ORIGINAL ARTICLE

Literature Review of Subcortical Mapping Techniques in Glioblastoma Surgeries

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ABSTRACT

Subcortical mapping of glioblastoma is an intraoperative technique used during tumor resection to identify the motor and language pathways in the central nervous system of the brain that are possibly affected by glioblastoma, an aggressive type of brain tumor that develops from glial cells with poor prognosis. This technique involves using electrical probes in varying brain tissues in an awake patient to stimulate different brain regions and critical areas responsible for language and movement. Combining intraoperative modalities like somatosensory evoked potential (SSEP), direct electrical stimulation (DES), electromyography (EMG), and electrocorticography (ECoG), Electroencephalography (EEG), Train of four (TOF) and Phase reversal, the surgical team can monitor neural activity. Penfield and Taniguchi have developed two methods to map the corticospinal tracts intraoperatively. One of these approaches may be used depending on the tumor's location, the patient's medical history, the surgery, and other considerations. Like other intraoperative monitoring techniques, the use of subcortical mapping during tumor resection in glioblastoma helps surgeons minimize the risk of postoperative deficits with the possibility of improving surgical outcomes for patients with this disease.

INTRODUCTION

Gliomas are brain tumors that usually affect the brain and develop in the glial cells, which are supporting cells. While most tumors are malignant, other varieties, like glioblastoma, do not always act malignantly [1]. According to Ostrom et al. (2014), glioma incidence rates differ considerably by histologic type, time of diagnosis, gender, race, and nation. Glioblastoma, a devastating disease, occurs approximately in 3 cases per 1000,000 people and tends to increase with age, with men affected more than women in a ratio of 1.6:1. Survival chances after 5 years of initial diagnosis with the disease are usually slim for glioblastoma. The rate of survival tends to increase with overall good health and younger age combined with aggressive treatments of tumor resection surgery, chemotherapy, or radiation therapy.

During tumor resections, surgeons encounter difficulties while operating anywhere close to the corticospinal tract (CST) with the intent to remove as much tumor tissue as feasible while preserving motor function. The best resection technique should preferably extend slightly beyond the margins of the tumor because the greatest risk of tumor recurrence occurs within 2 cm of these areas either during anesthetized or awake mapping [2]. Studies have shown that removing 1-2% of the deepest and last tumors in eloquent areas provides the most benefits and improves the chances of survival during tumor resection [3].

Subcortical Mapping is an intraoperative stimulating multimodality that helps identify the descending subcortical motor pathways in patients undergoing surgery for hemispheric gliomas within or adjacent to the Rolandic cortex. This paper describes this technique's morbidity and functional outcomes [4]. Subcortical mapping can also help identify the language and movement pathways in frontal and temporal lobe tumors and postoperatively preserve critical brain function. Mapping the subcortical structures helps to localize white matter tracts during various stages of tumor resection.

Growing evidence suggests that increasing the extent of tumor resection can improve survival rates in low-grade and high-grade glioma surgeries. To identify the corticospinal tract (CST) during surgery and reduce the risk of motor impairments—primarily when operating on infiltrative tumors—surgeons often use an intermittent subcortical mapping technique with a handheld probe for electrical stimulation. Various other techniques can also be employed, including subcortical stimulation (SCS), somatosensory evoked potentials (SSEP), direct cortical stimulation (DCS), electromyography (EMG), electroencephalography (EEG), electrocorticography (ECoG), and the Train of Four (TOF) method. Additionally, sensory mapping with phase reversal and focusing on motor thresholds during cortical mapping of the corticospinal tracts may help reduce postoperative deficits.

METHODS

Search Criteria: Inclusion & Exclusion and Patient selection

All the criteria for subcortical mapping and intraoperative multi-modality techniques were researched for this review using PubMed, Cuneatus, and other scholarly article sources. Entry into clinical investigations and eligibility for aggressive therapy is typically contingent upon a minimum score of 70 [7]. The selected patient data is based on patients with craniotomy of newly diagnosed glioblastoma, and the exclusion criteria were gliomatosis cerebri. Patients were monitored in the patient department after discharge with clinical exams and MRIs (or CCTs in a few cases when patients could not undergo MRIs due to technical issues) every three months. From the day of the craniotomy until the day of the patient's death, the survival time was calculated. Patients alive at last contact were excluded from the survival analysis [7].

Study Population

The population targeted for tumor resection is newly diagnosed glioblastoma WHO grade IV, either primary glioblastoma or secondary glioblastoma with previously diagnosed astrocytoma WHO grade II or III [7]. The patient's age is ≥21 years, including that of men and women. 1.26:1 was the male-to-female ratio. At the time of the operation, the patient was 62 years old (mean: 60.42 years, range: 22-93 years). The best age cutoff to distinguish between patients with better prognoses and those with worse ones is 60. Other variables from patients included demographics, tumor size, pathology, operative time, surgical procedure, immune status, and postoperative spinal nerve function [7].

Anesthesia

General anesthesia can be used for surgeries that do not call for testing the patient's voluntary motor and verbal abilities during surgery. Awake craniotomy using the asleep-awake-asleep type of anesthesia must be used when a patient's motor functions require several assessments or when linguistic mapping is conducted. As a result, the patient will be given a little anesthetic while the dura is being opened. Patients will then be woken for surgical functional assessments. Before surgical manipulation, baseline recordings will help account for the effects of the anesthetic. Propofol and an analgesic delivered using the total intravenous anesthesia (TIVA) technique are the recommended anesthetic drugs. Ketamine, etomidate, and benzodiazepines are among the additional anesthetics that can be utilized [5]. Given that patients who undergo inhalation anesthesia have higher MEP thresholds and weaker, harder-to-interpret signals, using inhalation anesthetics during the entire surgery may result in more subsequent deficits for the patients. The constancy of the patient's body temperature must be considered at the recording location, as low temperatures lengthen signal delays [5].

Intraoperative Neurophysiological Monitoring (IONM)

The use of intraoperative modalities in tumor resection of glioblastoma surgeons and IONM clinicians could help to improve the postoperative outcomes for patients with glioblastomas.

Somatosensory Evoked Potentials (SSEPs)

Somatosensory evoked potentials (SSEPs) are vital for monitoring the integrity of neural pathways, particularly when assessing the spinal cord and sensory pathways in various clinical contexts. In the case of glioblastoma, SSEPs play a crucial role in accurately locating the central sulcus, which is essential for surgical planning and minimizing damage to critical brain areas.

