Bidder Tıp Bilimleri Dergisi

2009 • Yıl: 1 • Sayı: 2 • 21-26

INTRAOPERATIVE EVOKED POTENTIAL MONITORING: COMBINED USAGE OF EVOKED POTENTIALS FOR A TETHERED CORD SYNDROME

İNTRAOPERATİF UYARILMIŞ POTANSİYELLERİN MONİTÖRİZASYONU: BİR GERGİN OMURİLİK SENDROMUNDA UYARILMIŞ POTANSIYELLERİNİN KOMBİNE KULLANIMI

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ÖZET

İntraoperatif nöromonitorizasyon, EMG'nin cerrahi sırasında kullanılması amacıyla geliştirilmiş bir metoddur. Altı aylıkken sırtında kese nedeniyle opere edilen 26 yaşındaki bayan hasta son 3-4 yıldır bacaklarında incelme ve kuvvetsizlik nedeniyle birçok merkeze başvurmuş ve retethering ve gergin omurilik sendromu tanısı ile izlenmiş. Son 1 aydır yürümesinin iyice bozulması, karanlıkta yürüyememe ve idrar kaçırma yakınmalarının başlaması üzerine kliniğimizde değerlendirilerek, intraoperatif nöromonitorizasyon (MEP, SEP) eşliğinde opere edilmiştir. Bazı kas motor ve duyu potansiyellerinde bozulma saptanması üzerine, radyolojik olarak görülen tethering kısmından daha kranialde yerleşmiş, MR'da görülmeyen dermal sünüs kalıntısı, T10 laminektomi yapılarak açılmış ve dura içinde kordu asan sinus kalıntısı kesilmiştir. Ameliyat süresince cerrahi prosedüre bağlı olarak MEP ve SEP parametrelerinde geçici ve önemli düzeyde olmayan değişiklikler de izlenmiştir. Ameliyat sonunda, MEP ve SEP parametrelerinde belirgin düzelme kaydedilmiştir. Hastanın post-op dönemde izleminde, bacak ve ayak kuvvetleri, posterior kolon disfonksiyonu ve idrar inkontinansı düzelmiştir. Cerrahi işlemler ile MEP ve SEP'te olan değişikliklerin eş zamanlı olarak izlenebilmesi güvenli, etkili ve invazif bir metoddur. Operasyon ilerledikçe kas potansiyellerinde meydana gelen düzelmeler; ameliyatı sonlandırma, hastanın daha uyanmadan önce nörolojik muayenesini tahmin etme gibi konularda yol gösterici olmaktadır.

Anahtar kelimeler: İntraoperatif nöromonitorizasyon, gergin omurilik sendromu, neurophysiology

CASE REPORT

ABSTRACT

Intraoperative neuromonitorisation (IOM) is a method that aims to use electroneuromyography (EMG) during neurosurgical procedures. 26 year-old woman who underwent a myelomeningocele operation at 6th month-old, had been applied with the complaints of thinning of her legs and difficulty in walking for the last 4 years. She was diagnosed as tethered cord syndrome. In admission, she had paraparesis, she could not have walked in the darkness, and had urinary incontinence for one month. The patient was operated for untethering of spinal cord with four extremities MEP and SEP monitorisation. During the operation, the data of electrophysiological monitoring and important events were both recorded. According to the decrease of MEP and SEP, the laminectomy area was extended cranially. A dermal sinus remnant tethering the cord which was not seen on MRI and on the skin due to prior operation scar was observed. Along the operation, reversible, and unsignificant changes of electrophysiological values had been observed. As the operation progressed and the spinal cord was untethered, improvement of MEPs and SEPs were also recorded. After the operation, the strength of the leg and foot muscles was increased, and the posterior colon dysfunction and urinary incontinance were recovered. Intraoperative monitoring of EPs serves as a safe, effective and invasive method for monitoring of the function of the nervous system and can detect the potential risk of operative procedures and improve the safety of subsequent procedures.

