Continuous mapping of the corticospinal tracts in intramedullary spinal cord tumor surgery using an electrified ultrasonic aspirator

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Intramedullary spinal cord tumors (IMSCTs) represent a rare entity, accounting for 4%–10% of all central nervous system tumors. Microsurgical resection of IMSCTs is currently considered the primary treatment modality. Intraoperative neurophysiological monitoring (IONM) has been shown to aid in maximizing tumor resection and minimizing neurological morbidity, consequently improving patient outcome. The gold standard for IONM to date is multimodality monitoring, consisting of both somatosensory evoked potentials, as well as muscle-based transcranial electric motor evoked potentials (tcMEPs). Monitoring of tcMEPs is optimal when combining transcranial electrically stimulated muscle tcMEPs with D-wave monitoring. Despite continuous monitoring of these modalities, when classic monitoring techniques are used, there can be an inherent delay in time between actual structural or vascular-based injury to the corticospinal tracts (CSTs) and its revelation. Often, tcMEP stimulation is precluded by the surgeon’s preference that the patient not twitch, especially at the most crucial times during resection. In addition, D-wave monitoring may require a few seconds of averaging until updating, and can be somewhat indiscriminate to laterality. Therefore, a method that will provide immediate information regarding the vulnerability of the CSTs is still needed.

The authors performed a retrospective series review of resection of IMSCTs using the tip of an ultrasonic aspirator for continuous proximity mapping of the motor fibers within the spinal cord, along with classic muscle-based tcMEP and D-wave monitoring.

The authors present their preliminary experience with 6 patients who underwent resection of an IMSCT using the tip of an ultrasonic aspirator for continuous proximity mapping of the motor fibers within the spinal cord, together with classic muscle-based tcMEP and D-wave monitoring. This fusion of technologies can potentially assist in optimizing resection while preserving neurological function in these challenging surgeries.

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KEY WORDS IMSCT; intramedullary spinal cord tumor; spine surgery; intraoperative nerve monitoring; mapping; ultrasonic aspirator; diagnostic technique

INTRAMEDULLARY spinal cord tumors (IMSCTs) represent a rare entity in children and adults.^{26,33} The most common intramedullary tumors can be classified as primary neoplasms or, less commonly, metastatic lesions.¹⁹ Ependymomas are common in adults, while astrocytomas are far more common in children.¹⁰ Most ependymomas have relatively demarcated borders, while astrocytomas are more infiltrative and need to be resected until a white matter “interphase” appears.²⁰

Microsurgical resection of IMSCTs is currently considered the primary treatment modality, while radiotherapy

and/or chemotherapy are reserved for recurrent or malignant tumors.^{3,9,41} The observation that the majority of IMSCTs are benign and consequently gross-total removal might result in long-term survival further supports the need for safe resection.¹⁰ The extent of resection has been correlated with progression-free survival⁴ and lower recurrence rates.²¹ Advances in microsurgery have contributed to safer resection ability. However, despite all advances, surgery for IMSCTs is still very challenging and may carry significant morbidity. Proximity to crucial neural elements necessitates use of surgical adjuncts such as high-

ABBREVIATIONS CMAP = compound motor action potential; CST = corticospinal tract; IMSCT = intramedullary spinal cord tumor; IONM = intraoperative neurophysiological monitoring; SSEP = somatosensory evoked potential; tcMEP = transcranial electric motor evoked potential.

