ORIGINAL ARTICLE

Spinal Cord Mapping with Somatosensory Evoked Potentials (SSEP) in Cervical and Thoracic Surgeries

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Faisal R. Jahangiri [1,2,3]
Aisha Khan[1]
Tal Allouche [2]
Hiral Gorasia[2]
Yabsera Mesfin[2]
Nicholas Bathurst[2]

[1]Global Innervation LLC, Dallas, Texas, USA.
[2]Department of Neuroscience, School of Behavioral & Brain Sciences, The University of Texas at Dallas, Richardson, Texas, USA.
[3]Labouré College of Healthcare, Milton, Massachusetts, USA.

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ABSTRACT

Intraoperative neurophysiological monitoring (IONM) is commonly used in surgeries to reduce post-operative deficits. IONM uses multiple modalities, including SSEP, TCeMEP, and EMG. In this chapter, we will discuss the use of SSEP in mapping the spinal cord for cervical and thoracic surgeries that involve intramedullary tumor resections.

We use SSEP phase reversals and collision studies to find the midline raphe to make a safe incision. We can either directly stimulate the spinal cord and record from the brain to tell the difference between the right and left dorsal columns, or we can stimulate the peripheral nerve (median or tibial), cause a collision with an epidural stimulator, and look for decreased amplitude of signal in the cortex.

Mounting evidence suggests that mapping the spinal cord using SSEP is a safe and effective method that can be used to determine the location of the midline raphe separating the sensory tracts for the midline myelotomy and epidural stimulator placement. SSEP monitoring is also an effective way to prevent postoperative deficits by constantly monitoring SSEP throughout the surgery.

In conclusion, we can say that cortical spinal mapping helps locate the midline raphe, which can help surgeons during surgical procedures to help keep the dorsal columns unharmed.

INTRODUCTION

Overview

Intraoperative neurophysiological monitoring (IONM) is a collection of methods to surveil a patient's nervous system during surgery. IONM is usually done by delivering electrical impulses to a patient's nervous system and measuring responses. A trained technician is present during an operation, monitoring and giving the surgeon real-time feedback during surgery. If a significant change occurs, feedback is immediately provided to the surgical team, who can quickly respond. This can significantly reduce the chances of long-term complications from surgery [1]. Cervical and thoracic spinal cord tumor resections often lead to postoperative deficits without IONM [2,3].

The two types of spinal cord tumors are extradural (outside the dura) and intradural (underneath the dura) [3]. Intradural tumors can be extramedullary (inside the dura but outside the spinal cord) or intramedullary, meaning they are within the spinal cord (Figure 1). One of the significant contributions of IONM to surgery is monitoring during intramedullary spinal cord tumor resections [4]. These intramedullary tumors have a very high incidence of postoperative deficits due to anatomical distortion, which can be avoided using IONM [5].

Figure 1: Magnetic Resonance Imaging (MRI) of the cervical spine showing spinal cord tumor.

To go over a brief history, IONM use dates to the 1930s when brain stimulation was used to find the motor cortices for patients with epilepsy. In the 1980s, new technology was invented, allowing for the widespread use of novel techniques [5]. In the 1990s, transcranial motor evoked potentials allowed spinal monitoring and helped predict post-op motor problems. This technology is still continuously evolving and improving [2]. Nowadays, computer networking allows for remote neuromonitoring, further popularizing the technique [3].

Multimodality IONM methods include somatosensory evoked potential (SSEP) and electromyography (EMG), further discussed in this paper. There is also the idea of "mapping." Mapping helps provide rapid anatomical data of neural structures and their locations using electrical stimulation with a hand-held probe [6]. This chapter reviews data from patients who underwent median and tibial nerve SSEP with dorsal column stimulators. We review stimulation, recording, and phase reversal for SSEP, spontaneous electromyography (S-EMG), and multimodal intraoperative monitoring. Using SSEP monitoring significantly reduces post-op defects in the tumors mentioned above.

Methods:

Patient Selection Criteria:

Common types of thoracic or cervical procedures that use spinal cord mapping are intramedullary spinal cord tumors and spinal cord stimulator implants.

Anesthesia:

All procedures using SSEP use intravenous anesthesia, like fentanyl and propofol. Halogenated inhaled anesthetics like isoflurane or sevoflurane will affect the IONM data. Muscle relaxants cannot be used while recording EMG responses [2].