Key words: Intraoperative neurophysiology, spinal surgery, neuromonitorisation

INTRODUCTION

Neurophysiologic monitoring during surgery aims to prevent permanent neurological injury resulting from surgical manipulation. To improve the accuracy and sensitivity of intraoperative neuromonitoring (IOM), combined monitoring of transcranial electrical stimulation motor evoked potentials (TES-MEPs), somatosensory evoked potentials (SSEPs) and brainstem auditory evoked potentials (BAEPs) was attempted in different cranial and spinal diseases inclu-

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ding intracranial aneurysm, posterior fossa tumor, intramedullary spinal cord tumor, spinal deformity, brain surgeries around motor and somatosensory cortex, and aortic aneurysm (1,2). SSEPs are an established modality for monitoring of the function of the somatosensory pathways during surgery, but this method is not suitable for monitoring motor function (3,4). Moreover, BAEPs reflect functional state of the brainstem indirectly by evaluation of the brainstem auditory sensory pathways. These methods could not present a complete, accurate status of the motor pathway system. The compound muscle action potentials (CMAPs) evoked by transcranial electrical stimulation (TES) to the motor cortex, i.e. myogenic motor evoked potentials (myogenic MEPs), are regarded as pure motor evoked potentials (5,6) for intraoperative monitoring of motor function.

Amidst controversy about methodology and safety, intraoperative neurophysiology has entered a new era of increasingly routine transcranial and direct electrical brain stimulation for motor evoked potential (MEP) monitoring. Based on literature review and the illustrative case presented, this article aims to remind the topic for experienced practitioners, surgeons, and anesthesiologists and to present an overview those new to the field as well.

CASE REPORT

26 year-old woman had been applied to a number of clinics with the complaints of thinning of her legs, decreasing of her right-side shoe number for the last 4 years. The patient's history was notable for an operation due to myelomeningocele when she was 6 month-old. A series of MRI of the whole spine was obtained and she was diagnosed as tethered cord syndrome. She was explained that the operation was difficult and had a great risk of paraplegia. Though she was recommended to have physiotherapy. She had physiotherapy periodically, but her walking has been changing slowly, getting difficult. When she was admitted to our clinic, she could not have walked in the darkness, and had urinary incontinence for one month. The patient was able to ambulate, although her neurologic examination revealed paraparesis more on the right side, posterior colon dysfunction and perianal hypoesthesia. Her MRI showed that increasing of lumbar lordosis, fusion of T11, T12, and L1 vertebras and scoliotic deformity. At the level of L1 vertebrae, posterior fusion defect, enlargement of postero-anterior diameter of spinal canal, posterior displacement of spinal cord and attachment to the subcutaneous tissue (tethering) are observed. Diplomyelic appearance was between T11 and L2 level and intradural lipom was on the posterior of the cord at the T11 and T12 level (Fig-1 and Fig-2).

The patient was operated for untethering of spinal cord with four extremities MEP and SEP monitorisation (Fig-3). Anesthesia was induced propofol 3 mg/kg, fentanyl 2 mcg/kg, and vecuronium 0.07 mg/kg. Then the patient was entubated. Anesthesia was maintained with propofol 2 mg/kg/hr, remifentanil 7 mcg/kg/hr and, 50-50% O_2-air without any neuromuscular blocking agent.

Epoch XP Neurological Workstation (Axon system, Hauppage, USA) was used to monitor evoked potentials intraoperatively. The corkscrew electrodes were used as stimulating electrodes (CS electrode, Viasys Healthcare WI, MA, USA), and for MEP recording the twisted pair of needle electrodes were used (TP, Viasys Healthcare WI, MA). According to the international 10 to 20 system instituted by the International Electroencephalographic Society, the stimulating electrodes were placed C3§C4 and C1§C2 points over the scalp. The stimulation parameters were short train consisting of 3 to 5 stimuli with 0.5 ms duration each. These stimuli were separated by 4 ms interstimulus interval, with a train repetition rate of 2 Hz and an intensity of up to 200 mA.. Meanwhile, MEPs were recorded from the bilateral

