Intraoperative neurophysiological monitoring for spinal tumor surgery: Workflow and set-up

**Background**

**Intraoperative neurophysiological monitoring**

Intraoperative neurophysiological monitoring (IONM) was introduced in the 1960´s and was primarily used to prevent neurological complications when performing surgery for correcting spinal deformities. (ref). The term "monitoring" denotes the continuous assessment of the functional integrity of neural pathways. The primary objective of monitoring is the rapid detection of surgically induced neurophysiological alterations, enabling timely intervention to address the underlying cause and prevent potential neurological deficit.

**Somatosensory evoked potentials (SSEP)**

SSEP monitoring is recorded by placing electrodes along the sensory pathway of the nerve that is monitored, all the way to the scalp of the patient where the electrodes pic up cortical responses to the evoked potentials transmitted from the peripheral placed electrodes. (ref)

This technology was developed during the 70´s and intraoperative use commenced in the 80´s. (ref) First at academic centers but by 1989 as a protocol for standard care by the American Academy of Neurology. (ref). SSEP monitoring is valuable for assessing the functional integrity of sensory pathways, tracking signals from the peripheral nerves through the dorsal columns to the sensory cortex.

**Motor evoked potentials (MEP)**

The monitoring of MEP is used to safeguard the motor neural pathways during surgery of the spinal cord. A stimulus induced at a needle in the scalp generates a stimulus in the motor cortex that travels along the corticospinal tract along the spinal cord. The impulse goes out the nerve root and terminates in the muscle where a receiving electrode needle is placed. If the signal is detected the neural pathway is intact. (ref)

Muscle MEPs are elicited using transcranial electrical stimulation (TES) with a multi-pulse technique, where the stimulus is delivered to the motor cortex via subcutaneously placed corkscrew electrodes, and the resulting potentials are recorded using needle electrodes inserted into various upper and lower extremity muscles bilaterally.

Although a lot of work had been done as early as the 1950´s to map the motor cortex of the brain the possibility to monitor motor evoked potentials (MEPs) was not clinically available until 2002 when the FDA approved the use of transcranial electrical stimulators. (ref) IONM is today widespread in spine surgery, especially surgery involving the spinal cord. Neurophysiological monitoring with SEP, MEP and D-wave are today considered gold standard. Monitoring all these parameters allows for a safer surgical approach to achieve radical tumor resection. (Sala. Et.al 2007) (sutter 2007, Multimodal…)

**Direct wave (D-wave)**

Monitoring D-waves during spinal surgery is a method for selectively monitoring the lateral corticospinal tract. This method is especially used when resecting intramedullary tumors in the spine. By placing an electrode in the epidural space above, and below the segment where the tumor is located the lateral corticospinal tract can be closely monitored by eliciting single-pulse transcranial impulses and any sign that the resection is affecting the function of the corticospinal tract can be detected early. (ref). This waveform is a highly reliable parameter for monitoring the functional integrity of the corticospinal tract intraoperatively, as it represents a population of fast-conducting fibers of the corticospinal tract and is robust under general anesthesia (ref).

**Bulbocavernosus reflex (BCR)**

Monitoring the bulbocavernosus reflex (BCR) is an intraoperative method to gain information about the sphincter function and the state of the sacral spinal cord segments (S2–S4) during spinal cord surgery. The dorsal nerves of the penis or clitoral are usually stimulated with bilateral electrical stimulation and recordings are obtained bilateral from the sphincter ani externus.

Although neurophysiological monitoring is recommended and considered necessary when performing surgery on intramedullary tumors there appears to be no consensus considering intraoperative monitoring set-up with regards to who is analyzing the intraoperative signals. A popular set up is one where a technologist is usually present in the OR while the neurophysiologist physician is supervising, often off-site and sometimes monitoring several cases simultaneously. (ref) Other set-ups include a technologist in the OR with a physician close by to be summoned to the OR if needed, or a physician present in the OR at all times. (ref)

In some set-ups the operating surgeon is also the one monitoring the neurophysiological parameters intraoperative (ref)

**Intramedullary spinal surgery**

Approximately 10-20% of spinal tumors are located in the intramedullary part of the spinal cord.

The symptoms of intramedullary spine tumors are neuropathic pain as well as motor and sensory symptoms from the spinal cord segments affected by the tumor. (Ref) If left untreated, the patients may suffer worsening pain, and neurologic deterioration that can lead to paraplegia or quadriplegia. Surgery with radical resection is the best treatment option and associated with increased long-term survival. (ref)

The localization of these tumors makes surgery difficult and the risk of causing permanent damage to the spinal cord high. To avoid causing neurological damage during surgery intraoperative neurophysiological monitoring is used.

