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ARTICLE FOR PRACTITIONERS / РАД ЗА ПРАКСУ

Use of intraoperative neurophysiological monitoring in surgical treatment of spinal diseases

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SUMMARY
Intraoperative neurophysiological monitoring (IONM) is a method, which uses different kinds of electrophysiological methods for monitoring and mapping of neural structures during surgical procedures with the aim to preserve them. If we know how important the function of the spine, spinal cord, nerve roots, and all other structures are, it is obvious how important it is to preserve them in surgical procedures where these structures are under risk. Although the frequency of neurological complications is not high, it is considered that these deficits are devastating complications of spinal surgery, which can have serious consequences on the quality of life and can increase health care costs. Because of that, the accent is on intraoperative neurophysiological methods development, which provide optimal monitoring of the spinal cord function during routine and complex spinal procedures and has high efficacy detecting possible neurological deficits. The concept of multimodal neuromonitoring, which is used today, relies on advantages of each modality separately and then in combination of these modalities it achieves a more reliable estimation of functional integrity. Today IONM is routinely used worldwide, but in Serbia, its use is still limited even though its advantages are well known.
Keywords: intraoperative neuromonitoring; neurological complications; spine surgery

Intraoperative neurophysiological monitoring (IONM) is a method, which uses different kinds of electrophysiological methods for monitoring and mapping of neural structures during surgical procedures with aim to preserve them. Certain kinds of IONM were used in the early 1970s and 1980s. Their use became everyday practice in different types of surgery, especially in neurosurgery and orthopedic surgery. Today IONM is routinely used worldwide, but in Serbia, its use is still limited, even though the advantages are well known.

Pathology of the spine is very diverse. There are deformities, degenerative diseases, injuries, and tumors, which could be primary and metastatic. The conservative therapy can be used in some occasions, but surgery is often the only possible option. If we know how important the function of the spine, spinal cord, nerve roots, and all other structures are, it is obvious how important it is to preserve them in surgical procedures where these structures are under risk. Recent data from literature report that new deficits in scoliosis surgery in adolescent population vary between 0.4–4.5% and in adult population 1.9–2.4% [1, 2]. Cramer et al. [3] reported the rate of neurological deficits of 0.178%, in a ten year-long retrospective study that included degenerative, neoplastic, traumatic, and infectious disease. Hamilton et al. [4] reported new neurological deficit in 1% of cases in their study from 2011, which included 108,419 spinal procedures, in adult and pediatric population. Although the rate of neurological complications is not that high, it is considered that these deficits are devastating complications of spinal surgery. Even if complications are rare, there is always a risk of neural structures injuries, which can have serious consequences on the quality of life, and an increase of health care costs [5, 6, 7]. Because of that, it is important to develop intraoperative neurophysiological methods, which could reliably monitor spinal cord during the surgical interventions.

Depending on spine pathology, symptoms could be various, but neurological deficits of varying degrees are very often present. The most often pathologies are certainly degenerative diseases of spine. The first symptom includes pain, usually lumbar pain, neck pain, or rarely arm pain, and thoracic pain is the rarest. Disc herniation in the cervical spine is usually at C5–6 level and C6–7 level, and anterior cervical discectomy and fusion is one of the most frequently performed procedures in neurosurgery. Depending on the herniated disk position and affected neural structures, clinical appearance can be either in the form of radiculopathy, myelopathy or both. Different authors reported complications in treatment of cervical myelopathy, with the most severe consequence being cervical medulla compression, from 4.4–20% [8, 9]. The rate of complications in patients without myelopathy is very low 0.09–0.6% [10, 11]. Kelleher et al. [12] found that sensitivity

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of somatosensory evoked potentials (SSEP) was 52% and specificity 100% in a study, which included 1055 cases with operation on the cervical spine. Sensitivity of motor evoked potentials (MEP) was 100% and specificity 96%, sensitivity of EMG was 46% and specificity 73%. In the lumbar spine, the most commonly affected levels are L4–5 and L5–S1. Gunnarson et al. [13] found sensitivity of SSEP 28.6% and specificity of 98.7%, EMG sensitivity was 100% and specificity 23.7% in the lumbar spine procedures. Therefore, it is considered that combined use of different modalities of IONM in these procedures provide higher sensitivity and specificity, allow timely intervention, decrease postoperative complications, and improve final outcome [14].

