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Running head: INTRAOPERATIVE NEUROPHYSIOLOGICAL MONITORING

ANESTHESIA CONSIDERATIONS FOR INTRAOPERATIVE NEUROPHYSIOLOGICAL
MONITORING

By

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ABSTRACT

Title: Anesthesia Considerations for Intraoperative Neurophysiological Monitoring

Background: Neurophysiological monitoring involves monitoring evoked potential waveforms that result from electrical stimulation and depicts the integrity of the neurological pathway being monitored. When the monitoring produces a change in waveform, there is likely an insult that is occurring to the area being monitored. Evoked potential waveforms are obtained, recorded, and compared to the baseline waveforms during the surgery to determine potential injuries to the neurological pathway that is being monitored. Some different insults that can occur that produce changes in the neurophysiological waveforms include decreased blood flow to the area being monitored, systemic hypotension, anesthetic agents, hypoxia, hypothermia, and hypercarbia/hypocarbia. Anesthesia professionals have the ability to make corrections to the reversible insults to restore the evoked potential waveform back to baseline and likely avoid any new onset neurological deficit.

Purpose: The purpose of this independent project is to conduct a literature review to determine the current recommendations for anesthesia considerations during intraoperative neurophysiological monitoring.

Process: A thorough literature review was conducted using CINAHL and PubMed databases from the University of North Dakota's Health Sciences Library. Each article was carefully analyzed to determine its relevance and significance to this topic. The literature review was limited to articles written in the last ten years.

Results: Halogenated inhalational agents are known to cause a significant decrease in amplitude in both somatosensory evoked potential (SSEP) and motor evoked potential (MEP) monitoring.

In fact, these agents are capable of making it impossible to detect or acquire any evoked potentials. MEPs are affected more than SSEPs. Increased latency and decreased amplitudes will occur with higher MAC value of the inhalational agent. Intraoperative neurophysiological monitoring is likely to be conducted with up to a 0.5 MAC of either desflurane or sevoflurane. With that being said, sevoflurane is more likely to produce MEP suppression as compared to baseline evoked potentials than desflurane. Intravenous anesthetics and anesthetic adjuncts that are used with intraoperative neurophysiological monitoring produce a varied effect on the evoked potentials, but these effects are less than those produced by inhalational agents. Examples of intravenous agents commonly used include propofol, lidocaine, dexmedetomidine, ketamine, and opioids. The total intravenous anesthesia (TIVA) approach is often the preferred method of anesthesia because the approach allows for consistent MEP and SSEP monitoring as compared to inhalational agents.

Implications: Careful attention to anesthetic management is necessary when providing anesthesia for a patient undergoing intraoperative neurophysiological monitoring to minimize adverse outcomes and enhance patient safety.

Keywords: Neurosurgery procedures, intraoperative neurophysiological monitoring, anesthesia management, and evoked potentials.

Anesthesia Considerations for Intraoperative Neurophysiological Monitoring

Intraoperative neurophysiological monitoring is commonly utilized in neurosurgical procedures. When this type of monitoring is used, there are several factors that the anesthesia professional needs to consider with their anesthetic management of the patient. If these factors are not observed or are ignored, the patient can potentially face devastating new onset neurological deficits. Further, it is important for the anesthesia professional to be aware of the current anesthesia related recommendations for intraoperative neurophysiological monitoring that will be discussed in the literature review.

Case Report

A 65-year-old, 113.9 kg, 185.4 cm female with a body mass index (BMI) of 32.84 kg/m² presented for right sided Anterior Cervical Discectomy and Fusion (ACDF) of C4/C5, C5/C6, and C6/C7 levels due to cervical degenerative disc disease with severe stenosis and radiculopathy with upper extremity weakness. Her pertinent past medical history included bradycardia, peripheral vascular disease, hypothyroidism, lumbar degenerative disc disease, chronic thrombocytopenia, spondylosis of lumbosacral region, postoperative nausea/vomiting, GERD without esophagitis, iron deficiency anemia, hyperparathyroidism, depression, anxiety, bipolar disorder, chronic opioid use, and osteoarthritis. Her past surgical history included Roux-En-Y gastric bypass surgery, pannus removal, right hemicolectomy with closure of the hepatic flexure ileostomy, takedown of ileostomy, ventral herniorrhaphy, total knee arthroplasty X2, right L4-5 and L5-S1 facet injections under fluoroscopy, and incisional hernia repair with I&D of deep pre-fascial abscess. Allergies to bupropion and environmental. The patient's home medications consisted of levothyroxine, ferrous sulfate, morphine ER, oxycodone, clonazepam, lamotrigine, Calcium Carb-Cholecalciferol, trazodone, omeprazole, Cranberry Concentrate,

Vitamin D, Gabitril, Lasix, Bismuth Subgallate, Miralax, and Metamucil. Lab values consisted of K 4.2 mEq/L, TSH 5.18 mIU/L, HGB 10.8 g/dL, HCT 31.8 g/dL, PLT 118,000 mcL, Na 139 mEq/L, Cl 104 mmol/L, CO2 28 mEq/L, BUN 17 mg/dL, Creatinine 0.7 mg/dL, and GFR > 60.

