Basics of Neuromonitoring and Anesthetic Considerations

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KEYWORDS

- Evoked potentials • Electroencephalography • Burst suppression

KEY POINTS

- Amplitude and latency.
- Intraoperative changes in neuromonitoring signals.
- Effect of anesthesia on neuromonitoring.
- Controversies in neuromonitoring.

INTRODUCTION

Neuromonitoring is a modality involving recording electrical potentials generated by neurons or their axons throughout the nervous system. Commonly used modalities include electroencephalography (EEG), somatosensory evoked potentials (SSEPs), motor evoked potentials (MEPs), and brainstem auditory evoked potentials (BAEPs).

Intraoperative neuromonitoring (IONM) modalities are extensively used in adult and pediatric intracranial surgeries to facilitate near complete and safe surgical resection of brain tumors, resection of arteriovenous malformations, aneurysm clipping, and coiling. They are also widely used in spine surgeries to monitor integrity of the spinal cord during spine fusion/fixation and tumor resections. In addition, neuromonitoring techniques are commonly used during carotid endarterectomy surgery. Sudden changes in any signal aids in rapid diagnosis of acute change in clinical condition and alerts the surgeon and anesthesiologist to intraoperative critical events.

In this article, we discuss basics of neuromonitoring, indications, contraindications, and effect of anesthetic medications on various types of neuromonitoring techniques. We also discuss controversies associated with the use of IONM.

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ELECTROENCEPHALOGRAPHY
Indications and Contraindications

The EEG records electrical potentials generated by the neurons in cerebral cortex. Electrodes made of silver disks with conductive gel are placed on the scalp or sterilized and placed directly in the surgical field. The most commonly used description for the location of scalp electrodes is the 10- to 20-lead placement system (**Fig. 1**), where the specific electrodes are placed in relation to specific areas of the cerebral cortex.

However, during a craniotomy requiring EEG monitoring, the complete 10 to 20 system cannot be fully used because of surgical incision and exposure, hence the leads are usually placed as close as possible to the surgical site to facilitate monitoring. Each scalp electrode gives a continuous recording of spontaneous superficial brain activity covering an area of 2 to 3 cm in diameter (**Fig. 2**).[1]

Indications of EEG monitoring include the following procedures:

- Surgery involving eloquent cortex
- Carotid endarterectomy to aid in diagnosis of stroke
- Aortic arch surgery to monitor cerebral perfusion
- Certain seizure surgeries

There are no major contraindications for intraoperative EEG monitoring. Presence of scalp infection may preclude the placement of scalp electrodes. Emergency surgeries often proceed without any type of neuromonitoring because of clinical urgency.

Basic EEG waveforms are described next and shown in **Fig. 3**A.

- Delta (0.5–4 Hz): Delta rhythm is physiologically seen in deep sleep states and is prominent in the frontocentral head regions. Pathologic delta rhythm presents in awake states in case of generalized encephalopathy and focal cerebral dysfunction. Frontal intermittent rhythmic delta activity is normally present in adults.[2] Temporal intermittent rhythmic delta activity is seen in patients with temporal lobe epilepsy.[3]
- Theta (4–7 Hz): This is often seen in the frontocentral regions, and travels posteriorly, replacing the alpha rhythm during early drowsiness. This waveform is enhanced by heightened emotional states.
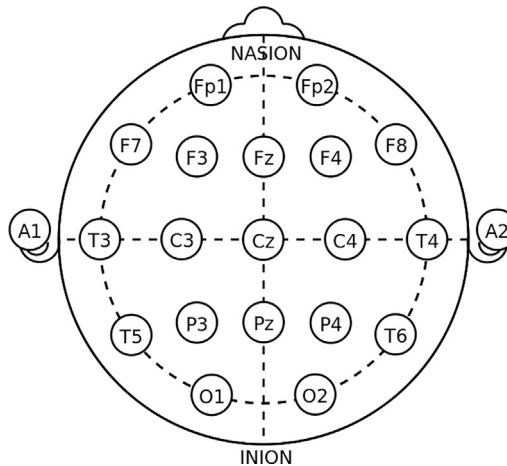

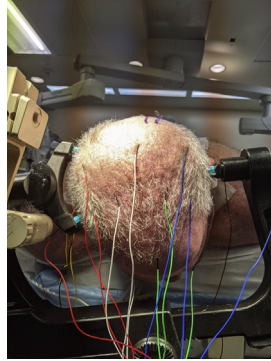**Fig. 1.** A 10- to 20-EEG lead placement system.