To obtain SSEP recordings, electrodes are strategically placed on the nerves of the upper extremities, specifically targeting the median and ulnar nerves. These recordings focus on two key peaks, the N20-P30 and P22-N30, which correspond to the sensory processing of stimuli in the cortex. For assessments involving the lower extremities, electrodes are placed on the posterior tibial and peroneal nerves, with recordings aligning to the P37-N45 and N36-P44 peaks, critical for understanding the sensory pathway integrity from the feet to the brain (Figure 1).

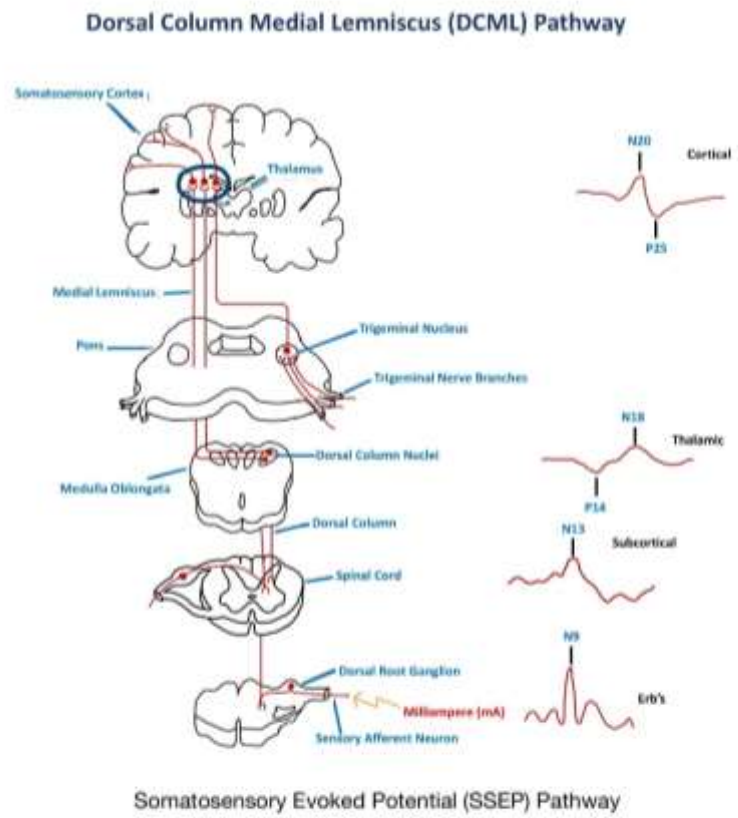

Figure 1. Somatosensory Evoked Potential (SSEP) pathway in spinal cord cross-sections with cortical waves. *(Illustrations by Mehak Satsangi*).

The stimulation parameters for performing SSEPs involve applying electrical stimuli to the peripheral nerves. A frequency range of 2.66 to 4.79 Hz allows optimal nerve activation. The intensity of the electrical stimulation varies for the median and ulnar nerves. It is set between 15 to 30 mA, while the intensity is increased for the posterior tibial and peroneal nerves, ranging from 40 to 100 mA. The pulse duration is maintained at 300 microseconds to ensure effective stimulation, and the filter settings are critical for differentiating responses: they are set at 30-1500 Hz for capturing peripheral and subcortical responses, while cortical recordings utilize a narrower band of 30-500 Hz. Data sweeps are adjusted according to the targeted nerve, with a sweep speed of 5 ms/div for the median and ulnar nerves and 10 ms/div for the posterior tibial and peroneal nerves.

For optimal recording accuracy, subdermal needle electrodes are placed per the international 10-20 electrode placement system at key locations: FPz (frontal polar), CPz (central polar), CP3, and CP4. Subcortical recording electrodes are meticulously positioned at Cv5, peripheral recording electrodes at Erb's point for upper extremity assessments, and the popliteal fossa for lower extremity evaluations.

Monitoring criteria during the procedure are strict, focusing on the integrity of the recordings. Warning indicators include a significant increase in latency greater than 10% compared to baseline measurements and a substantial decrease in amplitude exceeding 50%. These criteria are essential safeguards to detect any potential changes that may indicate neurological compromise during surgical interventions.

Electromyography (EMG)

The recording of muscle activity is specifically tailored to the location and effects of the brain tumor. Subdermal needles are carefully placed in targeted muscles on the contralateral side of the body, including the face and upper and lower extremities (Table 1). The recording system is configured with a frequency filter ranging from 10 to 5000 Hz to ensure accurate data capture. The recording sweep is set to 300 ms per division for spontaneous electromyography (s-EMG) and 10 or 100 ms per division for triggered electromyography (t-EMG). This advanced electromyography setup delivers real-time feedback, enabling immediate observation of any changes in muscle activity, which is essential for evaluating the tumor's impact on motor function.

Upper Extremity	**Lower Extremity**	**Facial Muscle**
Deltoid	Quadriceps	Orbicularis Oris
Biceps Brachii	Tibialis Anterior	Mentalis
Flexor Carpi Ulnaris	Gastrocnemius	Tongue Muscle
Brachioradialis	Abductor Hallucis	
Abductor Digit Minimi	Extensor Hallucis Brevis	
First Dorsal Interosseous		

Table 1. Documenting the specific muscles involved in electrode placement during intraoperative neuromonitoring (IONM) in the context of glioblastoma tumor resection.

Phase Reversal

Phase reversal is an advanced technique used in surgical neurophysiology to explore how the brain processes sensory information. This complex procedure involves the precise electrical stimulation of the median or ulnar nerves on one side of the body, specifically targeting the opposite side—the contralateral side—where responses will be recorded. At the same time, sensory responses are carefully monitored from the cortex on the same side as the exposed brain area referred to as the ipsilateral side.

To facilitate this process, specialized clinical teams use a carefully arranged grid of electrodes placed directly on the exposed surface of the cortex (Figure 2). This configuration is crucial for obtaining high-resolution data that reflects cerebral activity, enabling the neuromonitoring team to capture intricate response patterns accurately.

During the procedure, clinicians pay close attention to a phenomenon known as phase reversal within the recorded data (Figure 3). Phase reversal is marked by significant changes in the signal patterns detected among multiple electrode grids strategically positioned across the brain's central sulcus, which separates the motor cortex from the sensory cortex. The ability to detect and analyze these variations provides valuable insights into the complex dynamics of sensory processing and the communication pathways between neurons in the brain.

