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The Impact of Intraoperative Monitoring on Spinal Cord Surgery Outcomes: A Comprehensive Review.

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Abstract

Intraoperative neurophysiological monitoring (IONM) is an important method used in spinal surgery, which is aimed at the maintenance of the functional integrity of the nervous system, in particular, the spinal cord and its neural structures. This is a narrative review that focuses on the effect of IONM on postoperative neurological outcomes. The search was conducted in electronic databases covering the studies published in the last five years (2015 to 2025) and included the following study types: clinical studies, observational studies, systematic reviews, and key case series; all studies were excluded based on the following criterion: animal study, non-spinal surgeries, and lack of outcome data. It has been shown that IONM is an important way of improving the safety of spinal surgery, especially in high-risk surgery like intramedullary or extramedullary tumor resections, cervical myelopathy, and corrections to spinal deformities. IONM can help prevent postoperative complications and enhance recovery by enabling surgical teams to act in time to prevent neurological compromise, which results in postoperative complications and death. Multimodal monitoring Multimodal monitoring, which includes somatosensory evoked potential (SSEPs), motor evoked potential (MEPs), electromyography (EMG), and D-wave recording, provides a complete real-time evaluation of both sensory and motor pathways and has been shown to be particularly useful in complicated situations. IONM is based on the presence of qualified personnel and effective communication between surgeons and anesthesiologists and monitoring specialists during operations. Possible shortcomings are the absence of false negatives, inconsistency in sensitivity between different pathologies and the requirement of specific equipment and training. However, systematic reviews indicate that the routine use of IONM in the high-complexity spinal surgery procedures is cost-effective, decreases complications, reoperation, and the expenses of healthcare in the long run. The more advanced technologies, standardization of protocols and the wide availability of trained personnel are likely to increase IONM utility even more. IONM is a required precaution in spinal surgery today that allows anesthetists to identify and avert neural injury early in the course of surgery and enhances the patient's safety and future neurological performance.

Keywords: Intraoperative monitoring (IOM), Neurophysiological technique, Spinal surgery, Multimodal approach, Neural pathway.

Introduction

Intraoperative monitoring (IOM) is a neurophysiological technique that aims at maintaining the functional integrity of the nervous system, particularly the spinal cord and other associated neural pathways. The overall objective of intraoperative neurophysiological monitoring is to eliminate nerve injury as it happens in real time such that it greatly impacts patient safety and surgical outcomes specifically in procedures involving the correction of spinal deformities or the resection of tumors, both of which carry significant neurological risk (1). Damage to the nervous system is one of the gravest possible complications and thus needs close and constant supervision. Spinal surgery is a procedure that is vital in enhancing the life of individuals with deformities, abnormalities or tumors and therefore the preservation of neural integrity in these cases is very crucial. However, during the operation, Ischemia due to vascular compression or mechanical stress of the spinal cord as a consequence of incorrect minor technical errors or corrective approach may lead to postoperative complications, i.e. paralysis, loss of sensation or motor functions, respiratory dysfunction, in severe cases. When problems with higher spinal nerves are not noticed the consequences can be permanent for the patient and have major legal responsibility for the medical team (2,3). Moreover, neurological monitoring (reduced in real time) during surgery allows checking the early signs of neural damage, which is reported to the surgical team immediately. This is a specialized division of intraoperative management comprising electrical activity of the nervous system. It uses numerous modalities to monitor numerous neural pathways on a continuous basis. Multimodal approach, which involves the combination of multiple monitoring methods, improves sensitivity and specificity, which in turn improve patient outcomes and maximize patient safety during surgery (4).An additional advantage of using multimodal intraoperative monitoring is that it integrates other modalities to make up for deficiencies in techniques, therefore ensuring a more complete evaluation of the preservation of the spinal cord function. The multimodal intraoperative monitoring technique consists of four methods:

1) Somatosensory evoked potentials (SSEPs) evaluate the dorsal column-medial lemniscus tract, that is, information concerning the sensory pathways is obtained, and ischemia or compression can be detected.

2) Motor evoked potentials (MEPs) measure the corticospinal tracts, which provide essential information on the integrity of the motor pathways and make it possible to identify a possible motor compromise at an early stage.

