FCA REFRESHER COURSE

Neuromonitoring

KK Purbhoo (iD)

Department of Anaesthesia, Helen Joseph Hospital, University of the Witwatersrand, South Africa
Corresponding author, email: kashmirapurbhoo@gmail.com

Intraoperative neuromonitoring (IONM) is used during surgery as a method of real-time evaluation of the functional integrity of neural structures.[1] It is a simple and minimally invasive tool designed to detect, treat, and prevent potential damage to the nervous system during high-risk medical procedures such as brain, nerve, and spine surgery.[2] IONM allows correlation between surgical interventions with neurophysiological changes at a time when damage from surgical trauma can be avoided or reverted.[3]

The type of neuromonitor used should be one that is specific for the parameter of interest, affordable, practical, reliable and ideally give reproducible or continuous results. Frequently, multiple techniques are used together in order to increase the utility of monitoring and to overcome limitations of individual techniques.[4]

As modern health care shifts toward value-based systems, questions arise as to the exact cost-effectiveness of IONM. Also, despite advancements in the understanding of IONM and the popularity of this technique in modern surgery, controversies still exist regarding its effectiveness and the necessity for its use in routine procedure.[5]

Monitoring modalities

The oldest way of detecting gross motor function deficit is the Stagnara wake-up test. It is done intraoperatively, after extensive preoperative counselling, by the reduction of anaesthesia, waking the patient up and asking them to move their limbs. This test is considered to be almost 100% accurate, as the best neuromonitor is an awake patient. In the conscious state, the complex interactions of individual parts of the nervous system can be assessed more accurately. Due to drawbacks such as not being able to detect neurological insults when they occur in real time, the risk of self-extubation, loss of intravenous lines, dispositioning, air embolism, as well as potential psychological stress, this test is nowadays only rarely used when IONM recordings are unavailable or fail to return after excluding all technical, anaesthetic and surgical factors.[6]

Neuromonitoring can include the recording of spontaneous activity (e.g. electroencephalogram and spontaneous electro-myogram) or evoked response to stimulus (e.g. somatosensory-evoked potentials, motor-evoked potentials, triggered electro-myography, and brainstem auditory-evoked potentials).[4]

Electroencephalography

Electroencephalography (EEG) records electrical activity in the cerebral cortex. Electrodes are usually placed on the scalp in a standardised array as defined by the International 10-20 system and give a continuous recording of spontaneous superficial brain activity.[7]

EEG data may be used to monitor brain function during surgery and is a valuable means of early detection of cerebral ischaemia, changes in depth of anaesthesia (processed EEG) and detection of seizure activity.[3] (Figure 1)

Occasionally, EEG electrodes are placed intraoperatively on the surface of the brain during epilepsy surgery, awake brain mapping, and for selected tumour resections. EEG is particularly useful in procedures with a high risk of vascular injury, cardiovascular procedures, laser thermal ablation for temporal lobe epilepsy and electrocortical stimulation mapping.[3]

EEG monitoring is often used during carotid endarterectomy (CEA) surgery in order to assess cerebral perfusion during carotid cross-clamping. With ischaemia, progressive decrease in synaptic activity results in loss of high-frequency activity and ultimately EEG silence (Figure 1). In the setting of CEA surgery, EEG slowing or asymmetry between the recordings on the operative and contralateral sides can provide evidence of ischaemia.[8] Raw EEG in the experienced eye has been proven on multiple occasions to be effective in predicting the need for selective shunt placement in CEA surgery.[9]