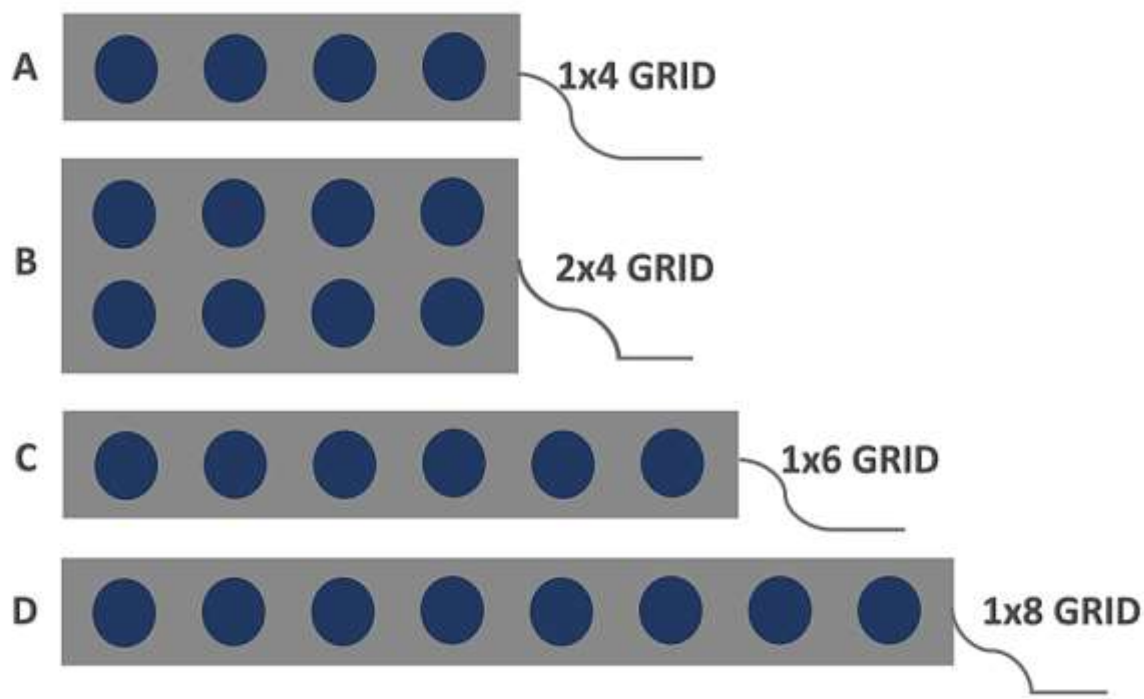

Figure 2. Cortical grids. Schematic presentation of the cortical grids. A: four-contact grid (1 x 4); B: eight-contact grid (2 x 4); C: six-contact grid (1 x 6); and D: eight-contact grid (1 x 8). *(Reprinted with permission Jahangiri et al. 2020, Cureus) [7].*

Stimulation of the contralateral median and ulnar nerves results in phase reversal, or inverted responses, across the central sulcus. This inverted response occurs in the dipoles of the sensory signals generated in the somatosensory cortex. The stimulation frequency is typically between 2.66 Hz and 4.79 Hz, with a pulse width of 0.3 milliseconds.

The recording filter bandwidth is configured to capture 30 Hz to 3000 Hz signals, with data sweeps plotted on a time scale of 5-10 milliseconds per division. The current intensity needed for effective nerve stimulation can vary; for example, median nerve stimulation usually requires an intensity between 15 mA and 30 mA, while posterior tibial nerve stimulation often requires a higher intensity, ranging from 40 mA to 100 mA.

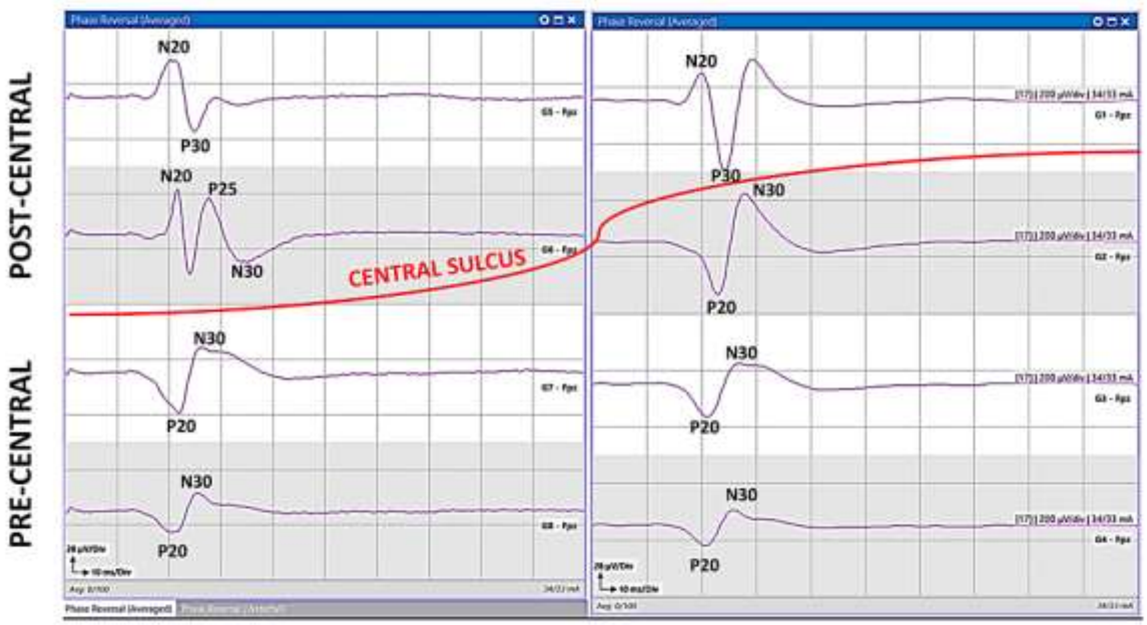

Figure 3. Off-axis mapping. Incomplete on-axis (off-axis) MN sensory mapping by a 2 x 4 grid with a triphasic PR, including a P25 response. The PR is between G1/G2 and G6/G7 localizing the CS (red line). The responses from G1, G5, and G6 are postcentral, and G2, G3, G4, G7, and G8 are precentral. MN, median nerve; PR, phase reversal; CS, central sulcus. *(Reprinted with permission Jahangiri et al. 2020, Cureus) [7].*

Direct Cortical Stimulation (DCS)

Direct cortical stimulation (DCS) is an advanced technique for precisely identifying the motor functional areas of the brain (Figure 4). This method is particularly favored in glioma resections, especially during procedures such as awake craniotomy and general anesthesia. DCS plays a crucial role in pinpointing essential expressive regions of the brain, thereby minimizing the likelihood of postoperative neurological deficits and facilitating a greater extent of tumor resection.