A preoperative airway evaluation revealed a Mallampati 2 classification, a thyromental distance greater than three finger breadths, adequate mouth opening with incisor distance greater than 3 cm, and full neck range of motion with no increase in pain or numbness/tingling.

Preoperative vital signs were blood pressure 122/80, respirations 16, temperature 36.8, heart rate 59, and oxygen saturation 96% on room air. A 20 gauge peripheral IV was inserted preoperatively and used for IV induction. After the IV was started, a lactated ringer infusion was started. The patient was pre-medicated with 1 mg of versed and was then transferred to the operating room. She was then transferred to the OR table, standard monitors were applied, and vital signs were obtained. The patient was pre-oxygenated by mask with 10 L/min of oxygen for 10 minutes. A 20 gauge left radial arterial line was established prior to intubation.

Intravenous induction of general anesthesia consisted of the following medications: lidocaine 100 mg, propofol 200 mg, succinylcholine 180 mg, ketamine 50 mg, and methadone 14 mg given intravenously. Video laryngoscopy produced a good view of the vocal cords and the patient was intubated with a 7.0 endotracheal tube. The tube was secured after bilateral breath sounds were confirmed and the patient was then placed on the ventilator to maintain appropriate oxygenation and ventilation. A 22 gauge peripheral IV was inserted at this time and a normosol infusion was started. A nasopharyngeal temperature probe was inserted to monitor temperature. Neurophysiological monitoring electrodes were applied and baseline waveforms were obtained which showed low amplitude in both right upper and lower extremities.

Maintenance of anesthesia consisted of keeping expired sevoflurane at 0.75 MAC. The patient also received an intravenous infusion of ketamine at 10 mcg/kg/min and lidocaine at 3 mg/min. The patient received cefazolin 2 grams intravenously prior to incision. During the procedure, the patient also received ephedrine 15 mg for bradycardia and hypotension with SBP less than 100mmHg, total of glycopyrrolate 0.4 mg for bradycardia with HR in the 40s, dexamethasone 10 mg, and ondansetron 4 mg.

The ketamine infusion was decreased to 8 mcg/kg/min an hour and a half prior to extubation and was stopped 45 minutes prior to extubation. The patient also received labetalol 10 mg for tachycardia and hypertension with a SBP greater than 150 mmHg and HR in the 120s. The lidocaine infusion continued at 3 mg/min until the patient was transferred to PACU. Final neurophysiological monitoring waveforms indicated improved amplitude in both right upper and lower extremities while the left waveforms remained at baseline. The patient was extubated and placed on oxygen 8 L/min via simple mask. A simple neurological exam indicated that the patient was able to follow commands with all extremities. After the neurological assessment, the patient was transported to PACU. Total fluid infused was Lactated Ringer 400 mL and Normosol 1200 mL. Urine output for the case consisted of 475 mL and estimated blood loss was 200 mL.

Background

When a patient is having high risk neurosurgery, such as procedures to the spine, brain, and/or nerve injury, intraoperative neurophysiological monitoring is used to detect, and hopefully prevent, postoperative neurological deficits. There are several different types of monitoring that comprise neurophysiological monitoring including: electroencephalogram (EEG), brain auditory evoked potentials (BAEPs), electromyography (EMG), somatosensory

evoked potentials (SSEPs), and motor evoked potentials (MEP) (Nagelhout & Plaus, 2014). The different types of monitoring can be used either alone or in combination with each other.

Neurophysiological monitoring involves monitoring evoked potential waveforms that result from electrical stimulation and depicts the integrity of the neurological pathway being monitored (Pino, 2016). When the monitoring produces a change in waveform, there is likely an insult that is occurring to the area being monitored. Evoked potential waveforms are obtained, recorded, and compared to the baseline waveforms during the surgery to determine any new potential injury to the neurological pathway that is being monitored.

Some different insults that can occur that produce changes in the neurophysiological waveforms include decreased blood flow to the area being monitored, systemic hypotension, anesthetic agents, hypoxia, hypothermia, and hypercarbia/hypocarbia. Neurological deficits can be avoided, for the most part, if interventions are conducted in order to reverse the insults and restore the waveform back to baseline. New neurological deficits are likely to occur if the waveform is unable to be restored back to baseline. CRNAs have the ability to make corrections to the reversible insults to restore the evoked potential waveform back to baseline and avoid any new onset neurological deficit (Miller, 2015).

Discussion of Literature Search Strategies

For the gathering of research to determine anesthetic considerations for intraoperative neurophysiological monitoring, it is important to use databases because of the massive amounts of research that are credible, scholarly, and peer reviewed. Conducting health research in this manner is considered to be of the highest quality (Mateo & Foreman, 2014). The two databases that were used for this paper include PubMed and CINAHL. The two databases were accessed through the University of North Dakota's Health Sciences Library. PubMed, which is one of the

largest health databases, was chosen because it contains literature from life and medical sciences (Stillwell, Fineout-Overholt, Mazurek, & Williamson, 2010; Mateo & Foreman, 2014). CINAHL was chosen because it is an extensive collection of allied health and nursing literature (Mateo & Foreman, 2014).