Primary tumors of the spine are rare, but metastatic tumors are common. Tumors can affect bone structures of the spine or they can be intraspinal. There are a few subgroups of intraspinal tumors. They can be extradural and intradural, while intradural tumors can be extramedullary and intramedullary. These tumors could be benign or malign, but due to their localization, they have a very high risk of neural complications during surgery, particularly intramedullary tumors.

During the surgical procedures, neurological deficits may arise from direct surgical injury of neural tissue, compression, traction, or compromised blood supply in the neural tissue [15]. Compressive spinal epidural or subdural hematoma can occur after surgical treatment and can be detected early using IONM [16]. In degenerative spinal disease mechanical compression from ligamentum flavum, posterior longitudinal ligament, intervertebral disc or bone structures can affect neural elements [16]. Positioning is also a crucial factor, which can cause compression or neural structures injury during spinal procedures [17]. The use of IONM in spinal surgery significantly decreases the risk of intraoperative damage of neural structures during each phase of a surgery and improves the outcome of surgical treatment.

SSEP were primarily used in scoliosis surgery and they significantly improved positive outcome of these operations. It is considered that the use of SSEP reduces paraplegia for 60%. SSEP estimate dorsal column medial lemniscus system from the periphery to the somatosensory cortex. Stimulation is performed on periphery mixed nerves, for upper extremities typically on median or ulnar nerve, while for lower extremities on posterior tibial nerve or common peroneal nerve. Needle and surface electrodes are usually used. Registration can be performed at appropriate places on the scalp, above somatosensory cortex, according to 10–20 International Electrode System, but also on subcortical and peripheral level. At the intraoperative phase of procedures, before and after positioning, we set the base line up, which serves as a control for potentials obtained during the operation. They can be recorded continuously throughout the operation, while they change the amplitude and latency, which are compared to the base line. At that moment, it is necessary to analyze all the variations in the context of technical issues, anesthesia effects, general effects, and surgical manipulation. An alarm criterion is the amplitude decrease for 50% with or without the increase of latency [18]. It is very important to keep in mind sensitivity to inhalational anesthetics, systemic factors such as hypothermia, hypotension, and hypoperfusion. In addition, not all decreases of amplitude are clinically significant. If amplitude decreases on 50% or lower of the base line, risk is higher, but an appropriate and timely reaction can lead to SSEP recovery and it can preserve the function. It is crucial whether changes occur gradually or suddenly. The most difficult is a sudden and complete loss of potentials without recovery. Stable intraoperative potentials are good predictors of a positive neurological outcome. Nuwer et al. [19] estimated the clinical efficacy of SSEP monitoring during scoliosis surgery in their extensive multicentric study, and they found that sensitivity was 92% and specificity 98.9% in detection of postoperative neurological deficits.

MEP managed to take standard place in IONM in the last three decades. In the 1980s, it was shown that transcranial use of high voltage pulses could induce contralateral motor activity. This technique is very sensitive to anesthesia, so during the time multi-pulse stimulation technique was developed with variation of anesthetics use. In the 1990s, this technique became a routine for monitoring corticospinal tract. These potentials are safe and reliable for use in spinal procedures [20]. The most common way for eliciting MEP is transcranial electrical stimulation with electrodes placed on the scalp over the motor cortex according to 10–20 International Electrode System, and with direct cortical stimulation. The most suitable for use on the scalp are corkscrew electrodes because of their stability and low impedance, and for direct cortical stimulation, strip electrodes are used. Registration can be done on peripheral muscles, as compound muscle action potential (CMAP), which are the result of α motor neuron activation and on spinal cord as the D wave. Registration from muscles is performed with needle electrodes, which are placed on the appropriate places. D wave registration is performed with special electrodes, which can be placed in epidural or subdural space. MEP is very sensitive to anesthetics and myorelaxants. Anesthesia is based on the use of propofol and opioids such as fentanyl and remifentanil, while myorelaxants can be given only at the beginning for intubation. It is very important that D wave is not under the effects of anesthesia. Amplitude and latency of D wave vary depending on the spinal cord level. If the change is more caudal, amplitude will decrease and latency will increase. Below the T9 level, it is very difficult to record a reliable D wave. It is considered that D wave is the most important during intramedullary spinal tumor operations [21]. At the beginning of the surgery, we set up the base line before and after positioning of a patient. Amplitude, latency, and intensity of stimulation are monitored. In addition, all changes of MEP are considered in the context of anesthesia, systemic effects, surgical manipulation and their development, whether they be gradual or sudden. There are different criteria, which can warn us that MEP changes could be significant. One group of authors suggest intensity of stimulation, others propose changes of amplitude, while some recommend only presence or absence of MEP [22, 23, 24]. Quinones-Hinojosa et al. [25] state that changes in amplitude and reduction of complexity of MEP curve correlate with motor outcome. Multichannel monitoring of MEP has higher specificity, sensitivity, and prediction of postoperative motor deficits [26]. In spine surgery of intramedullary tumors, one of the most reliable criteria is combination of MEP and D wave. Complete loss of MEP without changes of D wave, or with changes above 50% of D wave amplitude correlate with temporary motor deficit. Complete loss of MEP and decrease below 50% of D wave amplitude, or loss of D wave is a predicator of permanent deficit [27].