Fig. 2. Photograph showing EEG lead placement in a craniotomy. (*Courtesy of* Courtney Alles, CNIM.)

- Alpha (8–12 Hz): The dominant alpha rhythm is typically present in normal awake EEG recordings in the occipital region. It is best recorded with the eyes closed and during mental relaxation and is attenuated by eye opening.
- Beta (13–30 Hz): This is the most frequently seen rhythm in normal adults and children. Most sedatives increase the amplitude and quantity of beta activity. Beta wave attenuation can occur with cortical injury, and any fluid collection in the brain.

Several factors can affect EEG waveforms including pharmacologic interventions, physiologic factors (mostly sleep and awake status), and disease states.

Pharmacologic interventions

- General anesthesia causes progressive slowing of the raw EEG waveforms and can potentially cause gradual burst suppression in deeper states.
- Inhaled anesthetics (eg, sevoflurane), intravenous anesthetics (eg, propofol), and barbiturates produce slowing of the EEG frequency when used in higher
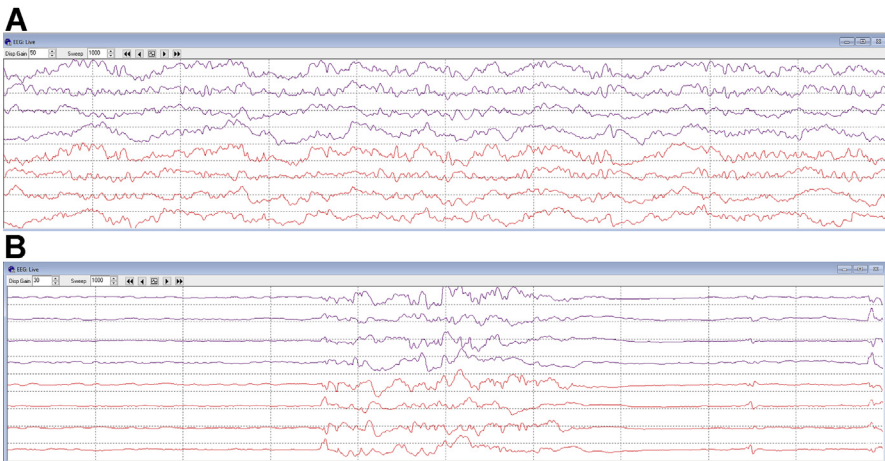

Fig. 3. (*A*) Normal EEG waveform recording. (*B*) EEG recording showing burst suppression. (*Courtesy of* K. Eggan, CNIM, New Haven, CT.)

concentrations. During deep anesthesia with these agents, a "burst suppression" pattern is noticed (Fig. 3B), which is characterized by high-frequency "bursts" alternating with flat tracings "suppression."

- Nitrous oxide does not produce burst suppression but produces fast oscillatory activity.
- Ketamine increases theta frequencies and decreases alpha oscillations but does not produce burst suppression.
- Opiates produce loss of beta waves, slow alpha waves, and an increase in delta wave activity. Commonly used opiates do not cause burst suppression in clinical doses.

Pathologic factors

- Hypoglycemia causes EEG changes that are characterized by increased activity in the delta and theta frequencies.
- Any cortical injury that alters the brain homeostasis (eg, trauma, bleeding, or hematoma).
- Diffuse encephalopathy (eg, virus induced, drug induced, or metabolic derangements).
- Hyperventilation-induced hypocapnia (Paco$_2$ <20 mm Hg), which causes generalized slowing of the EEG activity.
- Changes in the cerebral blood flow produce rapid changes in the EEG. With progressive reduction of cerebral blood flow and ischemia, progressive decrease in synaptic activity results in loss of high-frequency activity, loss of power, and ultimately EEG silence (Table 1).
- Temperature: Hypothermia with core temperature less than 35°C.
- Seizures: Intraoperative EEG can aid in the diagnosis of focal or generalized seizure, which is seen as polyspike discharges from the affected area.