During the DCS procedure, the brain's cortical areas are electrically stimulated. This process can utilize two primary approaches: the high-frequency short-train stimulation technique, known as the Taniguchi method, which typically employs a monopolar flexible probe, and the bipolar slow-frequency long-train stimulation, referred to as the Penfield method (Table 2). Both methods have distinct applications based on the clinical context and specific patient needs.

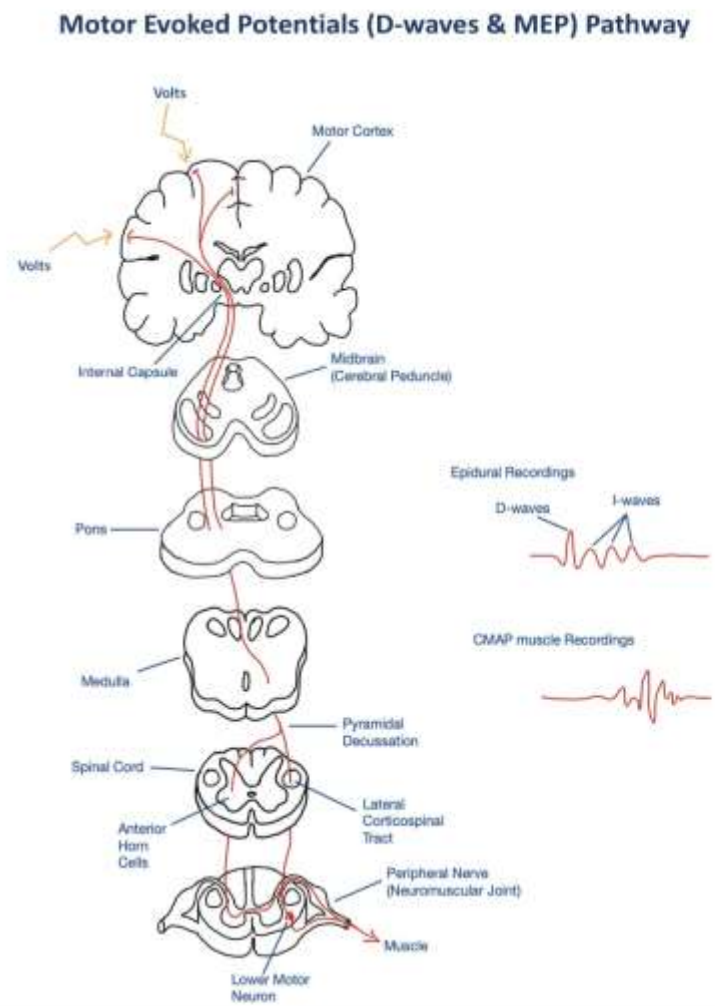

Figure 4. Motor Evoked Potential (MEP) pathway in spinal cord cross-sections with corticospinal waves. (Illustrations by Mehak Satsangi).

It is important to acknowledge the potential risks associated with DCS, particularly concerning adverse events (ADs) that can occur following discharge from the procedure. Among these risks are the possibility of seizures and the potential for misidentifying the localization of various cortical regions, which could extend neurological complications.

Specific warning criteria are established as an essential part of the DCS monitoring process. Any noticeable changes in motor, speech, or sensory functions during stimulation can serve as critical indicators of potential compromise to the assessed cortical areas. Recognizing these changes is paramount for ensuring patient safety and optimizing surgical outcomes.

Recording Parameters	**Technique- Penfield**	**Technique Taniguchi**
Low-cut filter	10Hz	10Hz
High cut filter	5000Hz	5000Hz
Notch Filter	off	off
Dynamic Range	200-500 µV/div	200-500 µV/div
Sensitivity	200 µV	200 µV
Time- base	100 ms/div	10 ms/div
Electrode impedance	>5 kΩ	>5 kΩ

Table 2. Penfield and Taniguchi techniques for subcortical and cortical mapping intraoperative corticospinal tracts during Tumor Resection in Glioblastoma.

Penfield Method

The Penfield method involves using a handheld bipolar ball tip probe for direct cortical stimulation (DCS) at 50 or 60 Hz frequencies. This method sends monophasic pulses, each lasting between 200 and 1,000 microseconds. Stimulation is applied for 2 to 5 seconds. The stimulation intensity starts at 1 mA and is gradually increased until a response is detected in the muscles (Figure 5). This continues until either an after-discharge (AD) occurs or the maximum intensity of 20 mA is reached. Electrocorticography (ECoG) recordings are taken during DCS to check for after-discharges caused by the stimulation. If an AD occurs, iced saline at 4°C is applied right away to help prevent a seizure. This method is often used in surgeries that involve mapping language areas because it has longer stimulation durations.

