

Review Article

Intraoperative Neurophysiological Monitoring in Intramedullary Spinal Cord Tumour Surgery

Kazlauskas E^{1*}, Szabo Z² and Raudsepp M³

¹Department of Clinical Neurophysiology, Lithuanian University of Health Sciences, Kaunas, Lithuania

²Department of Neurosurgery, Semmelweis University, Budapest, Hungary

³Department of Neuroanaesthesia, Tallinn University of Technology, Tallinn, Estonia

*Address for Correspondence: Egle Kazlauskas, Department of Clinical Neurophysiology, Lithuanian University of Health Sciences, Kaunas, Lithuania; E-mail: egle.kazlauskas@lsmu.edu

Received: 2 May 2024; Accepted: 26 July 2024; Published: 21 October 2024; DOI: 10.5281/zenodo.22310425

Citation of this article: Kazlauskas E, Szabo Z and Raudsepp M (2024) Intraoperative Neurophysiological Monitoring in Intramedullary Spinal Cord Tumour Surgery. Curr Res Neurol Neurosurg, 7(1): 01-08.

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Abstract

Background: Intramedullary spinal cord tumours (IMSCTs) sit within eloquent tracts, so resection risks worsened weakness. Intraoperative neurophysiological monitoring (IONM) — somatosensory evoked potentials, the epidural D-wave, muscle motor evoked potentials (mMEPs) and free-running or triggered electromyography — gives surgeons real-time feedback on cord integrity.

Objective: To review evidence on IONM modalities, alarm criteria, anaesthesia and outcomes in IMSCT surgery.

Methods: Narrative review of cohort studies, systematic reviews, meta-analyses and position statements.

Findings: A historical control study found MEP monitoring roughly halved new severe deficits. D-wave decline beyond 50% predicts permanent deficit, while isolated mMEP loss is often reversible; intravenous anaesthesia preserves mMEP amplitude far better than volatile agents. Multicentre cohorts and meta-analyses link protocol-driven IONM to reduced permanent morbidity across paediatric and adult series.

Conclusions: Multimodal IONM, interpreted against explicit D-wave and mMEP criteria under intravenous anaesthesia, is central to safe IMSCT resection, though prospective comparative data remain limited.

Keywords: Intramedullary spinal cord tumour; Intraoperative neurophysiological monitoring; Motor evoked potentials; D-wave; Total intravenous anaesthesia

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Introduction

Intramedullary spinal cord tumours — predominantly ependymomas, astrocytomas and haemangioblastomas — arise within the substance of the cord itself, immediately adjacent to or interwoven with the corticospinal tracts and dorsal columns that carry motor and proprioceptive information to and from the limbs. Maximal safe resection is the principal determinant of long-term tumour control, particularly for ependymoma, yet the same dissection plane that permits complete

removal also threatens the white-matter tracts on which neurological function depends. For decades, surgeons relied on anatomical landmarks, the midline myelotomy and subjective tactile feedback alone; the introduction of real-time electrophysiological feedback fundamentally changed this calculus.

Intraoperative neurophysiological monitoring (IONM) combines several complementary modalities: somatosensory evoked potentials for the dorsal columns, the direct epidural D-wave and myogenic motor evoked potentials (mMEPs) for the corticospinal tracts, and free-running or electrically triggered electromyography (EMG) for segmental nerve root and lower motor neuron integrity [1]. Combined use of these modalities, correlated against clinical outcome in large single-centre series, established IONM as more than an adjunct: a landmark historical control study demonstrated that MEP monitoring materially altered surgical decision-making and reduced new severe deficits compared with an unmonitored historical cohort [2]. This review synthesises the published literature on IONM modalities, alarm criteria, anaesthetic requirements and the outcome evidence specific to IMSCT resection, rather than presenting an individual institutional experience.

The rationale for multimodal monitoring rests on the anatomy of the tumour-cord interface. Ependymomas typically arise from ependymal cells lining the central canal and often present a discernible dissection plane, whereas infiltrative astrocytomas blur the boundary between tumour and functioning cord, and haemangioblastomas carry a distinct risk of intraoperative haemorrhage that can itself precipitate ischaemic injury to adjacent tracts. In all three, the surgeon must repeatedly decide whether continued resection along an ambiguous plane is safe, a decision historically made on visual and tactile cues alone. IONM reframes this decision around a physiological read-out obtained in near real

time, at the cost of technical complexity, added operating time, and the need for close, continuous collaboration between surgeon, neurophysiologist and anaesthetist. The sections that follow consider the modalities themselves, the interpretive criteria used to trigger surgical pause, the anaesthetic regimen required to keep those signals interpretable, and the accumulated outcome evidence linking their use to preserved neurological function.

