ORIGINAL ARTICLE

Benefits of Intraoperative Neurophysiological Monitoring (IONM) for the Localization, Mapping, and Resection of Tumors in the Fourth Ventricle: A Literature Review

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Cesia M. Alvarez [1,2]
Rida Farhan [1]
Faisal R. Jahangiri [1,2,3]

[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

Although uncommon, fourth ventricular tumors are considered a highly complicated and risky diagnosis. The fourth ventricle, which is part of the ventricular system of the brain, is one of the primary providers of cerebrospinal fluid (CSF), which, apart from supplying nutrients to the nervous system, also acts as a cushion-like substance, thus providing crucial neuroprotective properties to the nervous system. In addition to its saliency, the location of the fourth ventricle presents several challenges for medical professionals and surgeons when treating tumors in that region since crucial cortical areas and cranial nerve nuclei neighbor the limits of this ventricular cavity. Intraoperative Neurophysiological Monitoring (IONM) modalities such as Motor Evoked Potentials (MEPs), Somatosensory Evoked Potentials (SSEP), Brainstem Auditory Evoked Potentials (BAEP), and Electromyography (EMG), etc., play a fundamental role in providing the immediate tools and feedback in which the surgical team can rely on and use as a compass to prevent neural damage and significantly reduce the possibility of postoperative deficits.

The goal of this literature review is to investigate the different types of IONM modalities that have been recorded in the available literature to play a substantial role in surgical procedures involving fourth ventricular tumors and emphasize the importance and the protective critical role that using a multimodality IONM protocol could play in this type of surgeries. Furthermore, it discusses the possible causes, symptoms, statistics, and different types of fourth ventricular tumors, as well as the neuroanatomy delineating this crucial ventricular region.

INTRODUCTION

Overview

Brain tumors have often been classified as one of the most delicate, complex, and difficult cases. Like any other type of tumor, brain tumors are classified as either benign or malignant. Benign brain tumors are not cancerous or, in other words, a tumor that does not spread to other areas of the nervous system and is usually harmless. In contrast, a malignant tumor is a cancerous growth that usually invades other areas and presents with a fast-abnormal growth rate (medlineplus). According to the statistics provided by The National Cancer Institute, more than 25,000 malignant brain tumor cases were estimated to have been diagnosed (with more than 18,000 deaths being estimated) in 2022, with an estimated 5-year survival rate of around 32.5%, which is very low. Furthermore, according to the grading system created by the World Health Organization (WHO), which classifies the different types of tumors by their benign or malignant levels through the analysis of histological characteristics, some of the most malignant types of tumors are classified as WHO grade IV are: Pineoblastoma, Ependymoblastoma, and Medulloblastoma, the latter being a common type of fourth ventricular tumor (AANS).

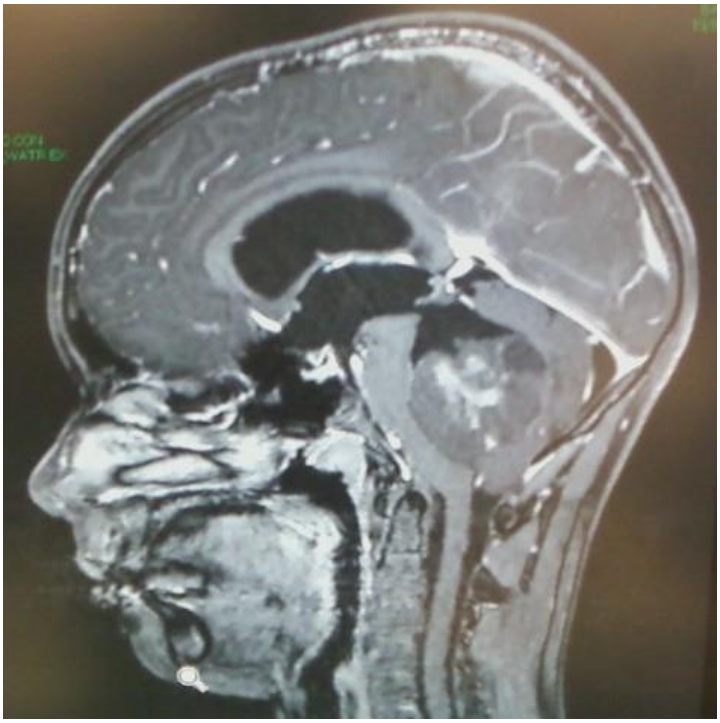

Figure 1: A sizeable fourth ventricle tumor seen on magnetic resonance imaging (MRI) pressing the brainstem in a pediatric patient.

Fourth ventricular tumors (Figure 1), the focus of this literature review, are some of the rarest types of brain tumors, representing only 1-5% of all intracranial anomalies and ⅔ tumors affecting any area of the ventricular system [1]. Symptoms such as headaches, nausea, visual, memory, speech, sensory, and gait impairments/anomalies, dizziness, seizures, etc., are common signs of a brain tumor in the fourth ventricle [2]. Although there are different treatments and surgical approaches to treat and remove fourth ventricular tumors, it is crucial to understand the grade of difficulty and danger these procedures represent to the patient. Surgical approaches such as the telovelar, transvermian, and median occipital approaches, which will be discussed later in further detail, are common surgical treatments utilized to localize and resect fourth ventricular tumors [3]. Due to the risks and the difficulty of surgical treatments regarding these types of tumors, intraoperative neuromonitoring (IONM) has become an essential part of surgical protocols involving the fourth ventricle [4]. Moreover, due to the complicated location of the fourth ventricle and its proximity to vital brain regions and cranial nerve nuclei such as the ones for the vagus and hypoglossal cranial nerves, several deficits could be presented postoperatively affecting a wide range of multi-sensorial and motor abilities such as auditory and cranial nerve paralysis [4]. Modalities such as somatosensory

evoked potentials (SSEPs), motor evoked potentials (MEPs), brainstem auditory evoked potentials (BAEPs), electromyography (EMG), and train of four (TOF) have become crucial tools when it comes to providing a safer pathway for the localization and removal of fourth ventricular tumors [4-5]. Furthermore, a multimodality approach (using various IONM modalities simultaneously) is recommended since it provides a more wholesome panorama of the medical case [6].

