Intraoperative Neurophysiological Monitoring for Spinal Fusion

Monitorização neurofisiológica intraoperatória para fusão espinhal

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Abstract

The surgical techniques of spinal fusion are frequently used in the treatment of many spine conditions. Apart from having anatomical knowledge, in order to perform those procedures safely, it is essential to utilize all the tools available to assure the appropriate positioning of the materials and avoid neural injury. The goal of this article is to review the literature on the use of intraoperative neurophysiological monitoring for spinal fusion procedures and to discuss the controversies regarding this issue.

Keywords
- intraoperative neurophysiological monitoring
- spinal fusion
- review

Resumo

As técnicas cirúrgicas de fusão espinhal são frequentemente utilizadas no tratamento de muitas condições da coluna vertebral. Além do conhecimento anatômico, para realizar esses procedimentos com segurança é essencial utilizar todas as ferramentas disponíveis para assegurar o posicionamento adequado dos materiais e evitar lesões neurais. O objetivo deste artigo é revisar a literatura sobre o uso de monitorização neurofisiológica intraoperatória para procedimentos de fusão espinhal e discutir as controvérsias relacionadas a essa questão.

Palavras-chave
- monitorização neurofisiológica intraoperatória
- fusão espinhal
- revisão

Introduction

Spinal decompressions and fusions are among the most frequently performed surgeries,[1] carrying a real chance of neural injury[2–5] with possibly disastrous consequences for the patients' quality of life and elevated health care costs.[6] Over the last decade, the use of intraoperative neurophysiological monitoring has become essential in neurosurgical procedures, because it brings safety to the patients,[7–10] as it can detect impending neurologic compromise, modifying the actions of the operating team to avoid injuries, and it might be considered as a minimal acceptable standard of care for all spinal procedures.[11,12] The decision of using intraoperative neurophysiological monitoring is still made mostly by the surgeon.[13]

The effectiveness of intraoperative neurophysiological monitoring has been challenged by some studies based on the assumption of a low risk of postoperative deficits and additional costs with small differences in clinical outcomes.[14–17]

In the surgical treatment of spinal pathologies, there are three main goals to achieve: decompression of the neural structures, spinal stability, and preservation of the patient's function. In order to achieve these goals, spine surgeons must have adequate training on the specific surgery and utilize all the tools available to assure the appropriate positioning of the materials and to avoid neural injury.[2–5,18] Nevertheless, some health insurance companies still insist on denying the coverage for intraoperative neurophysiological monitoring. The main reason for those denials is the financial cost.[16,19–21]

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Unfortunately, the economic power of those companies frequently prevails over the medical indications, many times with losses to the patients. A scientific approach, with knowledge of the benefits of the technique, should be used more frequently. In this article, the authors review the literature on the use of intraoperative neurophysiological monitoring for spinal fusion procedures.

Methods

The Medline/Pubmed database was utilized for the crossed search of articles on the subject with the use of the narrow terms *intraoperative neurophysiological monitoring* and *spinal fusion*, with no filters. The LILACS database was also searched, with the use of the narrow term *intraoperative neurophysiological monitoring*. The resulting articles were analyzed, and their contents were summarized and discussed.

Results and Discussion

In the literature, there are many publications on the use of intraoperative neurophysiological monitoring (on the PubMed database alone, we found 660 articles with a narrow term research). With more restricted terms, the crossed search using *intraoperative neurophysiological monitoring* AND *spinal fusion* resulted in 31 articles. Studying those articles, we found interesting results. From the 31 articles, by applying the article type filtering, there were 9 case reports,[22–30] 5 reviews,[28,31–34] and 2 clinical trials.[11,35] Twenty five articles (80.64%) were published in the period between 2013 and 2017. On the LILACS database, with the use of the narrow term *intraoperative neurophysiological monitoring*, we found 13 articles, but only 9 were related to spinal surgery.[36–44]

Anterior Fusion

Legatt et al[22] reported a case of anterior cervical discectomy and fusion surgery in which findings on somatosensory-evoked potential monitoring led to the correction of carotid artery compression in a patient with a vascularly isolated hemisphere (no significant collateral blood vessels to the carotid artery territory), and the patient suffered no neurological morbidity. During anterior cervical spine surgery, carotid artery compression by the surgical retractor can cause hemispheric ischemia and infarction in patients with inadequate collateral circulation. Changes in the cortical somatosensory-evoked potentials and no changes in the cervicomedullary somatosensory-evoked potentials warn to the possibility of hemispheric ischemia.

Nair et al[30] reported a case in which vascular injury was detected by multimodality neurophysiological monitoring during an L3-S1 anterior lumbar interbody fusion, demonstrating the need for multimodality monitoring and the combined use of somatosensory-evoked potentials and motor-evoked potentials.

