Intraoperative Neurophysiological Monitoring for Brainstem Tumor Surgeries

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Abstract

Intraoperative Neurophysiological Monitoring (IONM) is routinely utilized to detect and prevent injuries to the nervous system during surgeries. IONM can be used to map and monitor cranial nerves that may be displaced due to large tumors or at risk of being damaged during tumor resection. Surgical procedures involving the removal of brainstem tumors may risks damage to the Facial nerve (cranial nerve VII) and Vestibulocochlear Nerve (Auditory nerve/cranial nerve VIII). Any injury to the Facial nerve can lead to facial muscle paralysis, loss of taste sensation, and tear production. Lack of tear production can result in damage to the cornea that may lead to loss of vision. Injury to the auditory nerve due to stretch, thermal, or ischemia (loss of blood supply) has a high risk of postoperative hearing deficits or hearing loss. IONM can be used to mitigate deficits when resecting various brainstem tumors. During brainstem tumor resections, a multimodality neuromonitoring approach may include Somatosensory Evoked Potentials (SSEPs), Motor Evoked Potentials (MEPs), Brainstem Auditory Evoked Potentials (BAEP), Cranial Nerve Electromyography (CN-EMG). IONM is crucial for minimizing and preventing damage to the cranial nerves, corticospinal tracts, and ischemia. The likelihood of injury, the severity of the damage and permanency of loss can be minimized with IONM by alerting the surgeon before the damage is irreversible. Large tumors, especially those larger than 2.5 cm, may shift anatomy in the brainstem and require lower cranial nerves from IX to XII neuromonitoring.

Keywords: IONM; Intraoperative Neurophysiological Monitoring; Somatosensory Evoked Potentials; SSEP; Transcranial Electrical Motor Evoked Potentials; TCeMEP; Corticobulbar Motor Evoked Potentials; CoMEP; Electromyographic; EMG; Brainstem Auditory Evoked Potentials; BAEP; Brain Tumor Neurosurgery

Introduction

A brainstem tumor is an abnormal growth of tissue within the brainstem, from the rostral midbrain to the caudal medulla. There are four main types of brainstem tumors. The majority of the present research focuses on gliomas in children and schwannomas in adults. Other major types of brainstem tumors are brainstem neuromas and meningiomas. Brainstem gliomas are the most common brainstem tumors, making up 78% of all malignant brain tumors [1], with a significant portion of gliomas tumors being diagnosed in childhood [2]. There are two subtypes of brainstem gliomas: tectal gliomas and pontine gliomas. Tectal gliomas are the more common and less severe of the two [3]. The second most common type of brainstem tumor is Schwannoma and is a tumor of the Schwann cells. There are four subtypes of brainstem schwannomas, each ranging in severity [4]. However, the most common type of Schwannoma is an acoustic neuroma [1].

Schwannomas almost always involve the cranial nerves and stem from the vestibular branch of the eighth cranial nerve, the vestibulocochlear nerve [5]. The third major type of brainstem tumors is a brainstem neuroma, which is a tumor of neurons. These tumors typically form at the junction between CNS and PNS within the supratentorial region [6]. Meningioma is a tumor of the meninges and generally has a reasonably good prognosis. However, they are challenging to operate on given the nature of the tumors [7]. They are the most common type of brainstem tumor in adults [1] (Table 1).

