Intraoperative monitoring of motor evoked potentials in very young children

Clinical article


1Neuro-Spine Program, Division of Pediatric Neurosurgery, Texas Children’s Hospital, Department of Neurosurgery, Baylor College of Medicine; 2Division of Neurophysiology, Texas Children’s Hospital; 3Department of Neurology, Baylor College of Medicine; 4Division of Pediatric Anesthesiology, Texas Children’s Hospital, Department of Anesthesiology, Baylor College of Medicine, Houston, Texas

Object. Neurophysiological monitoring of motor evoked potentials (MEPs) during complex spine procedures may reduce the risk of injury by providing feedback to the operating surgeon. While this tool is a well-established surgical adjunct in adults, clinical data in children are sparse. The purpose of this study was to determine the reliability and safety of MEP monitoring in a group of children younger than 3 years of age undergoing neurosurgical spine procedures.

Methods. A total of 10 consecutive spinal procedures in 10 children younger than 3 years of age (range 5–31 months, mean 16.8 months) were analyzed between January 1, 2008, and May 1, 2010. Motor evoked potentials were elicited by transcranial electric stimulation. A standardized anesthesia protocol for monitoring consisted of a titrated propofol drip combined with bolus dosing of fentanyl or sufentanil.

Results. Motor evoked potentials were documented at the beginning and end of the procedure in all 10 patients. A mean baseline stimulation threshold of 533 ± 124 V (range 321–746 V) was used. Six patients maintained MEP signals ≥ 50% of baseline amplitude throughout the surgery. There was a greater than 50% decrease in intraoperative MEP amplitude in at least 1 extremity in 4 patients. Two of these patients returned to baseline status by the end of the case. Two patients had a persistent decrement or variability in MEP signals at the end of the procedure; this correlated with postoperative weakness. There were no complications related to the technique of monitoring MEPs.

Conclusions. A transcranial electric stimulation protocol monitoring corticospinal motor pathways during neurosurgical procedures in children younger than 3 years of age was reliably and safely implemented. A persistent intraoperative decrease of greater than 50% in this small series of 10 pediatric patients younger than 3 years of age predicted a postoperative neurological deficit. The authors advocate routine monitoring of MEPs in this pediatric age group undergoing neurosurgical spine procedures. (DOI: 10.3171/2011.1.PEDS10255)

Key Words • intraoperative monitoring • pediatrics • spine surgery • motor evoked potentials

Intraoperative neurophysiological monitoring is a valuable safety measure in complex spine surgery. Monitoring of SSEPs alone may not detect injury to the corticospinal tract or prevent postoperative weakness. Recording MEPs with TES provides the best information about the integrity of the descending motor pathways in the spinal cord. While monitoring of MEPs is well established in adults, its use and reliability in the pediatric population are still being defined.

Motor evoked potentials are sensitive to the patient’s underlying neurological condition, the anesthesia technique, and the extent of myelination of the corticospinal pathways. Previous authors have shown an age-dependent decrease in reliability of MEP monitoring in children. Younger age is also associated with an increase in the threshold voltage required to obtain a robust MEP response. The goal of our study was to examine the reliability and safety of MEP monitoring in very young patients.
children. To the best of our knowledge, our series of children younger than 3 years of age represents the first report of the routine use of MEPs in this patient population.

Methods

All pediatric patients undergoing neurosurgical procedures with spinal cord monitoring between January 1, 2008, and May 1, 2010, at Texas Children’s Hospital were studied. Over this time period, we performed a total of 81 cranial and 122 spinal procedures with intraoperative monitoring. Ten of the spinal surgeries were performed in children who were younger than 3 years of age. All underwent MEP monitoring. These 10 consecutive patients formed the basis for our study.

Anesthesia

Patients who required premedication received either 0.5 mg/kg of oral or 0.1 mg/kg of intravenous midazolam. Anesthesia was induced using an inhalation technique with 8% sevoflurane, 70% nitrous oxide, and oxygen. Once intravenous access was established, the sevoflurane and nitrous oxide were discontinued and the patient received a dose of propofol (2–3 mg/kg). A bolus of fentanyl (2–3 μg/kg) or sufentanil (0.5 μg/kg), with or without a single dose of 0.6–1 mg/kg rocuronium, was used prior to intubation. Maintenance of anesthesia was provided with propofol 100–250 μg/kg/min based on hemodynamic response. Intermittent fentanyl boluses of 2 μg/kg or sufentanil infusion at 0.2–0.6 μg/kg/min were used as needed. Neuromuscular monitoring was performed with the train-of-four or train-of-seven technique.1