The different types of tumors that develop in this area of the ventricular system and their respective physiological characteristics will be discussed in further detail in later sections of this paper, as well as treatments such as common surgical procedures used to treat this type of malignant anomalies. Before going deeper into fourth ventricular tumors, it is imperative to understand and discuss the anatomy of the fourth ventricle to have a better understanding of why tumors located in this area represent a significant threat to the patient as well as the difficulties that surgeons and medical professionals encounter at the time of treatments and/or removal of this abnormal and malignant tissue.

Anatomy of the fourth ventricle

The fourth ventricle is one of the four intracranial areas where cerebrospinal fluid (CSF), the substance in which the central nervous system is suspended, is constantly being produced by a tissue rich in a lining of choroid plexus where ependymal cells are the sole manufacturers of it (Singh, 2010). This rhomboidal yet triangular-shaped brain cavity, located within the posterior fossa region of the brain, is tightly located at the far end of the cerebrospinal junction, where it is surrounded by several vital brain structures such as the cerebellum and parts of the brainstem as well as the spinal canal and the initial segment of the spinal cord [7-8].

It is through the aqueduct of Sylvius that the fourth ventricle connects with the rest of the ventricular system, more specifically, with the third ventricle. Moreover, the main irrigation system of the fourth ventricle is through the foramina of Luschka and the foramen of Magendie, where cerebrospinal fluid is constantly being drained throughout the ventricle's surrounding structures and, most importantly, into the central canal, which encases the spinal cord [3,7].

The biological function the fourth ventricle exerts and represents is essential for the normal functioning of various brain areas and the spinal cord [7]. It is through this ventricular cavity that the constant flux of this substantial cerebrospinal fluid can reach the deepest and most difficult structural levels of the human nervous system [7]. As the cerebrospinal fluid passes through the five recesses of the fourth ventricle, which are elongations of the ventricle, it is rerouted into different directions, which lead to different ventricular openings such as the foramen of Magendie (central roof aperture), foramina of Luschka (two apertures in the lateral side of the roof), the cerebral aqueduct, etc. [7]. From the brainstem where it bathes the brainstem and where several structures such as the medulla and the cerebellum, which are exceptionally vital for the maintenance of life, are located to the filling of one of the meningeal brain coverings, the subarachnoid space, which does not only cushion the entire brain but also serves as a shock absorbent [7]. Thus, through its location and function, the fourth ventricle plays a fundamental role in the flux and rerouting of the CSF (Singh, 2010).

In addition to the previously mentioned ventricular recesses/extensions, the fourth ventricle has a highly characteristically neurophysiology. Angles, boundaries, an upper and a lower roof, and a structurally rich floor where well-known neurological landmarks such as the median sulcus, medial eminence, superior fovea, sulcus limitans, as well as the hypoglossal and vagal triangles – all of these serve as boundaries and margins to delineate and shaped the cavity and ventricular frontiers of the fourth ventricle as a whole system [7]. Furthermore, since the fourth ventricle is in a very strategic area, these structures not only play fundamental structural roles but are also neighboring several brain structures and cranial nerves (hypoglossal and vagus cranial nerves), which increases even further its neurophysiological saliency [7-8] (Figure 2-3).

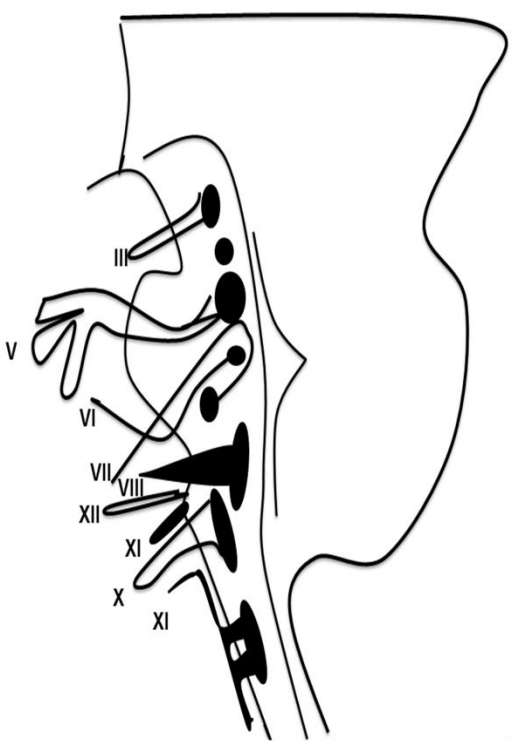

Figure 2: Illustration of the anatomy of the cranial nerve nuclei in the fourth ventricle at the brainstem [9].