<table>
<thead>
<tr>
<th>Tumor Type</th>
<th>Tumor Location</th>
<th>Median Age of Diagnosis</th>
<th>Prevalence</th>
<th>Adult v Child Distribution</th>
<th>Gender Distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glioma</td>
<td>Glial cells generally in pons</td>
<td>Mid-30s</td>
<td>1.5-2% of all brain tumors</td>
<td>Children</td>
<td>Males</td>
</tr>
<tr>
<td>Schwannoma</td>
<td>Schwann cells; the vestibular branch of CN VIII</td>
<td>40-60</td>
<td>4.2/100,000</td>
<td>Adults</td>
<td>Females</td>
</tr>
<tr>
<td>Neuroma</td>
<td>Neurons; transition zones from CNS to PNS</td>
<td>Mid-50s</td>
<td>1/100,000</td>
<td>Adults</td>
<td>Females</td>
</tr>
<tr>
<td>Meningioma</td>
<td>Meninges</td>
<td>50 - 60</td>
<td>37% of all brain tumors</td>
<td>Adults</td>
<td>Females</td>
</tr>
</tbody>
</table>

Table 1: The most common type of brainstem tumor in adults.

Intraoperative neurophysiological monitoring (IONM) is routinely used to minimize any postoperative neurological deficits in patients undergoing resection of brainstem tumors. IONM is used to detect changes in intraoperative data in the nervous system while still reversible [8]. The use of multimodality IONM is beneficial in brainstem tumor resections to preserve the functional integrity of the nervous system. Modalities used in brainstem tumor resections include; Somatosensory Evoked Potentials (SSEP), Transcranial electrical Motor Evoked Potentials (TCE MEP), Corticobulbar Motor Evoked Potentials (Co-MEP), Brainstem Auditory Evoked Potentials (BAEP), Electromyography (EMG), Cranial Nerve Electromyography (CN-EMG), Electroencephalography (EEG), and Train of Four (TOF).

Methods

Anesthesia

Anesthesia protocol during brainstem surgery includes total intravenous anesthetic (TIVA). It often consists of a combination of propofol and opioids to allow for intraoperative monitoring [9]. The Train of Four (TOF) is monitored from the most distal muscle to assess neuromuscular blocking agents [10].

Intraoperative neurophysiological monitoring (IONM)

Somatosensory evoked potentials (SSEP)

Peripheral nerves are stimulated by placing surface adhesives at the median or ulnar nerves at the wrist for upper extremities and the posterior tibial nerve at the ankle or the peroneal nerve for the lower extremities. The subdermal needle recording electrodes are placed at CPz, CP3, and CP4, CV5 (5th cervical spine) right and left Erb's points and popliteal fossas. Standard stimulation parameters indicate a repetition rate of 2 - 8/s and a pulse width of 300 µs. Recording parameters include 200 - 500 averages, sweep of 50 - 100 milliseconds, a low-frequency filter set at 30 Hz, and a high-frequency filter set at 500 - 1500 Hz, depending on the recording. Alarm criteria usually consist of a 50% decrease in amplitude or a 10% delay in latency [11].
Brainstem auditory evoked potentials (BAEP)

Brainstem auditory evoked potentials are utilized for monitoring the functional integrity of the auditory pathway, including the cochlea, auditory nerve, cochlear nucleus, superior olivary, and inferior colliculus of the brainstem. Foam inserts are placed bilaterally in the auditory canal for auditory click stimulation. A broadband stimulation with a single 100-μs monophasic square pulse with a click intensity of 100 dB pe SPL or 60 - 70 dB HL is commonly utilized [12]. The stimulus rate of 8-10/s with a timebase of 15 milliseconds, 500 - 100 averages, and filter settings between 100 - 2500 Hz is used. Stimulation is performed by stimulating one ear at a time, with more frequent stimulation in the ipsilateral ear. Higher click intensities may be needed if any pre-existing hearing loss is present or if fluid collects in the middle ear during the surgery. In order to remove any bone-conducted crossovers responses, contralateral or non-stimulated ear white noise masking is recommended at 60 dB SPL. BAEP recording is performed by placing either standard disk EEG electrodes or sterile subdermal needle electrodes on the scalp at Cz and over anterior to the left and right ear preauricular notch (A1 and A2) or mastoid process. The montage derivation used for BAEP recordings are Cz-A1/Cz-M1 and Cz-Ac/Cz-Mc. Alarm criteria consist of 1.0 ms latency delay or a 50% drop in amplitude of wave V. A delay in the Inter Peak Latency (IPL) can differentiate if the changes are due to the auditory nerve or the brainstem [12].
Transcranial electrical motor evoked potentials (TCeMEP)

