Published in final edited form as:
Curr Opin Anaesthesiol. 2019 October ; 32(5): 580–584. doi:10.1097/ACO.0000000000000753.

Neurophysiological monitoring during neurosurgery: anesthetic considerations based on outcome evidence

Benjamin F. Gruenbaum[a], **Shaun E. Gruenbaum**[b]

[a]Department of Anesthesiology, Yale University School of Medicine, New Haven, Connecticut

[b]Department of Anesthesiology and Perioperative Medicine, Mayo Clinic, Jacksonville, Florida, USA

Abstract

Purpose of review—This article reviews the recent outcome studies that investigated intraoperative neurophysiological monitoring (IONM) during spine, neurovascular and brain tumor surgery.

Recent findings—Several recent studies have focused on identifying which types of neurosurgical procedures might benefit most from IONM use. Despite conflicting literature regarding its efficacy in improving neurological outcomes, many experts have advocated for the use of IONM in neurosurgery. Several themes have emerged from the recent literature: the entire perioperative team must always work together to ensure adequate communication and intervention; systems and checklists, in which each member of the perioperative team has a clearly defined role, can be useful in the event of a sudden intraoperative changes in electrophysiological signals; regardless of the IONM modality used, any sudden change in electrophysiological signal should prompt an immediate and appropriate intervention; a multimodal IONM approach is often, but not always, advantageous over a single IONM approach.

Summary—For neurosurgical procedures that can be complicated by neural injury, the use of IONM should be considered according to specific patient and surgical factors. Future studies should focus on improving IONM technology and optimizing sensitivity and specificity for detecting any impending neural damage.

Keywords

intraoperative neurophysiologic monitoring; neurosurgical anesthesia; patient outcome

INTRODUCTION

Intraoperative neurophysiological monitoring (IONM) is commonly employed during neurosurgical procedures to assess the functional integrity of targeted neural structures. The most commonly used electrophysiological methods include somatosensory-evoked

Correspondence to Shaun E. Gruenbaum, MD, PhD, Department of Anesthesiology and Perioperative Medicine, Mayo Clinic, Jacksonville, FL 32224, USA. Tel: +1 904 956 3398; gruenbaum.shaun@mayo.edu.

Conflicts of interest
There are no conflicts of interest.

potentials (SSEPs), motor-evoked potentials (MEPSs) or transcranial motor-evoked potentials (tcMEP), brainstem auditory-evoked potentials (BAEPs), electroencephalography (EEG), and electro-myography (EMG). In recent years, these techniques have largely replaced intraoperative wake-up testing in patients at risk for neurological injury [1].

The quality of IONM can be significantly affected by several modifiable factors, such as patient core temperature, systemic blood pressure, and the depth and type of general anesthesia. Although recent advances in monitoring devices and anesthetic techniques have greatly improved the reliability and accuracy of IONM [2], sudden changes in IONM signals are often difficult to interpret. The role of the anesthesiologist in identifying and correcting modifiable risk factors is paramount for the prevention of neurological injury and optimization of neurological outcomes. A fundamental understanding of the limitations of IONM and the evidence that guides its use is, therefore, of great importance. Here, we review the recent outcomes studies that investigated IONM during spine, neurovascular and brain tumor surgery.

SPINE SURGERY

Permanent neurological deficits, such as paraplegia and quadriplegia are devastating potential complications after spine surgery, and multimodal IONM (e.g. SSEP and MEP) is often employed to assess the integrity of the spinal roots and sensory and motor pathways. Alterations in baseline IONM patterns are thought to reflect impeding spinal cord injury, which allows the surgeon and anesthesiologist to intervene and correct potential risk factors. Several studies have shown that IONM can reliably and effectively assist in the diagnosis of impending neurologic injury in spine surgery, thereby improving patient outcomes [3]. Although IONM is widely regarded by many experts as the ‘standard of care’ during spinal column or spinal cord procedures, its role in these procedures remains controversial [4].