**The aim of this study was to present our institutional integrated workflow for neurophysiological monitoring during intramedullary spinal tumor surgery and to describe our experience using this workflow in a consecutive series of surgeries.**

We also wanted to look at the possible correlation between intraoperative neurophysiological monitored parameters and postoperative outcome.

**Methods**

In this historical cohort we included all adult patients that had undergone intramedullary spine surgery from 2007-2021. All patients had a pre-op screening for motor and sensory deficiency, pain, bowel and bladder function as well as modified McCormic and AISA scores. The same screening was made 3-month post-op, and at long term follow up at least a year after surgery.

The study hospital is a publicly funded and owned tertiary care center serving a region of roughly 2.3 million inhabitants, and the only neurosurgical center in the region.

**Workflow**

**Anesthesia**

Patients were induced with Propofol and muscle relaxed with Rocuronium 0,6mg/kg. Throughout the surgery total intravenous anesthesia was given using Target Controlled Infusion (TCI) of Propofol® and Remifentanil®. Dosing according to Ce-values, concentration on effect site the brain. For Propofol® the Modified Marsh model and for Remifentanil® the Minto model was used. Rocuronium® was used as a muscle relaxation for endotracheal intubation. No additional dose of Rocuronium® was given during surgery to avoid interfering with neurophysiological monitoring responses. A special chewing block were placed in the patients mouth to prevent injury to the endotracheal tube and the patient from biting due to muscle twitching during neurophysiological stimulation.

For patient monitoring non-invasive and invasive blood pressure, ECG, SpO2 and End-Tidal CO2 capnography were used during the entire procedure.

**Preparing the patient**

While in a supine position the electrodes for neurophysiological monitoring were connected to the front of the patient. A Mayfield head clamp was attached if surgery was performed in the cervical or upper thoracic spine. For lower spine cases the patient’s head was rested on a pillow. The patient was turned over to a prone position from one OR table to another. The remaining electrodes were connected, and the surgery started.

Baseline values for SEP and MEP were acquired at the start of the surgical procedure.

**Intraoperative Neurophysiological Monitoring Methods; MEPs, D-wave, SSEPs & BCR**

Here we describe a summary of our sensory evoked potentials (SSEPs) and motor evoked potentials (MEPs) methodologies. The Cadwell Cascade IONM System was used for intraoperative stimulation and recordings.

**Motor Evoked potentials (MEPs)**

Short trains of 5–9 square-wave stimuli of 0.5 ms duration and interstimulus interval (ISI) of 3 ms are delivered at a repetition rate of up to 2 Hz through screw electrodes placed at C1 and C2 scalp sites, according to the international 10-20 EEG system. The stimulation intensity ranges from 200 to 1000 V. MEPs are recorded via needle electrodes inserted into upper and lower extremity muscles bilaterally. For the cervical tumors, signals are usually recorded from the abductor digiti minimi for hands and tibialis anterior and the abductor hallucis for legs. For thoracic tumors, in addition to the above-mentioned muscles, we record from muscles rectus abdominis, iliopsoas, adductor magnus, vastus lateralis, gastrocnemius caput mediale and sphincter ani externus.

MEPs are assessed intermittently to minimize the impact of muscle twitches on microsurgical precision. It is widely recognized that the loss of MEPs with preserved D-wave signals typically indicates a temporary motor deficit post-operatively. In contrast, the combined loss of MEPs and a reduction of more than 50% in D-wave amplitude is predictive of severe long-term motor deficits (ref).

**D-wave**

When the spinal canal is open, the D-wave catheter is placed in the epi- or subdural space of the spinal cord distal (caudal) to the tumor. Whenever possible, we place an epidural electrode also proximal (rostral) to the tumor as a control recording. A single transcranial electrical stimulus is applied, using the same stimulation parameters as for MEPs. The D-wave is continuously monitored throughout the procedure, Baseline D-waves are recorded before the dura is opened, prior to any surgical manipulation of the spinal cord. A decrease of 50% or more of the baseline amplitude recorded caudally from the tumor is considered significant leading to an immediate halt in the surgical procedure and the initiation of corrective actions.

**Somatosensory Evoked Potentials (SSEPs)**

For SSEP registration corkscrew electrodes are placed on the cortex with four localizations Fz', Cz', C3' and C4' according to the international 10-20 EEG system. Needle electrodes are placed over the plexus bilaterally. For electrical stimulation disposable electrodes or needle electrodes are placed on the median nerve and posterior tibial nerve bilaterally. The SSEP potential is defined based on the latency and duration in milliseconds (ms) and the amplitude in microvolts (μV). The electrical stimulation parameters vary around 10-30 mA.