Somatosensory Evoked Potentials (SSEP):

Stimulation: In any cervical or thoracic surgery, the SSEP baseline must be recorded before the surgery begins. Surface adhesive stimulating electrodes are placed bilaterally on the median nerve at the wrists to monitor the patient's upper extremities. The cathode should be placed 2 cm from the wrist crease and between the palmaris longus and flexor carpi radialis, while the anode is 2-3 cm distal to the cathode. Surface adhesive stimulating electrodes are placed on the medial malleolus at the ankle for the posterior tibial nerve for monitoring the lower extremities. The cathode should be on the posterior part of the ankle, while the anode is 2-3 cm distal to the cathode. The peroneal nerve may be stimulated at the head of the fibula or the popliteal fossa, but the ankle has easier accessibility. The stimulation intensity should be 15-35 mA for the upper extremities. For the lower extremities, the stimulation intensity should be 40-100 mA. A pulse duration of 300 microseconds should be used. The stimulation rate for upper and lower extremities should be 2.66-3.79 per second.

Recording: These signals travel to the sensory cortex primarily through the dorsal column-medial lemniscus (DCML) pathways. Subdermal needle electrodes are placed on the scalp according to the International 10-20 System to record SSEP responses. The recording electrodes are placed in various areas to increase SSEP reliability. This includes Erb’s point, the popliteal fossa, the cervical spinal cord, and the cortical/subcortical region (anesthesia affects the cortical responses and produces false positive responses, while the subcortical is less likely to be affected). We can also record antidromically elicited SSEP by stimulating the dorsal columns and recording from the medial malleoli bilaterally. After identifying the midline, stimulate on either side at 1mm intervals at 1.0 mA. An area of no response would indicate abnormal tissue [8].

Phase reversal: The phase reversal technique is used to identify the midline raphe in intramedullary spinal cord tumor surgeries. The dorsal midline raphe separates the left and right dorsal columns of the spinal cord, which are the areas that relay vibration and proprioception senses of the upper and lower limbs to the sensory cortex (Figures 2 and 3). The tumor makes it difficult for the surgeon to locate the midline raphe, increasing the chances of a wrong incision to the gracilis tract and resulting in irreversible damage. An 8-contact mini-electrode strip can be placed on the dorsal columns, stimulating the left and right gracilis tracts at 3.17 Hz, 0.2 mA intensity, and 0.3 ms pulse width using a handheld bipolar stimulator. After each stimulation, cortical SSEP is recorded at scalp electrodes. A phase reversal in the cortical SSEP (CP3—CP4 montage) indicates the location of the midline raphe between two adjacent contacts on the mini-electrode strip [6].

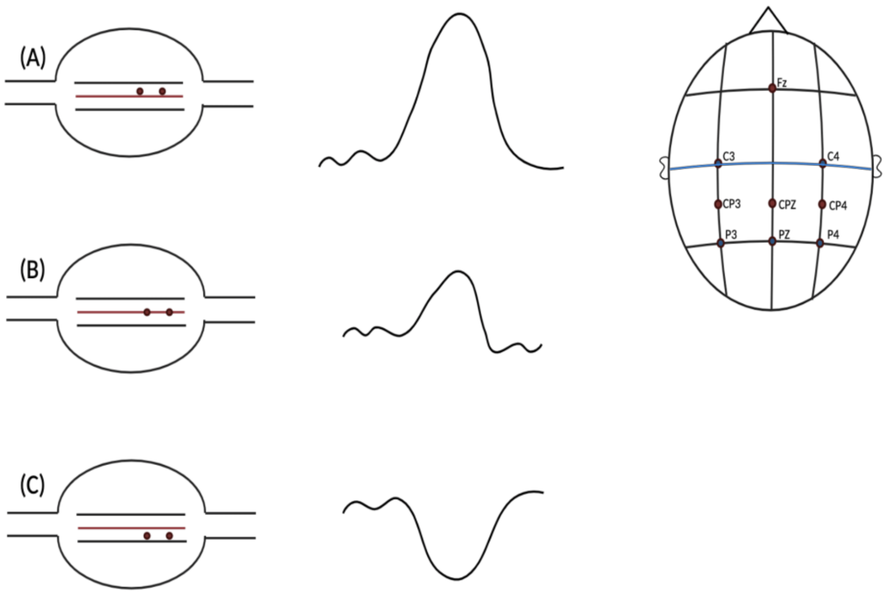

Figure 2: Cervical Montage: (A) shows the stimulation of the right dorsal column, and the resulting CP3-CP4 wave shows a strong upward peak. (B) shows the stimulation of the right dorsal column but a bit closer to the midline, and the resulting CP3-CP4 wave shows a weaker upward peak. (C) shows the stimulation of the left dorsal column, the resulting CP3-CP4 wave shows a strong downward peak, indicating a phase reversal (illustration by Aisha Khan).