Clinical Utility

Multichannel EEG is used as a monitor of global or focal cerebral perfusion and to detect epileptiform activity. In the intraoperative period it is indicated for cases with

Table 1
EEG frequency: beta greater than 12 Hz, theta 4–8 Hz, delta 0–4 Hz

Cerebral Blood Flow (mL/100 g/min)	EEG Changes	Severity and Neuronal Injury	Time to Cell Death
35–70	Normal	None	
25–35	Loss of fast (beta) frequencies, often not seen during general anesthesia	Mild, reversible	
18–25	EEG slowing into theta range, decrease in amplitude	Mild, reversible	Hours
12–18	Further slowing to delta range, decrease in amplitude	Moderate, reversible	
8–12	Severe amplitude loss at all frequencies	Severe, cell death	Minutes
<8	Loss of activity, isoelectric EEG	Loss of neurons	

Adapted from Jameson LC, Janik DJ, Sloan TB. Electrophysiologic monitoring in neurosurgery. Anesthesiol Clin 2007; 25:605; with permission.

a high potential for cortical ischemia, such as carotid endarterectomy, select supratentorial surgery, and epilepsy surgery for monitoring epileptic activity. EEG analysis can also be used to monitor for isoelectricity under hypothermic arrest. Similarly, it is used to avoid isoelectricity by titrating anesthetics to avoid reaching excessively deep planes of anesthesia.

Processed Electroencephalography

EEG waveform data is "processed" using power spectral analysis. Sine waves extracted at different frequencies are plotted over time and then overlaid using Fourier transformation to produce a single dimensionless value. There are several commercially available processed EEG monitors with slight variations in signal processing and information displayed. In general, all processed EEG uses fewer electrodes (usually one to four) compared with the full EEG. These monitoring modalities have simpler electrode placement in the operating room setting and are more straightforward to analyze and interpret. Each of the commercially available monitors use propriety algorithms to process EEG waveforms (**Table 2**).

The goal of processed EEGs is to monitor the relative density of different waveforms corresponding to the following states: awake, sedated, surgical anesthesia, and burst suppression. Data are then used to titrate anesthetic agents to avoid periods of possible awareness under anesthesia and unnecessary burst suppression. Bispectral index is the most widely used with a typical target goal of 40 to 60 for general anesthesia.

Caveats of Electroencephalography Monitoring

EEG monitoring modalities are expensive, and do not completely guarantee the presence of unconsciousness, lack of awareness, or the absence of cerebral ischemia, especially if there is preexisting neural damage. Furthermore, use of intraoperative EEG is prone to multiple artifacts, from the use of cautery, skin contact and impedance, patient movement, and location of lead placement.

SOMATOSENSORY EVOKED POTENTIALS

Intraoperatively, SSEPs are used in a variety of surgeries to monitor the integrity of the posterior (dorsal) columns of the spinal cord. An electrical stimulus is applied to a peripheral nerve, typically the median or ulnar nerve at the wrist for upper extremity SSEPs and the posterior tibial nerve at the ankle for lower extremity SSEPs, using needle or surface electrodes near the nerve.[4] Impulses ascend primarily in the dorsal column fibers of the spinal cord, which then synapse in the lower medulla. These then decussate at the level of the medulla and travel up the brainstem as the medial lemniscus to synapse in the contralateral thalamus. From there, relay neuron nerve fibers form the thalamocortical radiations, which travel through the internal capsule and synapse in the primary sensory cortex of the parietal lobe. SSEPs are useful in assessing the integrity of the sensory system from the peripheral nerves through to the cerebral cortex (**Figs. 4** and **5**).

Common indications for use of SSEPs include:

- A wide variety of spine surgeries, including scoliosis repair and posterior spinal instrumentations/fixations
- Carotid endarterectomies
- Some intracranial tumors
- Cardiovascular surgeries

