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Intraoperative Neurophysiological Monitoring in Spine Surgery

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Intraoperative neurophysiological monitoring (IONM) is a rapidly developing medical field that plays a critical role in preventing neurological damage by detecting dysfunction before it reaches an irreversible stage during spine and other surgical procedures. This article focuses on the intraoperative application and clinical utility of somatosensory evoked potentials (SEP), motor evoked potentials (MEP), and both spontaneous and triggered electromyography (EMG). SEP monitoring was introduced several decades ago and has been widely used to prevent neurological deficits. However, motor compromises have occurred despite the preservation of SEP. As a result, MEP recording following transcranial electrical stimulation has emerged as a reliable technique for intraoperative assessment of the functional integrity of motor pathways. More recently, both spontaneous and triggered EMG have become widely utilized for monitoring nerve root function during spine surgery. Although IONM provides sensitive and specific indications of neurological injury, it has limitations that must be acknowledged and understood. The monitoring team must be highly trained, capable of providing real-time feedback to the surgeon, and able to coordinate activities effectively with both the surgical and anesthesia teams.

Keywords: Intraoperative neurophysiological monitoring; Evoked potentials, somatosensory; Evoked potentials, motor; Spontaneous electromyography; Triggered electromyography

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Introduction

Intraoperative neurophysiological monitoring (IONM) is a rapidly evolving field with significant potential to improve the safety of spinal surgery. A thorough understanding of the strengths and limitations of each monitoring modality is essential for the optimal application of IONM [1]. The primary aim of IONM is to facilitate changes in intraoperative strategy that minimize or prevent neurological deficits. Additionally, IONM enables surgeons to undertake more aggressive maneuvers with increased confidence [2].

Somatosensory evoked potential (SEP) monitoring was first introduced as part of IONM several decades ago. Subsequently, motor evoked potential (MEP) monitoring became feasible with the advent of intravenous anesthesia, which exerts less depressive effect on motor neuron activity compared to traditional gas-based general anesthesia techniques [3]. SEP and MEP monitoring were first combined in the 1990s using multiphase techniques and are now recognized as complementary approaches. Triggered electromyography (EMG) was eventually introduced as a neuromonitoring tool in spine surgery [4].

Currently, multimodal spinal cord monitoring is widely regarded as advantageous for improving accuracy, since no single modality is without limitations. Several studies have demonstrated that combined modality monitoring offers greater sensitivity than single-modality monitoring [5-7].

Theoretically, using both MEP and SEP in combined intraoperative neurophysiologic monitoring for all spine operations would be ideal for predicting and minimizing possible postoperative complications. However, in practice, either MEP or SEP alone may be employed depending on the surgeon's preference and technical availability. Moreover, there is no absolute guideline or defined consensus regarding the combinations of intraoperative neurophysiologic monitoring modalities.

This article reviews the principal modalities of IONM, with a particular focus on the clinical utility and efficacy of combined IONM in spine surgery.

Somatosensory Evoked Potentials

In spine surgery, SEP specifically monitors the dorsal column-medial lemniscus pathway by propagating action potentials from peripheral nerves to the contralateral sensory cortex. SEP can be monitored continuously; however, because it relies on signal averaging over time, significant decreases in SEP may lag behind changes detected by transcranial MEP monitoring. As a result, there is a risk of false-negative findings [8].

The most critical and definitive alarm criterion is the sudden disappearance of the SEP waveform, which may indicate neural transection. In addition to this, significant changes such as a decrease in amplitude greater than 50% or an increase in latency of more than 10% from baseline should be promptly communicated to the surgeon [1].

Some reports have indicated that changes in central conduction time (CCT) should be recognized as meaningful indicators—specifically, when CCT is prolonged by more than 1 ms or by more than 20% of the reference value, or when the main waveform becomes distorted (desynchronization) [9,10].

Motor Evoked Potentials

MEP monitoring involves assessing compound corticospinal action potentials initiated by direct axonal activation to track the activity of the corticospinal tract. These potentials can be elicited by magnetic or electrical stimulation; however, transcranial electrical stimulation (TES) is the most suitable approach in the operative setting.

1) Transcranial motor evoked potential

In 1980, Merton and Morton [11] demonstrated that the human brain could be stimulated through the intact scalp using a high-voltage single electrical stimulus, and that TES responses could be recorded from limb muscles. Over the past decade, TES has become the most popular method for monitoring the functional integrity of the motor system during surgery [11,12].

It is recommended that TES-MEPs be recorded from at least two muscles within the same extremity to ensure precise monitoring. Differentiating MEP responses in various muscles of the same limb helps discriminate artifacts during monitoring [13].

Train stimuli—consisting of 5 to 7 square-wave pulses with a 1–4 ms interstimulus interval—are preferred over single stimuli due to the muscle MEP's build-up effect [14,15]. Warning criteria include a decrease in amplitude of 50% or more, an increase in stimulus intensity of 20% or more, or a latency increase of 10% or more [16]. However, for scoliosis or deformity surgery, the absolute alarm criterion remains the presence or absence of MEP response.