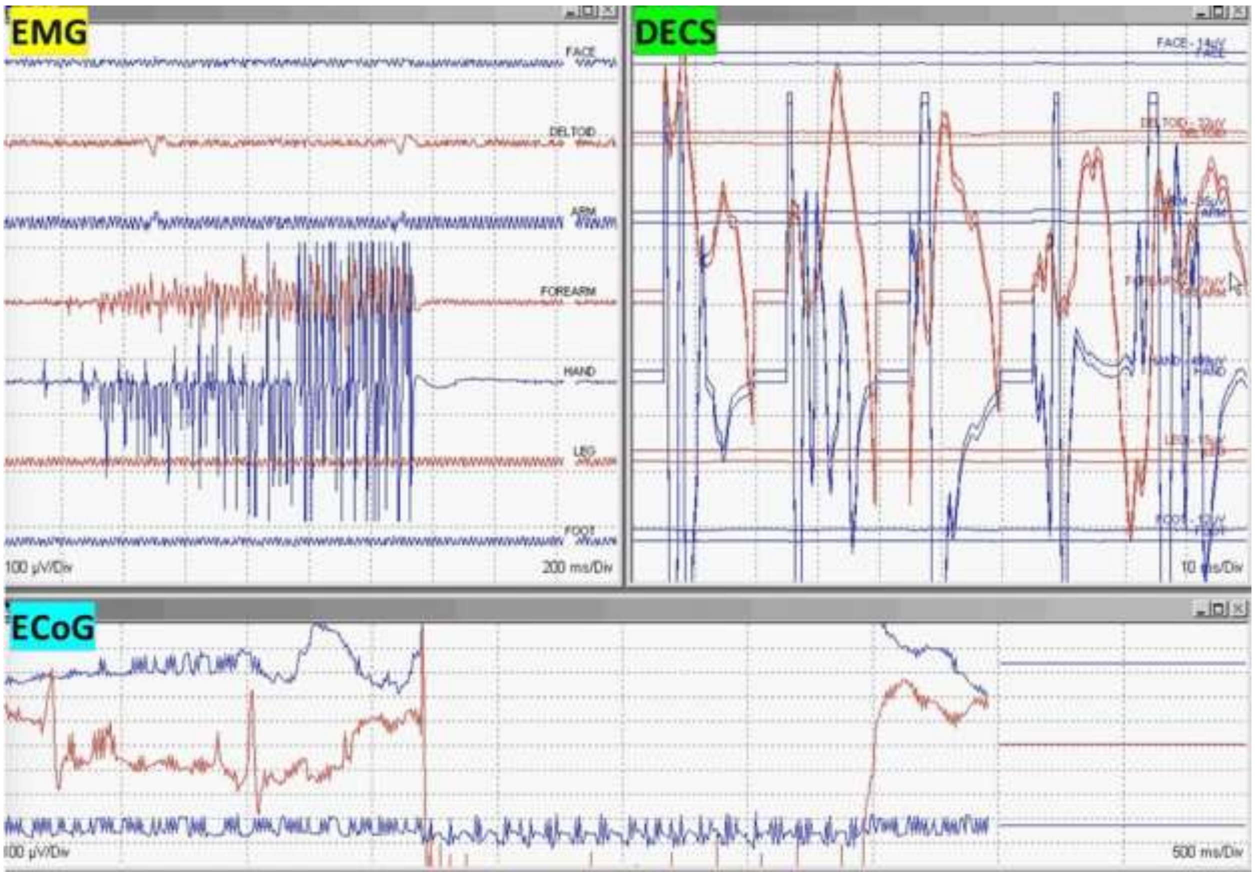

Figure 5. Penfield motor mapping method. Penfield 50 Hz motor mapping evoked responses after bipolar handheld stimulation. Multiple responses are recorded in the forearm and hand muscles. Face: orbicularis oris; deltoid, arm: biceps brachii; forearm: brachioradialis/flexor carpi ulnaris; hand: abductor pollicis brevis/abductor digiti minimi; leg: tibialis anterior; foot: abductor hallucis. EMG: electromyography; DECS: Penfield direct electrical cortical stimulation; ECoG: electrocorticography. *(Reprinted with permission Jahangiri et al. 2022, Cureus) [8].*

Taniguchi Method

The Taniguchi method changes the Penfield method by adjusting the pulse width and intensity. It uses monopolar anodal direct cortical stimulation. For subcortical stimulation, it employs monopolar cathodal stimulation. This method uses five pulses with a width of 200 to 500 microseconds and a frequency of 250 to 500 Hz. The intensity starts at 1.0 mA and gradually increases until a muscle response is detected, an after-discharge occurs, or the maximum of 20 mA is reached (Figure 6). For subcortical stimulation, the intensity is decreased starting from 10 mA to find the distance from motor fibers, with 1 mA indicating approximately 1 mm from the corticospinal tract.