Table 2
Commercially available processed EEG monitors

	Index	Company	Index Range	Works with Agents	Not Work with Agents/ Disadvantages
1	Bispectrum Index (BSI)	Aspect Medical Systems (now Covidien), United States, 1992	0–100	Propofol, midazolam, and isoflurane Outperformed all	Nitrous oxide and ketamine Problems with EMG
2	Narcotrend Index NCT	MonitorTechnik, Germany, 2000	0–100	Children, sevoflurane propofol/ remifentanil EMG susceptibility Good artifact removal	Neuromuscular blocking agents Complex algorithm Slowest response to a change in sedation
3	Entropy Index	Datex-Ohmeda Company, United States, 2003	0–100 1–91	Desflurane, sevoflurane propofol, thiopental	Ketamine
4	Patient State Index (PSI) or (PSA)	Physiomatrix (now SED Line Systems), United States, 2001	0–100	Propofol, alfentanil, nitrous oxide EMG susceptibility	—
5	AEP-Monitor (AAI)	Danmeter, Denmark, 2001	0–100 or 1–60	Propofol, midazolam, and isoflurane	No effects of nitrous oxide and ketamine
6	Snap Index	Everest Biomedical Instruments, United States, 2002		Sevoflurane and sevoflurane/ nitrous oxide	Sensitive to unintentional awareness
7	Cerebral State Index (CSI)	Danmeter A/S, Denmark, 2004	0–100	Propofol	Nitrous oxide

Abbreviation: EMG, electromyographic.
Data from Al-Kadi MI, Reaz MB, Ali MA. Evolution of electroencephalogram signal analysis techniques during anesthesia. Sensors 2013;13(5): 6605-35.
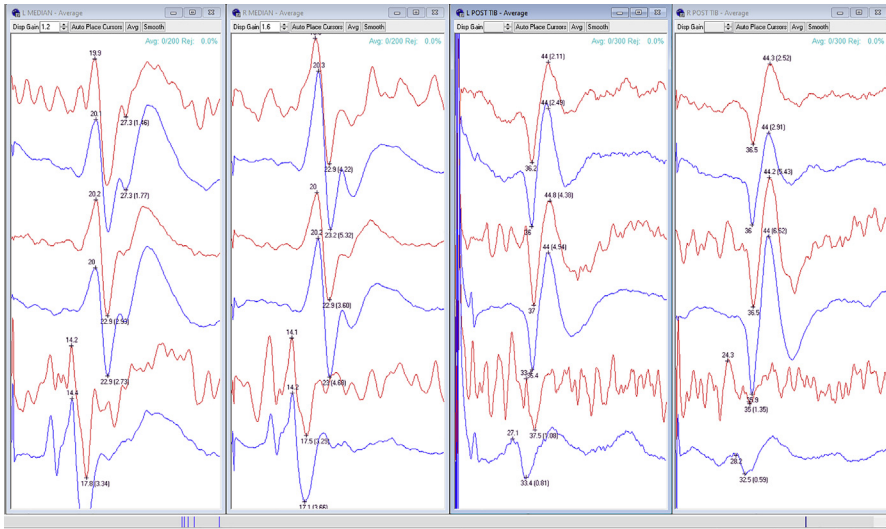
Fig. 4. Normal SSEP waveform during a spine surgery. (*Courtesy of* K. Eggan, CNIM, New Haven, CT.)

Factors Affecting the Amplitude and Latency of Somatosensory Evoked Potentials Waveforms

Similar to the EEG waveform, several factors including pharmacologic and physiologic and disease states influence SSEP signals.