2) Direct waves (D-waves)

Direct waves (D-waves) are generated by direct activation of the corticospinal tract from the primary motor cortex and are recorded at the spinal cord by placing a recording electrode in the epidural or subdural space, in contrast to muscle MEPs. Whereas TES responses recorded in muscle require synaptic transmission through vertically oriented excitatory interneurons, the D-wave directly reflects activation of the motor neuron axon, making it less susceptible to anesthetic agents with muscle relaxation effects. As a result, D-wave monitoring is useful for obtaining semiquantitative data on the functional integrity of the corticospinal tract (Fig. 1) [17,18].

Despite its utility, D-wave monitoring is limited in Korea due to the lack of approval for epidural recording electrodes and the absence of approved cost codes. Nevertheless, it remains an essential modality for precise neurophysiological monitoring, especially during spinal cord tumor surgery [13].

Electromyography

EMG is less well established as a standalone modality of IONM, as it is typically used to support SEP and MEP. Nonetheless, it offers unique advantages in minimally invasive spine surgeries, particularly during posterior pedicle screw placement. Stimulating the screw can help determine whether there is a medial breach and can reduce the need for perioperative fluoroscopy by enabling early correction of screw trajectory [3,19].

1) Spontaneous (free running) electromyography

Spontaneous or free-running EMG is widely employed to monitor selective nerve root function during spinal surgery. Since postoperative radiculopathy is more likely than spinal cord injury during spinal instrumentation and pedicle screw placement, spontaneous EMG is well suited to these procedures [1]. While it provides the advantage of continuous real-time monitoring during surgery, it is subject to false positives resulting from

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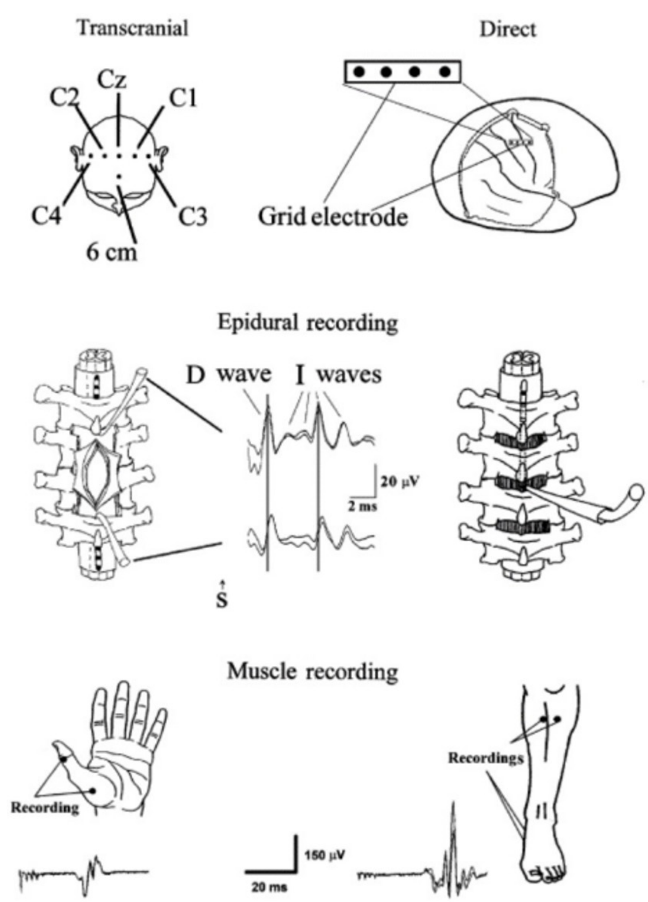

Fig. 1. Intraoperative methodology for eliciting and recording motor evoked potential from the spinal cord and limb muscles [18].

changes in body temperature or electrical cauterization.

2) Triggered electromyography

Triggered EMG can be used to prevent nerve root injury caused by pedicle screw misplacement. The underlying principle is that intact cortical bone should electrically insulate a properly placed pedicle screw from the adjacent nerve root, whereas a medial pedicle breach results in reduced insulation.

By directly stimulating the pedicle screw and measuring the lowest threshold voltage required to generate compound muscle action potentials, the likelihood of a medial breach can be assessed [1]. It has been reported that correct screw placement is confirmed in 99.5% to 99.8% of cases when stimulation thresholds are 8.0 mA or higher [20].

Combined Multimodality IONM

Multimodal monitoring can compensate for the limitations of each individual modality and has become standard practice for a range of spinal procedures. The combination of SEP and MEP monitoring has long been used in scoliosis surgery to monitor both ascending and descending pathways.

Adding spontaneous and triggered EMG enhances the detection of nerve root injuries. Multiple studies have reported that the combined sensitivity and specificity of multimodal neuromonitoring approaches 100% [1,5].

Conclusion

IONM is now commonly used and recognized as a cost-effective means of reducing neurological deficits during surgery. However, its effectiveness depends on an experienced monitoring team comprising neurophysiologists, surgeons, anesthesiologists, and technicians. Active communication among these professionals during the operation is essential.

Recently, multimodal IONM has become mainstream to compensate for the limitations of each modality. Therefore, a thorough understanding of the strengths and weaknesses of each monitoring technique is critical for optimal IONM application.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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