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6

Neurophysiological monitoring and spinal cord integrity

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An integral part of a major spine surgery is the intraoperative neurophysiological monitoring (IONM). By providing continuous functional assessment of specific anatomic structures, IONM allows the rapid detection of neuronal compromise and the opportunity for corrective action before an insult causes permanent neurological damage. Thus, IONM functions not just as a diagnostic tool but may also improve surgical outcomes. Effective clinical application requires a thorough understanding of the scope and limitations of IONM modalities not only by the monitoring team but also by the surgeon and anesthesiologist. Intraoperatively, collaboration and communication between monitorist, surgeon, and anesthesiologist are critical to the effectiveness of IONM. In this study, we review specific monitoring modalities, focusing on the relevant anatomy, physiology, and mechanisms of neuronal injury during major spine surgery. We discuss how these factors interact with anesthetic and surgical management. This review concludes with the current controversies surrounding the evidence in support of IONM and directions of future research.

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Introduction

When applied correctly, intraoperative neurophysiological monitoring (IONM) enhances the safety of spine operations not only through early detection of compromised neuronal structures but also through demonstration of preserved function. The diagnostic performance of IONM depends on choosing the appropriate monitoring techniques based on sound anatomic and physiologic principles while factoring in surgical and anesthetic considerations [1]. The information derived from IONM provides a continuous surrogate marker of homeostasis and anatomic integrity, and permanent changes in IONM signals typically herald new postoperative deficits. Therefore, postoperative neurological status can be inferred from intraoperative signals, and early corrective action can be taken before the injury becomes permanent [1–3]. A note of caution is due because correlating neuromonitoring signal changes with the presence or absence of a true neurological deficit is problematic. Signal changes may reverse with an intervention performed in response to the alarm, creating uncertainty about the "true" meaning of these changes and posing real obstacles to gathering randomized, blinded evidence [2–6].

Anatomic and physiologic properties that underlie intraoperative risk

Various neuronal structures are amenable to intraoperative monitoring, and the best monitoring approach is ultimately determined by considering the relevant anatomy and understanding the potential mechanisms of injury the surgical approach could inflict.

The various nerves, neuronal pathways, connective tissues, and their blood supply are channeled within the relatively tight compartments of bony structures that make up the spine. The spinal canal contains the spinal cord and nerve roots, supporting membranes (dura, arachnoid, and epidural fat), cerebrospinal fluid, and blood supply. The foramina act as conduits for nerve roots, spinal nerves, and feeding blood vessels. The spinal cord foreshortens relative to the spine and terminates as the conus medullaris usually above the first lumbar vertebral body (L1). The lumbosacral nerve roots comprise the cauda equina below. During certain stages of operative intervention, this foreshortening determines the neuronal structures that are at risk of injury at different spinal levels, particularly during pedicle screw placement, which is an important element of complex spine instrumentation. For example, at the thoracic level, nerve roots run horizontally at the superior and inferior margins of the pedicles. Immediately medial to the pedicle lies the anterolateral spinal cord and its membranes. Therefore, both nerve roots and the spinal cord could be injured during procedures rostral to the first lumbar vertebra in case of a superior or inferior and a medial breech. However, in operations performed caudal to L1, the only neuronal structures at risk are the nerve roots, which have a more vertical course and traverse the intervertebral foramina at a more acute angle. They will therefore approximate the pedicles medially, laterally, superiorly, and inferiorly [7] (Fig. 1). Neuromonitoring therefore must be tailored to the anatomical level, which determines the specific neuronal structures in question.

The homeostasis and function of the spinal cord and its nerve roots are primarily determined by adequate blood flow and oxygen supply. Spinal cord autoregulation, which maintains constant blood flow between wide ranges of mean arterial pressures (MAP), has very similar range limits to the brain [8]. The critical lower limit of this range, below which blood flow becomes pressure passive, has significant intra- and interindividual variability influenced by comorbidities, due to surgical and anesthetic factors. Blood flow may become pressure passive between MAPs of 50 and 70 mmHg in most cases; therefore, careful consideration should be given to this lower limit of autoregulation to avoid hypoperfusion [9].

Blood flow is distributed within the spinal cord via three vertical arteries. The anterior spinal artery (ASA) runs in the ventral median fissure and supplies the anterior two-thirds of the spinal cord, also covering most of the gray matter through end arteries. The two posterior spinal arteries (PSA) run alongside the dorsolateral columns and supply mainly the white matter of the posterior one-third of the spinal cord. The remaining anterolateral parts of the white matter are supplied through a circumferential anastomotic plexus between the ASA and PSA [10]. Blood flow through the ASA and PSA is primarily determined by a rich collateral network from the subclavian and iliac systems and from aortic segmental arteries [11]. The cervical and lumbosacral enlargements have a relatively