It is, however, known that EEG as a standalone procedure has only modest sensitivity in spite of a high specificity and can be affected by multiple factors such as the number of channels used, type of anaesthetic given or experience of the neuro-physiologist interpreting the changes.[9] Another limitation of EEG monitoring is that surface EEG recordings do not detect ischaemia in subcortical regions.[8]
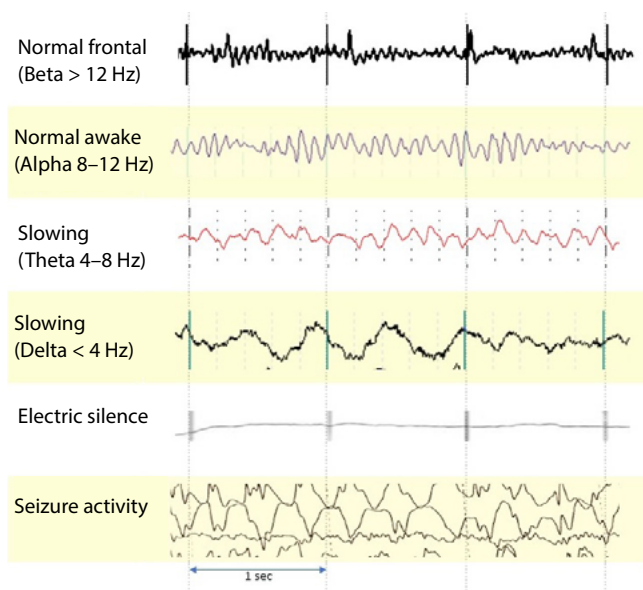
Figure 1: EEG changes

Electromyography

Electromyography (EMG) is a technique for evaluating and recording the electrical activity produced by skeletal muscles either by spontaneous (continuous) or evoked (triggered) compound muscle action potentials (CMAPs).[10] Intraoperatively, EMG is monitored in muscles that are innervated by nerves that are at risk during surgery.[7,11]

Intraoperative EMG is used to monitor intracranial and peripheral nerves, evaluate nerve integrity and locate nerves based on the muscles they innervate. The electrodes may be placed on the surface or inside the innervated muscle using a needle; the latter technique is more sensitive.[3]

Spontaneous EMG detects mechanical and/or metabolic nerve irritation to cranial nerves or spinal roots at risk during surgery. Muscle innervated by non-irritated and non-stimulated nerves should be quiet in their activity. During monitoring of spontaneous EMG, two types of discharge patterns of different clinical significance may be observed: tonic and phasic. The tonic pattern consists of a constant and repetitive signal lasting seconds to minutes, a pattern often observed in traction-related nerve ischaemia and thermal irritation from electrocautery or saline irrigation. In contrast, the phasic pattern is a short and relative synchronous burst associated mainly with contusion injury.[3]

EMG is commonly used in spine surgery involving instrumentation in order to help prevent postoperative radiculopathy, which is a more common complication than spinal cord injury, by identifying nerve irritation before injury. Multiple muscles are usually monitored. If the nerve root is irritated, continuous electrical activity in the muscle is noted with 100% sensitivity, but only 23.5% specificity.[4,11]

Triggered EMG can help identify intact nerves. During tumour resection, it is used to identify a nerve in order to avoid cutting or coagulating it. A mono or bipolar stimulator can be used within the surgical site to stimulate the nerve, and a resulting CMAP is recorded from the innervated muscle. The advantage of this method is that it provides the surgeon with information on anatomical variations in the motor nerves. Triggered EMG can also be used to stimulate pedicle screws or pilot holes to identify mispositioned screws that are too close to nerve roots.[3,11]

Cranial nerve monitoring, done during various intracranial surgeries as well as thyroid and parotid procedures, and radical neck dissection, is a form of EMG.[7] It is obviously only possible to monitor cranial nerves with a motor component viz. cranial nerves III, IV, V, VI, VII, IX, X, XI, and XII. Stimulus-triggered EMG can also be used for brainstem and motor-strip mapping during intracranial tumour surgery, as well as to identify the motor cortex by recording EMG activity from the impacted area (e.g. upper extremity, lower extremity, or face).[12]

Evoked potentials

Evoked potentials (EPs) are used to assess the integrity of neural pathways. A stimulus is applied to a neural tract and a response is evoked and measured. This response tests the integrity and functionality of a specific neural tract.[13]

The morphology of the recorded waveform (response) will vary depending on the site used for stimulation and the site used for recording. The amplitude and latency of the waveform are assessed to provide functional neurological assessment. Amplitude is measured peak-to-trough in microvolts, and latency is measured from stimulus application to peak appearance in milliseconds[14] (Figure 2).

