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Outline and Benefits of Multi-Modality Intraoperative Neuromonitoring in Spine Surgery Explained with a Case Report

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Abstract*: *The major complication of any form of spinal surgery is neurological insult which can result in serious post-operative sensory or motor deficit. Intraoperative neuromonitoring has evolved to identify and help to avert these insults through real time assessment of the spinal cord function. This paper is to provide an outline of the major modalities utilised in Intraoperative neuromonitoring during spine surgery, how they help in identifying neurological insults and aid in reducing post operative deficits, all explained through a case report.

Keywords* : *Neuromonitoring, Spine Surgery

I. INTRODUCTION

Intraoperative neuromonitoring (IONM) is widely used in spine surgeries and is now part of standard medical practice. The purpose of IONM is to allow early intervention by identifying neural insults intraoperatively which can help minimize or eliminate irreversible damage to the neurological structure thereby preventing a postoperative neurologic deficit. The American Society of neurophysiological monitoring defines neurophysiologic monitoring as "includes any measure employed to assess the ongoing functional integrity of the central or peripheral nervous system in the operating theatre or other acute care setting. Its mission is protection of the patient's nervous system. Neurophysiologic signals are monitored continuously during surgery for adverse changes, detection of which enables corrective action. Risk of postoperative neurological deficit, such as weakness, loss of sensation, hearing loss and impairment of other bodily functions is thereby reduced."

II. IONM TECHNIQUES

IONM helps to improve patient outcomes by preventing post-operative neuro deficits. Multi-modality neuromonitoring with commonly used modalities or techniques for spinal surgeries include (Figure 1):

SSEP-The somatosensory evoked potentials (SSEP) are electrical potentials recorded from the somatosensory cortex in response to stimulation of a peripheral nerve (most commonly the median or ulnar nerve at the wrist for upper extremities or the posterior tibial nerve at the ankle or peroneal nerve at the knee for lower extremities). These potentials are recorded by subdermal needle electrodes placed along the medial lemniscus dorsal column pathway and over the scalp, using the 10-20 international system, as they travel from the peripheral nerve through the pathway to the sensory cortex. Cortical responses are usually recorded at a latency of 20msec for the uppers and 37msec for the lower extremities. The patient is his own control, all changes are measured against his baseline. A decrease in amplitude of greater than 50% or an increase in latency of greater than 10% is considered as alarm criteria for post-operative deficit.

SSEP is monitored continuously throughout procedures to assess the functional integrity of the somatosensory pathway. Though they are a good indicator of spinal cord function, SSEP are also susceptible to anesthetic and physiologic changes. Halogenated agents, hypothermia, hypotension are some factors that should be taken into consideration when a change in amplitude or latency is noticed.

TcMEP-Transcranial motor evoked potentials (TcMEP/ MEP) monitor the descending motor pathways (corticospinal tracts) from the motor cortex to the peripheral muscles. The blood supply for the motor tracts is from the anterior spinal artery while the somatosensory tracts are perfused by the posterior spinal arteries, hence there can be motor deficits without changes in SSEPs. This is where TcMEP monitoring plays a significant role.

MEP responses are generated by transcranial electrical stimulation on the scalp by using subdermal needle electrodes placed at C1 and C2 or C3 and C4 positions of the 10-20 international system or via direct cortical stimulation. The transcranial electrical stimulation is a multipulse stimulation and compound muscle action potentials (CMAP) are measured over the spinal cord or in the muscle of interest. At the spinal level, the response is measured in the epidural or intrathecal space and is called a D-wave (direct). The muscle responses are recorded from electrodes placed in the muscle innervated by specific nerve root, brain region or cranial nerve. Muscles are selected based on the surgical procedure and spinal levels involved. Frequently used sites are thenar muscles for the hand, tibialis anterior and abductor hallucis for the leg. The muscle groups rostral to the surgery level are typically used as a control. For interpretation of MEP

responses, either a all or none response criteria or a decrease in amplitude of greater than 50% is considered as alarm criteria for post-operative deficit.

MEP responses are highly sensitive to anesthetic and physiologic changes. Total intravenous anesthesia using propofol and fentanyl is used to achieve reliable recordings. To record CMAPs from the muscles there should be no neuromuscular blockade, hence there may be patient movement during stimulation. Having a defibrillator, cochlear implant, deep brain stimulator and other implanted devices are relative contraindications for MEP monitoring and the benefits of monitoring should be assessed in these situations. Despite the limitations, TcMEP monitoring is highly beneficial in assessing motor cord function and preventing permanent motor deficits or paraplegia.