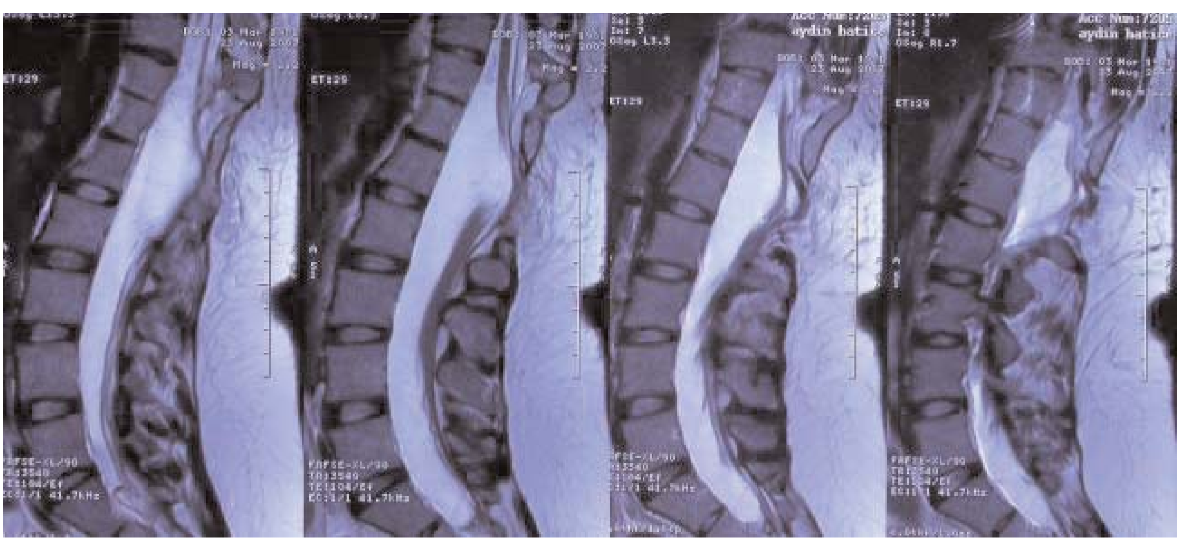

Figure 1— T2-weighted sagittal lumbal MRI showing increased lumbar lordosis, fusion of T11, T12, and L1 vertebras and scoliotic deformity.

