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REVIEW

Progress in Intraoperative Neurophysiological Monitoring for the Surgical Treatment of Thoracic Spinal Stenosis

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Abstract Thoracic spinal stenosis (TSS) is a group of clinical syndromes caused by thoracic spinal cord compression, which always results in severe clinical complications. The incidence of TSS is relatively low compared with lumbar spinal stenosis, while the incidence of spinal cord injury during thoracic decompression is relatively high. The reported incidence of neurological deficits after thoracic decompression reached 13.9%. Intraoperative neurophysiological monitoring (IONM) can timely provide information regarding the function status of the spinal cord, and help surgeons with appropriate performance during operation. This article illustrates the theoretical basis of applying IONM in thoracic decompression surgery, and elaborates on the relationship between signal changes in IONM and postoperative neurological function recovery of the spinal cord. It also introduces updated information in multimodality IONM, the factors influencing evoked potentials, and remedial measures to improve the prognosis.

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THORACIC spinal stenosis (TSS) is a slowly progressive disease that usually occurs in patients with severe spinal cord compression. Conservative treatment is usually ineffective, and surgical decompression is the only effective treatment to prevent further compression of the spinal cord. The thoracic spine is regarded as a "restricted zone" in spinal surgery, mainly due to the characteristic blood supply and

anatomy. Because of the high risk of spinal cord injury in patients with TSS, intraoperative neurophysiological monitoring (IONM) is an important means to ensure patients' safety during the surgery. This technique mainly involves somatosensory evoked potentials (SEPs) and motor evoked potentials (MEPs). It can reflect the functional state of the spinal cord or nervous system in time, and help the subsequent management during operation, so that surgeons could make remedial measures to avoid disastrous consequences. This article provides an overview of progress in applying IONM in patients with TSS.

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Theoretical basis of IONM in decompression of TSS

The volume of the thoracic spinal canal is relatively small, and the flavum ligamentum and posterior longitudinal ligament occupy a certain space of spinal canal, leading to a significantly reduced working space for surgical instruments. The pedicles of the thoracic vertebrae are smaller than those of the lumbar vertebrae, and the spinal cord is closer to the inner walls of the pedicles.¹ The spinal cord and nerve roots are prone to be injured during pedicle screw insertion. The reported failure rate of thoracic pedicle screw placement ranges from 3% to 55%.² Additionally, the blood supply of the thoracic spinal cord is poor compared with that of the cervical and lumbar segments, making it vulnerable to the impact of ischemic stimulation.³ Moreover, thoracic decompression surgery is likely to cause ischemia-reperfusion injury,^{4,5} and to aggravate spinal cord edema. These factors increase the difficulty and the risk of the surgery. The reported incidence of neurologic deficit reached 13.9%.⁶ Therefore, it is essential to apply IONM to monitor functional status during the decompression surgery for patients with TSS.

Relationship between changes in IONM signals and postoperative neurological function

Preoperative baseline waveform of IONM

Factors including age, diabetes mellitus, hypertension, lesion location, and preoperative neurological deficits can influence the success rate of baseline recordings.^{7,8} Ma *et al*⁹ classified the preoperative SEP wave pattern into four grades during surgery for patients with TSS. According to the monitoring results, the author believed that, for patients with Grade I preoperative waveform, because of their severe spinal cord dysfunction, intraoperative spinal cord injury did not manifest as waveform alternation, and thus intraoperative monitoring may not be beneficial for these patients.

Lee *et al*¹⁰ reported that it was usually ineffective to apply MEPs to patients with Medical Research Council grade 1 to 2 muscle strength. Wang *et al*¹¹ reported that for patients with dyskinesia, especially when the muscle strength of lower extremities is grade 1 or less, maximum stimulation still could not produce reliable baseline MEP.

Preoperative monitoring signals represent the functional status of the spinal cord: the inability to obtain preoperative signals indicates severe spinal cord dysfunction. Additionally, the preoperative MEP or SEP amplitudes of TSS patients are usually lower than patients without neurological deficits, which increases the difficulty in monitoring. The ratio of MEP derivation below 50% may

indicate paralysis.¹² Therefore, we recommend using IONM to assess the functional status of the spinal cord for patients with preoperative spinal deficits, especially for those with TSS. However, large clinical trials are needed to confirm whether IONM is beneficial to patients whose preoperative monitoring signal cannot be obtained.

Improved or stable signals during the operation

Improvement in the intraoperative signals is characterized by an increase in amplitude and/or latency.¹³ Liu *et al*¹⁴ observed the efficacy of intraoperative cortical SEP monitoring in patients with TSS. Twenty-three patients had no abnormal cortical SEP waves intraoperatively and no nervous system complications postoperatively; 12 patients showed improvement in their cortical SEPs during the surgery, and their postoperative symptoms were significantly improved. Matsuyama *et al*¹⁵ recorded compound motor action potentials during the surgery of TSS, and divided the patients into three groups according to their intraoperative signal changes: Group A, no change in potentials; Group B, decreased potentials; and Group C, improved potentials. The recovery rates of Japanese Orthopedic Association (JOA) scores were 50.0%, 48.0%, and 68.3% in Group A, B, and C respectively. The clinical manifestations in Groups A and C were significantly improved compared with the preoperative status. From this viewpoint, the neurological function in the majority of patients after the surgery can be improved, and the prognosis might be better when the intraoperative signals improve or keep stable than when they get worse.

In addition, new neurological deficits or deterioration of the original neurological deficits may appear postoperatively, while the intraoperative signals may not show obvious changes. In this case, a false-negative event occurs.¹⁶ Although the incidence of false-negative intraoperative monitoring in detecting postoperative neurologic deficits during spinal surgery is only 0.36%,¹⁷ the outcome is disastrous for the patients. Therefore, spinal surgeons should be alert to the existence of false-negative tests during thoracic decompression surgery, and endeavor to achieve timely detection and appropriate treatment.