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resolution MRI, intraoperative neurophysiological monitoring (IONM) of nerves, and intraoperative ultrasound.¹⁹ To date, the use of an ultrasonic aspirator as the resective tool during IMSCT surgery is considered state of the art.⁸

Intraoperative neurophysiological monitoring has been shown to play an important role in IMSCT surgery.^{6,34,35} Current common modalities enable continuous somatosensory evoked potential (SSEP) monitoring as well as motor potential monitoring, by both muscle-based transcranial electric motor evoked potentials (tcMEPs) and by D-wave monitoring.^{22,34} TcMEP monitoring alarms alert the surgeon when the corticospinal motor conduction has been compromised in both a reversible and nonreversible manner. It has previously been shown that loss of the muscle tcMEP signal predicts postoperative functional outcome²⁸ as it corresponds to at least a short-term motor deficit postoperatively,^{23,28} while attenuation of over 50% of the D-wave amplitude correlates with long-term permanent motor injury.¹¹ This allows for a tailored approach to surgery: maximizing resection while minimizing permanent neurological deficit.

The desire for continuous mapping of functional areas during resection with the ultrasonic aspirator, aiming at improving surgical strategy and maximizing resection, while preserving neural elements in spinal cord surgery, led to our current trial. Herein we present our preliminary experience with a multipurpose resective tool (i.e., ultrasonic aspirator connected to IONM) to allow real-time continuous mapping of the corticospinal tract (CST).

Methods

This study is in compliance with and was approved by the “Sourasky” Medical Center IRB.

Resection

The technique for resection of IMSCTs has been described extensively elsewhere.⁷ An ultrasonic surgical aspirator (CUSA, Integra Life Sciences) was used for tumor resection in all 6 cases. The aspirator was introduced into the surgical field after entering the spinal cord, either through the midline or (in a single case) through the dorsal root entry zone. Our common practice in resection of intramedullary tumors is to begin with combined sharp and blunt separation of dorsal tumor margins, only when they are easily recognizable. When those margins become blurry to a “white matter interface,” we almost always use an ultrasonic aspirator, at low amplitudes, for tumor resection up to the margins.

CUSA Stimulation and Recording

Spinal stimulation was applied using the CUSA 36-kHz Hand Piece CEM Nosecone (Integra) (Fig. 1). All neurophysiological data were recorded using a 16/32 channel intraoperative evoked response unit (NIM Eclipse, Medtronic). Disposable subdermal needle and scalp electrodes were manufactured by Rhythmlink, and D-wave electrodes were manufactured by Ad Tech Medical Instrument Corp. Muscle-tcMEPs, D-waves, and SSEPs were monitored in a fashion described in our previous study,²² and the CUSA-mediated stimulation parameter settings

FIG. 1. The standard ultrasonic resective tool with the attached nosecone for an electrified tip.

were as follows: stimulation train-of-three pulses with an interstimulus interval of 3 msec, pulse duration 200 μ sec, 1.2 trains per second, intensity range 0.5–2 mA, in a monopolar cathodal fashion with the return electrode (anode) placed in the sterile field close to the wound.

Time-locked sweeps of 100 msec were collected after each CUSA stimulation and analyzed for evoked compound motor action potential (CMAP) activity in the following muscles: for cervical-level tumors, the deltoid, biceps, triceps, thenar, and tibialis anterior muscles; for thoracic-level tumors, the quadriceps, tibialis anterior, and abductor hallucis muscles; and for lumbar-level tumors, the quadriceps, tibialis anterior, gastrocnemius, and abductor hallucis muscles (Table 1 lists the individual case settings).

All evoked activity detected was immediately brought to the surgeon's attention.

Monitoring Intermodality Dynamics

The standard protocol for cord stimulation was as follows: SSEP, tcMEP, and D-wave data were collected as the main monitoring modalities. After induction of anesthesia and positioning, SSEP and tcMEP baseline data were collected. SSEP data were averaged until an acceptable signal-to-noise level was reached, typically after 200–500 sweeps at 4.37 Hz. High-amplitude artifacts, beyond 50 mV, were automatically rejected. The time to final average, and thus updates to the surgeon, was about 1–2 minutes. Transcranial MEP data were collected separately in a single-train stimulus manner, with no averaging and therefore no “lag” time. When working within the cord or other sensitive areas in the wound, transcranial stimulation was performed in coordination with the surgeon to avoid injury emanating from the patient twitching. D-wave data were collected beginning at D-wave electrode introduction, after dural opening. When necessary, averages of 5–10 sweeps were collected, at a stimulation repetition rate of 2 Hz, leading to a maximum lag time of approximately 5 seconds. These modalities were collected in series, not in parallel.