Neurophysiological Modalities and Their Rationale

Somatosensory evoked potentials, generated by stimulating peripheral nerves and recording cortical or subcortical responses, monitor dorsal-column function but correlate poorly with motor outcome when used alone, motivating the addition of motor pathway monitoring [1,3]. The corticospinal tract is assessed through two complementary signals recorded after transcranial electrical stimulation: the D-wave, a direct epidural recording of the earliest descending corticospinal volley that requires little contribution from spinal interneurons, and the mMEP, a compound muscle action potential that depends on a full transcortical-to-muscle circuit and is therefore far more sensitive to anaesthetic and physiological confounders [4]. Free-running EMG passively detects mechanical or thermal irritation of nerve roots or motor neurons during dissection, while triggered EMG confirms the identity of tissue before it is cut or coagulated; a position statement from the American Society of Neurophysiological Monitoring formalised technique, electrode placement and interpretation for this modality [5,6].

Because no single modality is sufficient, contemporary practice uses SEPs, D-wave, mMEP and EMG together, a combination validated across large multimodal series spanning both intramedullary and extramedullary spinal tumours [7]. A position statement from the American Society of Neurophysiological Monitoring on MEP technique underscores that consistent methodology —

montage, stimulus train parameters and muscle selection — is a prerequisite for meaningful comparison across the literature [8]. In practice, SEPs are recorded continuously from posterior tibial and median nerve stimulation to flag positioning-related plexus or peripheral nerve injury as well as dorsal-column compromise, while mMEPs are typically sampled from a montage of upper- and lower-limb muscles after multipulse transcranial stimulation, and the D-wave is recorded from an epidural electrode placed rostral or caudal to the lesion before myelotomy. Free-running EMG runs throughout the resection on a dedicated channel, generating an audible signal that alerts the team to mechanical or thermal irritation without requiring active stimulation, while triggered EMG is used selectively to confirm whether tissue at the resection margin is functional neural tissue before it is transected [3].

Table 1: Principal intraoperative neurophysiological monitoring modalities used in intramedullary spinal cord tumour surgery [1,4,5,6,8,3].				
Modality	Pathway assessed	Signal source	Key sensitivity	Key limitation
Somatosensory evoked potentials (SEP)	Dorsal columns	Cortical/subcortical response to peripheral nerve stimulation	Detects dorsal-column and positioning-related injury	Poor correlation with motor outcome alone
D-wave	Corticospinal tract (direct)	Epidural recording after transcranial stimulation	Low interneuronal dependence; highly specific for permanent injury	Not recordable below the conus; technically demanding placement
Muscle motor evoked potentials (mMEP)	Corticospinal tract (transsynaptic)	Compound muscle action potential after transcranial stimulation	High sensitivity to evolving injury	Highly sensitive to anaesthetic and haemodynamic confounders
Free-running / triggered EMG	Nerve roots, lower motor neuron	Continuous or stimulus-evoked muscle recording	Detects mechanical/thermal irritation in real time	Does not assess corticospinal tract integrity

D-Wave Monitoring: Value and Limits

The D-wave has emerged as the single most outcome-predictive corticospinal signal in IMSCT surgery, because a persistent D-wave despite mMEP loss reliably predicts a transient rather than permanent deficit, whereas D-wave amplitude decline beyond roughly 50% predicts permanent paresis [9,10]. This dissociation gives surgeons an actionable intraoperative rule: mMEP disappearance alone is a warning to pause, reposition retraction or irrigate, while combined D-wave and mMEP loss is a stronger signal to abandon further resection in that plane. A recent systematic review and meta-analysis directly comparing the diagnostic accuracy of D-wave and myogenic MEP monitoring confirmed that D-wave amplitude change carries higher specificity for permanent motor outcome, while mMEP change carries higher sensitivity, supporting a combined interpretive framework rather than reliance on either signal alone [11]. A large single-centre analysis of D-wave utility across IMSCT resections reinforced its predictive value while highlighting practical limitations: the D-wave cannot be recorded reliably below the conus, and epidural electrode placement is technically demanding in reoperative or previously irradiated fields [12]. A focused review of direct-wave neuromonitoring situates these findings within the broader literature on spinal tumour resection and highlights ongoing variability in electrode technique and reporting between centres [13]. Most recently, a large cohort study refined warning criteria for combined D-wave and MEP loss specifically for intramedullary resection, proposing thresholds intended to reduce false alarms without sacrificing sensitivity to genuine injury [14]. Taken together, this body of work supports a graded response protocol: an isolated, partial mMEP decrement prompts closer observation and a pause in dissection; a complete unilateral mMEP loss with preserved D-wave allows cautious continuation with heightened vigilance; and any substantial D-wave decline, particularly when

paired with bilateral mMEP loss, is treated as a signal to stop resection in that region regardless of how much macroscopic tumour remains, since the D-wave's low interneuronal dependence makes it comparatively resistant to anaesthetic and haemodynamic confounding.