Deteriorated signals and the achievement of the "alarm point" during the operation

The present criterion for an abnormal SEP, namely a 50% decrease in amplitude and/or a 10% increase in latency, has been widely used in the surgical treatment of TSS.^{14,16} In the study by Liu *et al*,¹⁴ the deteriorated signals of two patients that were caused by rupture of internal pedicle wall gradually recovered after re-fixing the pedicle screws,

and no obvious symptoms of spinal cord injury were observed postoperatively. The other two patients with deteriorated signals were treated with methylprednisolone, but the signals did not recover. These patients had complete paralysis postoperatively.

Currently there has been no consensus regarding the specific alarming criterion for myogenic MEPs during thoracic decompression.¹⁸ Some criteria exist, such as decreased amplitude by 50%, 70%, 80%, or even 88%.^{11, 19-21} It was reported that the risk of MEP deterioration was higher in patients with preoperative spinal deficits than in normal patients.¹¹ Taher *et al*⁵ found that when deteriorated MEPs followed by thoracic decompression did not recover with adjusting the position of internal fixation devices and hormone shock therapy, the patient suffered from new neurological deficits. Matsuyama *et al*¹⁵ also reported that the postoperative recovery rates were lower in patients with signal deterioration than in those with improved or stable signals, and these patients had to receive a second surgery to achieve a gradual recovery of neurological function.²² Therefore, changes in the intraoperative monitoring signals that last for a long period of time following high-risk manipulation always indicate the affected neurological function of the spinal cord. In such patients, emerging symptoms of spinal cord injury may affect the prognosis, which potentially result in severe loss of sensory function, incomplete paralysis, or paraplegia.

Multimodality intraoperative monitoring (MIOM)

SEP is a method of monitoring the sensory pathway, and it cannot directly monitor the motor conduction pathway in the anterior column of the spinal cord. This is the basic cause of false-negative SEP monitoring. Tsutsui *et al*²³ considered that approximately 80% of activities from motor units to the target muscles couldn't be detected by MEP monitoring, which constitutes the theoretical basis of false-negative events during MEP monitoring. Theoretically, MIOM not only minimizes the incidence of false-negative events, but also provides acquisition of preoperative monitoring signal.²⁴ SEPs and MEPs complement each other in the monitoring process and accurately respond to the functional state of spinal cord in a timely manner. MIOM has been widely used in clinical practice due to its great advantages.²⁵⁻²⁷ More and more studies have reported that applying MIOM to TSS surgeries can effectively prevent spinal cord injury, and thus lead to better prognosis.

Factors influencing evoked potentials

The intraoperative signal changes are mainly caused by factors related to anesthesia, physiology and surgery.

Total intravenous anesthesia is recommended for maintenance of anesthesia during IONM, because inhalation anesthetics reduces the signal amplitude and prolong the latency significantly.^{28, 29} In addition, Muscle relaxants are not recommended in MEP monitoring after anesthetic induction due to their inhibiting effects on muscle action potential responses.^{30, 31} Massive bleeding during thoracic decompression surgery could cause reduced perfusion pressure of the spinal cord, and insufficient blood supply of the spinal cord will lead to signal deterioration. In addition, low temperature was reported to be related to the prolonged latency of evoked potentials.³⁰

The malposition rate of thoracic pedicle screw placement ranges from 3% to 55%,² and the most common cause of true-positive events in spinal surgery is malposition of pedicle screw placement.³² Spinal cord injury can also result from pressing the spinal cord, spinal cord concussion, stretching the ossified dura, and local kyphosis aggravation, any of which could cause changes of the intraoperative monitoring signals during thoracic surgery of decompression or cage placement.

Treatment measures

When intraoperative signals of IONM change significantly, it is recommended to immediately stop any surgical manipulations and closely observe the patient, which may help for spontaneous recovery of SEPs or MEPs.³¹ Rinsing the surgical operative field with warm saline solution should be performed to clear out irritants and metabolites.³² Zuckerman *et al*³³ recommended to keep the mean arterial pressure (MAP) at least 10% greater than baseline during surgery, while Wang *et al*³⁴ suggested that the MAP should be maintained at >81 mmHg to reduce neurological deterioration in thoracic decompression. When all above methods failed to regain signals, the position of the internal fixation instruments should be checked, and local kyphosis of the decompressed segments should be corrected.¹⁵

If no significant signal recovery after these treatments, Stagnara wake-up test and shock therapy using methylprednisolone are suggested. Shock therapy involves an initial bolus of 30 mg/kg of methylprednisolone followed by an infusion of 5.4 mg/kg/h for 23 hours.³⁵ Methylprednisolone therapy should be maintained till the end of the surgery. After the surgery, whether to apply the drug continuously or to change to other rehabilitation treatments depends on the recovery status from the postoperative neurological functional evaluation.

Summary and prospects

In summary, the application of IONM during thoracic

decompression reflects the state of the spinal cord function, and provides reliable information for surgeons to reduce the risk of permanent neurological deficits. Significant deterioration in signals of IONM during operation indicates a possible spinal cord injury. If systematic factors have been excluded, immediate remedial measures should be implemented. Improvement in the waveform of the signals of IONM after decompression surgery indicates a promising prognosis. Large clinical trials are needed in patients with TSS to explore the clinical significance of signal changes during surgery, and to determine whether IONM is suitable for patients whose preoperative monitoring signal cannot be obtained.

Statement of conflict of interests

The authors have no conflict of interest to disclose.

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