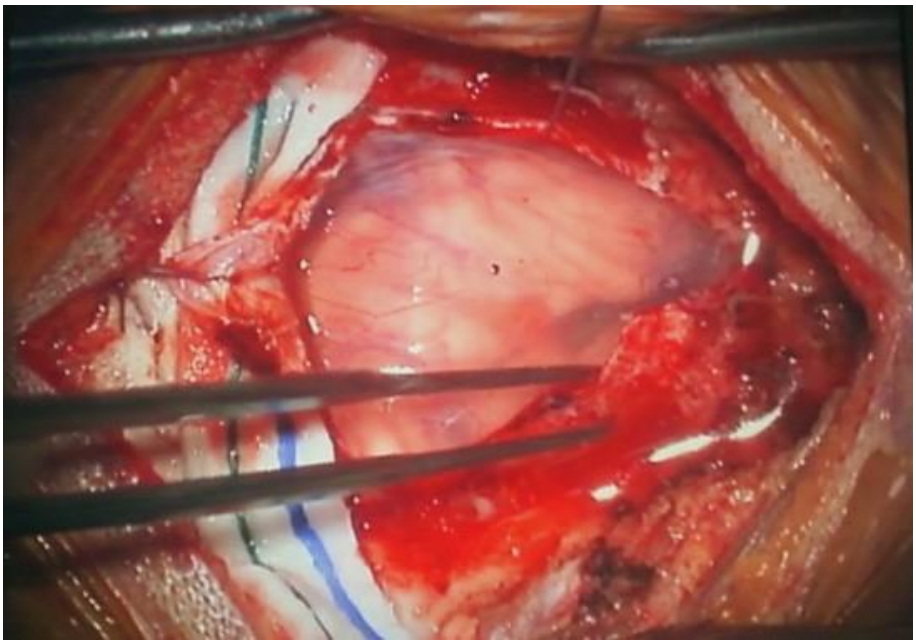

Figure 3: Floor of the fourth ventricle exposed during the brainstem surgery.

Tumors commonly develop in the fourth ventricle.

Although the fourth ventricle is somewhat remote, it is subject to different neuropathologies that could lead to highly unstable or even deathly states. Tumors, although rare, have become a significant diagnosis that represents a diagnostic and surgical challenge for medical professionals. This is primarily due to its intricate location in the posterior fossa, which borders several crucial brain regions and structures, as previously

mentioned. Thus, reaching the posterior fossa-fourth ventricle area requires a highly precise line of work and awareness of the surroundings and the implications of any surgical procedure on the patient's life. Moreover, pediatric populations have presented higher indexes of tumors in the fourth ventricle compared to adult populations [10-11].

Different types of tumors emerged in the posterior fossa-fourth ventricle area, which also affects the areas of the cerebellum and brainstem [10]. Some fourth ventricular tumors include Ependymomas, medulloblastomas, choroid plexus papillomas, meningiomas, and subependymomas [11] (Figure 4).

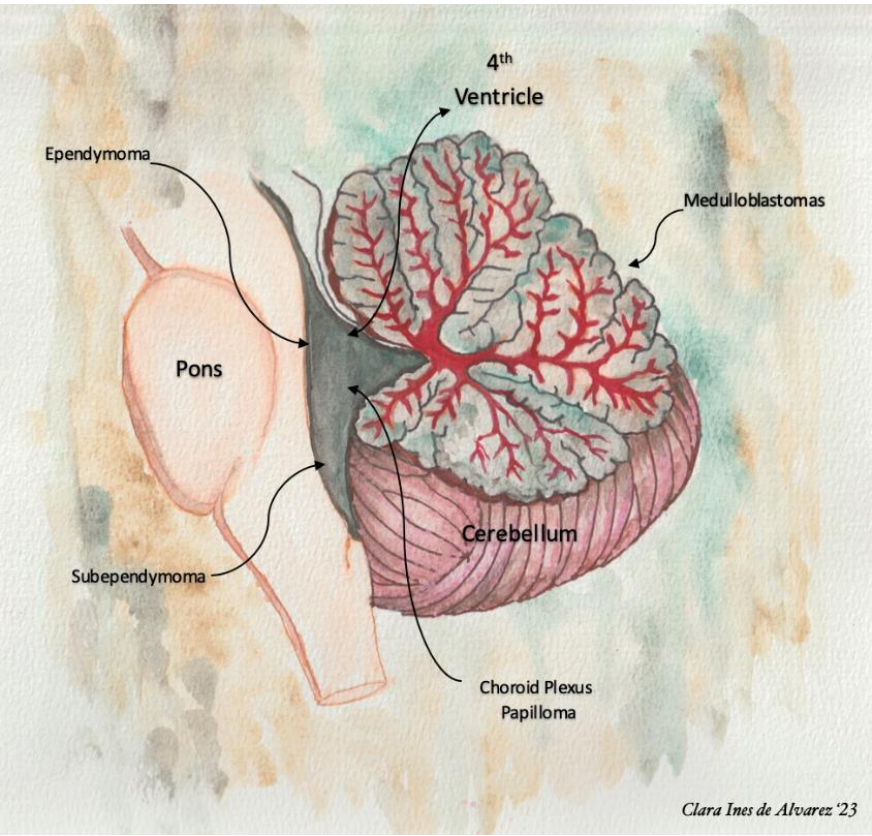

Figure 4: Common tumors found in the fourth ventricle of the brain (illustration by Clara Ines de Alvarez).

Ependymoma, the most common type of tumor found in the fourth ventricle, is usually identified through MRI [11]. As this imaging technique delineates the very common tender and convoluted shape of the Ependymoma, it is common for this type of tumor to arise from the floor region of the fourth ventricle [10]. Additionally, ependymomas can squeeze their way through the foramen of Luschka and the foramen of Magendie, reaching subarachnoid spaces and even some areas of the spinal cord [9-10]. Due to their morphology and location, ependymomas can result in symptoms such as headaches and nerve palsies affecting several cranial nerves (specifically, the sixth, seventh, and eighth cranial nerves). Also, depending on the affected areas, ependymomas can cause damage directly to the spinal cord, resulting in neck issues [10-11].