At the point the CUSA was introduced into the surgical wound for tumor emulsification, the recording of muscle tcMEPs, SSEPs, and D-waves was halted. On the IONM unit, a separate physical stimulation port was used for CUSA stimulation, and a separate set of CMAP traces was collected and displayed on the IONM unit for this modality.

CUSA-based stimulation was undertaken in between D-wave and muscle tcMEP collection sets. If a duration of 30 seconds was noted without D-wave or muscle tcMEP updates, CUSA stimulation was halted in coordination with the surgeon, and these modalities were tested. Likewise, these modalities were tested each time an active

TABLE 1. Summary of 6 case-based clinical experiences with the electrified ultrasonic aspirator tip

Case No.	Tumor Spinal Levels	Pathology	Recording Muscle Setup	No. of Pulses/ Pulse Width (usec)/ Intensity (mA)	Preop Assessment	Intraop Continuous Mapping Result	Concurrent Monitoring Changes	Postop Motor Deficit/Postop Sensory Deficit
1	T3–4	Ependyoma (WHO Grade II)	Bilat tibialis anterior, abductor hallucis, thenar	5/200–500/0.5–2.0	Mild spastic paraparesis w/ diffuse bilat lower-extremity hypesthesia	Rt abductor hallucis evoked CMAP when working at pole	Transient bilat lower-extremity toMEP loss w/ return at closure, D-wave attenuation	None/transient proprioceptive loss & nonspecific bilat hypesthesia (completely resolved)
2	C1–7	Pilocytic astrocytoma (WHO Grade I)	Bilat deltoid, biceps, triceps, thenar, hypotenar, tibialis anterior	2/200/0.5–0.9	Progressive rt hand intrinsic weakness & hypesthesia	Single evoked CMAP on lt triceps at 0.5 mA	Permanent abolished lt tcMEP; D-wave attenuation >50%; resection was halted in the off-ended area & residual tumor remained	Lt hemiplegia w/ mild gradual improvement; temporary rt hand deterioration w/ gradual improvement & gain of function; lt-sided diffuse hypesthesia
3	Holocord thoracic w/ extensive syrinx above & below	Pilocytic astrocytoma (WHO Grade I)	Bilat quadriceps, tibialis anterior, abductor hallucis, thenar	3/200/1.0–2.5	Transient T10–level hypesthesia; mild UMN signs on examination	Lateralized responses in accordance w/ CUSA position and 1.0-mA setting & good correlation to visualization of white matter tracts	None	None/mild transient bilateral proprioceptive deficits
4	C5–7	Ependyoma (WHO Grade II)	Bilat deltoid, biceps, triceps, thenar, tibialis anterior	3/200/0.3–1.0	Unsteady gait w/ hyperalgesia of rt lower extremity	Positive alarms from 1.0 mA lowered to 0.3 mA sustaining alarm in triceps channel	None	None/none
5	C3–7	Ependyoma (WHO Grade II)	Bilat deltoid, biceps, triceps, thenar, tibialis anterior	3/200/1.0–1.2	Slowly progressive lt hand intrinsic weakness	Evoked CMAP on lt & rt triceps muscles to resection in lat aspects of tumor	Transient loss of lt-sided triceps & tibialis anterior tcMEP during resection w/ return at closure	None/mild lt leg proprioception deficit
6	T5–10	Pilocytic astrocytoma (WHO Grade I)	Bilat quadriceps, tibialis anterior, abductor hallucis, thenar	3/200/2.0	Cervical pain, progressive gait disturbances, & mild UMN signs on neurological exam	One instance of evoked CMAP on lt lower-extremity muscles during early tumor resection	Transient abolishment of lt abductor hallucis tcMEP w/ labile return at closure	Transient lt leg weakness/transient mild lt leg proprioceptive deficit

UMN = upper motor neuron.