Motor Evoked Potential Monitoring

Motor evoked potential monitoring was performed in patients after the neuromuscular blockade dissipated. Transcranial electric stimulation with temporal facilitation (consisting of a train-of-four or train-of-seven pulses, 200–700 V, duration 50 μsec interstimulus interval 3 msec) was applied using a Digitimer MultiPulse Stimulator model D185—Mark IIa (Digitimer Ltd.) that provided an external trigger to the Endeavor CR recording device (CareFusion). Corkscrew electrodes were placed subdermally on the scalp at Fc3 and Fc4 according to the international 10-10 system, and each was alternately used to deliver a single stimulus train. The anode and cathode were switched according to the hemisphere stimulated. Motor evoked potentials were recorded using 2 monopolar needle electrodes placed 4–6 cm apart intramuscularly from the left and right tibialis anterior muscles in the lower extremities and extensor carpi ulnaris muscles in the upper extremities (Fig. 1).

Analysis of MEP Responses

A semiquantitative estimation of the responses was performed. The criterion for the presence, absence, or robustness of the response was determined as follows: at least 75% of the MEPs should have an amplitude ≥ 35 μV throughout the entire monitoring period. The level of 35 μV was chosen because in all cases MEPs of this amplitude were well above and clearly discernible from baseline noise level. A decrease of greater than 50% of baseline amplitude was differentiated from a complete loss of MEP signals. Either event was reported to the surgeon during the case. Motor evoked potentials were recorded approxi-
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approximately every 10 minutes but more frequently at the beginning and during critical periods of the surgical procedure.

**Results**

A total of 10 consecutive children younger than 3 years of age who underwent MEP monitoring were identified and included in the study (Table 1). All 10 patients had conditions affecting the nervous system, including tethered spinal cord, congenital scoliosis, occipitocervical instability with cord compression, intramedullary cervical tumor, or spinal dysraphism. The mean age of the 7 boys and 3 girls was 16.8 months (range 5–31 months).

Robust MEP signals were documented in all 10 patients at the start and end of surgery in at least 1 extremity. Baseline MEPs were attained at a mean baseline threshold of 533 ± 124 V (range 321–746 V).

Six patients had consistent MEPs with amplitudes ≥ 50% of baseline at the beginning and end of the case. Motor evoked potentials were recorded in all 4 extremities in 4 children (Cases 5, 7, 9, and 10). Two children (Cases 4 and 6) had absent signals in 1 or more extremity, but robust signals at the beginning and end of the case in the other extremities. All 6 of these patients were neurologically intact in the postoperative period and over the follow-up duration.

There was considerable variability in MEP signals throughout the procedure with decreases greater than 50% in MEP amplitude in 4 children (Cases 1, 2, 3, and 8). Two children (Cases 1 and 2) with intraoperative decreases in MEP had a return to baseline at the end of the procedure. There were no new neurological deficits in either of these patients.

Two children (Case 3 and 8) exhibited variable signals and persistent decreases in amplitude during surgery. Both these cases were in patients with cervical intramedullary spinal tumors. The patient in Case 3 had a persistent decrease of more than 50% in signals after resection (Fig. 2). This corresponded with postoperative right upper-extremity weakness. The patient in Case 8 initially presented with progressive left upper-extremity weakness.

There were no complications attributable to the intraoperative monitoring.

**Discussion**

Although intraoperative monitoring is being used more frequently, there are very few reports of its use in the pediatric age group. The study of monitoring of MEPs in the very young (younger than 3 years of age) has not been reported previously. Our data confirm that reliable signals predicting postoperative neurological function may be established in a majority of these patients with a standard anesthetic regimen and stimulation protocol, even in children with a preexisting neurological or muscular disease.

**Anesthesia**

The anesthesia plan must be carefully considered as both inhalation and intravenous anesthetics can affect the MEP response. There are a number of potential anesthesia regimens in children undergoing monitoring. Our standard anesthetic technique for procedures requiring electrophysiological monitoring consists of induction with sevoflurane and a single dose of muscle relaxant, followed by a titrated propofol drip with boluses of opioids. Sevoflurane had low solubility compared with other inhalation anesthetics and thus is eliminated rapidly, minimizing its effects during monitoring later in the case. Opioids have little effect on evoked responses while still providing anesthesia. Propofol has a dose-dependent depressive effect on MEPs but is routinely used in moderate doses in adult patients during spinal cord monitoring of the motor pathways. The loss or absence of MEP amplitude may be minimized when propofol is administered in small, titrated doses (100–250 µg/kg/min) in a child younger than 3 years of age.