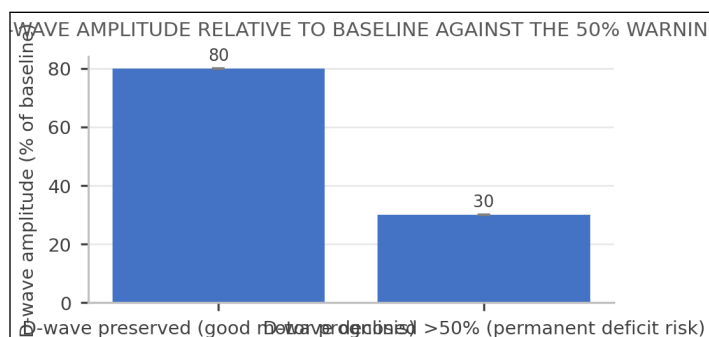


Figure 1: Illustrative D-wave amplitude relative to baseline against the widely used 50% warning threshold: preservation above 50% of baseline is associated with a good long-term motor outcome, whereas decline beyond 50% (or total loss) is associated with permanent motor deficit [9,10].

Alarm Criteria, False Positives and False Negatives

Because intraoperative alarms can prompt surgeons to abandon resection prematurely, well-calibrated alarm criteria are essential to avoid trading oncological completeness for a false sense of safety. An analysis of false-positive and false-negative MEP results during IMSCT surgery found that all-or-none amplitude loss criteria minimised false negatives at the cost of more frequent false alarms, whereas percentage-amplitude-decrease criteria reduced false positives but risked missing evolving injury, illustrating an unavoidable trade-off that must be tailored to tumour location and surgical goal [15]. The American Society of Neurophysiological Monitoring's position statement on MEP monitoring recommends that alarm criteria be interpreted alongside D-wave data whenever technically feasible, precisely because mMEP-only criteria carry a meaningfully higher false-positive rate in intramedullary surgery than in extramedullary or degenerative spine procedures [8]. The joint American Academy of

Neurology/American Clinical Neurophysiology Society evidence-based guideline update likewise concludes that combined SEP and transcranial MEP monitoring is probably effective for predicting and reducing the risk of postoperative deficit, while cautioning that evidence quality for isolated modalities remains weaker [16]. Beyond amplitude-based criteria, some centres additionally track stimulation threshold, since a rising threshold required to elicit a stable mMEP can itself indicate evolving injury even before amplitude collapses outright, and this threshold-based approach may reduce false alarms in prolonged resections where gradual haemodynamic drift, rather than acute mechanical injury, is the more likely explanation for a slow amplitude decline.

Table 2: Selected outcome and methodology studies of intraoperative neurophysiological monitoring in intramedullary spinal cord tumour surgery reviewed here [2,21,22,23,26,24,25,15].			
Study	Population	Design	Key finding
Sala et al. 2006	Adults, n=100 (50 monitored, 50 historical control)	Historical control study	MEP monitoring significantly improved long-term motor outcome
Cheng et al. 2014	Children with IMSCT	Single-centre cohort	Intraoperative MEP/SEP change predicted postoperative motor outcome
Rijs et al. 2019	Pooled adult and paediatric IMSCT cohorts	Systematic review and meta-analysis	Signal preservation consistently associated with favourable outcome
Mirza et al. 2022	Adults, single-centre surgical series	Retrospective case series	Intraoperative signal preservation an independent predictor of outcome
Kurokawa et al. 2018	Adults undergoing IMSCT resection	Retrospective cohort	All-or-none vs percentage-decrease alarm criteria trade false negatives against false positives
Rashad et al. 2017	Adults, single-centre series	Retrospective cohort	Monitoring informed extent of resection achievable without new deficit

Study	Population	Design	Key finding
Tropeano et al. 2023	Adults, 10-year single-centre experience	Retrospective cohort	Protocol-driven multimodal IONM associated with low permanent morbidity
Siller et al. 2026	Adults, cervical/thoracic IMSCT	Prospective quality-of-life cohort	Most patients maintained functional independence after IONM-aided resection