CUSA mapping alarm was raised. CUSA stimulation was independent of active CUSA emulsification as long as the CUSA tip remained within the spinal cord and closed the electrical circuit. No halting of normal CUSA function was necessary.

Significant attenuation or lability of the tcMEP or SSEP data was immediately brought to the attention of the surgical team for appropriate intervention, including pausing the procedure, shifting the resection focus, raising the patient's temperature, raising the patient's blood pressure, or irrigating with warm saline.

Illustrative Case

A previously healthy 36-year-old man presented with 4 years of discomfort in his neck and upper back. The patient gradually developed diffuse sensory disturbances, more notably in both legs than in the arms. Several weeks prior to surgery, he developed mild spastic paraparesis and gait disturbances. MRI (Fig. 2) revealed a T3–4 contrast-enhancing intramedullary lesion with both rostral and caudal syringes.

SSEP data were abolished at myelotomy. Left- and right-sided tcMEP data displayed lability and loss of data during deep stages of resection, with full recovery by closure. D-wave data were available both rostral and caudal to the tumor, with transient attenuation of approximately

50% concurrent with the tcMEP warnings. Along with the transient alarms, the CUSA activated the right abductor hallucis at a stimulation intensity of 0.5 mA (Fig. 3).

Postoperatively, there were no new motor deficits. The patient experienced loss of proprioception and diffuse hypesthesia, which gradually improved. Postoperative MRI demonstrated gross-total tumor resection (Fig. 2). The patient was discharged in good clinical condition, fully ambulating. A final pathology report revealed an ependymoma (WHO Grade II).

All 6 case-based clinical and neurophysiological experiences are summarized in Table 1.

Discussion

IONM in IMSCT Surgery

This is the first case-based study demonstrating a novel technique employing continuous intraoperative neurophysiological nerve mapping alongside classic monitoring in surgery for IMSCTs. Our current experience demonstrates the feasibility of using an ultrasonic aspirator connected to an electrode for continuous monitoring during IMSCT surgery. This fusion of technologies demonstrates that continuous motor evoked data could assist the surgeon, as it provides real-time detection of motor pathway proximity. The end goal of the introduction of this method would be to prevent permanent motor deficits based on a warning system that alerts the surgeon before iatrogenic injury is documented by classic monitoring.

Mapping Versus Monitoring

The application of neurophysiological recordings in neurosurgery has 2 main goals: mapping of “functional” neural elements and monitoring of eloquent pathways. Mapping is the process of delineating functional areas. This gives the surgeon a snapshot of the estimated danger zones of entry and allows for a tailored surgical plan. Monitoring is the process of continuously assessing functional neural integrity. Conceptually, during resection of an IMSCT, once the monitoring is disrupted, there is a high probability that the integrity of neural elements has already been compromised, either in a reversible or non-reversible manner. The current suggested protocols use multimodality IONM consisting of SSEP and muscle-based tcMEP along with D-wave monitoring.³⁴ Although this combination is widely accepted, there is still a search for an improved monitoring and mapping paradigm, as significant morbidity remains common in these complex and challenging surgeries.^{27,28,35} Historically, only SSEPs were monitored during spinal cord procedures. However, due to numerous reported false-negative results,^{16,18} i.e., postoperative motor deficit despite unchanged intraoperative SSEPs, use of SSEPs as a single modality has been largely abandoned. These supposed false-negative results are due to the fact that SSEPs do not reflect the functional integrity of motor pathways, and thus are not designed or expected to be sensitive to pure motor deficits. The role of monitoring sensory pathways in IMSCT surgery remains debatable, as attenuated SSEPs are common at myelotomy stages, even before lesion access and resection. Dorsal column mapping via recording of the ascending lemniscal

FIG. 2. Case 1. Pre- and postoperative representative MR images. **A and B:** Preoperative sagittal T1-weighted image with contrast enhancement (A) and sagittal T2-weighted image (B) showing a contrast-enhancing intramedullary tumor with associated cysts and peritumoral cord edema. **C and D:** Postoperative sagittal T1-weighted image with contrast enhancement (C) and sagittal T2-weighted image (D) showing the resection cavity.