The key words that were chosen are as follows: neurosurgery, intraoperative electrophysiology monitoring, anesthesia, anesthesia considerations/indications, and evoked potentials. MeSH controlled vocabulary from Pubmed for the corresponding key words are: anesthesia, anesthesia management, neurosurgery, neurosurgery procedures, intraoperative neurophysiological monitoring, monitoring intraoperative, and evoked potentials. The CINAHL Headings for the CINAHL database are: anesthesia, neurosurgery, intraoperative monitoring, and evoked potentials.

Only a few limitations were applied for this literature search due to the fear of limiting the amount of literature that was obtained from the search (Stillwell, Fineout-Overholt, Mazurek, Williamson, 2010). One of the limitations used was a date range for the publications. The date range was limited to 2010 to the present to ensure that the information gained from the research would still be applicable to present situations. Two other limitations that were used to conduct this literature search include articles only in the English language and studies based on human subjects.

The independent search of the controlled vocabulary resulted in a substantial amount of articles, therefore, the search was conducted with combinations of vocabulary using AND to combine the terms. The combined searches from the two databases still produced a substantial amount of pertinent articles and 15 articles were saved for a thorough literature review.

A grey literature search from Google Scholar resulted in an overwhelming amount of literature. Because of the vast amount of literature that was accumulated with PubMed and CINAHL, the literature that was obtained with the grey search will not be utilized at this point in time.

Review of Literature

Pathophysiology

Spinal stenosis is the result of a narrowing in the spinal canal. This narrowing can be from an ossified or thickened posterior longitudinal ligament, hypertrophied facet, and/or bulging annulus (McCance & Huether, 2014). Once the spinal canal is narrowed, spinal compression occurs. Spinal stenosis and the resulting spinal cord compression leads to a variety of symptoms ranging from autonomic, sensory, and/or motor dysfunction at below the level of the spinal cord compression. If the compression occurs to a specific nerve root, generally localized muscle weakness or pain to the specific corresponding dermatome is present (Hines & Marschall, 2012). When the compression results in nerve root damage, radiculopathy occurs. Radiculopathy results in pain, numbness, tingling, and muscle weakness to the area that is innervated by the compressed nerve root (McCance & Huether, 2014).

Degenerative disc disease is a common cause of spinal stenosis. This condition results from a disturbance in the normal maintenance and production of the tissue that makes up the intervertebral discs. This disturbance results in an alteration in the disc function, structure, and hydration status. Because of the alteration of the intervertebral discs, there can either be herniation of the nucleus pulposus, the nucleus pulposus can turn to a fibrocartilage material, and/or prolapse of the annulus (McCance & Huether, 2014).

Initial treatment for cervical radiculopathy, associated with spinal stenosis, is with conservative treatment. Conservative treatment consists of a short course of oral corticosteroids,

oral analgesics such as NSAIDs, physical therapy, muscle relaxants, medications for neuropathic pain, short-term neck immobility, and/or cervical traction. Indications for surgery include cervical radiculopathy that is refractory to conservative treatment, progressive decline in motor function, and MRI and/or CT imaging that shows cervical root compression that is associated with clinical presentation (Robinson & Kothari, 2017).

Anterior Cervical Discectomy and Fusion

A common decompression surgery is an Anterior Cervical Discectomy and Fusion (ACDF) (Robinson & Kothari, 2017). During this procedure, an incision is made on the left side of the neck between the carotid sheath, esophagus, and the trachea. The level of the desired disc is then confirmed with radiographic imaging. After the disc is removed, instrumentation and fusion are used to reestablish cervical lordosis, to maintain the normal disc space height, prevent graft extrusion, and hopefully prevent complications associated with a collapsed disc space. Once the disc has been successfully removed, the osteophytes are then removed and a prosthesis or a bone graft is placed where the disc was removed (Hines & Marschall, 2012).

Neurophysiological Monitoring

Intraoperative neurophysiological monitoring, as described above, is useful in detecting potential neurological injuries (Ajiboye et al., 2017). Prior to the extensive use of intraoperative neurophysiological monitoring, according to Gunter and Ruskin (2016), the “wake up test” was the only way to assess for new onset neurological deficit during spinal procedures (p. 539). The wake up test consisted of allowing the patient to emerge from anesthesia to see if they were able to follow commands and move their extremities and then the patient would be placed back under general anesthesia. The wake up test had several limitations including not being able to detect neurological insults as they were occurring in real time. Because of this, the patient could suffer

from neurological damage either prior to or after the wake up test. If the neurological damage occurred prior to the wake up test, a new onset deficit would be present at the time of the wake up test. If the neurological damage occurred after the wake up test, the new onset deficit would be present after emergence with the neurological exam after the patient was alert enough to follow commands (Gunter & Ruskin, 2016).

Based on a systematic review and meta-analysis conducted by Ajiboye and associates, the two most commonly used types of intraoperative neurophysiological monitoring for the spinal cord, are somatosensory evoked potentials (SSEPs) and motor-evoked potentials (MEPs). Monitoring the spinal cord with SSEPs provides information regarding the ascending pathway. Monitoring the spinal cord with MEPs provides information regarding the corticospinal motor tract pathway (Ajiboye et al., 2017). The ascending pathway involves the sensory pathway but does not provide any information regarding the motor pathway and vice versa (Ajiboye et al., 2016). Because of this, it is useful to use both SSEPs and MEPs to detect potential neurological injuries during spine surgeries (Ajiboye et al., 2016).