3) D-waves offer a direct assessment of spinal cord motor pathways, and they are also valuable prognostic variables especially in cases of intramedullary tumors resection.

4) EMG Electromyography (EMG) measures the recording of activity along the peripheral nerves or along spinal nerve roots, which can be used to accurately localize nerve injuries, such as when placing pedicle screws or performing corrective spinal manipulations (4).

The multimodal approach is more sensitive and specific by combining these modalities and provides a complete, real-time evaluation of the neural functioning and decreases the chances of postoperative neurological impairment. The major point of discussion has been the high dependency on the operator by IOM (5). Signal interpretation, in this patient population, may be difficult and one that needs much experience because a mistake can lead to either false-positive result or false-negative result. There are also other constraints like intraoperative effects, which cause variation in signals due to the action of anesthetic agents, patient variation, and cost-effectiveness (especially in the low-risk procedures) among others, which complicate monitoring. Furthermore, the evidence gap is significant since the high-quality randomized controlled trials are scarce, and it is hard to build unconditional causality, which contributes to the issues of IONM implementation. Moreover, lack of literature also exists as there are not numerous high-quality randomized controlled trials proving causality and presenting more evidence of the value of IONM (6). Intraoperative monitoring results is important because it allows for advanced neuroprotection. Moreover, it allows early detection to intervene, prevents intraoperative mistakes which allows for better postoperative outcomes, speeding up the recovery time, and minimizing medicolegal liability (7,8).

METHODOLOGY

This paper is a qualitative narrative review study that examines the effects of intraoperative neurophysiological monitoring (IONM) on postoperative neurological outcomes among patients undergoing spinal surgery. Electronic databases (PubMed and Google Scholar) were used to search for and identify (the relevant research on the topic of IONM role in the prevention of neurological injuries after surgery. The search strategy employed both free-text terms and Medical Subject Headings (MeSH), which were sourced from the US National Library of Medicine. Primarily, they were terms related to “spinal cord,” “intraoperative monitoring,” “surgery,” and “outcomes.” The free-text keywords consisted of terms that were related to intraoperative monitoring (e.g., “Intraoperative neurophysiological monitoring, IONM”, “motor evoked potentials, MEP”, “somatosensory evoked potentials, SEP”, “D-wave” and “electromyography, EMG”),surgical procedures (e.g., “spinal cord surgery”, “scoliosis surgery” and “spinal tumor surgery”) and most importantly, postoperative outcomes (e.g., “neurological outcomes”, “neurological deficits”, and “length of stay”). To ensure a thorough and well-covered search that only provides relevant studies, Boolean operators (AND/OR) were used to integrate different concepts. Only articles published within the last 10 years, from 2015 to 2025, were incorporated into this study to ensure clinical applicability according to modern surgical techniques (9).

Inclusion Criteria: This review included clinical studies (provides primary data by including randomized and non-randomized trials to assess comparative results between patients with IONM and without IONM, also for patients that use one modality of IONM vs multiple-motor evoked potentials, sensory evoked potentials, and D-Wave), observational studies (includes cohort and case-control studies to specifically study surgical outcomes, post-operative neurological deficits, and effectiveness of IONM based on real-world practice) systematic reviews (gives a summary of all studies on IONM used in spinal surgery, such as tumor specific or scoliosis corrective surgery), and significant case series (particularly those with many patients to provide meaningful and applicable clinical observations), this combination of studies guarantees that the review is comprises of evidence that is clinically relevant, reliable and reflective of the current techniques and approaches that surgeons use in the present. Studies were included if they addressed outcomes related to any form of spinal surgery, such as tumors which could be intramedullary or extramedullary, deformities such as scoliosis and kyphosis, trauma causing spinal nerve damage, and degenerative conditions leading to disc herniation, spinal stenosis, and degenerative spondylolisthesis. It was crucial that only the studies that reported the use of IONM were kept, especially those that discussed neurological outcomes (10,11).