The first response potential is registered over the brachial plexus and results in the response potential N9 which arises approximately 9 ms after the electrical stimulation. The second response comes from the somatosensory cortex contralaterally from the stimulation corresponding to the path of the nerve impulse to the cortex and is marked out as N20 and arises after about 20 ms.

In case of a significant deterioration in SSEPs, the surgeon is notified, and the myelotomy is either temporarily paused or redirected to a different site. However, if the SSEPs do not recover but motor evoked potentials (MEPs) and D-waves remain stable, the procedure is allowed to proceed. Therefore, decreases in SEP signals are generally not considered a criterion to abandon surgery, as SEPs are highly sensitive to surgical manipulation.

**Bulbocavernosus reflex (BCR)**

In men disposable surface electrodes are used and active electrode is placed proximal and the reference on the distal penis. In women disposable electrodes or needle electrodes are used and the active electrode is placed in the clitoris and the reference is placed in labia majora. The recordings are made from the anal sphincter using needle electrodes. The stimulation settings were a single train of 5 stimulation pulses with duration of 500 μs, and the electrical stimulus intensity was between 20 mA to a maximum of 50 mA for generating a recordable BCR waveform.

We used the following alarm criteria in the monitoring of the patients in the study.

* 50% decrease in SEP amplitude, 10% increase in latency,
* 80 % or more decrease or total loss of muscle MEP
* 50 % or more decrease in the D wave amplitude

**Statistical analysis (to be written by David)**

HÄR

If any of the IONM signals decreased in amplitude past the alarm criteria or completely disappeared during surgery, the following checklist was followed.

Stop surgical manipulation and traction.  
Increase the blood pressure from MAP 70 to 80-90.  
Apply Papaverine to the spinal cord.  
Wait for the signal to stabilize.

If the signal was still lowering the were always a discussion about whether to continue the surgery or to back out, not to cause further damage.

The change in intraoperative monitored neurophysiological parameters were categorized as unchanged, amplitude decrease or loss of response.

The changes at 3 month, and long term follow up in motor and sensor deficiency, pain, bowel and bladder functions, modified McCormic and AISA scores were categorized as unchanged, worse or better.

Odds ratios were calculated between intraoperative changes in monitored neurophysiological parameters and changes in 3 month and long term follow up for motor and sensory deficiency, pain, bowel and bladder function as well as modified McCormic and AISA scores.

**Ethical considerations**

The study was approved by the national ethical authority: 2016/1708-31

Since this is a retrospective study, all data used in this study is already in the journal system of the hospital. No informed consent was needed when using this data retrospectively.

**Results**

A total of 71 (70) patients were included in the study.

(Table 1)

|  |  |  |
| --- | --- | --- |
|  | **n** | **%** |
| **Sex** |  |  |
| Male | 44 | 63% |
| Female | 26 | 37% |
|  |  |  |
| **Age, median** 43 (19-74) |  |  |
| 19-37 | 27 | 38% |
| 38-55 | 25 | 36% |
| 56-74 | 18 | 26% |
|  |  |  |
| **Confirmed diagnosis** |  |  |
| Ependymoma | 26 | 37% |
| Ependymoma (myxopapillary) | 9 | 13% |
| Subependymoma | 1 | 1.4% |
| Hemangioblastoma | 13 | 18.6% |
| Melanocytoma | 1 | 1.4% |
| Cavernoma | 6 | 9% |
| Astrocytoma | 2 | 2.8% |
| Lymphoma | 1 | 1.4% |
| Inconclusive PAD | 3 | 4.2% |
| Epidermal cyst | 1 | 1.4% |
| Malignant neuroectodemal tumor (Ewings tumor/PNET) | 1 | 1.4% |
| Lipoma | 1 | 1.4% |
| Syringohydromyelia | 1 | 1.4% |
| Schwannoma | 1 | 1.4% |
| Dermoid tumor | 1 | 1.4% |
| Metastasis (adenocarcinoma) | 1 | 1.4% |
| Diffuse glioma | 1 | 1.4% |
|  |  |  |
| **Level** |  |  |
| Cervical | 28 | 40% |
| Cervicothorasic | 10 | 14% |
| Thorasic | 14 | 20% |
| Thoracolumbar | 9 | 13% |
| Lumbar | 9 | 13% |

Odds ratios were calculated for changes in sensory deficiency, mMC, ASIA and pain based on intraoperative changes in SSEP.

Odds ratios were calculated for changes in motor deficiency, mMC, ASIA, bladder and bowel function based on intraoperative changes in MEP.