Medulloblastomas are usually found in the cerebellum areas and the vermis-roof of the fourth ventricle. These tumors follow different morphological patterns and develop into different variations that all become malignant, resulting in necrosis of the affected tissues, calcifications, hemorrhages, etc. [10-11]. Some of the symptoms caused by this type of ventricular tumor are headaches, vomiting, lethargy, ataxia, and motor difficulties, which could even result in coma [10].

Choroid Plexus Papilloma is a less common type of fourth ventricular tumor commonly found in adults than in younger populations [10-11]. Although it usually develops in the roof area of the ventricle, it can spread throughout the entirety of the ventricle. It highly depends on the individual's age [10, 12]. As its name implies, this type of tumor develops from the choroidal plexus coverings within the fourth ventricle itself, producing abnormal layers of tissue [10]. As previously mentioned, the choroid plexus is the tissue in charge of the production of CFS; thus, as this type of papilloma directly affects the ependymal cells within the choroid plexus, it ends up affecting the normal flow of CFS [11]. Furthermore, in some cases, it can develop into significant masses that could end up interfering with the flow of the cerebrospinal fluid within the ventricular cavity, which could end up causing hydrocephalus [10-11].

Sub-ependymomas are another highly uncommon intraventricular tumor primarily found in older populations [11]. These tumors, which develop into clusters of cells, are usually benign and often do not cause symptoms [9=19]. Nevertheless, if the tumor becomes significant in size, it can affect the normal flow of CSF, thus causing hydrocephalus [10].

Common surgical approaches to treat fourth ventricular tumors.

To understand the benefits and efficacy that modalities of intraoperative neurophysiological monitoring offer to different surgical procedures involving the fourth ventricle, it is imperative to research and get familiarized with the most common and current surgical approaches utilized in the operating room at the time of mapping, identifying, and resecting a fourth ventricular tumor which is the telovelar, transvermian, and median suboccipital surgical approaches. These procedures mainly differ in the region where the initial incision/surgical process is carried out.

Telovelar approach

This surgical procedure provides access to the fourth ventricle through an initial opening involving the inferior medullary vellum and telachoroidea [3]. Both areas are fundamental components of the roof of the fourth ventricle. When both areas are opened, the cerebellar tonsils are exposed, which are later pulled back to provide a clear pathway toward the fourth ventricular area [3].

Transvermian approach

As its name implies, the Transvermian approach is performed in the vermis, a region that belongs to the cerebellum [3]. As the initial opening is being made in the inferior vermis, which facilitates the separation of both halves of the vermis, it allows a direct pathway to the floor of the fourth ventricle [3].

Median suboccipital approach

According to the literature, the median suboccipital approach is also a common and recommended surgery for resection tumors in the fourth ventricle since it provides a more straightforward route to reach malignant tissue [5]. This surgical procedure is done by parting and exposing the posterior fossa halves, which end up exposing the cerebellum, vermis, etc., thus providing a more precise cranial panorama and an easier way to reach and navigate the tissue of interest [1]. Although it is considered one of the safest surgical ways to treat these types of tumors, it could also present serious side effects, such as leakage of cerebrospinal fluid (CSF) [1].

Patient selection criteria

According to the literature, patient criteria regarding fourth ventricular tumors involve a wide variety of factors such as the type and characteristics of the tumor in question, the type of symptoms and how many are being experienced by the patient, age, and personal preference of each surgeon - the latter regarding the Telovelar and the Transvermian approach [2]. For instance, in one study, the Telovelar approach was mainly used for adult patients undergoing surgeries compared to patients 18 years of age or less [2].

Which surgical approach is better?

Based on the literature, the three surgical approaches provide different alternatives and outcomes, depending on each patient's situation/case/diagnosis. For instance, the Transvermian approach is not recommended in minors suffering from cerebellar mutism syndrome since it can lead to issues during or after the surgery [3]. One of the significant benefits of the Telovelar approach against the Transvermian approach is that it does not include touching the vermis, which could end up causing life-threatening situations [3]. Moreover, the suboccipital approach known for providing a surgical safeway for removing fourth ventricular tumors is widely used and preferred. Still, it could also represent patient risks since major cortical areas are widely exposed to several significant iatrogenic and environmental risks [1]. Therefore, as mentioned above, a surgical preference must be based on the specifications and individuality of each patient's situation.

Methods

A narrative review was conducted using PubMed or Medline, ScienceDirect, and Google Scholar databases. The keywords used were fourth ventricle tumors, posterior fossa tumors, intraoperative neuromonitoring, motor evoked potentials, brainstem mapping, somatosensory evoked potentials, transcranial motor evoked potential, brainstem auditory evoked potentials, electroencephalography, and electromyography. Forty-two articles were reviewed, of which 19 articles were selected. Case reports, case series, and original articles discussed the effects of IONM during procedures involving fourth ventricle tumors. No language, time, or geographical restriction was employed. Review articles and articles with no findings from using IONM modalities were excluded. Articles involving brain tumors located elsewhere than the fourth ventricle were also excluded.

Anesthesia

Total intravenous anesthesia (TIVA) with propofol and remifentanil is preferred as inhalational agents decrease the sensitivity of IONM modalities. Short-acting neuromuscular blockade is used for intubation and monitored by Train of Four (TOF), which is done by stimulating the posterior tibial nerve and maintaining 4/4 twitches bilaterally in abductor hallucis muscles [13-14].