With somatosensory, visual, and brainstem auditory-evoked potentials, stimulations are applied to peripheral sites and responses are recorded from central locations. With motor-evoked potentials, the motor cortex is stimulated and recordings are obtained from the epidural space (D-wave) or, more commonly, from distal muscles.[2,14]

Several criteria have been proposed for identifying significant intraoperative change; complete loss of signal is always considered significant. A 50% reduction in amplitude and/or a 10% increase in latency in relation to baseline is reason for concern, requiring a need to modify surgical, patient or anaesthetic factors to prevent or minimise neurological injury.[14]

Somatosensory-evoked potentials

Somatosensory-evoked potentials (SSEPs) have been used since the 1970s and are currently the most common method of intra-
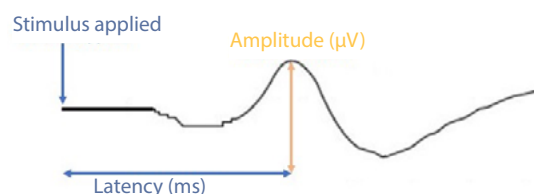

Figure 2: EP waveform

operative neuromonitoring in spine surgery. A peripheral or cranial nerve is electrically stimulated to evaluate functioning of the nerve, the dorsal root ganglia, the posterior (dorsal) columns of the spinal cord and part of the sensory cortex.[3] The level of the surgery determines which neural pathways to monitor. Usually, large mixed nerves are used, 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 are stimulated, using needle or surface electrodes near the nerve. Motor and sensory components of these nerves are stimulated. Activation of the motor component results in visible muscle twitches in distal musculature, confirming stimulation and lack of significant muscle blockade, and activation of the sensory component results in responses travelling along the sensory pathway and ascending to the brain.[2,3,13]

Responses can be recorded over the peripheral nerve, Erb's point, the popliteal fossa, the spinal cord, and the sensory cortex. The sensory cortex is monitored with scalp EEG electrodes placed according to the International 10-20 system.[3]

While SSEP monitoring is particularly useful during posterior spine surgery, it is also used in intracranial, cardiovascular and endovascular surgeries.[13]

Although sensory deficit is less debilitating than motor deficit, monitoring the sensory pathways does give some insight into the function of motor pathways, because the ischaemic or mechanical injury usually affects both pathways. Monitoring the dorsal columns with SSEPs has a sensitivity of up to 92%, and a specificity of up to 100%.[6]

Limitations of SSEPs include a time lag (as signal averaging is required), the monitoring of patients with pre-existing neurologic deficit (e.g. myelopathy or peripheral neuropathy), or situations with isolated motor pathway or nerve root injury, which can be detected only by MEP or EMG.[6]

Brainstem auditory-evoked potentials

Brainstem auditory-evoked potentials (BAEPs) are generated in response to acoustic stimuli (loud, repetitive clicks made in the ear canal using an ear insert device), and are used to monitor auditory structures (the eighth cranial nerve, the cochlear nucleus, a small part of the rostral brainstem, the inferior colliculus and the auditory cortex) which are relatively refractory to anaesthesia.[3]

The recording electrodes are usually placed on the scalp (near the ear, i.e. mastoid process or ear lobe), but internal structures and auditory nerves may be used as well. Five main short-latency peaks (I to V) are usually seen within the first 10 milliseconds after stimulation. Evaluation of BAEPs usually focuses on waves I, III, and V. Wave I is from cranial nerve VIII, wave III from the lower pons, and wave V from near the inferior colliculus (mesencephalon).[13]

The auditory system may be damaged during surgery of the posterior cranial fossa. BAEP provides information on critical neural structures, making timely preventive measures possible allowing for the prevention of postoperative hearing loss.[3]