Odds ratios were calculated for changes in motor deficiency, mMC, ASIA, pain, bladder and bowel function based on intraoperative changes in D-Wave.

First, we investigated the correlation of the intraoperative SSEP changes with the short-term (3 months) and long-term (>1 year) clinical outcomes that included the sensory function changes in the lower extremities, modified McCormick and ASIA scales, and the pain presence. The results are reported in Table 1. The odds of the sensory function worsening in the right or the left leg at 3 months post-operatively were 25.19 time higher if the intraoperative SSEPs were lost (CI=4.70 to 135.07, p-value<0.001). This odds ratio decreased to 11.00 (95%CI=2.76 to 43.80, p-value<0.001) at the long-term follow-up. The odds ratio of McCormick scale worsening in the right or the left leg at the 3 months post-operatively was 7.77 (CI=1.95 to 30.96, p-value=0.004) when the intraoperative SSEPs were lost. The odds ratio increased to 11.00 (95%CI=2.76 to 43.80, p-value<0.001) at long-term follow-up. The odds of the pain presence at the 3 months postoperatively were 5.25 times higher if the SSEP amplitude decrease was observed intraoperatively (CI=1.23 to 22.32, p-value= 0.025). Accordingly, this odds ratio for the presence of the pain long-term was 5.50 (CI=1.48 to 20.39, p-value=0.011) when the SEP amplitude was decreased intraoperatively, and 4.81 (CI=1.26 to 18.31, p-value=0.021) with loss of the SEP response.

No significant associations between ASIA IS change and intraoperative SSEP amplitude decrease, or loss were observed at either short- or longterm follow-ups.

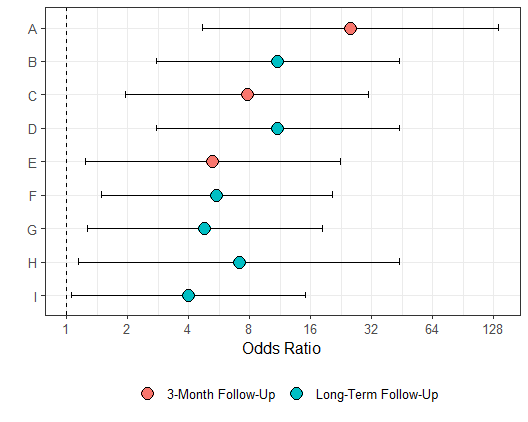
Table 1: SSEP correlation with the clinical outcomes,

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| --- | --- | --- | --- | --- |
| Outcome odds | Predictor odds | Odds Ratio  (95%CILB; 95%CIUB) | P-Value | Significance |
| Sensory function worsening at 3 months post-op vs. Unchanged | Amplitude decrease of SSEPs in the right or the left leg intraoperatively vs. Unchanged | 3.01  (0.86; 10.59) | 0.085 |  |
| Sensory function worsening at 3 months post-op vs. Unchanged | Loss of SSEPs in the right or the left leg intraoperatively vs. Unchanged | 25.19  (4.70 to 135.07) | <0.001 | \*\* |
| Sensory function worsening in the long-term post-op vs. Unchanged | Amplitude decrease of SSEPs in the right or the left leg intraoperatively vs. Unchanged | 3.30  (0.87; 12.53) | 0.080 |  |
| Sensory function worsening in the long-term post-op vs. Unchanged | Loss of SSEPs in the right or the left leg intraoperatively vs. Unchanged | 11.00  (2.76; 43.80) | <0.001 | \*\* |
| McCormick scale worsening at 3 months post-op vs. Unchanged | Amplitude decrease of SSEPs in the right or the left leg intraoperatively vs. Unchanged | 1.57  (0.33; 7.52) | 0.573 |  |
| McCormick scale worsening at 3 months post-op vs. Unchanged | Loss of SSEPs in the right or the left leg intraoperatively vs. Unchanged | 7.77  (1.95; 30.96) | 0.004 | \*\* |
| McCormick scale worsening long\_term post-op vs. Unchanged | Amplitude decrease of SSEPs in the right or the left leg intraoperatively vs. Unchanged | 1.27  (0.28; 5.85) | 0.76 |  |
| McCormick scale worseninglong-term post-op vs. Unchanged | Loss of SSEPs in the right or the left leg intraoperatively vs. Unchanged | 11.00  (2.76; 43.80) | <0.001 | \*\* |