Posterior Fusion

The importance of intraoperative electromyography monitoring for lumbar fusion was already prospectively evaluated by Welch et al,[7] once this method early warned the surgeon that redirection of the pedicle probe or screw was necessary to avoid nerve root irritation or injury. Those authors said that stimulus-evoked electromyography proved to be reliable and effective, especially when used in combination with spontaneous electromyography. Once neuroanatomical structures near the bony pedicles of the lumbar spine allow little room for technical error or compromise of the bone during pedicle screw insertion, in these procedures this safety item could be deemed essential.

Kulik et al[11] performed a computed tomography-based study investigating the relationship between the pedicle screw placement and the stimulation threshold of the compound muscle action potentials measured by intraoperative neurophysiological monitoring. They studied 68 thoracic and 136 lumbar screws placed under electromyography control in 30 patients, and found a more frequent true prediction of the correct position of the screw for lumbar than for thoracic screws. They also concluded that a screw stimulation threshold > 10 mA does not necessarily indicate correct pedicle screw placement, as there were some false negative cases in which a screw stimulation > 10 mA without muscle response was associated with misplacement of the screws; a gradual decrease in the screw stimulation thresholds was not observed as the screw placement approached the nerve root; otherwise, a threshold of 2 mA with muscle response indicates direct contact with nervous tissue. In spite of those limitations, the authors state that "[…]neurophysiological monitoring remains useful and might be regarded as a minimal acceptable standard of care for all spinal procedures except perhaps simple lumbar disc surgery."

Agarwal et al[45] performed a retrospective review of 784 patients undergoing posterior spinal fusion with intraoperative neurophysiological monitoring without any baseline deficits. Those authors found somatosensory-evoked potential and motor-evoked potential changes in 3.3% of the patients undergoing posterior spinal fusion, with the highest incidence at the cervicothoracic level. Eighty-eight percent of the patients with intraoperative neurophysiological monitoring changes had improvements in intraoperative neurophysiological monitoring signals following interventions during surgery. Fifteen percent of the patients had neurological deficits despite surgeon intervention following neurophysiological monitoring alerts.

In scoliosis correction surgeries, as there is a high number of levels, there is a real risk of occurrence of poor positioning of the pedicle screws inserted, even with the aid of intraoperative electromyographic stimulation.[36] Kobayashi et al[23] studied the characteristics of cases with intraoperative transcranial motor-evoked potential waveform deterioration (defined as a decrease in intraoperative amplitude $\geq 70\%$ of the control waveform) during posterior corrective fusion for adolescent idiopathic scoliosis. Waveform deterioration commonly occurred during rotation maneuvers and more frequently in patients with a larger preoperative Cobb angle. They also found significant relationships between the estimated blood loss and the number of levels fused with waveform deterioration. Rumalla et al,[46] in a study of trends in spinal fusion surgery for pediatric neuromuscular scoliosis, found an increase in intraoperative neurophysiological monitoring from 2009 to 2011. Additionally, in the univariate analysis, they found that the use of intraoperative neurophysiological monitoring was associated with decreased complications and length of stay. Those authors concluded that increasing the use of intraoperative neurophysiological monitoring and posterior-only approaches may combat the high complication rates in neuromuscular scoliosis.

Thirumala et al,[31] in a review, researched the diagnostic accuracy of somatosensory-evoked potential monitoring during adolescent idiopathic scoliosis fusion. This meta-analysis covering 4,763 operations on idiopathic scoliosis patients showed that the somatosensory-evoked potential is a highly sensitive and specific test, and that iatrogenic spinal cord injury resulting in new neurological deficits was 340 times more likely to present changes in the somatosensory-evoked potential compared with those injuries without any new deficits. Somatosensory-evoked potential monitoring during scoliosis correction surgeries in children remains a highly reliable method for reducing iatrogenic neurologic deficits with high sensitivity and specificity.[47]

Chung et al,[24] in a technical report, informed that the growing rod technique for spinopelvic dissociation under intraoperative neurophysiological monitoring could be a useful alternative surgical option, especially in patients without neurologic deficit.

Nakamae et al[28] described 2 cases of surgical treatment using intraoperative electrophysiological monitoring with transcranial electric motor-evoked potentials and continuous spontaneous electromyography for patients with high-grade dysplastic spondylolisthesis in adolescence. They successfully performed the surgeries without any neurological deficit using intraoperative electrophysiological monitoring.