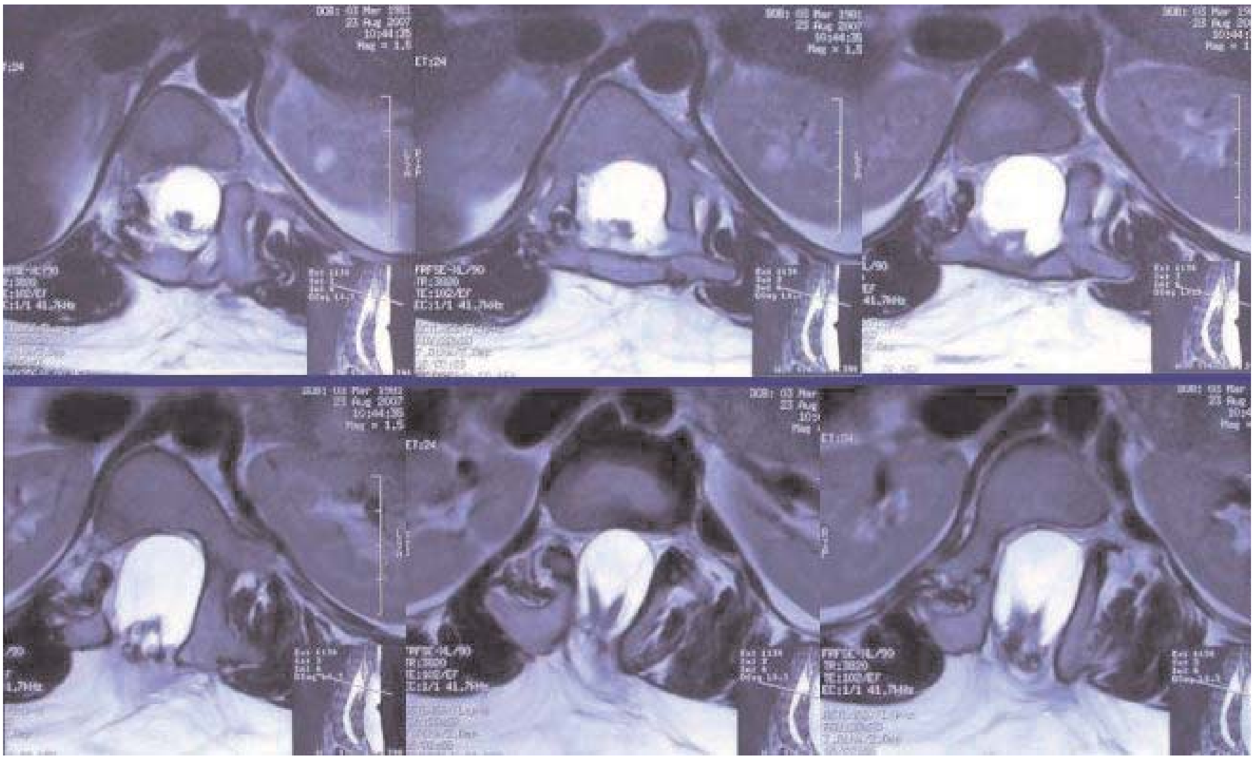

Figure 2— T2- weighted aksiyal lomber MRI showing posterior fusion defect at the level of L1 vertebrae, enlargement of postero-anterior diameter of spinal canal, posterior displacement of spinal cord and attachment to the subcutaneous tissue (tethering). Diplomyelic appearance between T11 and L2 level and intradural lipom on the posterior of the cord at the T11 and T12 level.

Abductor pollicis brevis, tibialis anterior, Abductor hallucis brevis muscles. Very low dose muscle relaxant agent was given during induction of intubation. After positioning and preparation for IOM (almost takes 30 minutes), the value of MEPs after induction of anesthesia was regarded as baseline, and the warning criteria for amplitude reduction of MEPs over 50% or significantly increased stimulation threshold compared with baseline and MEP loss was considered to be significant neurologic deterioration (7).

Figure 3— Placement of the electrodes for SEP and MEP, connections and the Epoch XP Neurological Workstation (Axon system, USA)

Monitoring of Cortical somatosensory eveoked potential) CCsSEPs

Cork screw electrodes were used as recording. To record CCsSEPs from the upper limbs, the reference electrodes were placed at the Fz point and the recording electrodes were placed at the C3', C4' points(2cm posterior of C3 and C4). The stimulating electrodes were placed on the bilateral median nerves at both wrists, with a stimulating intensity ranging from 15 to 25 mA, a frequency of 3.1 Hz, a wave band ranging from 50 to 300 Hz, and an analysis time for 50 ms. To record CCsSEPs from the lower limbs, the recording electrodes were placed at the Cz'(2 cm posterior of Cz) point. The stimulating electrodes were placed on the bilateral posteror tibial nerve at the medial malleolus, with a stimulating intensity ranging from 20 to 30 mA, an analysis time for 100 ms, and the other parameters as same as those of CCsSEPs monitoring in the upper limbs. The warning criteria as the amplitude reduction over 50% in contrast to baseline or as the prolonged latency for more than 10% (8).

Train of four twitch test (TOF)

Four consecutive electrical stimuli of 2 Hz (interval 0.5 s) were given to the left median nerve, while the recording electrodes were placed at the left abductor pollicis brevis.

During the operation, the data of electrophysiological monitoring and important events were both recorded. During the paravertebral muscle dissection, there was a tissue coming out through the posterior laminar fusion defect of T10 vertebra. The manipulation of this tissue caused decrease of MEP and SEP. That's why the laminectomy area was extended cranially, the T10 laminectomy was performed and dura was opened. A dermal sinus remnant which was not seen on MRI and on the skin due to prior operation scar was observed. It was dissected and cut. Along the operation, reversible, and unsignificant changes of electrophysiological values had been observed. The surgeon was informed simultaneously about those changes. As the operation progressed and the spinal cord was untethered, improvement of MEPs and SEPs were also recorded. At the beginning of the operation there was no MEP at the right quadriceps muscle, but at the end of the operation there was a significant MEP of this muscle (Fig-4A and 4B).

At the follow-up, the strength of the leg and foot muscles were increased, and the posterior colon dysfunction and urinary incontinance were recovered. The patient¢s pre-op and post-op neurological findings were shown in Table-1 comperatively. Abdominopelvic ultrasonography of the patient at the early post-operative period showed no post-voiding residue.