According to the recommended guidelines, TCeMEP stimulation is performed by placing spiral ‘corkscrew’ electrodes on the scalp at C1, C2, C3, and C4. Alternate sites used for the stimulus are M1, M2, M3 and M4 [13]. TCeMEP responses are recorded bilaterally from the upper and lower extremities. Subdermal needle electrodes are placed in the muscles for EMG and TCeMEP recordings. Standard transcranial MEP parameters include a train of 3 - 7 pulses, Inter-Stimulus Interval (ISI) of 2.1 - 4.1, bandpass filter of 10Hz to 5.0 kHz and sweep of 10ms/division (Figure 4). Alarm criteria consist of an 80% decrease in amplitude, change in morphology or more than 100V increase in the threshold [13]. Cranial nerve or Corticobulbar Motor Evoked Potentials (Co-MEP) can be used to evaluate the integrity of the corticobulbar tracts during brainstem procedures. CoMEP stimulation is performed by double train stimulation with a single pulse followed by a train of 3 or 4 pulses. The Inter Train Interval (ITI) varies between 15 - 50 ms, and the Inter Stimulus Interval (ISI) is shorter than the upper and lower extremity muscle MEPs (1.1 to 1.9). A response present after the first single pulse that shows activation of the facial muscles due to direct activation from the current spread over the skin instead of the corticobulbar pathway [14] (Figure 5).
Electromyography (EMG)

Cranial nerve (CN) EMGs are performed by placing paired subdermal needle electrodes in the muscles supplied by these cranial nerves. These include masseter (CN V), lateral rectus (CN VI), orbicularis oculi (CN VII), orbicularis oris (CN VII), soft palate (CN IX), false vocal cords (CN X), trapezius (CN XI), and tongue (CN XII) muscles. Stimulation parameters include 0.05 - 1.0 mA for direct CN and up to 2.0 mA for indirect CN. The filter settings for the EMG are the same as TCeMEP. Alarm criteria is an abnormal EMG activity of the cranial nerves [15,16]. Spontaneous (s-EMG) and triggered (t-EMG) are both utilized to monitor cranial nerves. A monopolar handheld probe with a 100 µs pulse is used for t-EMG between 0.05 - 1.0 mA intensity to identify and track the cranial nerves during the tumor resection. Direct cranial nerve stimulation should be performed proximal to the tumor before and after resection to confirm the integrity of the cranial nerves.

Discussion

There is a difference between mapping and monitoring: mapping involves intermittent identification of specific neural structures to avoid injury. In contrast, monitoring is the continuous acquisition of neural signals to determine the integrity of the full longitudinal path of the neural system of interest. Active monitoring is a continuous or frequent direct nerve stimulation during periods of tumor dissection when the nerve is at risk. Passive monitoring is referred to as monitoring, where one reacts only to mechanically evoked responses [16].

When monitoring and mapping, it is crucial to interpret the feedback given accurately. Various stimuli or changes may prompt an incorrect response. True-positive is a loss of IONM responses due to surgical events or patient positioning on the operating table that do not return to baseline despite surgical correction or patient repositioning. The patient will wake up with a possible postoperative neurological deficit. Transient true-positive is a loss of IONM responses due to surgical events or patient positioning on the operating table that return to baseline after surgical correction or patient repositioning. The patient will wake up with no postoperative neurological deficit. Transient false-positive is a loss of IONM responses, which is not due to surgical events or patient positioning that return to baseline after appropriate correction. The changes in responses are possibly due to the anesthetic, metabolic, technical, or unknown reasons. The patient will wake up with no postoperative neurological deficit. False-positive is a loss of IONM responses during a surgical procedure when the patient does not wake up with any postoperative neurological deficit. False-negative is where there are no changes in IONM responses during a surgical procedure, but the patient wakes up with a new postoperative neurological deficit [17].

