures that required operative intervention.(Table 3)

Most patients (*n* = 124) had no signal changes as defined by the criteria outlined in our Methods section. Among them, 121 patients were grade I on the McCormick Neurological Scale at 12 months. The other 3 patients turned out to have false negatives (discussed in the following paragraphs). Signal changes were observed in 26.6% of the cases (*n* = 45). Of these patients, 88% (*n* = 40) of changes were picked up through a combination of MEPs and SSEPs. Most of these signal changes were rectified through repositioning of the patient (*n* = 24). This involved changing the position of a limb, loosening intraoperative traction, or removing the subdermal probe and reapplying it in a different position. The other 21 patients saw no improvement in their signals before the end of their procedures. This brought our "rescue rate"—that is, the number of people who had signal changes and in whom we managed to regain these signals—to 43.6% (*n* = 24). The 21 patients who saw no improvement in their signals suffered no postoperative deficits (grade I) and had intact neurological status at 12 months and so were deemed to be false positives. This brought the false positive rate to 38% (21/55). Decompression caused the greatest disruption to signal (*n* = 9).

This study had a false negative rate of 1.8% (3/169). That is, these patients recorded no signal changes during their operation but suffered some form of postoperative deficit. One patient experienced complete loss of power in their right hand (grade IV) after an ACDF from C7-T1. The intrinsic muscles of the hand were most affected with gradual restoration of power over the next 12 months. No further surgical intervention was required in this case. Another patient experienced right upper limb weakness (grade II) after a cervical stabilization procedure at the level of C5-C7. The patient had marked weakness of shoulder abduction as well as elbow flexion and extension. Again, the symptoms resolved gradually without further surgery. The most notable false negative involved a patient whose index procedure was an ACDF from C4-C7 for cervical stenosis. It was an uncomplicated procedure with no signal changes detected by IONM. The patient awoke from surgery with a postoperative neuropraxia affecting the C5-C6 nerve root (grade III). He had decreased power in his upper limbs bilaterally and went on to have a revision ACDF less than 10 weeks following index procedure.

DISCUSSION

The fear of postoperative complications after spinal surgery, particularly neurological, is shared by both surgeons and patients. IONM helps to identify changes in the neural structures, ideally at the reversible stage. The prompt intervention by the surgeon and/or their team in response to this is what prevents negative neurological outcomes. Deficits are to be expected if continued deleterious forces are applied to vital structures.[20,21]

As mentioned, the idea behind IONM is to guide the surgeon and allow them to prevent injury to the spinal cord through production of signal changes. One assumes most changes are due to direct manipulation of the spinal cord and surrounding structures due to the small operative space and challenging anatomy. Patient positioning can have a significant effect on these signal changes. In our study, signal changes responded well to repositioning. This is important as it is often something relatively innocuous, such as an improperly positioned limb, that can cause the most damage. Brachial plexopathies are the most observed findings in these patients.[22,23] A total of 24 patients had signal changes detected by IONM. These changes were not permanent and responded to repositioning, in line with documentation by other authors.[23] It is possible that the IONM prevented further deficits from occurring by alerting us to these changes. Its continued use may also allow for greater care to be taken when positioning patients for future surgeries as surgeons, and technicians become more familiar with body positions that have the potential for injury.

A total of 55 cases had signal changes, and 24 of these were "rescued," in that their signals returned. However, in our most important finding in this study, the other 21 patients had signal changes, and while attempts were made to restore these signals, they were not recovered. This cohort didn't suffer any postoperative complications, and most importantly, their outcomes were the same as those who had signal changes and were rescued (ie, no postoperative deficits) (Table 4). The relevance of this finding is that it opens discussion regarding the necessity of IONM and calls into question the effectiveness of any intervention made as a direct result of a signal change. If the outcomes of all 55 patients were the same, then it suggests that the presence of IONM made no difference to these patients. In fact, it may have proved detrimental in some instances such as the 3 false negative results and interrupting proceedings in the 21 false positive cases.

Table 4. Comparison of effect of correcting a positive signal in terms of new deficits.