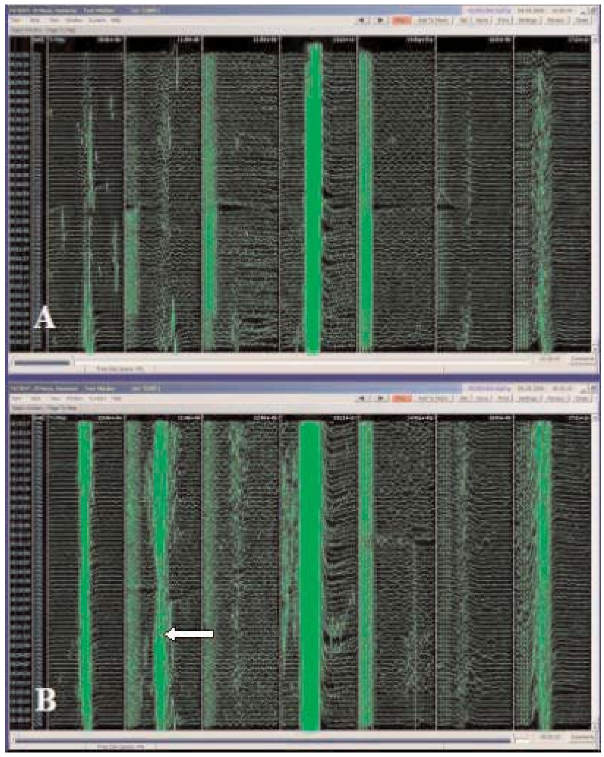

Figure 4– Intraoperative neuromonitorisation recordings. A-beginning of the operation, baseline, B-end of the operation. Increased amplitudes of all muscle potentials are obviously seen. Arrow showed the significant increase of MEP amplitude at the right quadriceps muscle.

DISCUSSION

We believe that a short overview of the physiologic basis of current monitoring techniques might help to evaluate their safety, understand interpretive controversies and outline some applications and results.

Patton and Amassian discovered that a single electric pulse applies to monkey motor cortex evokes several descending corticospinal tract volleys in 1954 (9). An immediate non-synaptic discharge of corticospinal axons was shown to produce the first and largest volley that was named the D wave, being directly generated by electric pulse. The following 1-5 volleys were shown to be due to the excitation of cortical synaptic circuits that discharge corticomotor neurons with 1.3-2.0 ms periodicity. These were called I waves, being indirectly generated by electric pulse.

Then in 1980, Merton and Morton found that single pulse TES produces a muscle MEP in conscious humans (10). The mechanism is believed to vary with the momentary excitability of alpha motor neurons, determined by their levels of background depolarization from facilitatory synaptic bombardment (11). Those close to action potential threshold fire in response to the initial D wave excitatory post-synaptic potential (EPSP), others fire after D and I wave EPSP summation and must to not fire. Thus each successive response represents a varying subpopulation of the recorded muscle's motor units.

In the mid-1980's, Barker et al. developed transcranial magnetic stimulation (TMS) introducing diagnostic MEP testing without the scalp discomfort of TES (12). This technique generates muscle responses predominantly through I wave volleys, although D waves can be evoked with coil orientations that induce lateral to medial current flow in the brain (13).

Intraoperatively, the synaptic interference of surgical anesthesia normally eradicates single-pulse muscle responses by reducing or abolishing I waves and reducing alpha motor neuron excitability. However, the remaining non-synaptic D wave recorded in the spinal epidural space following TES came into clinical use as a valuable corticospinal tract monitoring technique beginning in the 1980s (14-17).