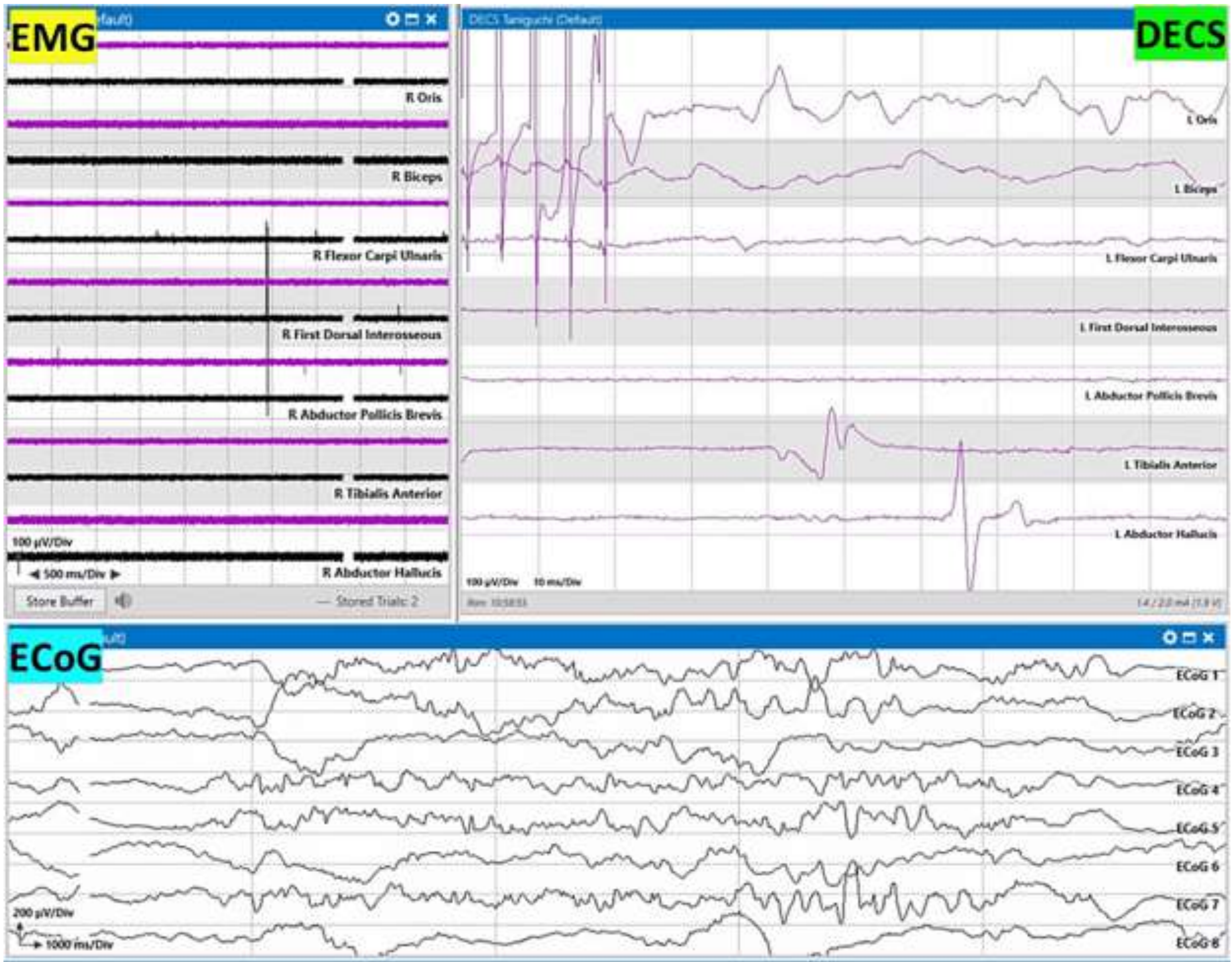

Figure 6. Taniguchi motor mapping method. Taniguchi 320 Hz motor mapping evoked responses after monopolar handheld stimulation. Responses are recorded in the tibialis anterior (leg) and abductor hallucis (foot) muscles. Oris: orbicularis oris; biceps: biceps brachii; flexor carpi ulnaris, first dorsal interosseous, abductor pollicis brevis, tibialis anterior, and abductor hallucis muscles. EMG: electromyography; DECS: Taniguchi direct electrical cortical stimulation; ECoG: electrocorticography. *(Reprinted with permission Jahangiri et al. 2022, Cureus) [8].*

Subcortical Stimulation

The mapping of deep white matter axons induces a motor-evoked potential that propagates downstream to target muscles. This modality uses monopolar ball tip electrodes, and it is cathodal stimulation. Pulse train 4-5 monophasic rectangular pulses. For subcortical mapping, the rule of 1.0 mA equals 1.0 mm distance from corticospinal tracts [4]. There are multiple readings from sweeps and changes in motor or sensory functions can indicate a subcortical area compromise.

Electroencephalography (EEG) and Electrocorticography (ECoG)

Electroencephalography (EEG) baseline recordings are recorded using subdermal needle electrodes strategically placed on the scalp prior to the surgical opening of the dura mater. Once the dura is incised, electrocorticography (ECoG) recordings are conducted with a subdural grid electrode carefully positioned near the stimulation area. This is done with direct cortical stimulation (DCS) to closely monitor any potential emergence after discharges (Figures 5-6).

For optimal clarity in the recordings, the time base is calibrated to 500 milliseconds per division, employing a gain setting of 200 and a sensitivity range of 20 to 100 microvolts per division. The bandpass filter is adjusted to capture frequencies between 0.5 and 70 Hz, deliberately avoiding a notch filter, as its application could inadvertently dampen seizure activity and hinder the detection of after discharges (ADs).

Suppose stimulation induces after discharges (ADs). In that case, immediate action is taken, and ice-cold saline, maintained at a chilling 4°C, is applied to the affected area to effectively mitigate seizure activity, thereby enhancing patient safety and comfort.

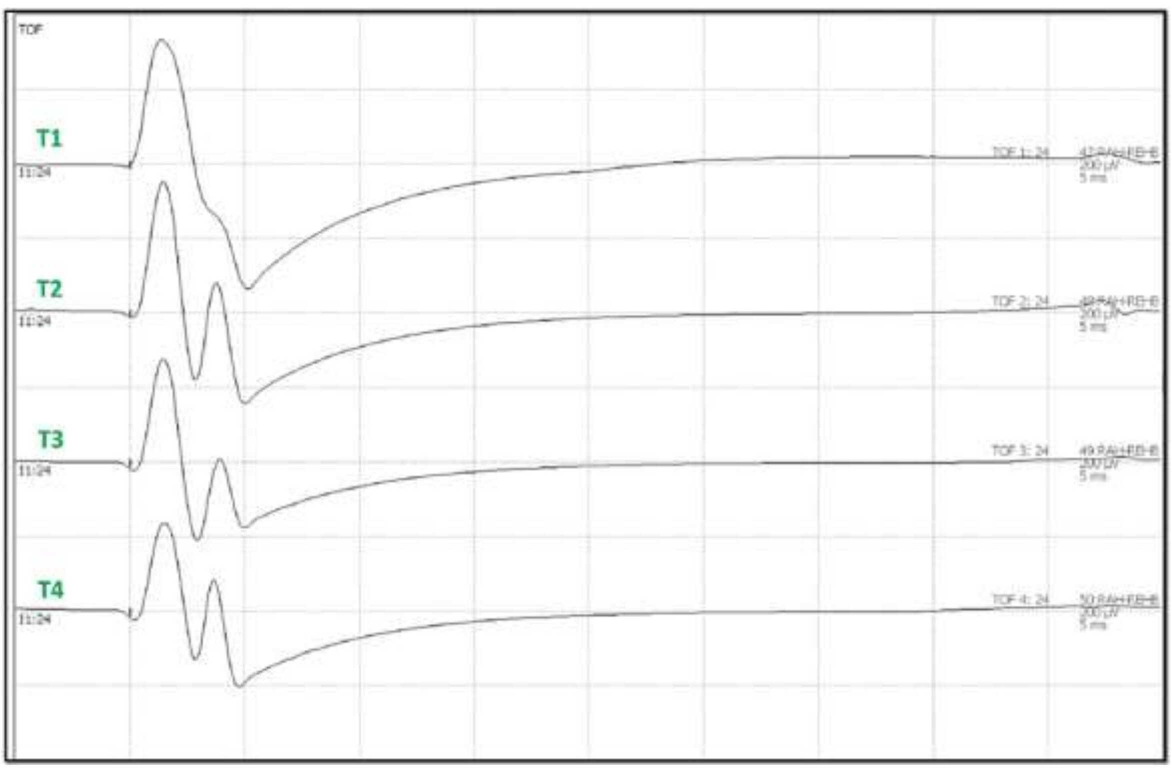

Figure 7. Train of Four (TOF). TOF was recorded at the baselines from the foot muscles (referenced Abductor Hallucis-Extensor Hallucis Brevis) lower extremities. AH: Abductor Hallucis, EHB: Extensor Hallucis Brevis. T1; Twitch 1, T2: Twitch 2, T3: Twitch 3, T4: Twitch 4. *(Reprinted with permission Jahangiri et al. 2022, Cureus) [9].*

Train of Four

TOF measures the level of muscle relaxation during the surgical procedure. Recording electrodes are placed in the foot muscles (Figure 7). The posterior tibial nerve is stimulated using four stimuli for two seconds, a frequency of 2 Hz and pulse width of 200 µs, are applied, sweep of 20 ms/div, and a gain of 100-500 µV/div. The ratio of the amplitude of the fourth twitch to the first twitch (T4/T1) ratio is used to measure the level of a neuromuscular blockade. The decrease in the number of twitches can signal a neuromuscular function compromise.