Several recent outcome studies in patients undergoing spine surgery have focused largely on identifying, which types of surgeries might benefit most from IONM. For example, a recent retrospective study investigated the role of IONM in guiding surgery and predicting postoperative outcomes in 24 patients who underwent spinal cord hemangioblastoma resection [5]. The study demonstrated that pathological IONM changes were associated with a higher risk of new sensorimotor deficits and worse long-term neurological outcomes compared with nonpathological IONM findings. The authors concluded that IONM (specifically EMG and tcMEP) effectively facilitated favorable long-term outcomes in these patients. Similarly, a recent review of 13 studies between 2000 and 2015 concluded that the use of multimodal IONM in patients undergoing surgical resection of intramedullary spinal cord tumors was effective in preventing spinal cord injury and improving postoperative neurological outcomes [6].

In patients undergoing cervical spine surgery, IONM techniques are commonly used to reduce the risk of neurological injury. Although spinal cord injury can happen at any time during the procedure, the period during head positioning is associated with a particularly high risk of spinal cord injury. In a recent retrospective study in 338 patients undergoing cervical spine surgery, Appel *et al*. demonstrated that IONM signals were lost in nine patients during head positioning [7]. In most patients, repositioning of the head was associated with a restoration of the electrophysiological signals, resulting in favorable neurological outcomes. The authors concluded that the use of IONM in patients undergoing cervical spine procedures was effective in alerting the surgical team to impending neurological injury, suggesting an important role of IONM in these patients.

In another recent retrospective study in 468 patients who underwent cervical spine surgery [8], Appel and colleagues demonstrated that permanent changes in IONM signals were predictive of new neurological deficits whereas transient changes were not. Moreover, the authors found that changes in IONM signals that occurred during the position and decompression phases of the procedure were associated with better clinical outcomes compared with changes that occurred in during other phases of surgery.

Changes in IONM signals can often be difficult to interpret, and some experts have advocated for the use of alarms to help guide when intervention is necessary. Few studies, however, have studied outcomes related to IONM alarms and interventions in patients undergoing spine surgery. To this end, a recent study investigated the influence of IONM alarms with and without interventions in 90 patients with new or worsened postoperative neurological deficit immediately after undergoing spine surgery [9■]. The patients who underwent surgical invention after an IONM alarm experienced an 80% recovery rate at discharge, compared with a 26% recovery rate in patients with IONM alarms without interventions and a 14% recovery rate in patients without IONM alarms and without interventions. The authors concluded that surgical interventions that were guided by the use of IONM alarms were effective in improving patient outcomes even when postoperative deficits are present in the early postoperative period.

Despite largely considered by many experts to be the ‘standard of care’ in spine surgery, the evidence for IONM for many spine surgeries has been conflicting and its utility has recently been questioned. In fact, several recent studies have failed to demonstrate any improvements in neurological outcomes when IONM is employed for anterior cervical discectomy and fusion surgery [10], thoracolumbar spine surgery [11], or surgery for tethered cord syndrome or spinal intradural tumors [12]. Another recent study in 26 patients who underwent intramedullary spinal ependymoma surgery demonstrated a high rate of false-positive and false-negative results when IONM methods were employed [13]. In light of these recent conflicting studies, many experts have argued that the indiscriminate use of IONM should be cautioned against, and because of a lack of evidence, the use of IONM in all spine surgeries should no longer be considered the ‘standard of care’ [14■].

Although the benefits of IONM on neurological outcomes have recently been questioned, many experts nonetheless continue to advocate for its use in spine surgery for other reasons. For example, in one recent study that failed to demonstrate a difference in clinical outcomes associated with IONM in 46 patients who underwent lumbar intradural schwannoma resection, the authors still preferred the use of IONM for ‘peace of mind’, easy data retrieval, and medicolegal considerations [4]. The authors pointed out, however, that the questionable utility in these patients should certainly be weighed against the significantly higher costs associated with IONM and a longer length of surgery. Similarly, another study in 32 305 pediatric patients undergoing spinal fusion demonstrated only a non-significant trend toward lower risk of neurological complications when IONM methods were employed [15]. However, the authors reported that the use of IONM had no impact on hospital length of stay, costs, or in-hospital complications, suggesting that there is little downside to its use.