With that being said, neurophysiological monitoring during an ACDF remains controversial. The main claims as to why neurophysiological monitoring in an ACDF is not beneficial is because it is an added cost to the patient and it is felt that there is no correlation between the abnormalities noted during intraoperative neurophysiological monitoring and postoperative neurological outcomes. The main claims as to why neurophysiological monitoring in an ACDF is beneficial is that it helps to improve patient's neurological outcomes and improves patient safety (Ajiboye et al., 2017). The decision as to whether or not intraoperative neurophysiological monitoring will be used during an ACDF is based on surgeon preference (Ajiboye et al., 2016).

As explained above, baseline SSEPs and MEPs are obtained prior to the start of the procedure (Gunter & Ruskin, 2016). Evoked potential waveforms for SSEPs are obtained by “stimulating the median and posterior tibial nerves and monitoring over the sensory cortex” (Gunter & Ruskin, 2016, p. 540). The waveforms are obtained and the amplitude and latency are monitored throughout the remainder of the procedure. A change in latency of 10% and/or a change in amplitude of 50% indicates that a neurological insult is occurring, and an impending neurological deficit could result if the insult is not remedied and the waveforms do not return to baseline (Gunter & Ruskin, 2016). Evoked potentials obtained from SSEPs are generally very consistent with regard to their degree of second to second stimulation response (Calancie, 2017).

Evoked potential waveforms for MEPs are obtained by transcranial electrical stimulation and the monitoring of the action potential of specific groups of peripheral muscles. The peripheral muscle groups consist of the tibialis anterior, adductor pollicis brevis, abductor hallucis, and/or the lateral gastrocnemius (Koht, Sloan, & Hemmer, 2017). A change in amplitude of 50% indicates that a neurological insult is occurring, and an impending neurological deficit could result if the insult is not remedied (Gunter & Ruskin, 2016). Evoked potentials obtained from MEPs generally vary quite a bit with regards to amplitude and latency with their second to second stimulation response (Calancie, 2017). Because of this, it is not uncommon for the MEPs to be based off the information gathered from several stimulus intervals (Gunter & Ruskin, 2016).

Anesthesia Considerations

As mentioned previously, there are several different insults that can produce changes in the neurophysiological waveforms. Some of these insults include localized decrease in blood

flow, systemic hypotension, hypothermia, hypoxia/hypercarbia, and anesthetic agents (Miller, 2015).

In order for the spinal cord and the corresponding nerve roots to function appropriately, they must be provided with adequate blood flow, oxygen and at an appropriate body temperature (Rabai, Sessions, & Seubert, 2016). When nervous tissue becomes ischemic, either from local hypo-perfusion or systemic hypotension, there will be changes in both MEP and SSEP that is either focal or global depending on the cause of hypo-perfusion (MacDonald, Skinner, Shils, & Yingling, 2013; Koht et al., 2017). The spinal cord processes autoregulation when the MAP is maintained between 50 mmHg and 70 mmHg, although the lower MAP might still produce hypo-perfusion (Rabai et al., 2016). Spinal cord ischemia can result in hemiplegia or paraplegia depending on the where the ischemia occurs, which is why it is important to maintain both local perfusion and systemic perfusion (MacDonald et al., 2013).

Because the nervous system requires a tightly controlled pH balance and oxygen to function properly, extreme changes in PaCO₂ and PaO₂ will also produce changes in intraoperative neurophysiological monitoring modalities (Koht et al., 2017). Body temperature can produce changes in both MEPs and SSEPs (Koht et al., 2017). A colder body temperature results in an increase in latency and a higher body temperature results in a decreased latency. The change in latency can be either focal or global depending on if there is a localized temperature change or a systemic temperature change (MacDonald et al., 2013). If the body temperature is cold enough, as with deep hypothermia, MEPs can be nonexistent.

Nearly all anesthetics result in a dose-dependent suppression in both MEP and SSEP waveforms. MEPs are generally more sensitive to the effects of anesthetic agents than SSEPs (Rabai et al., 2016). 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 (Penny, 2010). Inhalational agents produce their effect on the nervous system by enhancing the inhibitory pathways and depressing the excitatory pathways (Penney, 2010). Each individual intravenous agent exerts their independent effect on the nervous system by interacting with different receptor sites.

Sloan and associates conducted a retrospective review in 2015 of 127 different spine cases focusing on anesthetic techniques of 0.5 mean alveolar concentration (MAC) of desflurane with an opioid and propofol infusion as compared to an opioid total intravenous anesthesia (TIVA) with propofol to see what the effects were on intraoperative neurophysiological monitoring. This study reviewed information from cases involving anterior cervical procedures, posterior cervical procedures, and posterior thoracic and/or lumbar procedures. Their study discussed how halogenated inhalational agents are known to cause a significant decrease in amplitude in both SSEP and MEP monitoring. In fact, these agents are capable of making it impossible to detect or acquire any evoked potentials (Sloan, Toleikis, Toleikis, & Koht, 2015). Of course, MEPs are affected more than SSEPs. Increased latency and decreased amplitudes will occur with a higher MAC value of the inhalational agent (Shils & Sloan, 2015; Gunter & Ruskin, 2016). This increase in latency and decrease in amplitude will be first noted in the MEP and then the SSEP if the MAC value is allowed to increase above 0.5 MAC.