RESULTS

Study Characteristics

A literature search was conducted using Cureus, PubMed, and other scholarly sites. Seven papers were found, and all were accepted. The inclusion criteria used in the studies were EMG, SSEP, MEP, and ECoG (Table 3).

Authors & Year	Patient Population	Surgical Procedures	IONM Modalities used	Findings	Suggested actions (if any)
Tarapore et al. (2015)	12 patients with lesions around cortical language areas	N/A	nTMS ECoG	nTMS is a valid and reliable technique of language mapping. It is useful for non-invasively mapping language areas in patients with lesions in cortical regions related to language.	No action suggested
Han et al. (2018)	702 Patients who underwent resection of hemispheric perirolandic glioma	Subcortical Stimulation Mapping	SSEP MEP ECoG DCS	Subcortical stimulation mapping is a safe method for identifying the location of descending motor pathways in patients with perirolandic gliomas.	The study's findings support the integration of nTMS-based language mapping as a routine clinical practice for patients undergoing awake craniotomy for brain tumor resection. This technique can identify and preserve language function

					during the surgical resection of brain tumors, potentially improving patient outcomes.
Raabe et al. (2014, 2010)	33 Patients who had brain tumors (gliomas or metastasis) and underwent resection surgery	Variety of neurosurgical procedures	EMG	The use of IONM and DTI is an effective way of monitoring the corticospinal tract during surgery of motor eloquent brain tumors	Standardize IONM and DTI for mapping the corticospinal tract during motor eloquent brain tumor surgery.
Saito et al. (2021)	25 patients who underwent awake craniotomy for glioma resection	Awake craniotomy with the use of MEP to monitor glioma resection	TCeMEP SSEP	Transcortical MEP monitoring during awake craniotomy for the removal of gliomas located within or near motor-related areas of the brain may serve as a valuable technique for predicting postoperative motor function and potentially improving surgical outcomes	MEP monitoring can be used for mapping aggressive tumor resection while minimizing the risk of motor deficits
Krieg et al. (2017).	Patients who are healthy or patients with neurological deficits that affect motor or language function	N/A	nTMS	nTMS mapping is effective in identifying the location of motor and language regions in the brain	Standardize nTMS mapping and integrate it with MRI to improve the accuracy of mapping
Bello et al. (2014)	591 patients with glioma tumors within motor areas	Cortical mapping Subcortical brain mapping	EEG EcoG MEP	The results show that IONM techniques tailored to the clinical context increase the number of patients who would benefit from surgery and significantly increase the EOR while lowering permanent morbidity and the incidence of	No action suggested

			SSEP	intraoperative seizures. This is done by integrating low-frequency with high-frequency pulse stimulation during motor tumor removals.	
Kim et al. (2018)	Children of different ages with brain tumors	Variety of neurosurgical procedures	MEP SSEP DCS BAEP	All these techniques are efficient ways to map tumors during resection surgery, but they require extra consideration because children's neurophysiology is different.	Find a way to allow IONM to monitor the cerebellum to understand children's neurophysiology better.

Table 3. Overview of reviewed sources [3,11-16].

TCeMEP = Transcranial Motor Evoked Potential

MEP = Motor Evoked Potential

SSEP = Somatosensory Evoked Potential

EEG = Electroencephalography

ECoG = Electrocorticography

DTI = Diffusion Tensor Imaging

DCS = Direct Cortical Stimulation

nTMS = Navigated Transcranial Magnetic Stimulation

BAEP= Brainstem Auditory Evoked Potential

DISCUSSION

The research studies demonstrated that intraoperative somatosensory evoked potential (SSEP) monitoring, cortical (DECS), and subcortical stimulation mapping (SCM) are useful for enhancing surgical results and reducing morbidity rates in brain tumor surgery. Han et al. (2018) discovered that perirolandic gliomas responded better to SSM-guided surgery regarding motor outcomes and morbidity rates [11]. SSEP monitoring helped reduce the occurrence of new motor impairments and maximize the degree of resection. Saito et al. (2021) reported that the use of transcortical motor evoked potential (tcMEP) monitoring in conjunction with SSEP monitoring significantly increased the accuracy of predicting postoperative motor function during awake craniotomy for glioma resection [12]. Bello et al. (2014) investigated using SSEP monitoring to enhance resection and safety in gliomas involving motor pathways [13]. They discovered that it improved the precision of identifying motor pathways during surgery when combined with motor evoked potentials (MEPs) and cortico-cortical evoked potentials (CCEPs). In their assessment of SSEP monitoring's application in pediatric brain tumor surgery, Kim et al. (2018) highlighted its value in determining the health of sensory networks and spotting changes in the somatosensory cortex [14].

These studies imply that SSEP monitoring can assist surgeons in identifying crucial functional areas, modifying surgical approaches accordingly, and reducing the possibility of postoperative impairments. SSEP monitoring is a helpful tool for improving surgical results and lowering morbidity rates in brain tumor surgery, particularly for gliomas affecting motor or sensory pathways. It gives real-time input on the integrity of the motor or sensory pathways.

In a study involving more than 700 patients, Han et al. (2018) evaluated the effects of subcortical stimulation mapping (SSM) of the descending motor pathways on the morbidity and functional outcomes of perirolandic gliomas [11]. Compared to non-SSM-guided surgery, the study indicated that SSM-guided surgery produced better motor outcomes and decreased morbidity rates. The degree of tumor resection was increased, and the incidence of new motor impairments was decreased, primarily using intraoperative MEP monitoring. Bello et al. (2014) investigated MEP monitoring in gliomas involving motor pathways in conjunction with other neurophysiological techniques to customize surgical approaches, enhance resection, and increase safety [13]. The study demonstrated that improving the accuracy of identifying motor pathways during surgery by integrating MEP monitoring with SSEP and cortico-cortical evoked potentials (CCEPs). Additionally, real-time monitoring of MEPs enabled the detection of changes in the motor pathways and the adaptation of surgical approaches, resulting in a higher degree of resection and lower morbidity rates. A review of intraoperative neurophysiological monitoring (IONM) methods, including MEP monitoring, used for pediatric brain tumor surgery was published in Kim et al. (2018) [14]. The motor cortex can be located, and the health of the motor pathways during surgery can be checked via MEP monitoring, according to the authors. The study found that early detection of changes in the motor pathways and the ability to modify surgical approaches can help minimize postoperative motor impairments.