Lateral Fusion

Narita et al[48] studied 36 patients who underwent extreme lateral interbody fusion (XLIF) for lumbar spine degenerative spondylolisthesis or lumbar spine degenerative scoliosis at L4–5 or at a lower level. During the operation, the psoas major muscle was dissected using an index finger fitted with a finger electrode, and the threshold values of the dilator were recorded before and after dissection. The historical controls were 18 patients (who underwent the same procedure for the same indications without the use of the finger electrode). They had no serious neurological complications in any of the patients, but there was a significantly lower incidence of transient neurological symptoms in the finger electrode group (7 [38%] out of 18 cases versus 5 [14%] out of 36 cases; $p = 0.047$). They suggest that this neuromonitoring system using a finger electrode may be useful to prevent XLIF-induced neurological complications.

Grimm et al,[49] in a retrospective chart review of perioperative complications within the first year after extreme lateral interbody fusion (involving 108 patients), found 25 complications (23%) in patients who underwent the procedure. Four patients (3.7%) experienced major complications, including vertebral body fracture, contralateral nerve root injury, dense quadriceps paresis, and persistent stenosis. There also were minor complications (approach-related thigh pain and/or paresthesias) that were all ultimately resolved. The authors state that dense femoral nerve palsy is a complication that may occur despite intraoperative neurophysiological monitoring.

The femoral nerve preservation in transpsoas lateral access surgery of the spine with the aid of neuromonitoring was addressed by Block et al,[33] who proposed a theory and technique to utilize motor-evoked potentials to protect the femoral nerve at risk in those procedures. On multiple occasions, their neuromonitoring groups observed significantly degraded amplitudes of the femoral motor- and/or sensory-evoked potentials limited only to the surgical side. Most of these degraded response amplitudes rapidly returned to baseline values with a surgical intervention like the removal of surgical retraction.

Cheng et al[50] also debated the requirement for intraoperative neuromonitoring in 90° lateral transpsoas spine surgery (lateral lumbar interbody fusion). Considering that the lateral approach to the lumbar spine requires passage near or adjacent to the lumbar plexus, the mini-open lateral transpsoas approach uses evoked electromyography integrated into the approach, and instrumentation that stimulates in directional orientations and provides discrete threshold responses to avoid the nerves of the lumbar plexus. Some lateral transpsoas approaches to the lumbar spine have been developed that do not advocate for the use of neuromonitoring, instead relying on direct visualization and avoidance of nerves ("shallow-docking"). They state there is substantially more literature describing the use of neuromonitoring in lateral transpsoas surgery, but reports of direct visualization and avoidance of nerves (shallow-docking) are emergent.

Uribe et al[34] reviewed intraoperative electromyography neurophysiological monitoring methods and their application in minimally invasive spine surgery. They state that the use of electromyography during the minimally invasive lateral transpsoas approach to the lumbar spine for interbody fusion contributed to decrease the complication rate from 30% to less than 1%. The authors consider that in addition to knowledge of the anatomy and image guidance, directional intraoperative electromyography neurophysiological monitoring is crucial to guarantee a safe passage through the psoas muscle during the minimally invasive lateral retroperitoneal approach.

Cost-benefit Issues

James et al[21] investigated the increase in the use of intraoperative neurophysiological monitoring during spine surgery, concluding that as the costs of spine surgeries continue to rise, it becomes necessary to examine and justify the use of different medical technologies, including intraoperative neurophysiological monitoring, during spine surgery. Garces et al,[16] considering the widespread use of intraoperative monitoring in many types of spinal surgeries, with concerns about its overuse in routine and low-risk procedures, performed a retrospective database review of 112 patients undergoing a 1- or 2-level minimally invasive surgery for transforaminal lumbar interbody fusion.

They believe that the use of intraoperative monitoring for minimally invasive surgery for transforaminal lumbar interbody fusion provides no added benefit. Ney et al,[19] in a large, multiyear, nationally representative dataset, showed that neurophysiological intraoperative monitoring was associated with better clinical outcomes in non-complex spine surgeries (with the largest benefits for laminectomies). The risk of neurologic complications was 75% higher without the use of neurophysiological intraoperative monitoring. Additionally, the adjusted increase in hospital charges was of only 9%. They also emphasize that the actual cost of neurophysiological intraoperative monitoring is outweighed by a lifetime of lost wages and health care costs from neurologic complications, including spinal cord injury.[6,19] Husain et al[20] comment that this reduction in complications is preferred to the higher-cost issue.

The occurrence of iatrogenic neurologic deficit after lumbar spine surgery (mainly for degenerative spondylolisthesis, spondylosis, scoliosis, and lumbar stenosis) was reviewed by Ghobrial et al,[32] who worked with a population of 2,783 patients in 12 studies. The authors state that those complications were avoided with the use of neuromonitoring. Thirty patients out of 731 (4.1%) patients had a new onset of a neurologic injury after anterior lumbar interbody fusion or lateral lumbar interbody fusion. Thirty-seven out of 2,052 (1.9%) patients had a neurologic injury after posterior decompression and fusion. Screw malposition was responsible for 11 deficits. These data show that spinal surgery for lumbar degenerative disease carries a low but real chance of neurologic deficits. Gavrancic et al[51] recommend specific tests for the intraoperative neurophysiological monitoring during lumbar spine surgery monitoring. Yaylali et al[52] propose the use of intraoperative neurophysiological monitoring also in anterior lumbar interbody fusion.