Pharmacologic agents

- Halogenated inhalational agents cause dose-dependent reduction in amplitude and increase in latency, with a greater effect on cortex compared with spinal, peripheral, and subcortical tracings.[5]
- Nitrous oxide works synergistically with inhalational and most intravenous agents to decrease amplitude and increase latency of SSEPs.
- Intravenous agents with the notable exceptions of ketamine and etomidate decrease amplitude and increase latency of SSEP recordings.
- Barbiturates cause dose-dependent decreases in amplitude and increases in latency. Barbiturate doses that induce coma are still compatible with SSEP monitoring[6] even when they are dosed to produce burst suppression in the EEG.
- Propofol causes amplitude decrease and increased latency, although less pronounced than inhalational agents including nitrous oxide, or midazolam administered in doses to achieve comparable planes of anesthesia. Propofol is used for SSEP monitoring especially with opioids.[7]
- Etomidate causes increased amplitude with increased latency on SSEP cortical recordings.
- Ketamine causes increased amplitude with no change in latency or cortical potentials.[8]
- Opioids mildly decrease cortical SSEP amplitude and mildly increase latency with minimal effect on subcortical and peripheral potentials. Bolus dosing of opioids has a greater impact on SSEP changes than continuous infusion.[9]
- Benzodiazepines alone have little effect on SSEPs but may increase latency with the concomitant administration of nitrous oxide.
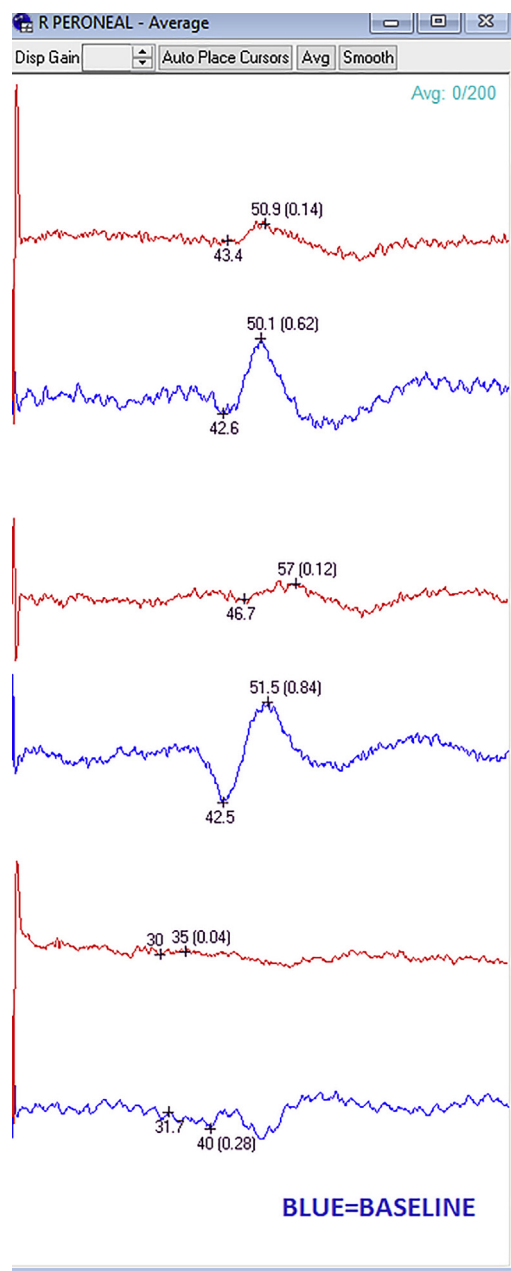
Fig. 5. Loss of greater than 50% amplitude in SSEP waveform during the placement of a spine fixator device, which was immediately removed. (*Courtesy of* K. Eggan, CNIM, New Haven, CT.)

Physiologic factors

- Temperature: Mild hypothermia increases SSEP latency but not amplitude. Although profound hypothermia silences SSEPs completely, mild hyperthermia decreases latency without affecting amplitude.[10]
- Tissue perfusion: Similar to EEG changes, cerebral blood flow less than 18 mL/min/100 g of tissue affects SSEPs. Amplitude is initially reduced and cortical SSEPs is lost with worsening hypotension. Regional ischemia caused by vascular injury, surgical traction, clipping, embolic effects, or positioning are common causes of altered SSEP monitoring during surgery. If mild, anemia can actually cause a mild increase in SSEP amplitude and reduced latency caused by improved viscosity effects, but worsening anemia causes decreases in amplitude and increased latency.[11]
- Although early responses to ischemia or hypoxia can manifest as a transient increase in SSEP amplitude, severe, progressive hypoxemia is associated with a decrease in SSEP amplitude and an increase in latency, eventually resulting in complete loss of cortical SSEP waves. Ventilation and Pa_{CO_2} levels have little effect on SSEP monitoring.[6]
- Intracranial hypertension causes decreased SSEP monitoring and eventual loss of responses in conjunction with uncal herniation.

MOTOR EVOKED POTENTIALS

MEPs are measured by exciting the motor cortex and subsequently measuring the electrical activity in the muscles of the hands or feet. MEP monitoring is a method of assessing the integrity of the corticospinal tract and the anterior segments of the spinal cord during spinal surgery. It has a high sensitivity and specificity to detect intraoperative neurologic deficits.[12]

Muscle responses to stimulation of the motor cortex are especially impacted by increasing concentrations of inhaled anesthetics and use of neuromuscular blockade, because MEPs are extremely sensitive to these medications. Special stimulation techniques and certain anesthetic regimens are used to optimize MEPs. Monitoring techniques are divided according to the site of stimulation (motor cortex or spinal cord), method of stimulation (electrical potential or magnetic field), and the site of recording (spinal cord or peripheral mixed nerve and muscle).