EMG-Electromyography (EMG) is real time recording of selective nerve root function specific to a muscle during spine surgery. One muscle group per nerve is monitored by using spontaneous EMG or triggered EMG technique. Since one muscle can have multiple nerve innervations or vice versa, multiple muscles should be used to maximize coverage. In Spontaneous EMG(SpEMG), subdermal needle electrodes are directly placed in the specific muscle to record its activity without any stimulation. SpEMG is sensitive to surgical manipulation such as compression or stretching of nerves which produces firing in the corresponding innervated muscles. Spikes, bursts or trains are indicative of injury. Continuous, repetitive firing or train indicates a high probability of nerve injury. SpEMG is highly dependent on having no neuromuscular blockade, hence train of four (TOF) is measured at regular intervals. A minimum TOF of 2/4 twitches is necessary to say EMG monitoring is reliable.

Triggered EMG for pedicle screw stimulation- Triggered EMG is used to check pedicle integrity and proper positioning during pedicular screw placement. The most common complication is a potential medial breach of pedicle wall into the spinal canal. A monopolar electrode stimulates the top of the pedicle screw with increasing current intensities. Subdermal needle electrodes are placed in the appropriate muscle groups to record CMAPs in response to the stimulation. Direct stimulation of nerve root can also be performed with less than 5mA intensity to identify target muscle activity. A screw that breaches the medial or inferior pedicle wall reduces the stimulation threshold and increases the risk of damage. An irritated or damaged nerve root produces a response at a significantly lower stimulation intensity. A muscle response at less than 10mA intensity is considered an alert for a possible breach. As in SpEMG, triggered EMG is also dependent on having no neuromuscular blockade. Train of four is measured and 4/4 twitches are required for optimal recording.

Train Of Four (TOF)- TOF is used to monitor degree of neuromuscular blockade. 4 single pulses of supramaximal stimulation are applied at a peripheral nerve and amplitude of corresponding muscle responses are recorded for each pulse. 1/4= 90% blockade, 2/4=80%, ¾=75% and 4/4=0-75%. Ideal is 4/4. Usually, the ulnar nerve is stimulated, and responses recorded from abductor pollicis brevis for upper extremities, posterior tibial nerve stimulated, and responses recorded from abductor hallucis for lower extremities.

EEG-Limited Electroencephalography (EEG)is monitored during surgeries as an adjunct to anesthesia, to measure depth of anesthesia.

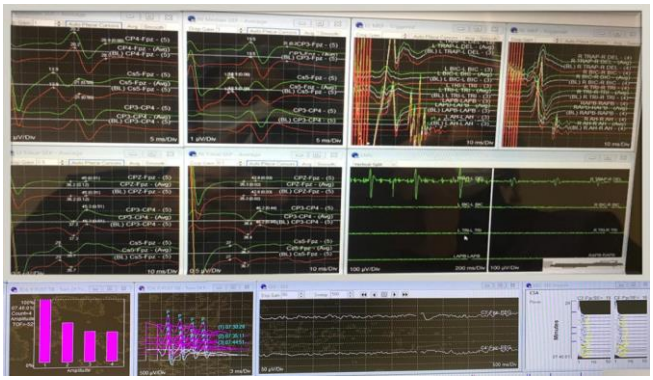

Figure 1: IONM screen showing all modalities monitored.

Left side of picture- Left and Right Median Nerve and Posterior Tibial Nerve SSEP responses.

Right upper corner- Left and Right Upper and Lower extremity MEP responses.

Right lower corner- Spontaneous EMG responses from muscles specific to surgical levels.

Below- TOF with analysis and EEG with CSA

III. KEY PLAYERS

For IONM to be reliable and prevent neurological insult, communication, and cooperation between intraoperative neuromonitoring (IONM) technician, anesthesiology team, and surgery team, is essential. CNIM certified technologist will setup and monitor the patient and identify changes. Interpreting Physician (remote or in room) confirms changes, interprets them to relay to surgeon. Surgeon plays a role in management with surgical manoeuvres or patient positioning to try to reverse the changes. Anaesthesia maintains the physiological, pharmacological, anaesthetic regime management. Discussion with anaesthesia about optimal monitoring requirements prior to a case is required. SSEPs and TcMEPs are susceptible to anaesthetic and physiologic changes, EMG relies on absence of neuromuscular blockade to be significant. SSEPs may be dampened or show false positive changes due to changes in concentration of inhalational agents, BP fluctuations or positional compression of limbs. TcMEPs require placement of bite block to prevent tongue lacerations. TcMEPs are also dampened by increased inhalational agents and require absence of neuromuscular blockade. TIVA (Total Intravenous Anaesthesia) is ideal for TcMEPs.

***Case Report** highlighting multi-modality IONM monitoring*:

A 58-year-old diabetic male presenting with low back pain radiating down left leg with numbness and tingling all the way to the feet. He had a previous spinal fusion L2-4 with hardware. The planned surgical procedure was T12-L2 PLIF (Posterior lumbar interbody fusion), L2-4 Revision. Multi-modality IONM with SSEP, TcMEP, EEG, EMG, triggered EMG and TOF planned. Optimal Anaesthesia requirements were discussed with Anaesthesia team.