There is a risk for propofol infusion syndrome in children. Propofol infusion syndrome is characterized by refractory bradycardia, base excess greater than 10 mmol/L, metabolic acidosis, rhabdomyolysis, and fatty infiltrates in the liver. It is more common in children, especially with prolonged infusion of doses greater than 4 mg/kg/hr. Although we have not observed this in our patients with the doses described, we recommend continuous cardiac monitoring with frequent blood gas measurements during surgery and avoidance in patients with inborn errors of mitochondrial fatty-acid metabolism.

Careful monitoring is mandatory in spine procedures, especially when using anesthetic regimens that potentially affect the hemodynamic status of the patient. Medication doses during MEP monitoring may be adjusted to hemodynamic response with noninvasive blood pressure measurements. However, we routinely use invasive arterial monitoring during spinal cord or scoliotic deformity surgery to carefully titrate all vasoactive medications. Hypotension must be avoided to ensure adequate cord perfusion. Central access is used when the surgery has a high potential for blood loss or at the discretion of the surgeon.

**Age and the Stimulation Threshold**

Compared with other published series in adults, we found a higher MEP threshold in young children. This may be related to the immaturity of the motor pathways. All children younger than 3 years of age required baseline threshold voltages greater than 300 V. Cortical changes with aging might affect MEP responses. Hagelthorn et al. observed faster evoked potential interhemispheric transmission time with increasing age (7–17 years), suggesting increased corpus callosal myelination and integration during childhood. Spinal cord motor pathways also undergo a period of maturation. The corticospinal tracts undergo a protracted period of myelogenesis and synaptogenesis, which continues well into the 2nd decade of life. Myelination in the spinal cord begins in the second trimester of pregnancy, yet the corticospinal tract is the only pathway of the spinal cord not myelinated by
<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age (mos), Sex</th>
<th>Pathology</th>
<th>Associated Diseases</th>
<th>Procedure</th>
<th>Baseline Voltage, Signal Comments</th>
<th>Follow-Up</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>19, M</td>
<td>occipitocervical instability, FM stenosis, apnea/bradycardia episodes</td>
<td>Pfeiffer syndrome, hydrocephalus, obstructive lung disease, craniosynostosis</td>
<td>C-1 laminectomy, Oc–T5 fusion</td>
<td>321 V; only bilat LE MEPs present, signals inconsistent but present at end; all responses good at end of case</td>
<td>no apnea/bradycardia events at 10 mos w/ good bony fusion, pt died of pneumonia at 13 mos</td>
</tr>
<tr>
<td>2</td>
<td>5, F</td>
<td>sacral lipomyelocele, tethered cord</td>
<td>omphalocele, malrotation, cloacal extrophy, lt hydronephrosis, absent rt kidney</td>
<td>tethered cord release, resection of lipoma</td>
<td>548 V; lt LE MEP not recorded because of cast, rt LE had strong signal at beginning of case, variable signals during case, &amp; good signals at end of case</td>
<td>stable neuro exam at 2 yrs</td>
</tr>
<tr>
<td>3</td>
<td>17, M</td>
<td>intramedullary cervical spinal cord tumor</td>
<td>none</td>
<td>C1–7 laminectomy, resection of tumor</td>
<td>481 V; good bilat UE/LE signals, decline in rt UE MEPs intraoperatively</td>
<td>went from 4/5 rt UE strength preop to 1–2/5 strength postop, strength returned to 4/5 at 29-mo follow-up</td>
</tr>
<tr>
<td>4</td>
<td>31, M</td>
<td>congenital scoliosis, rt T-10 hemivertebrae</td>
<td>developmental delay, hypoxic encephalopathy, cerebral palsy, multiple vertebral anomalies, tracheostomy, gastrostomy</td>
<td>rt T-10 hemivertebrectomy, T8–10 fusion</td>
<td>500 V, bilat LE MEPs absent, bilat UE signals good at end of case, bilat LE signals never present</td>
<td>stable, good leg strength &amp; improvement in angulation at 2 yrs</td>
</tr>
<tr>
<td>5</td>
<td>9, M</td>
<td>congenital scoliosis, L-1 hemivertebra, tethered spinal cord, spinal lipoma</td>
<td>hydrocephalus, macrocephaly, PDA, PFO</td>
<td>release of spinal cord, resection of lipoma, resection of L-1 hemivertebra, T12–L2 fusion</td>
<td>710 V; good signals bilat UE/LE, good signals at end of case</td>
<td>stable spinal deformity, stable motor function at 2 yrs, rt LE &gt; lt LE strength, pt required lt LE brace</td>
</tr>
<tr>
<td>6</td>
<td>19, M</td>
<td>tethered spinal cord, congenital scoliosis</td>
<td>none</td>
<td>release of tethered cord, placement of growing rods T3–L4</td>
<td>746 V, rt LE MEPs absent most of case, stable signals at end of case</td>
<td>stable neuro exam at 17 mos</td>
</tr>
<tr>
<td>7</td>
<td>24, M</td>
<td>congenital kyphosis w/ myelopathy</td>
<td>none</td>
<td>hardware adjustment &amp; removal from previous correction</td>
<td>486 V; good signals bilat UE/LE at beginning &amp; end of case</td>
<td>stable neuro exam at 17 mos</td>
</tr>
<tr>
<td>8</td>
<td>14, M</td>
<td>intramedullary spinal cord tumor</td>
<td>none</td>
<td>resection of intramedullary ependymoma</td>
<td>446 V; MEPs recorded from both arms &amp; rt leg, no MEPs generated in lt leg, SSEPs were obtainable on the lt side but at much lower voltage, cortical &amp; subcortical responses from stimulating the lt arm were variable or not present later in the case</td>
<td>patient presented w/ lt arm weakness, arm strength was worse (0/5) postop, pt had a gradually improving neuro exam at 5 mos w/ 4/5 strength in the lt triceps &amp; 3/5 in grip</td>
</tr>
<tr>
<td>9</td>
<td>5, F</td>
<td>lipomyelomeningocele</td>
<td>none</td>
<td>untethering of spinal cord, repair of lipomyelomeningocele</td>
<td>509 V; good signals in bilat UE/LE at beginning &amp; end of case</td>
<td>stable neuro exam at 6 mos</td>
</tr>
<tr>
<td>10</td>
<td>25, F</td>
<td>fatty filum</td>
<td>none</td>
<td>filum resection, untethering of spinal cord</td>
<td>586 V; good signals in bilat UE/LE at beginning &amp; end of case</td>
<td>stable neuro exam at 6 mos</td>
</tr>
</tbody>
</table>