	New Deficit	
All positive signals	**Yes**	**No**
Uncorrected positive signal ($n = 21$)	0	21
Corrected positive signal ($n = 24$)	0	24

Of note, we had 7 procedures performed for various instances of metastasis to the spine. It is important to highlight that these are technically challenging procedures where complete resection of the tumor is crucial. In these cases, IONM may be used as guide only, secondary to operator expertise and experience. It may be necessary to willfully proceed with the operation and override the IONM in the hands of an experienced surgeon; indeed, van der Wal et al's 2021 study would support this.[18] One of the perceived advantages of IONM is that it can document the presence of altered IONM signals. This may be useful in a medicolegal setting. Equally, proceeding with surgery in the face of deteriorating signals should not be a decision entered into lightly due to the potential legal ramifications to the surgeon.

As mentioned, we noted 3 false negatives with significant complications postoperatively. A false negative rate of 1.8% would be considered too high by many surgeons. A much larger study by Diab et al of 1301 operations for adolescent idiopathic scoliosis only identified one false negative (0.08%).[24] Interesting to note our 3 false negatives occurred in patients undergoing ACDF. IONM's role in ACDF surgeries is both controversial and conflicting.[25,26] Our study would suggest its judicious implementation in patients undergoing ACDF. The difficulty with IONM is that it can be falsely reassuring. In our study, it may have allowed the surgeon to think they were safe to proceed, whereas previously clinical judgment exclusively would have caused them to be more cautious in their approach.

The threshold for warning criteria in IONM is a subject of debate in the literature with some authors stating that guidelines are largely empirically derived, and thus IONM's clinical utility is difficult to assess.[27] Using our warning criteria, we had a "rescue" rate of 44%. This rescue rate, while occurring in a smaller patient cohort like ours, is in line with those of larger studies with rates of 52%.[28,29] These studies had higher thresholds for their MEP warning criteria (70% reduction) and may help to explain our high false positive rate ($n = 21$). Our findings would suggest that the higher thresholds for warning criteria in previously published studies are more appropriate. Raising the threshold in our center and perhaps in other centers that use a similar threshold, would minimize unnecessary interruptions to these complex procedures. Our findings lend weight to the argument for universal guidelines on warning criteria to be made available if IONM is to remain a useful clinical tool.[27] Indeed, it would be desirable to tailor the warning criteria based on patient anatomy, the goals of surgery, and the available literature.[30]

Our study was not without its limitations. This was a single-center retrospective cohort study without a non-IONM group for comparison, which prevented further regression analysis from being conducted. This group of patients was heterogeneous and included a diverse age range. We stopped our follow-up at 12 months post-surgery. It is possible that an extended follow-up period would be required to detect later changes. Due to the lack of a comparison group, it is difficult to determine whether the 24 patients who responded to repositioning were prevented from suffering a neurological deficit due to IONM's role in their surgery. As our study was a single-center cohort study involving a relatively small number of surgeons with extensive expertise in spinal surgery and using IONM, the results of the study are mainly relevant to other similar academic centers.

CONCLUSION

IONM is a noninvasive clinical tool that has become the standard of care for spinal surgery in many institutions around the world. Our study found that it can detect positioning-related changes well and allow the surgical team to respond to the same. It creates an intraoperative record, which some surgeons may think is useful from a medicolegal point of view. Our most important finding was that the patients we managed to "rescue" with the use of IONM had identical outcomes to those in whom we couldn't regain their signals. This meant our false positive rate for the study was 38%, which is very high. This may be attributed to our threshold for warning criteria. Our false negative rate was 1.8%, also too high for a study of this size and especially when compared to other larger studies. At best, the presence of IONM in our procedures prevented a few incidences of brachial plexopathy due to positioning issues (which is difficult to prove because of the lack of a comparator group). At worst, IONM missed 3 genuine cases and interrupted 21 procedures with no evidence for same (false positives, identical patient outcomes). Our study adds to the mounting body of evidence for and against IONM. It helps to raise awareness about IONM's strengths and weaknesses to inform future clinical practice. Based on our findings, we recommend that it is only employed by experienced surgeons with a good working knowledge of IONM because ultimately, IONM findings should be interpreted with caution and should not overrule good clinical judgment. It may also play a suitable role in the proper positioning of patients prior to surgery. Based on our high false positive rate, we would echo the call for tailored warning criteria to avoid this problem.

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Funding: The authors received no financial support for the research, authorship, and/or publication of this article.

Declaration of Conflicting Interests: The authors report no conflicts of interest in this work.

Ethics Approval: Granted by Clinical Research Ethics Committee of the University Hospital Galway.

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Published 27 April 2022