Intraoperative Neurophysiology of the Corticospinal Tract

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About thirty years ago, intraoperative monitoring (IOM) of orthopedic surgeries became the historical landmark that ushered in the entire field of intraoperative neurophysiology.[1] Even from these rudimentary beginnings, IOM had techniques and methodologies capable of predicting and preventing intraoperative neurological deficit. These earlier achievements eventually established IOM as a standard of care for spine and spinal cord surgeries Furthermore, monitoring SEPs during scoliosis surgeries in most institutions became a substitute for the "Stagnara Wake up test", or gave strong indication if this test should be performed when SEPs changes were significant.

Up to the 1990's, motor evoked potentials were not yet a part of IOM methodologies. Therefore, conclusions about the integrity of the CTs within the spinal cord were indirectly drawn from monitoring the dorsal columns with SEPs. Such indirect approach did little to encourage surgeons' confidence on the reliability of IOM to indicate imminent intraoperative injury to the spinal cord's motor system. It is understandable that such a correlation cannot always be correct and discrepancies between the functional integrity of the dorsal columns and of the CTs was reported.[2,3] These reports, together with the observation that the disappearance of SEPs during myelotomy for spinal cord tumor surgery is not necessarily followed by motor deficits, further questioned IOM's usefulness. Furthermore it was shown that "neurogenic MEPs" method, which electrically stimulates the spinal cord and records elicited activity from the peripheral nerves doesn't represent motor evoked potentials, but antidromic activity from the stimulated dorsal columns.[4-7] Further development of motor evoked potentials recorded from the spinal cord as a D and I waves as well as from the limb muscle after eliciting them with a short train of transcranially applied stimuli, has brought the full confidence of (neuro)surgeons in the ability of IOM to predict and prevent intraoperative injury to the spinal cord's motor system. It has been reported that there is a tremendous benefit to using MEPs and SEPs in combination for monitoring spinal surgeries.[8,9] Another combination that uses the D wave and muscle MEPs` to monitor spinal cord surgeries[10] has proven to be reliable tool for preventing intraoperative injury to the spinal cord's motor system. By contrast, the D wave–but not muscle MEPs–has shown false positive data, but only during scoliosis surgeries. This is due to the new anatomical relationship between recording electrode and the spinal cord after correction of the scoliotic curvature.[11]

Historically, intraoperative neurophysiology has progressed by means of trial and error. Unfortunately, this has resulted in a number of different opinions as to its utility in documenting and preventing surgically induced neurological injury. In spite of this, the methodology for monitoring the functional integrity of the CT has progressed over the last 15 years into a reliable, fast, and relatively simple tool that is easily utilized intraoperatively. The development of such a solid methodology has given us reliable and specific data that highly correlate with neurological outcome postoperatively. This correlation and the published surgical outcome data demonstrate the merits of these techniques.

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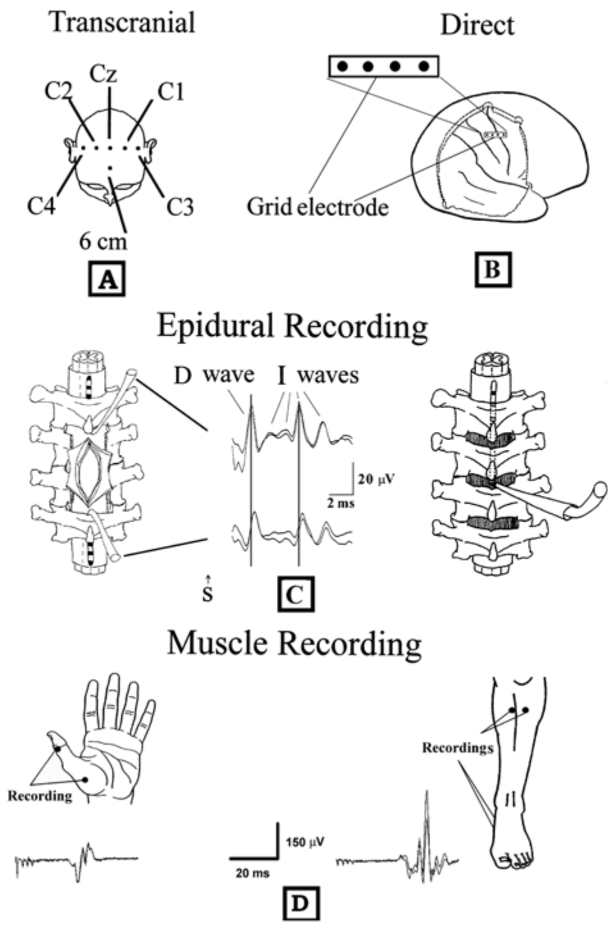