SSEP is the most commonly used modality in regards to assessing somatosensory pathways during various surgical procedures. Specifically, brain stem procedures such as fourth ventricle tumor resection, posterior cerebral artery aneurysm coiling, AVM resection, posterior fossa tumor resection, etc. [16]. Upper and lower SSEPs will provide additional information about the somatosensory cerebral

cortex and the blood flow to the brain stem regarding the brain stem and intracranial surgeries. It is crucial to avoid damage to those areas. Some advantages of using SSEPs include continuous monitoring without interrupting the surgery, provides continuous feedback to the surgeon and decreases the risk of mechanical and/or ischemic changes to the brain stem. Disadvantages of using SSEPs include limitation in assessing functional integrity because this modality only monitors sensory pathways, and it cannot detect changes in descending motor pathways [16].

BAEPs are routinely used for brain stem lesions, schwannomas, and acoustic neuromas. It is especially helpful in monitoring brain stem integrity during tumor resection, i.e. skull base meningioma. TCeMEPs are used to assess and interpret the corticobulbar and descending motor pathways by eliciting transcranial electrical stimulation. The advantages of TCeMEP include detecting ischemic changes in the spinal cord and peripheral motor nerves intraoperatively, as well as assessing the function of motor/corticospinal tracts. The disadvantages of TCeMEPs include not allowing for continuous monitoring, prohibiting neuromuscular blocking agents, and high sensitivity to inhalational agents. The uncommon complication reported during TCeMEP is tongue lacerations due to the forced contraction of facial muscles [13].

The advantages of EMGs include providing real-time information about nerve root function during the surgery, sensitivity for nerve root injury, and, if combined with SSEPs and TCeMEP, improves specificity. Disadvantages of EMGs may include the prohibition of neuromuscular blocking agents because muscle relaxants may interfere with/suppress muscle activity. If there is preoperatively nerve root damage, it will not allow providing real-time feedback [16].

Although intraoperative mapping and monitoring are aimed to minimize potential Intra and postoperative deficits, there is still a small margin for error or damage to occur. Surgical damage to the facial nerve, CN VII, most often occurs during the removal of vestibular schwannomas. Monitoring of CN VII is crucial during these surgeries because damage can result in difficulty eating, lack of tear production leading to corneal damage, and negative impacts on mental health due to the cosmetic effects of losing CN VII function. Electrocoagulation may cause heat damage to CN VII. The lowest current of coagulation should be used in short periods with cooling periods in-between. If damage occurs, the surgeon must decide between grafting CN VII during the tumor removal surgery or waiting until after the surgery to function will improve. Facial nerve neuromas are rare, and CN VII function is challenging to preserve.

In some cases, the surgeon may choose to do a nerve graft during the tumor resection. The location of a neuroma that lies in the path of nerve conduction can be determined intraoperatively by recording EMGs while stimulating a branch of the nerve electrically at different sites along its path [8]. Irritative EMG activity is supposed to occur during nerve manipulation. Neurotonic discharges and high-frequency trains are indicative of a potential nerve injury. There are strong correlations between EMG patterns and postoperative outcomes [15].

Conclusion

IONM has proven to help the early detection of potential injury and plays a significant role in guiding the surgeon and preventing any postoperative neurological deficits. In this review, we primarily focused on brainstem tumors and explained the IONM role and its...
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different modalities. Thus, it is essential to identify high-risk patients to implement multimodality IONM to minimize any neurological damage during procedures. Research shows experience matters as well. An experienced monitoring team has fewer than one-half as many neurologic deficits per 100 cases than less experienced teams. Although each modality has its advantages and disadvantages, using a multimodality approach has a better outcome.

Bibliography