Other recent studies have focused on determining, which IONM methodologies are most advantageous in patients undergoing spine surgery, largely with conflicting results. For example, some studies have argued that the combined use of SSEP and MEP during spine surgery confers superior outcomes over any other single IONM modality [16,17■], whereas another study recently reported that unimodal IONM might have a higher specificity than multimodal IONM [10]. Some studies, however, have demonstrated that transcranial MEPs are more sensitive in detecting impending neurological injury in spine surgery than SSEP or EMG [17■,18,19]. Another study observed that D-wave monitoring was feasible in all spinal surgery patients without severe preoperative motor deficits, and was superior in predicting postoperative deficits compared with SSEPs and MEPs alone [20]. It is important to note that regardless of the type of IONM method employed, most experts agree that the surgeon and anesthesiologist should always be alerted to an increased risk of neurological injury whenever significant IONM changes are discovered.

NEUROVASCULAR SURGERY

In recent years, there has been growing interest in the use of IONM in neurovascular surgery to reduce the incidence of stroke and paralysis. Some of the more common IONM methods used to detect neural injury include EEG, evoked potentials, and transcranial Doppler [21■], although no clear consensus has yet emerged regarding their efficacy. We found recent evidence in three types of neurovascular surgeries that have investigated the utility of IONM with varying results: aneurysm clipping, carotid endarterectomy (CEA), and carotid stenosis.

In patients undergoing craniotomy for aneurysm clippings, the evidence for IONM has been inconsistent and varies according to the specific modalities used. For example, one recent study failed to demonstrate a significant impact of SSEP and MEP use on overall neurological outcomes during elective aneurysm clipping [22■■], whereas another study found that intraoperative SSEP monitoring was useful in detecting ischemic complications [23]. A third study demonstrated that a multimodal approach that employs tcMEPs and SSEPs is highly sensitive and specific for detecting new neurologic deficits in these patients [24].

Studies that have investigated the utility of IONM in patients undergoing CEA have generally demonstrated positive results. There is strong evidence that intraoperative EEG is effective in predicting postoperative stroke in patients undergoing CEA [25], and carotid artery stump pressure measurements are effective in monitoring collateral cerebral perfusion and predicting the need for shunting during CEA [26]. Compared with awake monitoring, recent studies have found that the use of IONM results in fewer technical failures, reduced surgical and anesthesia times, and a possible reduction in the need for a temporary shunt [27]. Some experts have strongly argued that a multimodal approach that combines EEG and SSEP modalities for identifying and preventing strokes after CEA [28].

Two recent studies have provided conflicting results on the potential benefits of SSEP monitoring in patients undergoing carotid artery stenting. The first study demonstrated that intraoperative SSEP changes were highly sensitive in predicting postoperative complications and neurological outcomes [29], whereas the second study demonstrated that clinically significant changes in the SSEP were not useful in predicting neurological outcomes in these patients [30].

BRAIN TUMOR SURGERY

IONM is considered the gold standard to map and monitor brain function during intracranial surgery in critical brain areas. Recent studies have largely focused on the utility of IONM in pediatric patients undergoing brain tumor resection, and on determining which IONM modalities confer the highest prognostic value.

Compared with adults, the utility of neurophysiological monitoring in children with brain tumors is challenged by numerous factors including differences in neuroanatomy and physiology (especially during brain and spine development) and variance in the normal range of IONM signals that are dependent on patient age and size. Although prospective randomized trials are lacking in these patients, prospective longitudinal studies largely support the diagnostic utility of IONM in children undergoing brain tumor resection [31]. Moreover, recent studies have demonstrated that multimodal IONM are superior over a single modality to facilitate maximal resection of lesions in or close to eloquent brain regions [32].

COMMON EMERGING THEMES

Despite some variability in the utility of IONM in neurosurgery, we have identified several common themes that have emerged from the recent literature. Understanding these commonalities facilitate cooperation among neurosurgeons, anesthesiologists, and neurophysiologists in using IONM to most effectively identify and prevent impending neural damage and optimize neurological outcomes.

First, it should be apparent that the entire perioperative team (including the surgeon, anesthesiologist, and neurophysiologist) must work together to ensure adequate communication regarding the need for and type of IONM method employed, execution of an anesthetic plan that has minimal effects on IONM, and to facilitate appropriate intervention when sudden IONM changes are found. External noise and distractions during surgery should be kept to a minimum, and communication between all surgical team members should be immediate in the event that potential issues arise [33]. They should develop a surgical plan that includes a monitoring model [34■■].