These studies demonstrate that MEP monitoring, particularly for gliomas affecting motor pathways, is useful for optimizing surgical results and reducing morbidity rates in brain tumor surgery. By providing real-time input on the integrity of the motor pathways, MEP monitoring can assist surgeons in identifying crucial functional areas, modifying surgical approaches as necessary, and reducing the likelihood of postoperative motor impairments.

Saito et al. (2021) examined the effectiveness of transcortical motor evoked potential (tcMEP) monitoring in foretelling motor function during awake craniotomy for removing gliomas in or near motor-related areas [12]. According to the study, tcMEP and SSEP monitoring significantly improved postoperative motor function prediction compared to SSEP monitoring alone. According to the authors, including tcMEP monitoring in intraoperative monitoring approaches allowed for detecting motor regions that SSEP monitoring alone could not detect.

Another method used in intraoperative neurophysiological monitoring (IONM) to map cortical function during brain tumor surgery is electrocorticography (ECoG). In patients having epilepsy surgery, Tarapore et al. (2015) studied the use of ECoG to locate the eloquent cortex [10]. Researchers discovered that ECoG-based mapping enabled a more thorough resection of the epileptogenic zone with reduced morbidity rates. To maximize resection and reduce morbidity during brain tumor surgery, ECoG has been utilized to pinpoint the boundaries of the motor and linguistic areas. According to Bello et al. (2014), ECoG monitoring and cortico-cortical evoked and motor evoked potentials enhanced the precision of identifying motor circuits during surgery, leading to a higher degree of resection and reduced morbidity rates [13]. Like this, Han et al. 2018 observed that patients with perirolandic gliomas with subcortical stimulation mapping (SSM) in conjunction with ECoG monitoring saw superior motor results and decreased morbidity rates [4,11]. According to the authors, the resection area was improved, and the incidence of new motor impairments was reduced by intraoperative ECoG monitoring. These studies demonstrate the value of ECoG monitoring in identifying and protecting the eloquent cortex during removing brain tumors, which enhances surgical results and lowers morbidity rates.

According to Bello et al. (2014), SSEP monitoring in conjunction with motor evoked potentials (MEPs) and cortico-cortical evoked potentials (CCEPs) increased the accuracy of identifying motor pathways during surgery [13]. According to Kim et al. (2018), DCS can aid in identifying functional regions and preserving brain function during surgery [14]. Overall, the trials point to the potential benefit of IONM approaches in improving surgical results and reducing morbidity in brain tumor surgery.

According to Kim et al. (2018), BAEP monitoring helps evaluate the health of the auditory pathways and spot alterations in the auditory cortex following surgery [14]. The authors discovered that through early detection of alterations in the auditory pathways and appropriate surgical strategy adaptation, BAEP monitoring can help to prevent postoperative hearing impairments. Furthermore, BAEP monitoring can assist surgeons in recognizing crucial functional regions and reducing the possibility of postoperative deficits. Overall, the study indicates that BAEP monitoring, particularly for tumors involving the auditory pathways, is a helpful technique for enhancing surgical results and lowering morbidity rates in brain tumor surgery.

Transcranial magnetic stimulation (TMS) has become a promising method for mapping cortical function in brain tumor surgery. The effectiveness of navigated TMS (nTMS) in preoperative mapping of linguistic and motor function in patients with gliomas was examined in two studies by Tarapore et al. (2015) and Krieg et al. (2017) [10,15]. Compared to non-nTMS-guided surgery, Tarapore et al. (2015) discovered that nTMS-guided surgery led to more significant resection and improved language outcomes [10]. The scientists also noted that functional areas missed by conventional preoperative imaging might be found using nTMS. According to Krieg et al. 2017, individuals with tumors in motor areas who underwent nTMS-guided surgery had better motor results than those who underwent non-nTMS-guided surgery [15]. The authors also discovered that nTMS could recognize crucial motor regions that other imaging methods could not. Overall, these studies indicate that nTMS can enhance surgical results and reduce morbidity rates in brain tumor surgery. It is also a valuable technique for preoperative mapping of cortical function.

The impact of transcranial magnetic stimulation (TMS) on the corticomuscular coherence during a prolonged contraction of the biceps brachii muscle was examined by Raabe et al. (2014) [3]. Twelve healthy participants were used in the investigation, and they engaged in a sustained contraction of the biceps muscle while receiving genuine and sham TMS over the primary motor cortex. The findings demonstrated that whereas sham TMS had no effect, real TMS boosted the corticomuscular coherence during the prolonged contraction. According to the study, TMS can improve motor control and rehabilitation by altering the coherence between the motor cortex and the muscle during a prolonged contraction. The results of this study shed light on the brain mechanisms that underlie TMS and its potential clinical use in the treatment of motor disorders.

The cited research sheds light on applying various cortical and subcortical mapping and phase reversal methods. Results show that direct cortical and subcortical motor stimulation is a reliable tool for cortical mapping and can precisely pinpoint the location of the motor cortex [8]. Additionally, the cortical areas involved in producing language and speech have been mapped using ECoG stimulation. Results show that SSEP and BAEP stimulation were primarily used for subcortical mapping and that this technique can precisely pinpoint the brainstem and auditory nerve locations. Additionally, subcortical regions involved in motor function were mapped using nTMS stimulation. Finally, during brain surgery, phase reversal has been employed to distinguish between the corticospinal tract and the dorsal column-medial lemniscal tract, enabling more accurate target tissue localization [16-18]. These studies emphasize the significance of adopting a range of mapping methods for cortical and subcortical regions and the possible advantages of phase reversal in improving surgical outcomes.

CONCLUSION

Intraoperative techniques, such as cortical and subcortical mapping, are essential for reducing risks during glioblastoma surgeries. These mapping methods rely on intraoperative neurophysiological monitoring (IONM), which helps the surgical team protect critical areas like the motor cortex, language centers, and other subcortical regions. The effectiveness of brain mapping also heavily depends on the skill of the surgical team, as this can lead to better patient outcomes and fewer complications after surgery. Additionally, using multi-modality mapping is an effective strategy for identifying complex brain areas, helping to minimize surgery-related damage, and providing postoperative benefits, such as reduced neurological impairments.

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