MEP monitoring is new compared with SSEPs monitoring and has gained popularity after isolated motor injury without sensory changes was described following idiopathic scoliosis procedures. MEP monitoring is now the standard of care in spinal deformity surgeries. Importantly, MEP changes were noted in 6% of spine deformity surgeries and 72% of these changes were reversible.[13] The ability to maintain neural integrity and prevent devastating injury has led to MEP monitoring in a growing number of surgical cases. When intraoperative use of MEPs is planned, soft bite blocks should be placed between the upper and lower molars to prevent the patient from biting either the tongue or the endotracheal tube during stimulation.

CRANIAL NERVE ELECTROMYOGRAM MONITORING

Often, individual cranial nerves may be monitored depending on the location of surgical resection. Examples include cranial nerve V and VII during the resection of cerebellopontine angle tumors and/or acoustic neuroma resection. Lower cranial nerves (VII, IX, X, XII) are monitored in certain thyroid resections and brainstem tumor resections. The hypoglossal nerve is monitored during open carotid endarterectomy.

A single nerve electromyography aids in successfully isolating the "at risk" nerve during establishment of surgical access and while performing the resection, allowing preservation of its vital function. The anesthetic considerations focus solely on the avoidance of neuromuscular blockade during the monitoring period. A specialized neural integrity monitor electromyographic (EMG) endotracheal tube may be required in instances that require monitoring cranial nerve X and its laryngeal nerves.

BRAINSTEM AUDITORY EVOKED POTENTIALS

BAEPs are recorded using a loud acoustic stimulus in the ear canal with an ear insert device. The sound is transduced by ear structures, with information conducted to the brainstem via the eighth cranial nerve. Recording electrodes are placed at the head near the mastoid process or ear lobe. Five main short-latency peaks (I to V) are usually seen within the first 10 milliseconds after stimulation (Fig. 6).[14]

BAEPs are commonly used in conjunction with other neuromonitoring modalities during posterior fossa surgeries to assess brainstem function. BAEPs are typically resistant to anesthesia as compared with other evoked potentials.
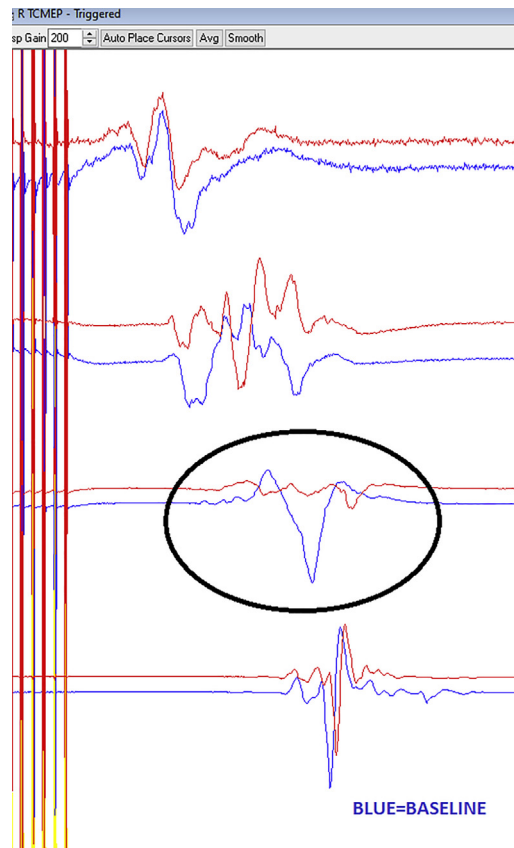

Fig. 6. The circled area captures the intraoperative change in waveform with greater than 50% decrease in MEP amplitude, during spine surgery. (*Courtesy of* K. Eggan, CNIM, New Haven, CT.)