Despite conflicting evidence for the use of IONM for some types of neurosurgical procedures, many experts have advocated for a well organized system for implementing IONM properly, including a critical event checklist for the loss of intraoperative signals, clinical pathways, and crew resource management [14■,17■,35■]. The use of protocols and checklists are also useful in reviewing the intraoperative course in the event of postoperative complications and litigation, and for preventing similar complications in subsequent cases.

Moreover, the team of individuals involved in monitored surgeries should have a clear understanding of their respective roles when IONM modalities are employed. Regardless of the IONM modality used, sudden changes in electrophysiological signals might reflect impending neural damage, and should always prompt an immediate intervention by the surgeon and anesthesiologist.

Many studies have found that a multimodal IONM approach is often advantageous over a single modality [16,17■,24,32], although some studies have shown that a single modality is often superior [10]. Moreover, even in surgeries where the utility of IONM is questionable, many experts have advocated for its use in specific high-risk patients, for complex cases, and in children [22■■,29,33].

CONCLUSION

For neurosurgical procedures that can be complicated by neural injury, the use of IONM should be considered according to specific patient and surgical factors. We reviewed the recent clinical outcomes studies that have investigated the utility of IONM in neurosurgery in spine, neurovascular, and brain tumor surgery. Although conflicting literature exists regarding which patients and procedures would benefit most from IONM, and which specific modalities confer the best diagnostic and prognostic utility, any sudden changes in neurophysiological signals should prompt an immediate response to restore the signals and preserve neural function and integrity. Future research should focus on improving IONM technology that results in high sensitivity and specificity for detecting impending neural damage. Although current IONM modalities might be associated with increased costs, false-positive or false-negative results, or longer surgery time, we believe that the potential benefits of improved patient outcomes outweigh the potential downsides in many patients undergoing neurosurgical procedures.

REFERENCES AND RECOMMENDED READING

Papers of particular interest, published within the annual period of review, have been highlighted as:

■ of special interest

■■ of outstanding interest

1. Gunter A, Ruskin KJ. Intraoperative neurophysiologic monitoring: utility and anesthetic implications. Curr Opin Anaesthesiol 2016; 29:539–543. [PubMed: 27380045]
2. Koht A, Sloan TB. Intraoperative monitoring: recent advances in motor evoked potentials. Anesthesiol Clin 2016; 34:525–535. [PubMed: 27521196]
3. Laratta JL, Ha A, Shillingford JN, et al. Neuromonitoring in spinal deformity surgery: a multimodality approach. Global Spine J 2018; 8:68–77. [PubMed: 29456917]
4. Kahraman S, Gocmen S, Alpsan Gokmen MH, et al. Intraoperative neurophysiologic monitoring for lumbar intradural Schwannomas: does it affect clinical outcome? World Neurosurg 2019 [Epub ahead of print]
5. Siller S, Szelenyi A, Herlitz L, et al. Spinal cord hemangioblastomas: significance of intraoperative neurophysiological monitoring for resection and long-term outcome. J Neurosurg Spine 2017; 26:483–493. [PubMed: 27982764]