Exclusion criteria: Studies were excluded if the data they provided were not relevant to human spinal surgery performed with the use of IONM; that is, all animal spinal surgeries were eliminated because the anatomy, monitoring outcomes, and surgical techniques do not translate directly to human-specific clinical practice. Non-spinal surgeries were also excluded, as this review focuses on the use of IONM for spinal surgeries and its effects on motor pathways of the body after surgical intervention. Studies without any outcome data were excluded, since this review primarily focuses on studying surgical outcomes, complications, neurological deficits, and the effectiveness of IONM to prevent long-term nerve damage. Meta-analyses were excluded to maintain focus on primary studies that collect original data from patients to provide detailed clinical observations on the effectiveness of IONM for spinal surgeries, all of which allows this paper to conduct a detailed qualitative discussion of surgical outcomes related to the usage of IONM in spinal surgeries (10).

The final results of the search were meticulously filtered to remove any duplicates as well as non-English articles. The authors independently appraised the full-text articles to decide the most suitable studies; a total of 18 papers were chosen. This review prioritized studies that reported neurological outcomes after undergoing spinal surgery with IONM, which aligned with the aim of this review to synthesize a qualitative report combining all the results of heterogeneous clinical studies. Instead of opting for a meta-analytic approach, which statistically aggregates results, a narrative approach was used to determine repetition of clinical patterns and trends across all relevant studies.

Overall, results were finalized according to surgery type, IONM method, and reported neurological outcomes. Comparisons focused on clinical outcomes between patients who underwent spinal surgery with or without IONM, differences in motor and sensory function, a combination of multimodal IONM, length of recovery, and methods of prevention of spinal/nerve injury (11).

DISCUSSION

Overview of Techniques:

Intraoperative Neurophysiological Monitoring has been a part of neurosurgical decision making for quite a while now. However, the argument about its usefulness and practicality are somehow still under debate. Questions including how to decide what technique to utilize, in what cases to utilize it in, all the way to how money and limitations affect the decisions made, are being currently researched extensively. The first and the most powerful arguments in the support of intraoperative neurophysiological monitoring (IONM) are the early detection of compromised spinal cords and the consequent minimization of neurological impairments. Millions of patients are performing surgery annually to treat a large variety of spinal disorders, and the use of IONM as a routine measure of perioperative care would be of great benefit in terms of protection (12). Now there are a few techniques available for intraoperative monitoring. Some of these are described as follows:

Spinal Somatosensory Evoked Potential (SSEP):

SSEPs are used more than any of the other IONM techniques in spinal surgeries. These are useful to determine the function of the somatosensory pathways leading to the spinal cord. Peripheral nerve stimulation is used, and the resultant evoked potentials are registered, which are the indications of the sensory input and the pathways of spinal cord in detecting touch. These responses have their amplitudes and latency then compared with predetermined baseline values to observe deviations which can form a signal that may be an alert. To record these signals, electrodes are carefully laid at various levels such as the peripheral nerves, spinal cord, and the somatosensory cortex such that one can continuously monitor the action potential along the sensory pathways. This can help neurosurgeons to alter or halt surgery till a solution can be figured out. For example, it was reported that use of SSEP as a monitoring technique led to significant reduction in postoperative paraplegia, a value ascertained to be up to 60% (13). Even though somatosensory evoked potentials (SSEPs) are mandatory in identifying intraoperative compromise, they have some limitations. The documented data is a time-average response, and this may delay the recognition of acute neurological changes. Due to this, the results can be delayed. Another important drawback is that this potential is also limited when it comes to detecting injuries to the nerve root. Moreover, SSEPs are very prone to exogenous factors including anesthetic drugs and intraoperative hypotension (12). Moreover, a few studies have indicated instances where patients have had postoperative motor deficits even when SSEP recordings were stable, thereby highlighting that use of this modality may not offer adequate reliability (14). Therefore, it is important to consider a conjunctive approach along with other techniques of IONM.