Chong and associates conducted a randomized crossover trial in 2014 of 14 patients undergoing elective spinal surgery. This study involved using a propofol and remifentanil infusion with desflurane and sevoflurane. For this study the anesthesia professional used propofol and remifentanil to maintain general anesthesia. Sevoflurane and desflurane were both used one at a time on the same patient to see the effects each inhalational agent had on

intraoperative neurophysiological monitoring. During the operation, one of the inhalational agents was initiated at 0.3 MAC after starting evoked potentials were recorded. The initial inhalational agent was then increased to 0.5 MAC and finally to 0.7 MAC after a set amount of time between each increase. Evoke potentials were recorded 15 minutes after each increase. After the final evoked potential was obtained with the initial inhalational agent, that agent was discontinued and the fresh gas flows were turned up to allow the inhalational agent to be washed out. Finally, the same process was initiated with the second inhalational agent. Desflurane and sevoflurane are more commonly used over isoflurane due to their low solubility which allows for both a rapid induction and recovery (Chong et al., 2014). In a review of the current literature regarding intraoperative neurophysiological monitoring, it is likely that SSEPs and MEPs can be conducted with up to a 0.5 MAC of either desflurane or sevoflurane (Gunter & Ruskin, 2016).

With that being said, sevoflurane is more likely to produce MEP suppression as compared to baseline evoked potentials than desflurane (Chong et al., 2014). In 2014, Tamkus and associates conducted a retrospective review of 1,814 patient's charts who underwent a variety of spinal surgeries. This study focused on the rate of false positives in patients undergoing either a TIVA technique, a balanced anesthesia technique, or solely having inhalational agents for general anesthesia. They found that sevoflurane is associated with more false positives in which intraoperative neurophysiological monitoring indicates that an insult is occurring to the neuronal pathway being monitored, when there is in fact no impending neurological damage from an operative insult. It was also determined that inhalational agents produced more false positives as compared to a TIVA technique (Tamkus et al., 2014).

Because any MAC value greater than 0.5 is likely to produce changes in the baseline evoked potentials, and it is unrealistic to be able to perform an operation with only 0.5 MAC of

inhalational agent, a balanced anesthesia technique can be used for intraoperative neurophysiological monitoring. A balanced anesthesia technique consists of inhalational agents plus intravenous anesthesia agents (Royan, Lu, Mannien, & Venkatraghavan, 2017).

The studies presented by Chong, Sloan, Tamkus, and their associates indicate that a balanced anesthesia technique can be successfully used along with intraoperative neurophysiological monitoring. With that being said, it is important to keep in mind that 0.5 MAC of desflurane is superior to sevoflurane because sevoflurane is more likely to produce false positives and results in more evoked potential suppression than desflurane. With the case report that was presented at the beginning of this paper, you will recall that the balanced anesthesia technique for this patient consisted of 0.75 MAC of sevoflurane. During this case, there was not an issue with MEP or SSEP suppression. If there had been an indication of MEP or SSEP suppression, the first action by the anesthesia professional should be to turn down the sevoflurane to 0.5 MAC.

The intravenous anesthetics and anesthetic adjuncts that are used with intraoperative neurophysiological monitoring produce a varied effect on the evoked potentials. Some of the intravenous agents used include propofol, lidocaine, dexmedetomidine, ketamine, and opioids. Propofol produces a decrease in MEP and SSEP amplitude that is dose dependent (Penny, 2010; Van Der Walt, Thomas, & Figaji, 2013). The amount of depression that propofol produces in MEPs and SSEPs is less than those produced by inhalational agents (Gunter & Ruskin, 2016). Given propofol's rapid metabolism, the infusion can be quickly titrated down to allow for improved MEPs and SSEPs (Penny, 2010; Van Der Walt et al., 2013). Propofol plays a large role in intraoperative neurophysiological monitoring. It is used to either decrease the amount of

inhalational agents that are used in a balanced anesthesia technique, or it is used as one of the main components of the general anesthetic as with a TIVA technique (Gunter & Ruskin, 2016).

In 2013, Sloan and associates conducted a retrospective case review of 129 patients who underwent spinal surgeries while receiving a TIVA approach either with or without intravenous lidocaine. Lidocaine is reemerging as an adjunct to anesthesia and it most definitely has a place within intraoperative neurophysiological monitoring. When a continuous infusion of lidocaine is used, either in conjunction with a balanced anesthesia technique or with a TIVA technique, the total amount of propofol used is decreased, the amount of opioids required is decreased, and the MAC value of an inhalation agent is able to be reduced. Intravenous lidocaine has no appreciated effect on either SSEPs or MEPs. It is important to monitor the dose of lidocaine that is given to avoid the side effects that can be apparent with higher doses. The recommended dose for intravenous lidocaine with intraoperative neurophysiological monitoring is 1-2 mg/kg/hr but not to exceed 120 mg/hr in obese patients (Sloan, Mongan, Lyda, & Koht, 2013).