RECOMMENDATIONS FOR CHOICE OF ANESTHETICS DURING THE USE OF VARIOUS NEUROMONITORING MODALITIES

The effects of medications used for induction of anesthesia typically do not persist long enough to influence IONM. Conversely, it is important to use an appropriate intra-operative maintenance regime to facilitate monitoring techniques. The authors recommend considering the following approaches:

- Use of SSEP monitoring: Propofol infusion at anesthetic doses (titrated to patient age and comorbidities; eg, 80–120 µg/kg/min) along with an opioid infusion (eg, remifentanil at 0.1–0.2 µg/kg/min, fentanyl infusion at 2–3 µg/kg/h, or sufentanil infusion at 0.15–0.4 µg/kg/h). An alternative to this is the use of a volatile anesthetic, such as sevoflurane at approximately 0.5 minimum alveolar concentration (MAC) along with propofol infusion and opioid. Neuromuscular blocking agents are used as necessary if SSEP monitoring is the only monitor that is being used intraoperatively.
- Use of SSEPs and MEPs monitoring: Propofol infusion at anesthetic doses (titrated to patient age and comorbidities; eg, 80–120 µg/kg/min) along with an opioid infusion (eg, remifentanil at 0.1–0.2 µg/kg/min, fentanyl infusion at 2–3 µg/kg/h, or sufentanil infusion at 0.15–0.4 µg/kg/h). Volatile anesthetics are typically avoided because of the exquisite sensitivity of MEPs to them. Neuromuscular blocking agents are avoided during the period of monitoring. A short-acting neuromuscular blocking agent may be used to facilitate intubation.
- Use of SSEPs and cranial nerve EMG: The approach to the anesthetic to what has already been described for MEP monitoring.
- Use of isolated cranial nerve EMG: No neuromuscular blocking agent during the period of monitoring. Up to 1.5 MAC volatile anesthetic and no restriction in opioid administration.
- Use of EEG, SSEPs, and MEPs: Volatile anesthetics are administered at approximately 0.5 MAC, and/or a propofol infusion is used in combination with an opioid infusion (eg, remifentanil at 0.1–0.2 µg/kg/min, fentanyl infusion at 2–4 µg/kg/h, or sufentanil infusion at 0.15–0.4 µg/kg/h). Alternatively, fentanyl boluses may be used to maintain analgesia. Dexmedetomidine is a valuable adjunct when this combination is being used and aids in reducing the dose of propofol required. Neuromuscular blocking agents are avoided during the period of monitoring. A short- or intermediate-acting neuromuscular blocking agent may be used to facilitate intubation.

CONTROVERSIES IN NEUROMONITORING

With the increasing use of neuromonitoring modalities in various types of surgeries, several studies have analyzed the benefits and cost effectiveness of their routine use.

According to the guidelines for the use of electrophysiologic monitoring for human spinal cord surgery,[15] the use of multimodal IONM including SSEPs and MEPs during spinal cord/spinal column surgery is a level I recommendation because of its reliability and validity in assessing spinal cord integrity. MEP recordings are superior to SSEP recordings during spinal cord/spinal column surgery as diagnostic adjuncts for assessment of spinal cord integrity and are recommended if used for this purpose. Use of multimodal IONM, including SSEPs and MEP recording, during spinal cord/spinal column surgery does not improve gross total tumor resection or improve neurologic outcome, when used during intramedullary tumor resection procedures (Level II evidence).[15]

Daniel and colleagues[16] performed a literature review and meta-analysis of six studies comparing neurologic events with and without IONM. Based on the evidence provided in the studies reviewed, they concluded that IONM did not result in fewer neurologic events compared with no monitoring (Level 2 evidence). For surgeries involving intramedullary lesions, there was a trend to fewer neurologic events in patients who underwent surgery with IONM.[16]

A literature search of Medline database was performed and relevant studies from all levels were included in a narrative review by Charalampidis and colleagues.[17] Nearly all of these studies investigated the use of IONM in the setting of spine surgery. Overall, these reports support the use of multimodal IONM in spinal tumor resections. The combined use of SSEPs and MEPs seems to provide increased accuracy for detecting injury to sensory and motor pathways, reaching a high sensitivity, specificity, positive predictive value, and negative predictive value.[17]