6. Verla T, Fridley JS, Khan AB, et al. Neuromonitoring for intramedullary spinal cord tumor surgery. World Neurosurg 2016; 95:108–116. [PubMed: 27474459]
7. Appel S, Korn A, Biron T, et al. Efficacy of head repositioning in restoration of electrophysiological signals during cervical spine procedures. J Clin Neurophysiol 2017; 34:174–178. [PubMed: 27574957]
8. Appel S, Biron T, Goldstein K, Ashkenazi E. Effect of intra- and extraoperative factors on the efficacy of intraoperative neuromonitoring during cervical spine surgery. World Neurosurg 2019; 123:e646–e651. [PubMed: 30576814]
9. Tamkus A, Rice KS, Kim HL. Intraoperative neuromonitoring alarms: relationship of the surgeon's decision to intervene (or not) and clinical outcomes in a subset of spinal surgical patients with a new postoperative neurological deficit. Neurodiagn J 2017; 57:276–287. [PubMed: 29236604] ■ This study examines the outcomes of patients with and without intervention after neuromonitoring alarms. It concluded that intervention after IONM alarm improves patient outcome.
10. Ajiboye RM, Zoller SD, Sharma A, et al. Intraoperative neuromonitoring for anterior cervical spine surgery: what is the evidence? Spine (Phila Pa 1976) 2017; 42:385–393. [PubMed: 27390917]
11. Atesok K, Smith W, Jones R, et al. The significance of upper extremity neuromonitoring changes during thoracolumbar spine surgery. Clin Spine Surg 2018; 31:E422–E426. [PubMed: 30036211]
12. Pusat S, Kural C, Solmaz I, et al. Comparison of electrophysiological outcomes of tethered cord syndrome and spinal intradural tumors: a retrospective clinical study. Turk Neurosurg 2017; 27:797–803. [PubMed: 27593807]
13. Park JH, Lee SH, Kim ES, Eoh W. Analysis of multimodal intraoperative monitoring during intramedullary spinal ependymoma surgery. World Neurosurg 2018; 120:e169–e180. [PubMed: 30096497]
14. Jea A. Editorial. Intraoperative neuromonitoring: gold standard or fool's gold? Neurosurg Focus 2017; 43:E9.■ This response to Zucarro (2017) provides a thoughtful reconsideration of the evidence for IONM.
15. George J, Das S, Egger AC, et al. Influence of intraoperative neuromonitoring on the outcomes of surgeries for pediatric scoliosis in the United States. Spine Deform 2019; 7:27–32. [PubMed: 30587317]
16. Thirumala PD, Huang J, Thiagarajan K, et al. Diagnostic accuracy of combined multimodality somatosensory evoked potential and transcranial motor evoked potential intraoperative monitoring in patients with idiopathic scoliosis. Spine (Phila Pa 1976) 2016; 41:E1177–E1184. [PubMed: 27172278]
17. Zuccaro M, Zuccaro J, Samdani AF, et al. Intraoperative neuromonitoring alerts in a pediatric deformity center. Neurosurg Focus 2017; 43:E8.■ This study suggests a high level of sensitivity and specificity for IONM in pediatric spinal deformity surgery.
18. Tobert DG, Glotzbecker MP, Hresko MT, et al. Efficacy of intraoperative neurophysiologic monitoring for pediatric cervical spine surgery. Spine (Phila Pa 1976) 2017; 42:974–978. [PubMed: 27792108]
19. Yue Q, Hale T, Knecht A, Laidacker J. Intraoperative loss of tibialis anterior transcranial electrical motor evoked potentials predicted postoperative footdrop. World Neurosurg 2017; 97:755.e1–755.e3.
20. Ghadirpour R, Nasi D, Iaccarino C, et al. Intraoperative neurophysiological monitoring for intradural extramedullary spinal tumors: predictive value and relevance of D-wave amplitude on surgical outcome during a 10-year experience. J Neurosurg Spine 2018; 30:259–267. [PubMed: 30497134]
21. So VC, Poon CC. Intraoperative neuromonitoring in major vascular surgery. Br J Anaesth 2016; 117(Suppl 2):ii13–ii25. [PubMed: 27566804] ■ This review examines many of the features of IONM application in neurovascular surgery.
22. Greve T, Stoecklein VM, Dorn F, et al. Introduction of intraoperative neuromonitoring does not necessarily improve overall long-term outcome in elective aneurysm clipping. J Neurosurg 2019; 1–9. [Epub ahead of print]■■ This study finds no significant improvement in neurological outcome with SSEP/MEP monitoring, yet suggests IONM may still have utility for high-risk patients.