Tablo 1– The neurological examination (muscle strength) of the patient before operation and post-operative 4th month

	Pre-op	Post-op
Right lower extremity/ distal	2/5	4/5
Right lower extremity / proximal	3/5	5/5
Left toe extension and flexion	1-2/5	5/5
Left lower extremity / distal	3/5	5/5
Left lower extremity / proximal	4/5	5/5
Romberg sign	+	–

Efforts to include alpha motor neurons in intraoperative MEP testing turned to invasive spinal cord electrical stimulation with recording from muscle (18-20) or peripheral nerve (21). However, cord stimulation is non-selective. Consequently, while leg muscle responses evoked by rostral cord stimulation are mediated through alpha motor neurons, these might be activated through any of several spinal cord pathways connecting to them. Theoretically, this could include antidromic volleys in dorsal column 1a afferent axons, whose collateral branches form monosynaptic excitatory synapses with alpha motor neurons. Thus, while lower motor neuron compromise should be reliably detected, the possibility of undetected motor tract damage exists. Even worse, peripheral nerve responses (formerly "neurogenic MEPs") were eventually shown to mostly be antidromic sensory potentials containing no reliable motor information (22).

Taniguchi et al. made a major breakthrough in 1993 by showing that a short train of 3-5 electric pulses with an inter-pulse interval of 2-4 ms applied directly to human motor neuron cortex evokes a muscle MEP under anesthesia (23). This is thought to be due to summation of EPSPs from 1. the evoked burst of D waves and 2. any I waves that may be facilitated by the second or third pulse even when absent to a single pulse (24). Finally, in 1996 three independent groups showed that pulse-train TES is also effective (25-27). Pulse-train TMS might work, but TES is more practical and its scalp discomfort is irrevelant under anesthesia. Thus, comprehensive tools for selective corticospinal motor system monitoring were finally in place 42 years after the discovery of MEPs. Today, pulse-train TES with muscle MEP monitoring is now widely applied and is indicated for any surgery threatening the motor system except open peri-rolandic brain surgery that removes the skull overlying motor cortex. It allows rapid assessment of motor system integrity from brain to muscle and is available from induction to closure.

This monitoring technique appears to be facilitated by intravenous anesthesia such as propofol and remifentanil or other opioids that have proven to be safe, effective and well-tolerated (28-31). Sometimes low-concentration nitrous oxide is added (32), but whether or not this practice detracts from MEP monitoring is unclear. Other examples of reportedly favorable anesthetics include ketamine/sufentanil (33), diazepam/ propofol/ fentanyl/nitrous oxide (34) and benzodiazepine/fentanyl (35).

The apparent benefits of intravenous agents for muscle MEP monitoring may be due to less interference with alpha motor neuron excitability than from inhalational anesthetics including nitrous oxide (36-39). Chen recently compared propofol and isoflurane in neurologically intact patients at similar anesthetic depths as judged by bispectral index (BIS) measurement (28). Muscle MEP monitorability was better with propofol at any given BIS level.

For obvious reasons, neuromuscular blockade is often omitted after intubation and this does not appear to interfere with monitoring or surgery (35,40-42). Otherwise, muscle relaxation must be incomplete and somehow tightly controlled according to the amplitude of muscle responses to peripheral nerve stimulation (33,34,43,44). This approach increases technical and interpretive complexity ans runs the risk of inadvertently disabling muscle MEP monitoring at a critical moment. Note that blockade potentiation occurs with the administration of magnesium and that some blood pressure lowering agents such as alpha2-receptor antagonists and ketanserin can depress MEP amplitudes (45).

A close relationship exists between postoperative motor function and the results of TES-MEPs monitoring. TES-MEPs are superior to SSEPs and BAEPs in detecting motor dysfunction, but combined MEPs and SSEPs could make monitoring of the integrity of nervous function more completely and accurately. The negative changes of the muscle potentials compared to the baseline recorded potentials are important to protect neurologic functions and, the surgeons must be informed simultaneously. As the operation progressed, increase in the MEPs and SSEPs can be useful to estimate the neurologic state of the patient before awakening.

Eventhough, intraoperative monitoring of EPs could detect the potential risk of operative procedures and improve the safety of subsequent procedures, its effectiveness in decreasing the overall morbidity awaits further investigation because of some irreversible intraoperative injuries and unpredictable postoperative injuries of nervous function. IOM also needs some well trained staff and special equipment. Additionally, the surgeon must be willing to act according to the findings of IOM for the technique to be helpful for the outcome. However, the insignificant and/or intermittant amplitude reduction or changes of potentials may also restrict the surgical manipulations. These limitations can be overcomed with a stable team who started the IOM with low-risk cases and, has been working for a long time together.

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