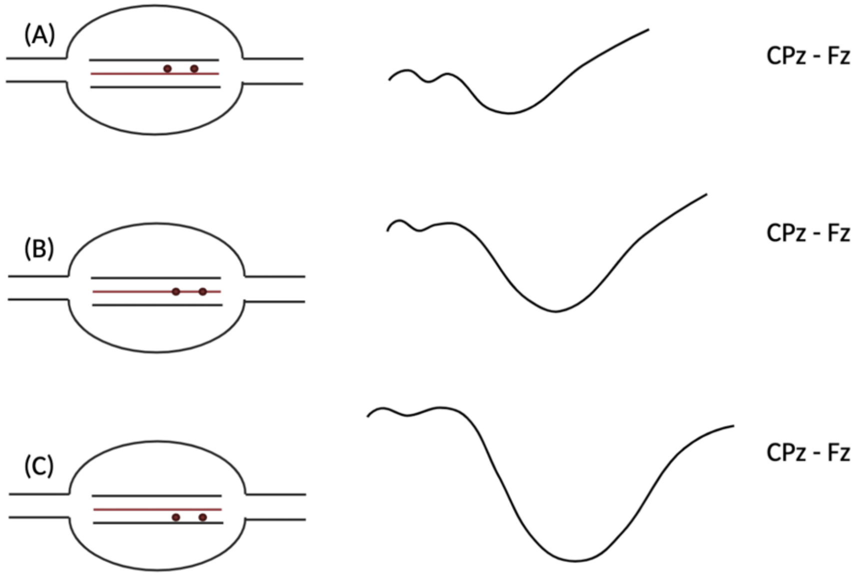

Figure 3: Thoracic Montage: (A)shows the stimulation of the right dorsal column, and the resulting CPz-Fz wave shows a small downward peak. (B) shows the stimulation of the right dorsal column but a bit closer to the midline, and the resulting CPz-Fz wave shows a stronger downward peak. (C) shows the stimulation of the left dorsal column, and the resulting CPz-Fz wave shows a very strong downward peak (illustration by Aisha Khan).

Collision Study: Data is collected from several patients undergoing median and tibial nerve somatosensory evoked potential (SSEP) monitoring during cervical laminectomy or hemilaminectomy. As mentioned earlier, the patients are undergoing monitoring for placement of dorsal column stimulators. The process encompasses paddle leads positioned laterally or near the midline and parallel to the axis of the cervical spinal cord. This was done to effectively treat what was most found to be the predominant unilateral pain syndrome. During SSEP recording, the spinal cord stimulator was activated to 1.0 Volts. The voltage was increased in increments of 1.0 volts to 6.0 total volts. The unilateral reduction or abolishment of SSEP amplitude is taken as an indicator of lateralized placement. The bilateral diminutive effect on SSEP was interpreted and used as a near midline lead or midline placement.

During the surgery, if the SSEP shows at least a 10% increase in latency and a 50% reduction in amplitude compared to the baseline, then there's a high likelihood that neurologic impairment has been done. Factors such as decreased body temperature/blood flow or body positioning can also cause the SSEP amplitude to reduce.

Electromyography:

Spontaneous or free-running electromyography (s-EMG) and triggered EMG (t-EMG) have become widely applied to monitor selective nerve root function during spinal cord surgery. Unlike SEP and SSEP data, this method utilizes "real-time" recording from peripheral musculature [8]. EMG can also be used to prevent postoperative radiculopathy, which may occur during spinal instrumentation surgery, which includes pedicle screw placement [9]. Subdermal needle electrodes are placed in upper or lower limb muscles, and anal and bladder foley electrodes for urinary sphincter muscles [2]. The muscles used for upper limb EMG are the deltoid, biceps brachii, triceps brachii, flexor carpi ulnaris, brachioradialis, abductor pollicis brevis, and abductor digitimini muscles. For lower limbs, adductor longus, quadriceps, tibialis anterior, peroneus longus, gastrocnemius, and abductor hallucis muscles. Research also shows that muscle relaxants cannot be used to monitor nerve roots as they will harm the recording.

Multimodal Intraoperative Neurophysiological Monitoring:

Electrophysiological monitoring throughout the spinal cord surgery procedure has been advocated as the primary means of measuring the functional integrity of the spinal cord during various procedures. These procedures include spinal column deformity correction, spinal cord decompression, and intramedullary tumor resection, along with others. Furthermore, this monitoring can also be utilized in cervical and thoracic spinal column traumatic injury procedures. During this role, electrophysiological monitoring is a potential diagnostic adjunct alongside spinal surgery. A technician in the operating room and a remote physician are present for oversight during all neurophysiological monitoring per The American Society of Neurophysiological Monitoring (ASNM) guidelines [4]. IONM of the spinal cord has also been evaluated as a therapeutic tool that can be utilized during spinal surgery to improve neurological outcomes in patients treated surgically.