Eager et al,[53] reviewing 2,069 spine cases, found 32 cases with possible intraoperative events. There were 17 cases in which intraoperative neurophysiological monitoring changes affected the course of the surgery and prevented possible postoperative neurological deficits (7 due to deformity correction, 5 due to hypotension, 4 due to patient positioning, and 1 due to a screw requiring repositioning), reinforcing the importance of multimodality intraoperative neurophysiological monitoring (including somatosensory-evoked potentials, transcranial electrical motor-evoked potentials, and spontaneous and triggered electromyography) in spinal surgery.

McClendon et al,[54] studying reoperation patients who received operative correction of proximal junctional kyphosis of the upper thoracic spine, used intraoperative neurophysiological monitoring in all patients.

New Developments

In a recent study, Turner et al[25] evaluated spinal cord perfusion (using a laser Doppler probe fixated to the dura at the level of the pedicle subtraction osteotomy and intrathecal pressure monitoring using a lumbar drain, somatosensory-evoked potential and motor-evoked potential) during adult spinal deformity surgery as a marker for the risk of spinal cord injury. The alterations of perfusion and potentials guided the correction of the deformity. This was direct evidence that fluctuations in spinal cord perfusion may contribute to neurologic changes during adult spinal deformity surgery, contributing to the development of strategies for spinal cord protection during high-risk cases. Eck et al[29] reported a case of a patient with an American Spinal Injury Association grade B (ASIA B) spinal cord injury with partially intact baseline intraoperative neurophysiological monitoring who made a complete functional recovery postoperatively, illustrating the potential prognostic value of intraoperative neurophysiological monitoring.

Anesthesia has a fundamental role on intraoperative neurophysiological monitoring,[26,27,55] as the drugs used may alter the parameters intraoperatively.[26] There are some options in the choice of anesthesia during intraoperative neurophysiological monitoring, and this choice must consider the specific needs of the procedure (as a more rapid awakening and the feasibility of a rapid wake-up test when irreversible changes in neurophysiological monitoring are noted).[27,35]

The use of different criteria to alarm neurophysiological monitoring during spine surgeries has also been addressed, and the reduction in amplitude potentials (sensitive or motor-evoked potentials) with maximal stimulation for motor-evoked potentials could be a better warning alert than the complete loss of any of these potentials.[37] The specific needs of the neuromonitoring technique must be discussed with the surgeon in order to obtain the best results possible. There is a type of misplacement of lumbar pedicle screws associated with radicular pain in the standing and seated positions, that may not be detected by conventional monitoring, for example, suggesting the use of systematic pedicle track stimulation prior to the insertion of the lumbar pedicular screw.[38] Actually, electrical stimulation enables a reduction in the risk of medial positioning, minimizing the use of intraoperative radiographs for thoracic screws.[40]

Concerning pediatric neurosurgical procedures, despite their recent application, neurophysiological monitoring represents an important tool in the prevention and reduction of possible neurological lesions,[39,46,56] and in some cases it may inform the anatomical site for the corrective surgical maneuver to be performed.[57]

Even in those cases considered simple spine surgeries, the use of intraoperative neurophysiological monitoring has been proved useful, enabling the dynamic neurophysiological diagnosis, the differentiation of the compression at the central or foraminal levels, and the clinical awareness of iatrogenic damage, thereby increasing safety.[41] Even though intraoperative neurophysiological monitoring does not substitute good surgical technique and care, it is an important tool to provide relevant information to the spine surgeon, and it may provide the best chance to detect and possibly avoid spinal cord and nerve root injuries.[58] During spine surgery, intraoperative neurophysiological monitoring is, thus, an effective method of monitoring the functional integrity of the spinal cord and nerve roots, reducing risks and improving postoperative results.[42–44,59] The actual trend is to use multimodal intraoperative neurophysiological monitoring on procedures near or involving neural elements.[46,56,58]

Conclusion

The spine surgery team has the challenge of reconciling the technological developments with the best interest of the health care system and its growing costs. We believe that this reconciliation is feasible to the benefit of the patients health. Based on the literature discussed, multimodal intraoperative neurophysiological monitoring is an extremely useful tool in the prevention of surgery-related neural damages. We can also foresee that the use of this kind of monitoring will be essential in all spine surgical procedures that involve the manipulation of or proximity to nervous structures.

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