Visual-evoked potentials

Visual-evoked potentials (VEPs) are generated in response to visual stimuli (light flashes stimulating the retina through closed eyelids) and are used to monitor the visual system (retina, optic nerve, optic chiasm, optic tract, lateral geniculate nucleus and occipital cortex). The recording electrodes are placed in the parietal, occipital and central part of the scalp (occipital lobe).[15]

Only a few studies have demonstrated its usefulness and no clear consensus exists about the correlation between intra-operative changes in VEP and postoperative visual outcome. In order to standardise VEP monitoring and determine its role in IONM further studies are necessary.[3]

Motor-evoked potentials

Motor-evoked potentials (MEPs) are generated by either magnetic or, more commonly, electrical stimulation of the motor cortex via needles into the scalp or by direct stimulation of the surface of the brain through a craniotomy. A sequence of stimuli is applied, and the responses are measured by electrodes placed in the innervated muscle (recorded as CMAPs) or, alternatively, in the spine (measured as direct (D) waves). MEPs thus monitor the motor tract (i.e. motor cortex, corticospinal tract, nerve root, and peripheral nerve) and has emerged as the most commonly used technique that allows motor tract assessment. An MEP reading takes less than 10s to obtain.[3,13]

When monitored as epidural D-waves, they are recorded by electrodes either placed percutaneously, or placed by the surgeon in the operative field. This technique is most often used in intramedullary spinal cord tumour surgery but can also be utilised for mapping of the location of the motor cortex.[16]

In scoliosis surgery, its usage is not the primary method of choice due to low sensitivity (27%), absence of D-wave at the baseline, undeveloped neural system in children, and long-term injury of the spinal cord.[6]

Responses are most commonly recorded as CMAPs in peripheral muscle groups. The muscles are selected based on the site of surgery. For the upper extremity, the adductor pollicis brevis is usually monitored, while the tibialis anterior, lateral gastrocnemius, and/or abductor hallucis are monitored for the lower extremities.[17]

Stimulation for MEPs can cause contraction of the masseter muscles. A soft bite block should be placed between the molars after induction to avoid tongue and cheek injuries. The bite block must be checked after positioning and periodically throughout the surgery.[17]

Contraindications to MEP monitoring include epilepsy, cortical injury, cranial defects or increased intracranial pressure.[17] Despite factors like diabetic neuropathy, hypertension, age extremes,

Table I: Effects of anaesthetic agents on the IONM modalities

Drug	Effect on EEG	Effect on evoked potentials			Other
		SSEP	MEP		
Volatiles	Low doses - ↑ in frequency and amplitude	Dose ↓ dependent in amplitude and ↑ in latency of EPs	↑↑↑ in cortical SSEP (CSSEP) latency and a ↓↓↓ in amplitude	↓↓↓ in amplitude	BAEPs are resistant
	Higher dose - ↓ in frequency and amplitude		In patients with no pre-existing neurological pathology, get adequate SSEPs at MAC < 1	Affected by even low levels of volatiles	VEPs are very sensitive
	± 1.5 MAC - burst suppression		In patients with pre-existing neurological impairment even low levels of volatiles can abolish potentials	Adequate MEPs at MAC < 0.5	
	Very high doses - electrical silence				
	Sevoflurane can cause seizure activity at a high dose				
N₂O	↑in frequency	Similar to volatiles	↑in CSSEP latency and in ↓↓ amplitude	↓in amplitude	Synergistic with volatiles
Propofol	Dose dependant ↓ in frequency and amplitude	Less effects vs volatiles but higher doses have greater effects	↑ in latency and ↓↓ in amplitude	↓↓ in amplitude	
	At higher dose - bursts suppression		Usually recorded at anaesthetic doses	More sensitive vs SSEP and may be lost at high doses	
	At very high dose electric silence				
Barbiturates	Same as propofol except methohexital		↑ in latency and ↓↓ in amplitude	↓↓ in amplitude	
	Methohexital activates epileptic spike activity				
Ketamine	↑ amplitude and frequency	Enhancement of EPs seen at low doses	↑ latency and amplitude	Minimal effect on amplitude	
	Evoke seizures in epileptic patients				
Etomidate	↓ amplitude and frequency	Enhancement of EPs at low doses and depression at very high doses	↑ latency	↑ amplitude at low dose and ↓ with induction dose	
	High doses electrical silence		↑↑ amplitude at low dose		
			↓ amplitude at high dose		
Opioids	↑ amplitude and ↓ frequency	Dose dependant ↓ in responses but even at high doses EPs can be recorded	Minimal effect	Minimal effect	
	No suppression at high dose				
	Spike activation with boluses				
Lidocaine	Low dose - anticonvulsant		Minimal	Minimal	
	High dose - convulsant				
Muscle relaxants				↓↓↓ ampltitude	
				Adequate MEPs can be achieved if 1 or 2 twitches maintain on TOF	
Dexmedetomidine	Mimics sleep	Limited studies available	Minimal effect at low dose	Minimal effect at low dose	Dexmedetomidine and clonidine ↓ anaesthetic requirements and may be beneficial
				↓ amplitude at high dose	