Conclusively, all modalities will have advantages and disadvantages. Thus, the use of multiple modalities will allow for the best outcome. SSEP phase reversal is utilized along with collision studies to find the median range. This is done to make the safest possible incision. The spinal cord can be directly stimulated to record from the brain. This will show the difference between the left and right dorsal columns. Other than this, the peripheral nerve, medial or tibial, can be recorded from the spinal cord.

DISCUSSION

Mapping of the spinal cord using SSEP is a safe method that can be used to determine the location of the midline raphe separating the sensory tracts. This allows the surgeon to know precisely where the myelotomy should be performed, even when an intramedullary tumor distorts the standard anatomy of the spinal cord. The distortion could be caused by displacement of the tracts, cord rotation, edema, neovascularization, or local scar formation [10]. Often, without SSEP, the surgeon will perform the myelotomy at the wrong place and damage the axons of the dorsal columns, leading to postoperative sensory deficits. One study on eight women and two men with thoracic and cervical spinal cord lesions evaluated the effectiveness of dorsal column mapping in guiding the surgeon to find the myelotomy's midline. In two patients with syringomyelia and five patients with tumors, the authors could not identify the midline anatomically with any certainty. However, dorsal column mapping allowed the identification of the midline [10].

Even after the initial myelotomy, when the tracts are pulled apart to expose the tumor, the pressure exerted on the tracts can cause postoperative deficits unless corrected within the reversible phase. SSEP detects these events with a sensitivity of up to 92% and a specificity of up to 100% [2]. There is a decreased rate of postoperative dorsal column dysfunction when SSEP is used during intramedullary tumor resections. In a study by Mehta et al. of 91 patients who underwent intramedullary tumor resections. Patients with dorsal column mapping by SSEP had a statistically significant decreased rate of new postoperative posterior column dysfunction of 9% compared with 50% without mapping [5].

One method of spinal cord mapping is using the SSEP phase reversal technique to identify the neurophysiological midline. One study on a 41-year-old man with a C3-C4 intramedullary spinal cord tumor who underwent successful myelotomy and tumor resection using an 8-contact mini electrode strip to stimulate the dorsal spinal cord and recording SSEPs from the scalp illustrates the utility of the technique. There were no changes to pre-myelotomy SSEPs post-resection, and postoperatively, the patient's posterior column function was preserved [9].

The midline could also be found using collision methods. When stimulating a peripheral nerve, the SSEP travels ipsilaterally up the dorsal columns, crossing over into the brainstem and ending in the contralateral somatosensory cortex. By repositioning an epidural electrode, you can block the SSEP by collision. Successful collision is indicated by decreased amplitude of the N20 (cortical) peak and signifies that the electrode is on the dorsal column ipsilateral to the stimulation site. Stimulation of the contralateral peripheral nerve would still produce a normal cortical signal. The epidural electrode can be repositioned to determine the midline separating the left and right dorsal columns.

SSEP can also help identify the correct epidural spinal cord stimulator placement to treat pain using the collision technique. The painful area can be stimulated to elicit SSEPs, and recording can be done from the cortex. As the epidural spinal cord stimulator is being relocated, SSEP will be used until the recordings from the cortex diminish, indicating that the epidural stimulator is in the right place to block the pain sensation. In one collision study of 15 patients with unilateral pain syndrome, epidural electrodes were repositioned to produce the most significant decreases in cortical SSEP amplitude, and found that these SSEP reductions corresponded with the patient's report of postoperative sensory alterations [1].

CONCLUSIONS

Cortical spinal cord mapping with SSEPs is safe, quick, and reliable, giving the surgeon an accurate measure for successful surgical resection of intramedullary or spinal cord tumors. Spinal cord mapping provides a solid basis for locating the midline raphe and makes sure no harm is caused to the dorsal columns. Continuous monitoring of the modalities is necessary so that the spinal cord tracts remain functional and intact during tumor resection. It provides the surgeon with real-time feedback of the neurophysiological signals, an invaluable piece of information to avoid neurologic postoperative deficits. Thus, mapping the spinal cord using electrical stimulation can be essential for intraoperative neurophysiological differentiation between these pathways in spinal cord surgeries. Neurosurgical treatments must be performed with intraoperative neurophysiological mapping to identify the incision's location accurately. However, the outcome also depends highly upon the familiarity with the technique and expertise of the neurophysiologist and the surgeon.

ORCID

Faisal R. Jahangiri https://orcid.org/0000-0002-1342-1977

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