In 2015, Rozet and associates performed a double blind, randomized control trial with 40 patients undergoing spinal surgery. The patients were randomly assigned to two groups. One of the groups received dexmedetomidine and a TIVA technique with propofol and remifentanyl. The second group received a normal saline and a TIVA technique with propofol and remifentanyl. As determined by this study, dexmedetomidine is another adjunct to anesthesia and can be used as part of a balanced anesthesia technique or as a TIVA technique along with propofol. When dexmedetomidine is used as a continuous infusion, it can decrease both the amount of propofol required for induction and the infusion rate. Generally, dexmedetomidine has little to no effect on SSEPs and MEPs, but if a loading dose is given too fast and the depth of anesthesia is deepened too quickly, both SSEPs and MEPs will be adversely affected. A

suppressible cumulative effect of SSEPs and MEPs can sometimes be seen with the co-administration of dexmedetomidine and propofol, but again this is mostly likely related to the speed and amount of the dexmedetomidine loading dose (Rozet et al., 2015).

Ketamine is also another helpful adjunct to anesthesia as it decreases postoperative pain based on its analgesic properties (Gunter & Ruskin, 2016; Penny, 2010). When ketamine is given as a continuous infusion, it has no effect on latency, but increases the amplitude of both SSEPs and MEPs (Penney, 2010). This increased amplitude can be useful when intraoperative neurophysiological monitoring produces evoked potentials that are difficult to monitor (Van Der Walt et al., 2013).

The studies by Sloan, Roxet, and their associates indicate that both dexmedetomidine and lidocaine infusion are beneficial to intraoperative neurophysiological monitoring as an anesthesia adjunct with either a balanced anesthesia technique or a TIVA technique. Both lidocaine and dexmedetomidine have little to no effect on either SSEP or MEP, keeping in mind that dexmedetomidine can cause intraoperative neurophysiological suppression if the loading dose is given too fast.

For the patient presented in this case report, a balanced anesthesia technique was used. The balanced anesthesia technique consisted of sevoflurane, as discussed above, ketamine infusing at 10 mcg/kg/min, and lidocaine infusing at 3 mg/min. The patient also received a bolus of lidocaine 100mg and ketamine 50 mg. The information that has been gathered on this topic does not discuss any added benefits of giving lidocaine or ketamine boluses.

Opioids produce a very slight decrease in amplitude and increase in latency with SSEPs and MEPs. Remifentanyl, sufentanyl, and fentanyl can all be independently used with propofol as continuous infusions to provide anesthetic for intraoperative neurophysiological monitoring. The

benefit of using remifentanyl is that it is metabolized quickly so the effects of the medication are short acting once the infusion is turned off, which allows for a quicker emergence and a postoperative neurological assessment. The down side to remifentanyl is that it can contribute to hyperalgesia. The hyperalgesia can be diminished if the remifentanyl infusion is weaned off instead of abruptly discontinued. Sufentanyl and fentanyl have a longer half-life so they take a while longer to clear than remifentanyl does, resulting in a longer wake up time for a postoperative neurological assessment (Gunter & Ruskin, 2016).

Recommendations

As described above, there are several different anesthetics and anesthesia adjuncts that can be used to provide anesthesia for intraoperative neurophysiological monitoring. Although both the balanced anesthesia technique and TIVA technique can be used during SSEP and MEP monitoring, the inhalational agents can pose to be problematic with their effect on amplitude and latency. The TIVA approach is often the preferred method of anesthesia because the majority of the intravenous anesthetics discussed above allow for consistent MEP and SSEP monitoring over inhalational agents (Rozet, 2015).

When a balanced anesthesia technique is being used, it is recommended to use desflurane over sevoflurane when monitoring SSEPs and MEPs. If a balanced anesthesia technique is being used while intraoperative neurophysiological monitoring is being conducted, and the amplitude and latency become affected, the inhalational agents can be turned down or off. A TIVA technique can be started if the inhalational agents are to be turned off, and/or the mean arterial pressure can be increased to improve perfusion in the hopes of restoring the amplitude and latency (Gunter & Ruskin, 2016; Royan et al., 2017).

If none of these things restore the amplitude and latency, the concerns have been communicated to the surgeon and he/she has made adjustments on their end, a wake up test with a neurological check can be performed (Penny, 2010). If the patient presents with preoperative neurological deficits, baseline SSEPs and MEPs may be impaired (Royan et al., 2017). With this baseline impairment of SSEPs and MEPs, it is recommended to start off with a TIVA approach because the inhalational agents will further reduce the evoked potential waveforms making it difficult to monitor (Royan et al., 2017).

Future research studies that could help develop an evidence based gold standard protocol when it comes to intraoperative neurophysiological monitoring include a large scale randomized controlled trial comparing a balanced anesthesia technique to a TIVA technique. A large scale randomized controlled trial would allow for a significant number of patients receiving spinal surgery to be evaluated and provide information on what anesthesia technique is actually better with regards to intraoperative neurophysiological monitoring.