FIG. 3. Case 1. Neurophysiological data. **A:** TcMEP data (from *right* to *left*: left tibialis anterior, right tibialis anterior, left abductor hallucis, and right abductor hallucis muscles) showing lability of left- and right-sided data. **B:** D-wave data (caudal [*left*] and rostral [*right*] to the tumor) showing attenuation of caudal D-wave amplitude and stability of rostral amplitude. **C:** Abolishment of SSEP data at myelotomy (left [*left*] and right [*right*] posterior tibial nerve SSEPs [Cz-Fpz montage]). **D:** Recordings during mapping with CUSA showing activation of right abductor hallucis muscle with a stimulation intensity of 0.5 mA (vertical scale 50 μ V per division, horizontal scale 10 msec). Onset of significant attenuation is noted by the asterisks.

system conduction has been proposed to assist in identification of the anatomical and physiological midline for an optimally safe myelotomy entry point.^{23,29} Recently, Ando et al. demonstrated their experience with direct brain and spinal cord sensory stimulation in a method that resembles the D-wave technique but for sensory pathways.¹

The combination of SSEPs and muscle-based tcMEPs has been shown to be of higher specificity and sensitivity than single modalities.¹⁷ The advantages of monitoring of motor pathways have been widely advocated previously. A statement by the American Society of Neurophysiological Monitoring²⁵ demonstrates several examples of reversible muscle-based tcMEP deterioration with no new motor deficits, which provide circumstantial evidence for injury prevention.^{23,31} These examples also provide consistent

evidence that muscle-based tcMEP deterioration often occurs before and sometimes without SSEP changes, thus suggesting a greater chance for early detection, intervention, and motor-deficit prevention. A well-designed historical case-control study of IMSCT surgery demonstrated significantly better long-term outcomes with combined muscle-based tcMEP/D-wave monitoring compared with no monitoring.³⁵ Additionally, a review of descending aortic surgery provided evidence for reduced paraplegia rates with muscle-based tcMEP monitoring compared with other monitoring techniques or unmonitored surgery.¹⁴

Although difficult to estimate, changes in muscle-based tcMEP morphology have been suggested to predict motor deficits.³¹ It is important to note that it is difficult to continuously monitor muscle-based tcMEP data due to patient

movement resulting from transcranial stimulation, which is often paused during the most crucial stages of resection. Aside from altering the rhythm of surgery, these pauses for IONM testing may occur too late, possibly missing the stage of pyramidal injury leading to a permanent deficit. D-wave monitoring is considered an important addition to classic muscle-based tcMEP intraoperative alarms as it correlates with long-term motor function. Maintaining D-wave amplitude above 50% is considered indicative of intact neurological outcome in the long term.^{28,34} D-wave monitoring is critical in these surgeries as its data are both quantitative and continuous throughout surgery. D-wave information can be nondiscriminating to unilateral injury and is not possible when lesions are at or below the T-10 spinal level.¹³ Aside from muscle-based tcMEP and D-waves, free-running electromyography has also been suggested as a method to detect early motor-tract injury during IMSCT surgery.³⁸

IONM is considered by many to be a deserved standard in all surgeries for IMSCT. Nevertheless, despite supportive data, there is still no Level 1 proof for the efficacy of IONM in preventing injury during surgery for intramedullary tumors.^{24,28,34}