and preoperative motor deficit making MEP recording difficult, they can be reliably obtained even in young paediatric patients with permissive anaesthetic and neuromonitoring stimulating techniques.[13]

MEPs have proven to be very sensitive indicators of the spinal cord ischaemia during spinal deformity correction.[6] MEPs are more effective than SSEPs for detecting motor injury since changes in the MEPs precede SSEP changes, usually allowing time to react in order to prevent neurological damage.[2,17]

Multimodal intraoperative neuromonitoring

Each IONM modality has advantages and weaknesses, but together the modalities complement each other allowing for more comprehensive monitoring of the anatomical areas of the spinal cord. The concept of multimodal intraoperative neuromonitoring (MIONM) has gained in popularity and become the standard practice for a variety of surgical procedures. Despite this, reports still exist of false-positive alerts that can lead to unnecessary precautionary actions taken by the surgical team. Also, because of the lack of evidence-based protocols to respond to alerts in MIONM there is a critical knowledge gap in the management both during and after an event.[5]

In general, if a posterior approach is being used, SSEPs may be sufficient, but anterior approaches most likely warrant transcranial MEPs. In cases where there is concern about nerve root deficits, spontaneous EMG and triggered EMG monitoring will be of value. In cases where the entire spinal cord is at risk (e.g. spine deformity surgery, intradural tumours), MIONM is highly recommended.[6]

When SSEPs and MEPs are combined in spine deformity surgery, the sensitivity to detection of permanent motor and sensory neurological injury during spinal deformity surgery is 99.6–100.0%, and the specificity is 84–100%. But, false-negative results can still be found even with combined IONM.[6]

For MIONM during carotid surgery, EEG, SSEPs and more recently MEPs to detect cerebral ischaemia, have been used.[9]

Anaesthetic effects on neuromonitoring

Nearly all anaesthetic agents result in a dose-dependent suppression of the nervous system. Both inhalational agents and intravenous agents exert their effect by causing alterations in the excitability of neurons by changing the functional activities of the axon and synapse of the neuron.[18]

In general, inhalational agents have greater effects on all modes of neuromonitoring than intravenous anaesthetic drugs do. Evoked potentials of cortical origin (i.e. cortical portion of SSEPs and VEPs) are considered more prone to modification by anaesthetics than brainstem potentials (i.e. BAEPs and sub-cortical portion of SSEPs). Choice of anaesthetic drugs should be made depending on the modality used. One should aim to keep the level of anaesthesia constant during critical monitoring periods to avoid confounding interpretation of changes. It is important to discuss the monitoring plan and anaesthetic

techniques with the surgeon and the neuromonitoring team prior to starting the case.[2,13,16] Table I summarises the effects of commonly used anaesthetic agents on the IONM modalities.[3,9,18,19]

While induction and maintenance of anaesthesia are commonly done with propofol, studies have shown that a balanced technique with volatile (MAC ≤ 0.5) and low to moderate doses of propofol infusion (40–75 μ/kg/min) can be used with no change in outcomes.[9,19]

Physiological effects on neuromonitoring

Careful management of physiological parameters is extremely important because changes in physiological parameters can affect IONM signals. Manipulation of physiological parameters, during surgically induced IONM changes, can also help support the patient.