Intraoperative Neurophysiological Monitoring (IONM)

Motor Evoked Potentials (MEP)

Motor evoked potential (MEP) is a neuromonitoring modality to evaluate the functional integrity of the descending motor tracts in the brainstem, including lower cranial nerves [15-16]. For transcranial motor evoked potentials (TCeMEP), a double pair of corkscrew stimulation electrodes is placed on the scalp at C1, C2, C3, and C4. Stimulation is done at an intensity of 150-600 Volts, a band-pass frequency of 10-5000 Hz, and a pulse width of 50-75 microseconds [14]. A reduction in amplitude by greater than 70-80% is considered significant [13]. MEPs help reduce injuries to cranial nerves during the resection of fourth ventricle tumors and are especially useful in cases where lesions are near motor tracts [17-18].

Corticobulbar Motor Evoked Potentials (CoMEP)

Corticobulbar motor evoked potential (CoMEP) is used to monitor the corticobulbar pathways, including motor cranial nerves and their respective nuclei. For CoMEPs, stimulation is set up at the scalp according to an international 10-20 electrode placement system using corkscrew electrodes. To prevent peripheral activation, double-train stimulation is recommended, with the first train of 3-5 pulses followed by a single pulse. The inter-train interval (ITI) of 90 ms [19]. For constant voltage stimulations, a pulse duration of 50 or 75 μs, an inter-stimulus interval (ISI) of 2.0 ms, and a 120 ms sweep, stimulation intensity between 80-350 Volts [19-20]. While for constant current stimulation, pulse width of 500 μs, and stimulation intensity between 20-150 mA. For recording, subdermal needle electrodes are placed for CN VII in orbicularis oculi, orbicularis oris, and mentalis, CN IX in soft palate, CN X on false vocal cords with endotracheal tube, CN XI in the trapezius and the tongue to assess CN XII [15]. The alert criteria established are an increase in stimulation intensity of more than 20 mA and an amplitude decrease of more than 50% [21]. According to the literature, transcranial electrical stimulation (TES) is administered over the M1 motor strip to elicit motor signals to specific innervated muscles, resulting in CoMEP recordings [19].

Somatosensory Evoked Potential (SSEP)

Somatosensory evoked potential (SSEP) is a neuromonitoring modality used to evaluate the functional integrity of sensory pathways from the peripheral nerve to the sensory cortex. Since it does not provide information on the motor system, it is often combined with MEP [15]. Bilateral posterior tibial and median nerves are used as stimulation points, and a decrease in amplitude of greater than 50% in consecutive readings or an increase in latency by 10% can be considered a warning sign [4,13,20]. For the median nerve, stimulation is set up at the wrists with an intensity of 15-35 mA, time duration of 0.3 ms, and repetition rate of 3.7 Hz. For the posterior tibial nerve, stimulation is set up at the ankles with an intensity of 40-100 mA, time duration of 0.3 seconds, and repetition rate of 3.7 Hz. SSEP is used during tumor resection to identify cerebral ischemia and the central sulcus. The corresponding extremity is monitored depending on the tumor's location [13].

Brainstem auditory evoked potential (BAEP)

Brainstem auditory evoked potential (BAEP) is used for monitoring signals during surgeries involving the brainstem, posterior fossa, and cerebellopontine angle [14]. Five waves are recorded with waves I and II corresponding to the distal and proximal auditory nerve, wave III to cochlear nucleus/superior olivary complex, wave IV to contralateral lateral lemniscus, and wave V to contralateral inferior colliculus [20]. The alarm criteria are used as loss of wave III and/or wave V or greater than 1.0 ms delay interpeak latency of I-III, III-V, and absolute latency of wave V [4,13]. Previous literature has found irreversible loss of all waves to result in hearing loss, while waves that return to normal at or before the end of surgery result in preserved hearing [9,21]. Acoustic stimulation is provided bilaterally with an intensity of 90 dB, frequency of 11.3 Hz, band pass filter between 100 - 2000 Hz, and an analysis time of 15 ms [13].

Electroencephalogram (EEG)

Subdermal needle electrodes are placed on the scalp according to the international 10-20 system for recording electroencephalogram (EEG). An eight-channel scalp EEG is used to monitor cerebral blood flow for any ischemic changes and the depth of anesthesia during the procedure. EEG recordings are performed with a 0.5-70 Hz bandpass filter with a 50-100 uV/division sensitivity and a 1000 ms/division recording sweep [14]. EEG monitoring is also beneficial in lesions of the fourth ventricle presenting as seizures (Figure 5).

Electromyography (EMG)

Electromyography (EMG) is of two types: spontaneous or free-running or spontaneous EMG (s-EMG) to monitor muscles innervated by cranial nerves and triggered EMG (t-EMG) to map cranial nerve motor nuclei in the brainstem [16]. Subdermal needle or hook-wire electrodes are placed for recording s-EMG and t-EMG bilaterally to monitor the electrical activity of muscles innervated by the cranial nerves: masseter for CN V (Trigeminal), orbicularis oculi, orbicularis oris and mentalis for CN VII (Facial), soft palate for CN