Future research could also explore the potential benefits of administering boluses of lidocaine and ketamine during induction. Lastly, it would be interesting to investigate the efficacy of administering intravenous methadone during induction, as was done with the patient in this case report. Methadone could potentially affect postoperative pain control, emergence time for postoperative neurological assessment, and cause a decrease in intraoperative opioid use.

Conclusion

In conclusion, intraoperative neurophysiological monitoring of SSEPs and MEPs are important tools to help detect potential new onset neurological deficits with spine surgery. There are a variety of anesthesia interventions that can be carried out if the evoked potentials show a

decrease in amplitude or increase in latency. A thorough literature review has been completed and it appears that either a balanced anesthesia technique or a TIVA technique can be used in the setting of intraoperative neurophysiological monitoring. As discussed during administration of either of the anesthesia techniques, specific parameters are required to maintain consistent SSEP and MEP waveforms.

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Appendix A

Anesthesia Considerations for
Intraoperative
Neurophysiological Monitoring

Kimberly Moon, SRNA

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Introduction

- When a patient is having high risk neurosurgery, intraoperative neurophysiological monitoring is used to detect, and hopefully prevent, postoperative neurological deficits
- Neurophysiological monitoring involves monitoring evoked potential waveforms that result from electrical stimulation and depicts the integrity of the neurological pathway being monitored

(Nagelhout & Plaus, 2014;Pino, 2016)

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Introduction Continued

- Evoked potential waveforms are obtained, recorded, and compared to the baseline waveforms
- When a change in waveform occurs, there is likely an insult that is occurring to the area being monitored
- Examples of insults include:
 - systemic hypotension, anesthetic agents, hypoxia, hypothermia, and hypercarbia/hypocarbica

(Miller, 2015)

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Case Information

- Right sided Anterior Cervical Discectomy and Fusion (ACDF) of C4-C7
- 65-year-old female
- 185.4 cm
- 113.9 kg with a BMI of 32.84
- Allergies to bupropion and environmental
- ASA physical status: level 3

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Pre-operative Evaluation

- Past Medical History
 - bradycardia, peripheral vascular disease, hypothyroidism, lumbar degenerative disc disease, chronic thrombocytopenia, spondylosis of lumbosacral region, postoperative nausea/vomiting, GERD, iron deficiency anemia, hyperparathyroidism, depression, anxiety, bipolar disorder, chronic opioid use, and osteoarthritis
- Surgical History
 - Roux-En-Y gastric bypass surgery, pannus removal, right hemicolectomy with closure of ileostomy, takedown of ileostomy, ventral herniorrhaphy, total knee arthroplasty X2, right L4-S1 facet injections under fluoroscopy, and incisional hernia repair with I&D of abscess

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Pre-operative Evaluation Continued

<ul style="list-style-type: none"> • Pre-op VS <ul style="list-style-type: none"> – Blood pressure: 122/80 – Respirations: 16 – Temperature: 36.8 – Heart rate: 59 – Room air oxygen saturation: 96% 	<ul style="list-style-type: none"> • Mallampati: 2 • Thyromental distance: 3 finger breadths • CBC was within normal limits • HGB: 10.8 g/dL • HCT: 31.8 g/dL • TSH: 5.18
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Anesthetic Course

- Pre-induction
 - 20 gauge peripheral IV, Midazolam 1 mg IV, 20 gauge arterial line
- Intravenous induction
 - Lidocaine 100 mg, Propofol 200mg, Succinylcholine 180 mg, Ketamine 50mg, IV Methadone 14 mg
- Airway
 - Pre-oxygenated by mask with 10 L/min for 10 minutes, Video laryngoscopy facilitated placement of 7.0 cuffed ETT, ventilator was used to maintain oxygenation saturation greater than 96% and normal carbon dioxide levels.

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Anesthetic Course Continued

- Intraoperative neurophysiological monitoring
 - SSEP and MEP were applied and baseline waveforms were obtained
- Maintenance
 - Expired sevoflurane at 0.75 MAC, ketamine infusion at 10 mcg/kg/min, lidocaine infusion at 3 mg/min
- Additional medications
 - Cefazolin 2 grams, dexamethasone 10 mg, ondansetron 4 mg

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Intraoperative Issues

- Hypotension
 - Ephedrine 5 mg
 - Ephedrine 10 mg
- Bradycardia
 - Glycopyrrolate 0.2 mg give twice
- Hypertension
 - Labetalol 10 mg

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Anesthetic Course Continued

- Discontinuation of anesthetics
 - Ketamine infusion was turned down to 8 mcg/kg/min 90 minutes prior to extubation
 - Ketamine was stopped 45 minutes prior to extubation
 - Lidocaine infusion was continued until patient was in PACU
- Neurological assessment
 - Improved amplitude in both somatosensory evoked potentials (SSEP) and motor evoked potentials (MEP)
 - Post-op neurological assessment
 - Patient was able to follow commands and move all extremities

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Discussion

Anesthetic Considerations for Intraoperative Neurophysiologic Monitoring

- Prior to the extensive use of intraoperative neurophysiological monitoring, the wake up test was the only way to assess for new onset neurological deficit during spinal procedures
- The two most commonly used types of intraoperative neurophysiological monitoring for the spinal cord
 - SSEP:
 - Provides information regarding the ascending pathway
 - MEP:
 - Provides information regarding the corticospinal motor tract pathway