Motor Evoked Potential (MEP):

As the name indicates, MEPs are primarily used to assess the integrity of motor pathways. Contrary to SSEPs, MEPs detect the potentials traveling through the corticospinal tract, from motor cortex to the peripheral muscles (13). Stimulating the motor cortex can help assess cord function by using epidural electrodes and recording the generated potential through the peripheral muscles. Any alerts or alarms from the MEP monitoring signals compromise of a specific part of the corticospinal tract and if not reversed, lead to postoperative functional deficits (15). Use of MEPs along with SSEPs is more effective in determining postoperative motor outcomes. In the surgical treatment of Compressive Myelopathy, MEPs have been seen to be more sensitive than SSEPs meaning they are more reliable in detecting cord compromise (8). A significant limitation of MEP is its sensitivity to anesthesia (4). To accurately monitor the generated MEPs, continuous intravenous supply of anesthesia such as propofol and fentanyl are crucial (12). In addition to this, a highly qualified team is required to use this technique right as agents like halogenated anesthetics can drastically effect MEP recordings and render the results unreliable (2). Use of long-acting muscle relaxants should be avoided as relaxed muscles are unable to generate any MEPs (14).

Electromyography (EMG):

EMG is a technique used in monitoring nerve root function when the surgeon is probing and manipulating during spinal surgery (1). More specifically, spontaneous EMG gives real time recordings from peripheral muscles which is something other techniques such as SSEPs have been unable to. Moreover, a study has listed the use of EMG as a guide for the placement of stimulator for SCS surgery. The same study also reported reduced pain outcomes (2). One major advantage of EMG is the need to not have continuous stimulation to get recordings (12). A limitation of this technique however is that even manipulations like stretching, irrigating or cauterization of the area can elicit potential. In such cases, surgeons focus on high-frequency bursts to determine true injury (13). An important limitation of EMG is the instrument setup. Whenever nerve injury occurs, only certain neurons are affected in that certain location. The whole muscle fiber does not show movement and hence the recordings may be incorrigible. It is important to have the electrode correctly placed on those locations specifically. Moreover, it is also imperative for the surgeons to know the difference between nerve injury recordings and any chronic muscle condition the patient might have (3).

Direct waves:

Stimulation of white matter in the cortical and subcortical region of the spinal cord generates a host of waves. D-waves are the first waves to be observed by the electrodes (3). Just a singular pulse of myelinated Corticospinal tract can illicit huge response. These D-waves have an increased amplitude and latency which is a direct indication of the preservation of the motor pathways during spinal surgery. Any changes in D-wave recordings signals decline in function of the corticospinal tract neurons. Hence, this technique has advantages over the above-mentioned techniques when it comes to early detection of intraoperative decline as well as any postoperative neurological deficits (16). Also, a major advantage of using D-waves is its superiority to MEPs under anesthesia. D-waves are asynaptic and the first signals to be registered, therefore, can be transmitted even during relaxation of muscles.

D-wave monitoring has been demonstrated to be especially useful in intramedullary spinal cord tumor (IMSCT) surgery, and it has been proposed that it is associated with better long-term neurological outcomes (14).

Multimodality Monitoring:

A more common and all-encompassing technique is the multimodality approach to intraoperative neurophysiological monitoring. This basically refers to use of multiple modalities in a case to cover different neurological aspects. Firstly, SSEPs were the only available monitoring technique. The discovery of MEPs then led to both techniques to be used simultaneously for monitoring spinal surgeries such as IMSCTs and deformity corrections like scoliosis treatment, reportedly providing higher sensitivity than if only one technique were implemented (12). Use of both these modalities can help detect compromise at all levels of the spine instead of local changes only by using readings from all extremities (17). The most common combination as of now is the use of SSEPs, MEPs and Electromyography (EMG). Combination of the two techniques has demonstrated much better neurological outcomes as it helps in early identification of intraoperative compromise particularly in surgery like tumor excisions (6). Another important combination is the use of MEPs and D-waves monitoring simultaneously. In IMSCT resections, MEPs signal early compromise and help improve short term functions whereas, D-waves help improve long term motor functions postoperatively (14). Moreover, combination of these techniques has become more popular given the ability to overcome the inadequacies that arise if they are to be used individually. As mentioned before, SSEPs have their limitations which is where MEPs come in handy. Since EMG provides continuous monitoring, this technique can help observe nerve root function as well (1). In addition, another review explained how multimodal approach is more effective since SSEP readings can cause delays and MEPs are sensitive to other factors like anesthesia and even EMG has its issues like a high incidence of false alarms (5).