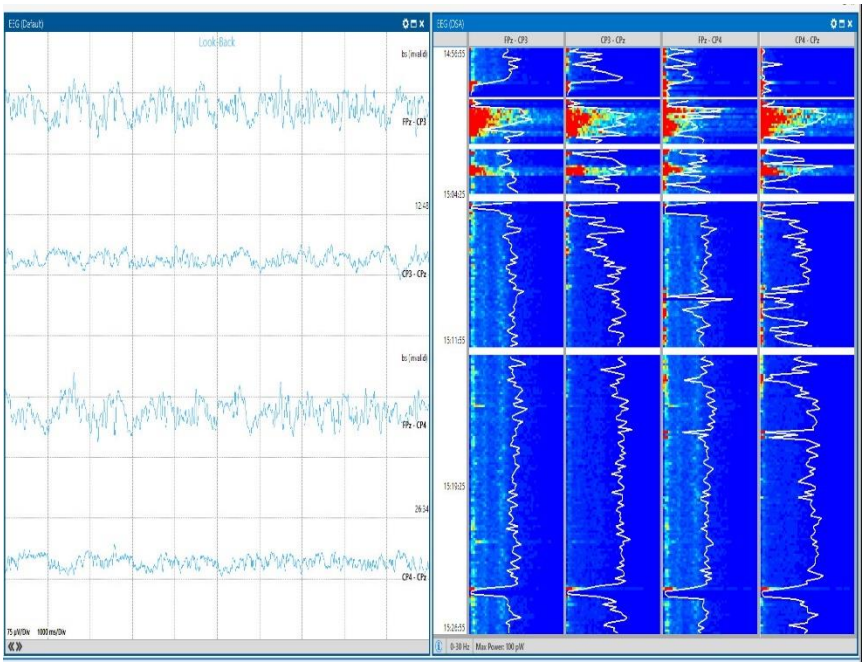

Figure 5: Scalp electroencephalography (EEG) recording.

Left: Raw EEG waves. Right: Quantitative EEG in Color Density Spectral Array (CDSA).

IX (Glossopharyngeal), false vocal cords for CN X (Vagus), trapezius for CN XI (Spinal accessory), tongue muscles for CN XII (Hypoglossal). The endotracheal (ET) tubes are used for CN X, especially when the ET tube is in contact with the false vocal cords [Figure 6]. During surgery, real-time feedback is given to the operating surgeon if the cranial nerves are either directly stimulated or undergo irritation, stretching, mechanical compression, or thermal injury, thus allowing modifications to the surgical procedure [12]. Signs concerning pathology include burst patterns of non-repetitive potentials or train activity of repetitive motor unit discharges [22]. Determination for which cranial nerves are to be monitored is based on the tumor's location and associated adverse outcomes in case of nerve injury [13].

T-EMG is used to map the floor of the fourth ventricle with the help of a monopolar hand-held fine tip probe with a starting stimulation intensity of 0.05 mA while moving 1 mm and maintaining for less than 5 seconds [13]. The stimulation intensity is decreased to identify the threshold intensity for the precise location of a CN motor nucleus. For example, the trigeminal nerve peaks have a latency of less than 5 msec, and the facial nerve peaks have a latency greater than 7 msec [4,13]. Stimulation should be 0.1 to 0.2 mA to elicit a full response, as higher currents can be determined inaccurately [17]. With t-EMG, surgeons can decide the extent of resection to avoid postoperative injuries [4].