(Gunter & Ruskin, 2016; Ajiboye et al., 2017; Ajiboye et al., 2016)

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Anesthetic Considerations for Intraoperative Neurophysiological Monitoring

- Baseline SSEPs and MEPs are obtained prior to the start of the procedure
 - A change in latency of 10% and/or a change in amplitude of 50% indicates that a neurological insult is occurring, and an impending neurological deficit could result if the insult is not remedied and the waveforms do not return to baseline
- The waveforms are obtained and the amplitude and latency are monitored throughout the remainder of the procedure

(Gunter & Ruskin, 2016)

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Anesthetic Considerations for Intraoperative Neurophysiological Monitoring

- In order for the spinal cord and the corresponding nerve roots to function appropriately, they must be provided with adequate blood flow, oxygen and at an appropriate body temperature
- Nearly all anesthetics result in a dose-dependent suppression in both MEP and SSEP waveforms
 - MEPs are generally more sensitive to the effects of anesthetic agents than SSEPs
 - Increased latency and decreased amplitudes will occur with a higher MAC value of the inhalational agent
 - The intravenous anesthetics and anesthetic adjuncts that are used produce a varied effect on the evoked potentials

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(Rabal, Sessions, & Seubert, 2016; Shis & Sloan, 2015; Gunter & Ruskin, 2016)

Anesthetic Considerations for Intraoperative Neurophysiological Monitoring

- Inhalational agents
 - A 2016 review of the current literature conducted by Gunter & Ruskin regarding intraoperative neurophysiological monitoring
 - It is likely that SSEPs and MEPs can be conducted with up to a 0.5 MAC of either desflurane or sevoflurane
 - Chong and associates conducted a randomized crossover trial in 2014 of 14 patients undergoing elective spinal surgery to evaluate the effects of sevoflurane and desflurane
 - Sevoflurane is more likely to produce MEP suppression as compared to baseline evoked potentials than desflurane

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Anesthetic Considerations for Intraoperative Neurophysiological Monitoring

- Inhalational agents continued
 - In 2014, Tamkus and associates conducted a retrospective review of 1,814 patient charts. This study focused on the rate of false positives in patients undergoing either a TIVA technique, a balanced anesthesia technique, or solely having inhalational agents for general anesthesia
 - Sevoflurane is associated with more false positives as compared to desflurane
 - Inhalational agents produced more false positives as compared to a TIVA technique

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Anesthetic Considerations for Intraoperative Neurophysiological Monitoring

- Intravenous agents
 - In 2013, Sloan and associates conducted a retrospective case review of 129 patients who underwent spinal surgeries while receiving a TIVA approach either with or without intravenous lidocaine.
 - Lidocaine has no appreciated effect on either SSEPs or MEPs
 - A continuous infusion of lidocaine results in a decrease in the total amount of propofol, opioids, and MAC value of an inhalational agent that are required for the case

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Anesthetic Considerations for Intraoperative Neurophysiological Monitoring

- Intravenous agents continued
 - In 2015, Rozet and associates performed a double blind, randomized control trial with 40 patients undergoing spinal surgery to determine to effects of dexmedetomidine
 - Dexmedetomidine generally has little to no effect on SSEPs or MEPs
 - If a loading dose is given too fast and the depth of anesthesia is deepened too quickly, both SSEPs and MEPs will be adversely affected

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Anesthetic Considerations for Intraoperative Neurophysiological Monitoring

- Intravenous agents continued
 - Propofol can cause a dose dependent suppression of SSEP and MEP
 - When ketamine is given as a continuous infusion, it has no effect on latency, but increases the amplitude of both SSEPs and MEPs
 - Opioids produce a very slight decrease in amplitude and increase in latency with SSEPs and MEPs

(Penney, 2010)

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Recommendations

- Future research studies that could help develop an evidence based gold standard protocol when it comes to intraoperative neurophysiological monitoring include a large scale randomized controlled trial comparing a balanced anesthesia technique to a TIVA technique
- Future research could also explore the potential benefits of administering boluses of lidocaine and ketamine during induction
- Future research could be used to explore the efficacy of administering intravenous methadone during induction, as was done with the patient in this case report

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Recommendations Continued

- There are several different anesthetics and adjuncts that can be used to provide anesthesia for intraoperative neurophysiological monitoring
 - Inhalational agents can pose to be problematic with their effect on amplitude and latency
 - Desflurane is better for monitoring than sevoflurane
 - The TIVA approach is often the preferred method of anesthesia because the majority of the intravenous anesthetics allow for consistent MEP and SSEP monitoring

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Conclusion

- Intraoperative neurophysiological monitoring of SSEPs and MEPs are important tools to help detect potential new onset neurological deficits with spine surgery
- There are a variety of anesthesia interventions that can be carried out to ensure optimum conditions for intraoperative neurophysiological monitoring
 - Maintaining adequate blood pressure, oxygenation/ventilation, and temperature
 - Following the specific parameters that are required to maintain consistent SSEP and MEP waveforms

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Thank You
Are There Any Questions?

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