Blood pressure

Reduction in blood pressure (systemic and/or regional) can affect cortical EPs and EEG recording. Local factors (e.g. spinal distraction, vascular compromise from positioning, retractor pressure) may result in ischaemia, even at normal mean arterial pressure (MAP), and this may be reflected in neuromonitoring changes. When monitoring changes occur, it is recommended to increase MAP to greater than 80 mmHg or higher to increase tissue perfusion pressure.[3,6,13]

Ventilation

Changes in partial pressure of oxygen (PaO_2) and partial pressure of carbon dioxide ($PaCO_2$) affect neuromonitoring, by either changing oxygen delivery or by changing blood flow. PaO_2 < 60 mmHg makes EPs deteriorate before other clinical variables are changed. $PaCO_2$ < 20 mmHg causes excessive cerebral vasoconstriction and neural tissue ischaemia followed by changes in EEG, cortical SSEP and MEP readings. In order to obtain adequate IONM readings, normocapnia and normal levels of oxygenation are necessary.[3]

Temperature

Changes in body temperature alter all EPs and EEG recordings. It is recommended that core body temperature be maintained within 2 to 2.5 °C of baseline temperature. Hypothermia increases latency and reduces conduction velocity of responses. Regional hypothermia, such as that caused by a cool extremity after infusion of cold intravenous solution or by an area being exposed to cold irrigation fluid also affects EP monitoring. At central temperatures below 28 °C, no SSEPs and MEPs are recorded.[3,17]

Haematocrit

Anaemia can affect both oxygen capacity and blood viscosity. Both of these can affect IONM readings. The ideal haematocrit level for IONM is 30–32%.[3]

Intracranial pressure

Due to its compressive effects, increased intracranial pressure (ICP) results in reduced cortical SSEP readings and slowing of EEG. With MEP readings, as the ICP increases, a gradual increase in latency occurs until no response is produced any longer at higher ICP.[3]

Patient positioning effects

Certain surgical positions (e.g. prone or neck in extreme flexion) can result in neurological or vascular compromise and will therefore affect IONM. In these patients, it might be better to perform baseline EPs after induction with the patient supine, and then repeated after positioning. Thus, if recorded potentials deteriorate, changes to the position can be made before surgery begins.[3]

In most patients, however, baseline evoked potentials are obtained after the patient is positioned for surgery. Changes can also occur during surgery, as a result of positioning (e.g. if limbs are moved, or because of pressure on peripheral nerves).[3]

Conclusion

For IONM to be most effective in the prevention of neural damage, good communication, interdisciplinary cooperation and awareness of the interdependence between the anaesthesiologist, the surgeon and the neurophysiologist is required. Changes in responses during neuromonitoring can result from a number of factors, and ideally, each institution should have a protocol for approaching and managing IONM changes.

Acknowledgement

The author would like to thank Dr KD Jivan for creating the table and diagrams.