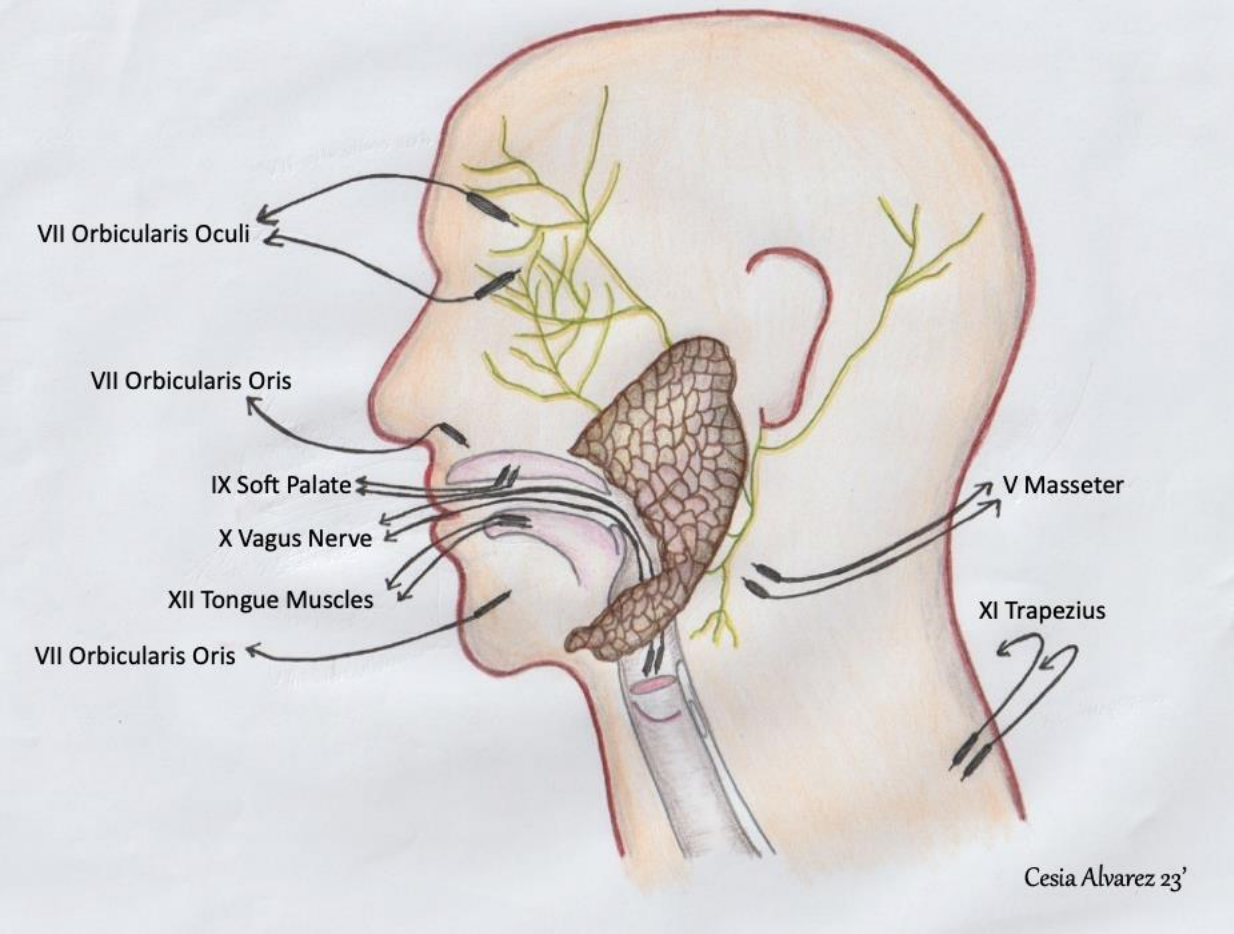

Figure 6: A drawing showcasing intraoperative neuromonitoring setup of the cranial nerves during brain surgeries. Electrodes are placed for recording from masseter (trigeminal nerve/ CN V), orbicularis oris and orbicularis oris (facial nerve/ CN VII), soft palate (glossopharyngeal nerve/ CN IX (illustration by Cesia M. Alvarez).

Brainstem mapping (BSM)

Brainstem mapping (BSM) is a technique to identify motor nuclei of cranial nerves on the floor of the fourth ventricle [23]. The cranial nerves (CN) located are CN VII using orbicularis oculi, orbicularis oris, mentalis, CN IX – X using the posterior pharyngeal wall, and CN XII using intrinsic tongue muscles [15,23]. Cricothyroid or vocalis muscle can also be used for CN X [9,24]. The nerve fibers or motor nuclei are stimulated using monopolar electrodes with an intensity of 1.0 mA, a pulse duration of 0.05 ms, and a stimulus frequency of 1.9-3.7 Hz [20]. This results in a compound muscle action potential (CMAP) in muscles innervated by CNs, helping to localize the motor nuclei [15,20,24]. A constant current of less than 2.0 mA is safe, and no adverse effects have been reported [20]. The tumor often distorts the normal anatomy; therefore, BSM allows functional preservation by identifying safe entry zones into the brainstem and facilitating resection.

Benefits of Intraoperative Neurophysiological Monitoring (IONM) in fourth ventricle tumors

Motor evoked potential (MEP)

According to Kodama et al. (2014), alteration of SSEPs and MEPs has been shown to occur significantly more in fourth ventricle tumors than in other locations ($p<0.001$). Out of 34 patients with fourth ventricle tumors, 19 developed MEP and/or SSEP alterations, of which 10 developed hemiparesis postoperatively. A high negative predictive value of 0.989, high sensitivity of 0.875, and high specificity of 0.918 were found. While a high rate of false positives was seen, it is safe and recommended [25]. Another study by Glasker et al. (2006) found the number of true positive events to be 17 times compared to false positive events eight times. In 57% of the patients, using IONM led to changing the surgery site, retraction, or irrigation [17]. Rauschenbach et al. (2021) showed that the association between intraoperative events and postoperative deficits was significant ($p<0.05$). In a study of 62 patients with brainstem cavernous malformations, MEP decreased in early functional disability ($p=0.047$) and new motor deficits ($p=0.022$) [26].

One study used parameters such as final to baseline MEP amplitude ratio and found patients with vagus glossopharyngeal amplitude ratio ≤ 1.47 μV to have a 3.4 times higher risk of uvula deviation ($p=0.028$). Final MEP width was also used to observe correlations, and it was found that patients with vagus glossopharyngeal final MEP width ≤ 11.6 ms had a 3.6 times greater risk of gag reflex becoming extinct ($p=0.027$) [27].

Somatosensory evoked potential (SSEP)

A decrease in SSEP amplitude intraoperatively was found to be significantly associated with early functional disability ($p=0.017$) as well as new sensory deficits on discharge and follow-up ($p<0.001$), with a sensitivity of 82% and a specificity of 80% on discharge [26]. Significant changes in SSEPs also led to persistent hemiataxia [20]. While transient CN activation did not significantly correlate with new postoperative deficits ($p=0.99$), sustained CN changes should limit resection [28].

Brainstem auditory evoked potential (BAEP)

In a case report on cavernous hemangioma, the loss of waves IV and V for 20 minutes postoperatively led to ipsilateral trigeminal nerve dysfunction. There was also a complete loss of waves on the other side for 1.5 hours, which led to severe facial nerve paralysis on the same side, likely because facial and auditory nerves are in proximity to the pons. These changes were thought to be due to diathermy use after excluding other causes; hence, cooling with irrigation is recommended when BAEP changes are recorded [29].

Electroencephalogram (EEG)

Intracranial EEG has shown utility in resecting fourth ventricular lesions presenting with seizures. A case report on hemifacial spasms used EEG monitoring to guide resection. The tumor boundary was not obvious macroscopically, and intraoperative monitoring confirmed the disappearance of seizures during the procedure, limiting resection and preventing postoperative deficits [30].

Electromyography (EMG)

S-EMG can help avoid cranial nerve injuries and limit the extent of resection. In posterior fossa tumors, CN V, VII-XII are usually selected to be monitored [13]. Five patients showed intraoperative EMG changes in a study with nine new cranial neuropathies in CN VI and CN VII. While CN VI dysfunction was not associated with lateral rectus activity, facial paresis was associated significantly with both CN VI ($p<0.001$) and CN VII ($p<0.010$) changes. This may be because of the facial nerve wrapping around the abducens nucleus in the pons. Additionally, there was a low incidence (38.5%) of facial nerve paralysis compared to EMG activity, likely due to surgeons modifying operative techniques upon recording significant EMG changes [30].