In 2010, Ayoub and colleagues[18] performed a cost-effectiveness analysis on a cohort of 210 patients who underwent cervical spine surgery with SSEP monitoring. The total cost of the surgery, hospital stay, neuromonitoring, and medical expenditures associated with postoperative neurologic injury was accounted for in the cost analysis. Given an incidence of 0.1% for spinal cord injury, the authors assumed that without SSEP monitoring 1 out of 201 patients would have had a permanent spinal cord injury. In their estimation, the total annual cost savings for a single injured patient would range from $64,074 to $102,192 for their institution, whereas the yearly expenditure on SSEP amounted to only $31,546.[18]

Recently, Ney and colleagues[19] constructed a simulated cost-effectiveness model to estimate the value of IONM to avert postoperative neurologic deficits. The model assumptions included parameters, such as the surgical risk, frequency of cases averted, and cost per case estimates. The authors concluded that use of IONM in spinal procedures was associated with a 49% reduction in relative risk for neurologic complications. They further estimated that the cost of monitoring to prevent a single neurologic injury was $63,387.[19]

Conversely, Traynelis and colleagues,[20] in a single-center study, reported a case series of 720 consecutive patients who underwent routine cervical spine procedures without the use of IONM. The authors reported a 0.4% rate of postoperative neurologic deficits. Furthermore, at 1-year follow-up, all patients had significantly improved, and their neurologic deficits had complete resolution. The authors, therefore, questioned the utility of IONM during routine cervical spine surgery. Additionally, further analysis was performed to explore the economic impact of IONM during cervical spine procedures. This cost analysis was based on the Current Procedural Terminology reimbursement codes. They concluded that significant savings could be achieved by not using IONM in simple cervical spine procedures.[20]

In a large retrospective propensity score matched analysis, using a national database, Cole and colleagues[21] investigated single-level spinal procedures, with and without the use of IONM, with the goal of comparing the occurrence of neurologic complications. Trauma, spinal tumors, and revisions were excluded from the analysis. A total of 85,640 patients were included in the analysis with a minority (13%) receiving IONM during the surgery. The authors found no differences in neurologic complications between those who did and did not receive IONM. They concluded that the use of IONM was associated with higher costs ranging from $2859 to $3841.[21]

In summary, currently there is conflicting evidence regarding the cost effectiveness of use of IONM in routine spine surgeries. Additional expenditures in terms of training neuromonitoring personnel, use of specialized equipment for monitoring, and choice

of anesthetic techniques would further complicate the evaluation of these monitoring modalities.

Multimodal IONM is also commonly used in carotid endarterectomies. Hong and colleagues[22] analyzed 668 carotid endarterectomy cases at six surgical centers, and found that a decrease in amplitude of 50% or more in any EEG or SSEP channel should be used as the criteria to indicate the need for shunting or to initiate a neuro-protective protocol. A reduction of 50% or greater in the beta band of the EEG or amplitude of the SSEP was observed in 150 cases, most of which occurred during cross-clamping. No patient showed signs of a cerebral infarct after surgery. Selective shunting based on EEG and SSEP monitoring can reduce carotid endarterectomy intraoperative stroke rate to a near zero level if trained personnel practice with standardized protocols.

In conclusion, the role of multimodal monitoring for the intraoperative detection of physiologic changes allows the care team to decrease the likelihood of potential cell or nerve injury. However, with the possible exception of certain spinal procedures and carotid endarterectomies, the benefits in terms of prevention of permanent neurologic complications or cost effectiveness are not well documented and data are generally inconclusive because of the absence of rigorously controlled trials.

DISCLOSURE

No conflicts of interest.

CLINICS CARE POINTS

- With the increasing use of neuromonitoring modalities during intracranial, carotid and spine procedures, it is important to understand the effects of physiological changes and pharmacologic interventions on these monitoring modalities.
- There is currently a level I recommendation for the use of multimodal intraoperative neuromonitoring (including SSEPs and MEPs) during procedures involving the spine. This recommendation is based on the reliability and validity of these monitoring modalities in assessing spinal cord integrity.
- MEPs are superior to SSEP recordings as diagnostic adjuncts for the assessment of spinal cord integrity.
- There is insufficient evidence for routine use of neuromonitoring for routine cervical spine procedures in neurologically intact patients.
- Controversies continue to exist regarding the cost effectiveness of use of intraoperative multimodal neuromonitoring for procedures other than spine surgery.

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