Anaesthetic Considerations: TIVA versus Volatile Agents

Motor evoked potentials are exquisitely sensitive to anaesthetic technique, because volatile halogenated agents and nitrous oxide suppress transmission at the corticomotoneuronal synapse in a dose-dependent manner, often abolishing mMEPs even when the corticospinal tract itself is intact. A comparative study of total intravenous anaesthesia (TIVA) against balanced anaesthesia incorporating 3% desflurane found substantially better MEP monitorability under TIVA, with more patients achieving reliable baseline responses [17]. A broader review of anaesthetic impact on transcranial MEP monitoring across spine surgery similarly concluded that propofol- and opioid-based TIVA, avoiding neuromuscular blockade beyond intubation, is the preferred regimen wherever mMEP monitoring is planned [18]. A focused review of anaesthesia for spinal cord monitoring extends this guidance to dosing strategy, monitoring depth of anaesthesia and managing haemodynamics to preserve amplitude without compromising surgical conditions [19]. Newer intravenous hypnotics are also being evaluated: a randomised controlled trial comparing propofol with remimazolam during TIVA for cervical spine surgery found comparable IONM signal quality between agents, suggesting remimazolam may offer a viable propofol alternative without degrading monitoring fidelity [20].

Evidence for Outcome Benefit

Beyond the foundational historical control study [2],

subsequent evidence has broadened across age groups and centres. In children, intraoperative MEP and SEP changes predicted postoperative motor outcome with high accuracy in a paediatric IMSCT cohort, supporting extension of adult-derived monitoring protocols to younger patients [21]. A systematic review and meta-analysis pooling IONM cohorts in intramedullary tumour surgery found consistent associations between preserved intraoperative signals and favourable postoperative motor status, while noting substantial heterogeneity in alarm criteria across included studies [22]. Large single-centre case series report similar findings: a prognostic-factor analysis across a substantial surgical series identified intraoperative signal preservation as an independent predictor of neurological outcome alongside tumour histology and preoperative function [23], a technique-outcome analysis emphasised how monitoring informed the extent of resection achievable without new deficit [24], and a ten-year single-centre experience with multimodal IONM reported low permanent morbidity attributable in part to protocol-driven intraoperative decision-making [25]. A quality-of-life study following IONM-aided resection found that most patients maintained functional independence at follow-up, reinforcing that intraoperative signal preservation translates into meaningful long-term status rather than short-term neurological scores alone [26]. A commentary examining the broader evidence base cautioned that outcome benefit, while consistently observed, is drawn mainly from historical-control and cohort designs rather than randomised trials [27]. Where nonoperative management is chosen for indolent ependymoma, natural-history data describing slow symptomatic progression provide useful context for weighing monitored resection against observation [28].

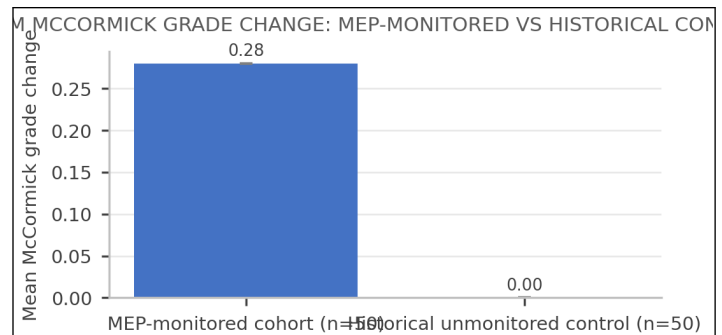


Figure 2: Long-term McCormick grade change in the landmark historical control study: the motor evoked potential (MEP)-monitored cohort (n=50) showed a significant mean improvement of +0.28 (P=0.0016), while the unmonitored historical control cohort (n=50) showed no significant change [2].

Conclusion

The published literature — spanning foundational historical-control data, modality-specific validation of the D-wave and mMEP, position statements and guidelines on technique and alarm criteria, anaesthetic optimisation studies, and an expanding base of paediatric, adult and multicentre outcome series — supports multimodal IONM as integral to contemporary IMSCT resection. D-wave and mMEP together, interpreted against explicit percentage- and all-or-none-based alarm criteria and recorded under intravenous anaesthesia, give surgeons real-time, reasonably specific feedback on corticospinal integrity that a purely anatomical approach cannot provide. Persistent gaps remain: reliable D-wave recording below the conus, standardisation of alarm thresholds across centres, and prospective comparative outcome data beyond historical controls. Addressing these gaps should be a priority for future multicentre collaboration in this field.

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