Impact on Surgical Outcomes:

Now that we know the major techniques commonly used for IONM, we will now discuss what evidence we found on the impact this has on surgical outcomes. We will include the fact that IONM is effective at identifying cord compromise at an early stage and preventing neurological deficits in the postoperative phase. Strong evidence of how MEPs help detect loss of function was shown in the case of a 17-year-old. The girl suffering from scoliosis in association with neurofibromatosis had deformity correcting osteotomies. Use of rods and screws caused loss of amplitude by 50% on the MEP recordings. The amplitude of MEP is restored by adjusting instruments and administration of dexamethasone. Subsequently, the patient reported no neurological decline and favorable outcomes (12). In the other study of 28 pediatric patients who were monitored using the SSEP and MEP, a total of 21 intraoperative alerts were reported by the two modalities. MEPs alerts were considered more significant and subsequent decompression and closure of osteotomy showed increase in MEPs. Overall, the study reported massively reduced postoperative deficits with no long-term outcomes (13). One of the recent studies (2017) consisting of 121 patients undergoing a broad spectrum of spinal surgery had intraoperative neurophysiological monitoring (IONM) to observe its efficiency in identifying an early compromise and eliminating the ensuing neurological losses. This resulted in 57.14% of patients having neurological deficits being detected (4). Moreover, the use of IONM showed significantly decreased deficits and improved surgical outcomes specifically in spinal deformity correction surgeries and tumor excision (5).Siller et al conducted a retrospective study for EMSCT patients and reported that when warning criteria for multimodal monitoring was reached, instant corrective steps were taken to recover, and surgeons went as far as to stop resection and even stop the procedure completely. Neurological status evaluation of postoperative patients showed that a lower percentage of them had new deficits, and 90 percent of patients had entire tumor resection, which is indicative of the high feasibility and clinical utility of IONM (6). Another retrospective study in patients with Intradural spinal tumor surgery revealed that use of IONM significantly improved postoperative outcomes. IONM alerts were helpful in detecting early deficits in these patients (1).

The case of 36-year-old patient with D-wave monitoring of the Intramedullary Spinal Cord Tumors (IMSCT) demonstrated some interesting findings in a study. IONM was employed, including SSEP and transcranial MEP. At different points during resection, both SSEP and MEP data was lost, with MEP recovering by the end of it. However, the availability of D-wave warnings resulted in complete tumor resection with no new motor deficits and short-term sensory deficits that were resolved over time (15). A case-control study, comparing two groups of 50 each undergoing spinal surgery for IMSCT, with one implementing IONM and one control group, were able to provide evidence that D-wave data helped improve postoperative long-term outcomes (14). Another important case study to analyze IONM importance is the use of subdural D-wave monitoring in a patient presenting with sub-ependymoma IMSCT. After an initial inability to record potentials, a subdural electrode was used to record D-waves. Consequently, the surgeons were able to manipulate instrumentation to monitor the resection (16). Use of IONM in degenerative spinal diseases such Cervical Compressive Myelopathy (CCM) has also been studied. A study of 58 patients undergoing decompressive surgery with focus on MEPs as the preferred IONM technique was conducted. Patients who recorded no change and increased amplitudes of MEPs were reported to have improved postoperative outcomes leading up to 6 months after surgery (8). In a similar study, out of 29 patients getting surgery for CCM, outcome improvement rate was significantly higher in the 11 who were reported to have positive changes in MEPs. This study emphasized the role of IONM in preventing postoperative motor deficits (18).

Limitations:

As evidenced from the literature presented in this research, IONM can significantly impact surgical outcomes. However, there are also limitations pertaining to its accessibility as well as functionality. Accounts of false positives and negatives, technical hindrance, costs and human resources are some of the limitations reported for IONM. For instance, Stecker reported that the potential of MEP to be variable increases the number of consequent false-positives and false-negatives (3). Moreover, use of SSEPs reported increased incidence of false-negatives and patients were left with postoperative deficits (17).