Dynamic Mapping of the CST

Mapping of the spinal cord motor elements has gained little attention in the literature. Conversely, mapping of the CST fibers in supratentorial surgery has gathered much attention over the past several years^{13,40} and has been shown to be accurate and effective in quantitatively identifying proximity to the CSTs.³⁰ It has also been shown that subcortical mapping reduces morbidity in the supratentorial patient group.² Recently, Shibani et al. demonstrated the feasibility of continuous motor mapping using subcortical stimulation via a surgical aspirator in cranial surgery. In comparison with the sequential use of a standard monopolar stimulation probe, this was found to be a feasible and safe method with few disadvantages.³⁷ Compared with the standard probe, the aspirator offers continuous information on the excitability of the tracts, and therefore continuously estimates the distance of the probe tip to the CST. Previously, in a similar concept, Raabe et al. described mapping of the CST using the tip of a suction device along with amplified acoustic display, suggesting that these continuous adjuncts lead to increased safety during resection.³²

Validity of Technique

The technical nuances and distance from motor tracts with respect to stimulation thresholds remain controversial even in supratentorial surgery.³⁶ Nossek et al. used a combination of neurophysiological assessment, tractography-based neuronavigation, and updated intraoperative ultrasound. This combination provided accurate localization of the CSTs and demonstrated a linear correlation between the distance to the CSTs and the threshold of subcortical stimulation, suggesting a 1-mA:1-mm threshold intensity to distance ratio correlation.³⁰ The correlation between the stimulation thresholds and the distance from motor tracts in the spinal cord has yet to be determined. Establishing neurophysiological and image-based correlations within the cord will be challenging due to the lack of standard

imaging protocols as well as the smaller scale and tighter fiber bundling compared with the supratentorial context.

Gandhi et al. described the use of a bipolar probe during resection of a cervicomedullary junction cystic ependymoma to perform high-resolution microstimulation motor mapping of CSTs that are responsible for individual muscle groups.¹⁵ This technique was not based on the aspirator, but, similar to data presented in our current study, aims at mapping the motor fibers during resection and minimizing the risk of surgical morbidity.

Our technique involves nonspecific stimulation of the spinal cord and its sub-elements. And while it is scientifically sound to assume that stimulation of the CSTs within the cord will result in an evoked motor response (i.e., a sensitive positive mapping result), we cannot rule out that stimulation of other fibers within the spinal cord, such as propriospinal fibers supporting corticospinal conduction or those involved in centrally mediated reflexes, will similarly result in a recorded motor response. Due to the expectation of similar latencies of muscle responses generated either by true CST activation or propriospinal fiber or reflex fiber stimulation, it would be difficult to differentiate between these scenarios on the basis of muscle response onset alone. In our current experience, for each instance of motor evoked activity by the CUSA, the motor response distribution was appropriate for the spinal level and side of the cord that was being stimulated.

Deletis and Bueno De Camargo¹² described a technique to map the CST in intramedullary surgery using a D-wave collision technique. They described simultaneous stimulation of the spinal cord with a monopolar stimulator at 2 mA together with transcranial stimulation used to evoke the classic D-wave. Since each stimulation site activates the CST independently, the descending and ascending volleys in the identical fibers at least partially cancel each other out when the location of the spinal cord stimulator is within 1 mm of either CST. This technique has the advantage of specific mapping since the D-wave is specifically CST mediated, to the exclusion of other spinal cord circuitry. However, the collision technique may be challenging on a practical level, due to concerns of laterality, signal interpretation, dynamic sensitivity, and nonapplicability in lesions below T-10. However, future studies comparing both techniques would serve as a good validation of cord stimulation-based CST mapping.