23. Byoun HS, Bang JS, Oh CW, et al. The incidence of and risk factors for ischemic complications after microsurgical clipping of unruptured middle cerebral artery aneurysms and the efficacy of intraoperative monitoring of somatosensory evoked potentials: a retrospective study. Clin Neurol Neurosurg 2016; 151:128–135. [PubMed: 27838495]
24. Staarmann B, O'Neal K, Magner M, Zuccarello M. Sensitivity and specificity of intraoperative neuromonitoring for identifying safety and duration of temporary aneurysm clipping based on vascular territory, a multimodal strategy. World Neurosurg 2017; 100:522–530. [PubMed: 28089809]
25. Thirumala PD, Thiagarajan K, Gedela S, et al. Diagnostic accuracy of EEG changes during carotid endarterectomy in predicting perioperative strokes. J Clin Neurosci 2016; 25:1–9. [PubMed: 26474501]
26. Sef D, Skopljanac-Macina A, Milosevic M, et al. Cerebral neuromonitoring during carotid endarterectomy and impact of contralateral internal carotid occlusion. J Stroke Cerebrovasc Dis 2018; 27:1395–1402. [PubMed: 29397311]
27. Marino V, Aloj F, Vargas M, et al. Intraoperative neurological monitoring with evoked potentials during carotid endarterectomy versus cooperative patients under general anesthesia technique: a retrospective study. J Neurosurg Anesthesiol 2018; 30:258–264. [PubMed: 28368914]
28. Thirumala PD, Natarajan P, Thiagarajan K, et al. Diagnostic accuracy of somatosensory evoked potential and electroencephalography during carotid endarterectomy. Neurol Res 2016; 38:698–705. [PubMed: 27342607]
29. Adhikari RB, Takeda M, Kolakshyapati M, et al. Somatosensory evoked potentials in carotid artery stenting: effectiveness in ascertaining cerebral ischemic events. J Clin Neurosci 2016; 30:71–76. [PubMed: 27291465]
30. Norton JA, Peeling L, Meguro K, Kelly M. Phenomenology of neurophysiologic changes during surgical treatment of carotid stenosis using signal analysis. Clin Neurophysiol Pract 2018; 3:28–32. [PubMed: 30215004]
31. Kim K, Cho C, Bang MS, et al. Intraoperative neurophysiological monitoring: a review of techniques used for brain tumor surgery in children. J Korean Neurosurg Soc 2018; 61:363–375. [PubMed: 29742889]
32. Brandmeier S, Taskiran E, Bolukbasi FH, et al. Multimodal intraoperative neurophysiological monitoring in neurosurgical oncology. Turk Neurosurg 2018; 28:204–210. [PubMed: 28481390]
33. Timoney N, Rutka JT. Recent advances in epilepsy surgery and achieving best outcomes using high-frequency oscillations, diffusion tensor imaging, magnetoencephalography, intraoperative neuromonitoring, focal cortical dysplasia, and bottom of sulcus dysplasia. Neurosurgery 2017; 64(CN_suppl_1):1–10. [PubMed: 28899045]
34. Rabai F, Mohamed B, Seubert CN. Optimizing intraoperative neuromonitoring: anesthetic considerations. Current Anesthesio Rep 2018; 8:306–317.■■ This review presents a thorough approach to IONM in many types of surgery and a thoughtful discussion on its efficacy and its relationship to anesthesia.
35. Vitale MG, Skaggs DL, Pace GI, et al. Best practices in intraoperative neuromonitoring in spine deformity surgery: development of an intraoperative checklist to optimize response. Spine Deform 2014; 2:333–339. [PubMed: 27927330] ■ Although several years old, this checklist continues to provide operating teams with a valuable format to organizing their IONM approach.

KEY POINTS

- In recent years, intraoperative neuromonitoring techniques (e.g. evoked potentials, electroencephalography, and electromyography) to assess the integrity of spinal roots and sensory and motor pathways have largely replaced intraoperative wake-up testing in patients at risk for neurological injury.
- Several recent outcome studies in patients undergoing spine surgery have focused mainly on identifying, which types of surgeries might benefit most from IONM.
- Although the benefits of IONM on neurological outcomes have recently been questioned, many experts nonetheless continue to advocate for its use because its potential benefits on neurological outcomes greatly outweigh associated costs and risk.
- Regardless of the type of IONM method employed, most experts agree that the surgeon and anesthesiologist should always be alerted to an increased risk of neurological injury whenever significant IONM changes are discovered.
- The entire perioperative team (including the surgeon, anesthesiologist, and neurophysiologist) must work together to ensure adequate communication regarding the need for and type of IONM method employed, execution of an anesthetic plan that has minimal effects on IONM, and to facilitate appropriate intervention when sudden IONM changes are found.