Monitoring modality	Stimulation parameters	Alarm criteria	Main findings from the literature
MEP	Corticobulbar MEPs: ▪ Pulse duration of 50 or 75 µs ▪ ISI of 1.7-2.0 ms. ▪ Pulses 3-5 + 1 ▪ Sweep 120 ms. ▪ Stimulation intensity 80-350 Volts Transcranial MEPs: ▪ Pulse duration of 50 or 75 µs ▪ ISI of 1.7-3.5 ms ▪ Pulses 3-7 ▪ Sweep 100 ms. ▪ Stimulation intensity of 150-600 Volts.	▪ A reduction in amplitude by 50% ▪ A reduction in amplitude by 70-80% ▪ Change in morphology. ▪ Increase in 100 V or more threshold	▪ Alterations are more common in fourth ventricle tumors. ▪ Significant associations of intraoperative events with postoperative deficits.
SSEP	▪ Pulse duration 300 µs ▪ Repetition rate 2.39-4.79 Hz ▪ Intensity: o Upper 20-40 mA, o Lower 40-100 mA	▪ A reduction in amplitude by greater than 50% or an increase in latency by 10%	▪ A decrease in amplitude was significantly associated with early functional disability and new sensory deficits. ▪ Sustained CN changes should limit resection.
BAEP	▪ Pulse duration 100 µs ▪ Repetition Rate 11.3-21.1 Hz ▪ Bandpass filter between 100 - 2000 Hz ▪ Sweep 15 ms ▪ Intensity of 90 dB	▪ Loss of wave III and/or wave V ▪ Greater than 1.0 ms delay in wave V. ▪ Greater than 1.0 ms delay in wave I-III or III-V interpeak latency.	▪ Ipsilateral trigeminal and facial nerve dysfunction was seen with loss of waves. ▪ Cooling with irrigation is recommended as the most likely cause is diathermy use.
EEG	▪ Bandpass filter 0.5-70 Hz ▪ Sensitivity 50-100 uV/division ▪ Recording sweep of 1000 ms/division.	▪ Presence of ictal activity	▪ No postoperative deficits were seen when used in lesions presenting seizures. ▪ Used as a guide to limit hazardous resection.
EMG	▪ Starting stimulation intensity of 1.0 mA while moving 1 mm, maintaining for less than 5 seconds, and decreasing stimulation intensity to identify threshold intensity	▪ Burst pattern of non-repetitive potentials or train activity of repetitive motor unit discharges	▪ Facial paresis was significantly associated with CN VI and CN VII changes. ▪ CN IX, X, and XI activity resulted in deficits in 73% of the patients. ▪ When the operative strategy changed, transient to no postoperative deficits were seen.
BSM	▪ Intensity of 0.1 mA, ▪ Pulse duration of 50 µs ▪ Frequency of 4 Hz	▪ Using a current greater than two mA	▪ Fast, safe, and reliable technique to enter the brainstem. ▪ Lesion at even a significant distance can distort the response area. ▪ Not undergoing BSM before incision can result in postoperative deficits.

Table 1: Summary of different monitoring modalities and their key findings. MEP: motor evoked potentials, SSEP: somatosensory evoked potentials, BAEP: brainstem auditory evoked potentials, EEG: electroencephalography, EMG: electromyography, BSM: brainstem mapping.

According to Gläsker et al. (2006), EMG of CN IX, X, and XI also showed good reliability, with intraoperative EMG activity in any of the nerves resulting in deficits in 73% of the patients. In contrast, activity in all three nerves was always associated with postoperative aspiration pneumonia or tracheotomy [17]. In such patients, delayed and careful extubation should take place. It was also seen that transient s-EMG activity led to temporary paralysis of the muscle, while permanent activity caused permanent deficits. Eisner et al. reported (1995) that in one surgery, a transient s-EMG discharge in lingual muscles followed by permanent discharges resulted in a permanent deficit of the lingual muscles. When surgeons changed operative strategy, t-EMG was seen to be of shorter duration and lower amplitude with transient to no postoperative deficits [32].

S-EMG can also be used to assess treatment effect, as seen in two case reports of hemifacial spasms caused by tumors of the fourth ventricle. In both cases, hyperexcitability was seen during resection, and the disappearance of spasm on EMG determined the limit of resection [30,33]. Symptoms were successfully resolved, and no deficit developed even at one year of follow-up [33].

Brainstem mapping (BSM)

BSM is recommended for surgeries that involve the rhomboid fossa [24,32,34]. One study showed that even a lesion at a significant distance from the facial colliculus could distort the response area [24]. In another study, CMAP was elicited from the lateral rectus and facial muscles upon stimulating the facial colliculus [32]. Stimulation of the rhomboid fossa is a fast, safe, and reliable technique to guide surgeons into the brainstem and spare vitally essential nuclei [34]. This can be seen in a case series of 16 patients, out of which one did not undergo BSM before incision and thus suffered motor deficit postoperatively [32].

Conclusion

Surgical procedures involving tumors in the fourth ventricle are challenging due to their location and proximity to vital structures. Intraoperative neuromonitoring is essential for preventing neural damage. MEPs, SSEPs, BAEPs, S-EMG, and BSM are all valuable modalities used to assess motor and sensory pathways and prevent injuries. Multimodality IONM protocols have been proven to provide a safer and more precise way to localize and reach tumors within this space. It is imperative to understand the importance of IONM in guiding, rectifying, and preventing neural damage to protect both the patient and the surgical team.

ORCID

Cecia Alvarez https://orcid.org/0009-0003-9575-0794

Rida Farhan https://orcid.org/0000-0002-8361-642X

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

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