IONM Protocol:

- SSEP- Ulnar Nerve at 25mA

Posterior Tibial Nerve (PTN) at 40mA

- Montages used for cortical responses: C3'–C4', C3'–Fz
  C4'–C3', C4'–Fz. Additional Cz-Fz for lowers.
- EMG muscles- abdominals, psoas, quadriceps, anterior tibialis, gastrocnemius, and abductor hallucis (AH) muscles.
- Muscles used for MEP recording- Abductor Pollicis Brevis-Adductor Digiti Minimi (hand), abdominals, psoas, quadriceps, anterior tibialis, gastrocnemius, and abductor hallucis (AH) muscles
- MEP stimulating electrodes placed at C3 and C4, 350-450V with train of 7-9 pulses.
- TOF recorded from AH with PTN stimulation.

Baselines obtained after patient intubated, positioned prone on Jackson table:

SSEP and TcMEP present in all extremities (Figure 2), EEG symmetric, EMG quiet, TOF 4/4

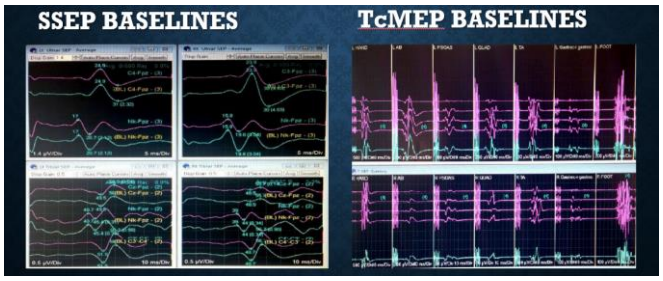

Figure 2: SSEP and TcMEP present in all extremities

As the procedure progressed, Anaesthetic measurements were recorded at regular intervals. Surgeon began removing previous hardware, replacing them with new screws and dissecting bone spurs. At this time, reduction in cortical response amplitudes is noticed in the LEFT PTN SSEP (Figure 3). After troubleshooting, checking electrodes, wires, stimulation parameters and confirming it was not technical, Surgeon is informed of the change in responses. TcMEPs were run on the surgeon's request. The MEPs showed loss of responses in Gastrocnemius and Abductor Hallucis (AH, foot) muscles (Figure 3). Surgeon is alerted of these changes. At this time, anesthetic measurements showed no significant changes. Increase in stimulation voltage from 350V to 800 V yielded no change in the MEP responses. SSEP is monitored continuously, the left PTN responses continue to be diminished.

Figure 3: SSEP and MEP changes. Left PTN SSEP, Bilateral Gastrocnemius and AH MEP responses as highlighted.

After checking for patient positioning, monitoring anesthesia measurements, Surgeon decided to explore the surgical field. On running TcMEPs after exploration, a return of the Gastrocnemius and AH responses was noted. Subsequently the left PTN responses also returned to baseline (Figure 4). The Surgeon explained that during hardware removal some of the bone spur had become lodged in the canal and it was compressing the cord. He also stated that this was not easily visible and would not have been caught had the signals not changed.

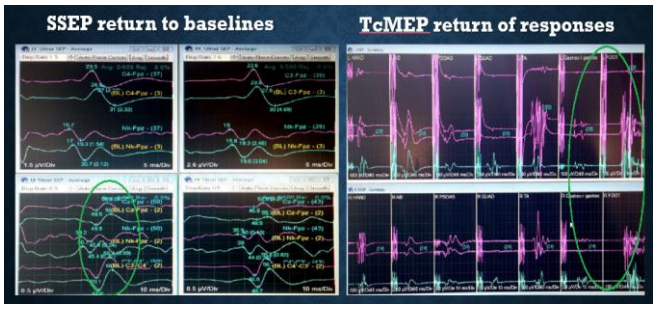

Figure 4: Return of SSEP and MEP responses.

Multi-Modality IONM was significant in this case for alerting the surgeon and averting a critical neurological insult. IONM has shown to have high sensitivity and specificity in detecting sensory and motor injury.

IV. CONCLUSION

Intraoperative neurophysiological monitoring (IONM) use during spine surgery, with a multimodality approach including SSEP, MEP and EMG, aids in early recognition of a neurological insult and, by management of signal changes during the procedure, can predict a favorable surgical outcome. Any significant variation from baseline IONM signals or a loss of signal during surgery indicates a neural insult and predicts a possible postoperative deficit.

Effective communication between multidisciplinary teams is critical to provide efficient patient care by decreasing adverse events and improving outcomes. IONM team works with the surgical and anesthesiology team to optimize signal acquisition and provide reliable monitoring. The goal of IONM is to detect surgical or physiological insults early while they are still reversible and help prevent damage to the neural structures by continuously evaluating the neural pathways while the patient is anesthetized, where clinical evaluation is not possible

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