Electromyography (EMG) records electrical activity of muscles. It can be a free-run EMG, which registers spontaneous muscle activity and it allows continuous monitoring, and it can be triggered EMG, which implies direct stimulation of peripheral motor nerves or spine roots and registration of CMAP in the appropriate muscle. Surgical manipulations in form of traction, dragging and compression lead to activation of specific muscles, and that could be registered on free run EMG. Changes can be in the form of spikes, bursts, and trains. Spikes and bursts give us information about the vicinity of a nerve root and they usually appear because of the contact with surgical instruments [28]. Trains appear when continuous force acts on nerve roots, and are clinically significant because they indicate possible injuries [28]. Use of triggered EMG is highly recommended for adequate positioning of pedicle screws, because breach of pedicle cortex can cause injuries of nerve roots and spinal cord. In anesthesia, paralytic agents are contraindicated, with the exception of myorelaxants when anesthesia is first introduced. Relaxation is checked with standard train of four methods. In addition, it is very important to determine whether there are comorbidities such as myasthenia gravis, muscle dystrophy, or similar pathology, which can have influence on EMG.

The concept of multimodal monitoring used today relies on advantages of each modality separately and then, in combination of these modalities, it achieves more reliable functional integrity estimation. In the study, which included spinal procedures of deformities, spinal stenosis and spinal tumors, Sutter et al. [29] found sensitivity of multimodal monitoring of 89% and specificity of 99%. American Academy of Neurology and American Clinical Neurophysiology Society guidelines recommend the use of intraoperative monitoring of MEP and SSEP in spinal surgery as an effective tool in prediction of increased risk of neurological complications [30].

The combination of SSEP, MEP, free-run and triggered EMG provides optimal monitoring of the spinal cord function during routine and complex spinal procedures and has high efficacy in detecting of possible neurological deficits.

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Примена интраоперативног неурофизиолошког мониторинга у оперативном лечењу обољења кичменог стуба

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САЖЕТАК

Интраоперативни неурофизиолошки мониторинг подразумева употребу различитих електрофизиолошких метода у сврху праћења функционалног интегритета и мапирања одговарајућих нервних структура током хируршке интервенције са циљем њиховог очувања. Ако знамо колико је важна улога кичме, кичмене мождине, нервних коренова, јасно је колико је важно очувати их током операција у којима постоји могућност њиховог оштећења. Иако стопа неуролошких компликација није висока, оштећења ових структура се сматрају поражавајућом компликацијом спиналне хирургије и могу имати значајан утицај на квалитет живота и повећање трошкова лечења ових болесника. Због тога се акценат ставља на развој метода интраоперативног неурофизиолошког мониторинга које омогућавају оптимално праћење функције кичмене мождине и нервних коренова током рутинских и комплексних захвата у спиналној хирургији, и имају високу ефикасност у детекцији могућих неуролошких оштећења. Концепт мултимодалног неуромониторинга који се данас користи ослања се на предност сваког модалитета посебно, а њиховом комбинацијом постиже се много поузданија процена функционалног интегритета. Данас се интраоперативни неурофизиолошки мониторинг користи рутински широм света; међутим, код нас је његова употреба још увек ограничена, иако су њене предности веома добро познате.

Кључне речи: интраоперативни неуромониторинг; неуролошке компликације; операција кичме