Technical Considerations

From our experience early in the series, some modification of the classic subcortical mapping parameters was necessary. Stimulation under classic parameters (cathodal trains-of-five pulses with an interstimulus interval of 3–4 msec, 500- μ sec duration per pulse) yielded responses in an oversensitive manner, giving warning at areas of the tumor that were visually distant to the pyramidal tracts. Another reason for alteration was the masking of responses by the relatively long stimulus artifact. Using classic train-of-five pulses at the accepted supratentorial parameters,³⁰ a response faster than 14.5–18.5 msec would be obscured. In supratentorial or spinal surgery, where the location of CST activation is far from the muscle target, this is not problematic, but in the context of IMSCTs it is of concern.

Therefore, we modified the technique to use train-of-three pulses and at 200 μ sec, each with an interstimulus interval of 3 msec. This limited the stimulus artifact to an ending latency of 6.2 msec, supporting the recording of early-latency motor responses.

We appreciate that there are various techniques for removing IMSCTs, and using a handheld suction device is also common. The ultrasonic aspirator settings can be adjusted during resection of tumor margins to offer suction only while still allowing for continuous mapping. Thus, in our opinion, this technique is generalizable for various surgical preferences.

Limitations

Certain limitations must be considered when using this multipurpose aspirator. The room for error in surgery for IMSCTs is minimal, and the optimal stimulation settings have yet to be determined. Undersensitive stimulation may lead to irreversible neural damage, while oversensitivity of the stimulation may lead to false-positive alarms, ending with suboptimal resections and leading to a suboptimal oncological result. Our current series is too small to accurately estimate the rates of specificity and sensitivity, neither for false-positive nor for false-negative alarms, thus making solid conclusions impossible at this point.

Another limitation is the dynamics of monitoring versus CUSA mapping. Since it is technically impossible to perform both simultaneously, the recording of one is at the expense of the other. In our study we alternated use of both, but ultimately we used the classic monitoring signs as indications for surgical intervention and postoperative prognostic evaluation. Future studies will need to delineate the hierarchical relationship between mapping and monitoring methodologies, as has been described in supratentorial surgery.³⁶

The ultrasonic aspirator itself may affect the IONM data when used on the dura or the spinal cord,³⁹ altering potentials in a manner unrelated to the resection. Furthermore, the relationship between the ultrasonic aspirator and monitoring of corticospinal pathways can potentially be misleading, as it has been shown that the use of a Cavitron aspirator in proximity to motor pathways may temporarily inhibit motor conduction in cortical mapping⁵ by a facilitatory effect due to the combination of both the electrical and mechanical stimulation.

However, in our experience using this methodology in supratentorial surgery, we have not found either to be an obvious confounding concern. Future studies will need to be designed to delineate the differences in excitability between cranial-based and cord-based CST excitation.

Conclusions

Continuous monitoring of motor tracts during IMSCT resection using a multipurpose resective tool is feasible and safe. It provides real-time continuous data regarding the integrity of motor functions and may serve as an alarm to proximity to the motor tracts prior to physical compromise, diminishing surgical risk in these complex resections. Although it remains to be validated, this new surgical adjunct has groundbreaking potential in resection of IMSCTs. The efficacy of this method needs to be

determined in larger scale studies. Many technical variables need to be considered, including the correlation to D-wave and muscle tcMEP monitoring. The importance of the continuous dialog between the surgical and monitoring teams cannot be overemphasized. The novel technique described herein appears to be promising, safe, and feasible. Larger series will determine whether it is beneficial.

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Disclosures

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author Contributions

Conception and design: Constantini, Barzilai, Korn. Acquisition of data: all authors. Analysis and interpretation of data: Constantini, Barzilai, Bitan-Talmor, Korn. Drafting the article: Barzilai, Korn. Critically revising the article: Constantini, Barzilai, Salame, Korn. Reviewed submitted version of manuscript: Constantini, Barzilai, Lidar, Salame, Korn. Approved the final version of the manuscript on behalf of all authors: Constantini. Administrative/technical/material support: Barzilai, Bitan-Talmor. Study supervision: Constantini, Barzilai, Lidar, Salame, Korn.

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