ORCID

KK Purbhoo (iD) https://orcid.org/0000-0002-9001-6764

References

1. Cioni B, Meglio M, Rossi GF. Intraoperative motor evoked potentials monitoring in spinal neurosurgery. Arch Ital Biol. 1999;137(2-3):115-26.
2. Minahan RE. Intraoperative neuromonitoring. Neurologist. 2002;8(4):209-26. https://doi.org/10.1097/00127893-200207000-00001.
3. Nunes RR, Bersot CDA, Garritano JG. Intraoperative neurophysiological monitoring in neuroanesthesia. Curr Opin Anaesthesiol. 2018;31(5):532-8. https://doi.org/10.1097/ACO.0000000000000645.
4. Lall RR, Lall RR, Hauptman JS, et al. Intraoperative neurophysiological monitoring in spine surgery: indications, efficacy, and role of the preoperative checklist. Neurosurg Focus. 2012;33(5):E10. https://doi.org/10.3171/2012.9.FOCUS12235.
5. Charalampidis A, Jiang F, Wilson JRF, et al The use of intraoperative neurophysiological monitoring in spine surgery. Glob Spine J. 2020;10(1 Suppl):104S-114S. https://doi.org/10.1177/2192568219859314.
6. Biscevic M, Sehic A, Krupic F. Intraoperative neuromonitoring in spine deformity surgery: modalities, advantages, limitations, medicolegal issues - surgeons' views. EFORT Open Rev. 2020;5(1):9-16. https://doi.org/10.1302/2058-5241.5.180032.
7. Jameson LC, Janik DJ, Sloan TB. Electrophysiologic monitoring in neurosurgery. Anesthesiol Clin. 2007;25(3):605-30. https://doi.org/10.1016/j.anclin.2007.05.004
8. Sloan MA. Prevention of ischemic neurologic injury with intraoperative monitoring of selected cardiovascular and cerebrovascular procedures: roles of electroencephalography, somatosensory evoked potentials, transcranial Doppler, and near-infrared spectroscopy. Neurol Clin. 2006;24(4):631-45. https://doi.org/10.1016/j.ncl.2006.05.002.
9. Pescador AM, Lorensu PJP, González ÁS, et al. Anaesthesia and multimodality intraoperative neuromonitoring in carotid endarterectomy. Chronological evolution and effects on intraoperative neurophysiology. J Clin Monit Comput. 2021;35(6):1429-36. https://doi.org/10.1007/s10877-020-00621-9.
10. Krishnakumar R, Srivatsa N. Multimodal intraoperative neuromonitoring in scoliosis surgery: A two-year prospective analysis in a single centre. Neurol India. 2017;65(1):75-9.
11. Holland NR. Intraoperative electromyography. J Clin Neurophysiol Off Publ Am Electroencephalogr Soc. 2002;19(5):444-53. https://doi.org/10.1097/00004691-200210000-00007.
12. Morota N, Deletis V, Lee M, Epstein FJ. Functional anatomic relationship between brain-stem tumors and cranial motor nuclei. Neurosurgery. 1996;39(4):787-93. https://doi.org/10.1097/00006123-199610000-00028.
13. Koht A, Sloan TB. Chapter 6 - Evoked response monitoring. In: Prabhakar H, editor. Neuromonitoring techniques [Internet]. Academic Press; 2018. p. 147-77. https://doi.org/10.1016/B978-0-12-809915-5.00006-1.
14. Kumar A, Bhattacharya A, Makhija N. Evoked potential monitoring in anaesthesia and analgesia. Anaesthesia. 2000;55(3):225-41. https://doi.org/10.1046/j.1365-2044.2000.01120.x.
15. Gutzwiller EM, Cabrilo I, Radovanovic I, Schaller K, Boëx C. Intraoperative monitoring with visual evoked potentials for brain surgeries. J Neurosurg. 2018;130(2):654-60. https://doi.org/10.3171/2017.8.JNS171168.
16. Glover CD, Carling NP. Neuromonitoring for scoliosis surgery. Anesthesiol Clin. 2014;32(1):101-14. https://doi.org/10.1016/j.anclin.2013.10.001.
17. Deletis V, Sala F. Intraoperative neurophysiological monitoring of the spinal cord during spinal cord and spine surgery: a review focus on the corticospinal tracts. Clin Neurophysiol Off J Int Fed Clin Neurophysiol. 2008;119(2):248-64. https://doi.org/10.1016/j.clinph.2007.09.135.
18. Shils JL, Sloan TB. Intraoperative neuromonitoring. Int Anesthesiol Clin. 2015;53(1):53-73. https://doi.org/10.1097/AIA.0000000000000043.
19. Royan N, Lu N, Manninen P, Venkatraghavan L. The influence of anaesthesia on intraoperative neuromonitoring changes in high-risk spinal surgery. J Neuroanaesth Crit Care. 2017;4(3):159. https://doi.org/10.4103/jnacc-jnacc-10.17.