Another important limitation in the use of IONM has been the frequency of technical factors skewing readings. Laratta et al. examined these in detail. They implied that SSEPs are subject to be askew because of certain factors like hypotension which can lead to incorrect data. In cases like these, surgeons or specialized personnel need to be trained to be aware of actual surgical emergencies as opposed to these faulty data changes (13). Some other factors can be electrode positioning error, irrigating the site and even traction or movement of muscles around the surgical sites (6).

One important aspect of a surgical procedure is determining how much it will cost. Both intraoperative running costs and consequent complications determine the cost effectiveness of using IONM. A threshold of 0.3% possible future neurological complications can warrant the use of IONM for spinal surgeries (5). This value would mean that for surgeries not meeting this threshold will be deemed low-resource and could lead to unmitigated deficits. In addition to this, IONM requires a highly trained staff of qualified technologists, anesthesiologists, neurophysiologists and neurosurgeons. This is hard to achieve in healthcare systems across the world and non-existent in resource-limited areas (17).

Future directions:

A huge part of research is the ability to generalize results. Most of the studies report small sample sizes which decrease the generalizability of the results obtained. A large-scale study including a large sample size needs to be conducted to label it meaningful (1,4). Moreover, further research is warranted to not only have a homogenous approach to standardized protocols for IONM use and response, but also to be able to incorporate the techniques with advanced robotics to increase the competence of neurosurgical procedures (5). In addition to this, IONM requires extreme precision to be able to record results and one important aspect of it is to establish threshold or warning criteria which are non-existent in some of the techniques. Machie learning models can help bridge that gap for precise recordings and excellent neurophysiological outcomes.

Conclusion

Intraoperative neurophysiological monitoring (IONM) has become an obligatory addition to spinal surgery due to the opportunity for continuous, real-time evaluation of neural performance. Data from various studies prove that it significantly contributes to the safety of the procedures, especially those that are defined as high-risk interventions, including intramedullary or extramedullary tumor resections, cervical myelopathy, and spinal deformity correction. IONM positively impacts surgical teams with early alerts of neurological injury and, therefore, improves the timely corrective action by the surgical team, thereby reducing postoperative complications and enhancing recovery. The clinical literature in different patient populations supports the use of multimodal monitoring, which includes SSEPs, MEPs, EMG, and in some instances, D-wave, as a way of identifying neural injury before surgery and leading to good postoperative outcomes. The combination of these two complementary modalities has proven particularly beneficial in complex cases, where the surgeons can customize the approach to monitoring the specific anatomy and pathology of each person. This customized approach does not follow a one-size-fits-all framework and will focus on the significance of flexibility in the planning of surgery.

IONM has also been found to be of significant help especially as a corrective measure in spinal deformity as well as in cervical spine surgery where monitoring can help direct the surgical team in technically challenging surgeries as well as help minimize the chances of causing an irreversible neurological loss. As noted in previous studies, positive intraoperative effects, especially in MEP amplitudes, are associated with better short-term recovery and that the combination of multiple modalities is associated with greater efficiency in error detection as compared to single methods. Irrespective of these advantages, IONM reliability is largely reliant on the skills of trained staff and good interaction between the surgeons, anesthesiologists, and monitoring specialists. There are still limitations, such as differences in sensitivity and specificity between various pathologies, the possibility of false negatives, and low usefulness in less risky procedures. However, systematic reviews indicate that in high-complexity spinal operations, its regular utilization is cost-effective in the long run because it decreases reoperations, complications, and related healthcare expenses.

In the future, the availability of IONM will have to grow, and it will need to be supported by the equipment, trained personnel, and uniform guidelines, especially in resource-constrained environments. New technologies like subdural D-wave and continuous corticospinal tract mapping promise to enhance accuracy and even earlier detection of injury. Such developments can be used wisely and strategically to streamline the process of making intraoperative decisions and reduce the likelihood of causing permanent neurological damage. To conclude, IONM is an effective safeguard in spinal surgery today. It has a value not just in minimizing risks during intraoperative period but also in enhancing the long-term patient outcomes. Further development of methods, standardization of protocols and attentive resource distribution will also be necessary to make the most out of it and make sure that patients in a wide range of surgical settings can be ensured protection against preventable neurological complications.

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