Figure 1. Schematic drawing of intraoperative methodology for eliciting and recording motor evoked potentials from the spinal cord and limb muscles. Top: Schematic illustration of electrode positions for transcranial and direct electrical stimulation of the motor cortex according to the International 10- 20 EEG system. Middle: Schematic diagram of the positions of the catheter electrodes (each with three recording surfaces) placed cranial to the tumor (control electrode) and caudal to the tumor to monitor the incoming signal passing through the site of surgery. In the middle are D and I waves recorded rostral and caudal to the tumor site. Please note the peak latency difference between cranial and caudal recordings of the D and I waves is marked with vertical lines. Bottom: Recording of muscle motor evoked potentials from the thenar, tibialis anterior and abductor hallucis muscles after eliciting them with a short train of electrical pulses applied transcranially.

After using parallel recordings of D wave and muscle MEPs, we can draw further conclusions:

A. The optimal stimulating parameters for eliciting muscle MEPs are:

The individual pulse duration should be 500 ìs, the inter-stimulus interval in the train of 5-7 pulses should be 4 ms, and a stimulation rate of up to 2 Hz should be used (Deletis et al., 2000, parts 1 and 2). The stimulus intensity should be up to 200 mA. Usually, 100 mA or less is required for consistently eliciting muscle MEPs. The "corkscrew like" stimulating electrode should be placed over the C1/C2 (10-20 International EEG system). The other stimulating sites on the scalp that could be used include C3/C4, or 1-2 cm in front of C3 or C4, or Cz/6 cm in front of Cz (governed by the particulars of the case). If surgically exposed motor cortex was stimulated through the grid assembly electrode, or handheld ball electrode, less current is required (only up to 20 mA). Other stimulating parameters are the same as for TES. In both settings the anode is the stimulating electrode. With regard to selecting muscles for stimulation, the abductor pollicis brevis muscle (APB) or forearm flexors or extensors are recommended for the upper extremities. For the lower extremities, the tibial anterior muscles (TA) and/or abductor hallucis brevis (AH) should be used. It is not necessary to average single responses.

For recording muscle MEPs, EEG needle electrodes are recommended (surface electrodes are acceptable as well).

B. For eliciting a D wave, the same stimulating sites are recommended as for muscle MEP. A single pulse of 500 ìs duration and a stimulation rate up to 2 Hz should be used. Intensity of stimulation should be set up as is required for eliciting muscle MEPs.

Note: If the chosen intensity elicits muscle MEPs on one side of body, a D wave recorded epidurally represents activity of only one CT tract. If surgery does not require laminectomy/laminotomy, a D wave recording can be achieved by placing a suitable catheter electrode percutaneously (using a Tuohy needle or through flavectomy). The averaging of 2-4 responses usually result in high quality D wave recordings.

C. General anesthetics and muscle relaxant do not influence a D wave.

D. A decrease in the temperature of the spinal cord temporarily prolongs the latency of D and I waves.

E. Muscle MEPs are sensitive to the use of halogenated anesthetics (isoflurane, flurane, and enflurane). They are also sensitive to the muscle relaxants. Note: Although muscle MEPs can be elicited at the level of relaxant which gives one response out of four (train of four technique), we do not recommend the use of any relaxant during surgery except a short acting one during patient intubation.

F. The clinical correlation between the behavior of the D wave and muscle MEPs consistently show that both potentials are necessary for the prediction of postoperative motor outcome. Their importance has been shown in the case of "transient paraplegia of surgical origin".[15] During surgery for intramedullary spinal cord tumors in the thoracic spinal cord, the loss of muscle MEPs with preservation of the D wave always predicts postoperative paraplegia with complete recovery in a short period of time (a few hours to a few days).

G. The D wave recorded from the spinal cord exclusively represents the electrical activity of a synchronized descending volley of the fast neurons of the CT.

H. The muscle MEPs elicited in an anesthetized patient presents mixed activity of the CT and the supportive system (propriospinal system) of the spinal cord. It is likely that the supportive system is being indirectly activated from the motoneurons of the CT.

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