Table 2: MEP correlation with the clinical outcomes

The odds of motor function worsening long-term were 7.09 times higher when MEPs amplitude was decreased intraoperatively (CI=1.14 to 43.96, p-value=0.035). In addition, the odds of worsening of McCormick were 4.00 times higher with the intraoperative MEPs loss (CI=1.06 to 15.08, p-value=0.041). We have not observed any statistically significant associations between ASIA IS, bladder and bowel function changes and intraoperative MEPs loss or amplitude decrease at either short- or long follow-ups.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Outcome odds | Predictor odds | Odds Ratio  (95%CILB; 95%CIUB) | P-Value | Significance |
| Motor function worsening at 3 months post-op vs. Unchanged | Amplitude decrease of MEPs in the right or the left leg intraoperatively vs. Unchanged | 5.14  (0.84; 31.31) | 0.076 |  |
| Motor function worsening at 3 months post-op vs. Unchanged | Loss of MEPs in the right or the left leg intraoperatively vs. Unchanged | 2.57  (0.71 to 9.33) | 0.151 |  |
| Motor function worsening in the long-term post-op vs. Unchanged | Amplitude decrease of MEPs in the right or the left leg intraoperatively vs. Unchanged | 7.09  (1.14; 43.96) | 0.035 | \*\* |
| Motor function worsening in the long-term post-op vs. Unchanged | Loss of MEPs in the right or the left leg intraoperatively vs. Unchanged | 3.55  (0.95; 13.2) | 0.059 |  |
| McCormick scale worsening at 3 months post-op vs. Unchanged | Amplitude decrease of MEPs in the right or the left leg intraoperatively vs. Unchanged | 4.00  (0.70; 22.88) | 0.119 |  |
| McCormick scale worsening at 3 months post-op vs. Unchanged | Loss of MEPs in the right or the left leg intraoperatively vs. Unchanged | 4.00  (1.06; 15.08) | 0.041 | \*\* |
| McCormick scale worsening long\_term post-op vs. Unchanged | Amplitude decrease of MEPs in the right or the left leg intraoperatively vs. Unchanged | 1.27  (0.28; 5.85) | 0.76 |  |
| McCormick scale worseninglong-term post-op vs. Unchanged | Loss of MEPs in the right or the left leg intraoperatively vs. Unchanged | 11.00  (2.76; 43.80) | <0.001 | \*\* |



|  |  |
| --- | --- |
| Sensory Worse at 3 Months / Intraoperative SEP Feet loss of response vs. unchanged | A |
| Sensory Worse Long-Term / Intraoperative SEP Feet loss of response vs. unchanged | B |
| McCormick Scale Worse at 3 Months / Intraoperative SEP Feet loss of response vs. unchanged | C |
| McCormick Scale Worse Long-Term / Intraoperative SEP Feet loss of response vs. unchanged | D |
| Pain Worse at 3 Months / Intraoperative SEP Feet amplitude decrease vs. unchanged | E |
| Pain Worse at Long-Term Follow-Up / Intraoperative SEP Feet amplitude decrease vs. unchanged | F |
| Pain Worse at Long-Term Follow-Up / Intraoperative SEP Feet loss of response vs. unchanged | G |
| Motor Worse at Long-Term / Intraoperative MEP Legs amplitude decrease vs. unchanged | H |
| McCormick Scale Worse Long-Term / Intraoperative MEP Legs loss of response vs. unchanged | I |

No statistically significant correlations were observed between intraoperative D-wave changes and motor function changes, McCormick, ASIA IS, Pain, Bladder and Bowel functions at 3 months and long-term, postoperatively.

Several ORs examining correlations of distal intraoperative D-wave changes with outcomes including 3-month motor function change (OR=2.75), 3-month and long-term McCormick scale (OR=3.11 and 4.87, respectively), log-term ASIA IS (OR=2.58) and long-term bowel function change (OR=4.00) were greater than 2 but none of the them were statistically significantly different from 1 (all p-values > 0.05).

**Discussion**

The use of intraoperative neurophysiological monitoring is of great importance for providing the safest possible environment for intramedullary spine surgery. In our study, the presence of a neurophysiologist physician in the OR at all times, being the one that interprets the live signals is a set-up that is not applied everywhere but highly recommended in the literature. (ref)

Having a neurophysiologist physician present in the OR contributes to more efficient communication with the surgical team. Increases the probability that the information about alterations in the signals are communicated in a correct way and that the communication leads to an action in the surgical field. (ref)

**Limitations**

The biggest limitation of this study is the small sample size. Intramedullary tumors are rare and even with an aggregated cohort over many years it is difficult to get enough patients to be able to perform good statistical calculations. Another limitation is the neurophysiological data only shows if signals are unchanged, decreased in amplitude or a total loss of response. Information about how much signals decreased would be valuable to try and calculate critical levels of signal decrease intraoperative and compare to postoperative neurological outcome parameters.