* FM = foramen magnum; LE = lower extremity; neuro exam = neurological examination; Oc = occiput; PDA = patent ductus arteriosus; PFO = patent foramen ovale; pt = patient; UE = upper extremity.
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![Examples of MEPs in the left and right extensor carpi ulnaris and tibialis anterior muscles in a 17-month-old child undergoing resection of an intramedullary spinal cord tumor.](image)

In our study, we defined a complete loss of signal or a greater than 50% decrease in MEP amplitude as probable for postoperative neurological deficit. However, there are no universally accepted criteria for identification of significant myogenic MEP signal changes. A number of criteria have been proposed, including a specific percentage of signal loss, presence versus absence of signals, an increase in stimulation threshold necessary to obtain signals, and complexity/polyphasia of the recorded response. Possible explanations for the absence, progressive decrease, or variability of MEP amplitudes intraoperatively include the effect of propofol, the duration of anesthetic, decreased spinal cord perfusion following hemodynamic instability or surgical manipulation or instrumentation, young age, or a combination of these factors. Gradual changes in signals more commonly reflect systemic factors or an “anesthetic fade” phenomenon. Therefore, gradual changes might be given less credence unless the onset of the change can be related to a surgical event. If the signals are poor initially, the criteria are usually limited to the signal presence or absence.

The technique of direct recording of MEPs from the spinal cord for intradural procedures may result in even more reliable and predictive data in the very young patient. This, however, is beyond the scope of the current study. We plan to study this option in future studies.

### Safety and Complications

There are a number of reported complications with MEP monitoring via TES. These include hypotension, metabolic or respiratory acidosis, tongue lacerations, movement during surgery, and bleeding or burns at the site of monitoring electrodes. Additionally, there is a potential risk of “kindling” or frank seizures. A review by MacDonald found 5 instances of intraoperative seizures in 15,000 cases. Cardiac arrhythmia was reported in 1 of the cases, but it was not clear whether this was directly related to MEP stimulation.

We undertook certain precautions to try to avoid these complications. Routine use of a soft bite block may prevent the most common complication, laceration of the tongue. The surgeon should be warned prior to MEP testing to prevent unexpected patient movement during a delicate part of the procedure. Scalp electrodes are placed in such a way as to avoid patent fontanels, suture lines, and other defects of the skull.

In our experience, intraoperative monitoring of MEPs via TES in children younger than 3 years of age appears safe. There were no intraoperative or postoperative complications related to the application or technique of recording MEPs with needle electrodes.

### Conclusions

Routine intraoperative monitoring of MEPs in children younger than 3 years of age during neurosurgical procedures appears feasible and safe. We were able to obtain robust signals with clinical implications in a small series of children younger than 3 years of age. Return of baseline MEPs at the end of surgery was reassuring that the patient would experience no new neurological defi-
cits; however, diminution or loss of signals at the end of surgery was worrisome for postoperative weakness. We recognize the need to continue to explore the neurophysiology and the interpretation of MEPs in this very young age group. We advocate monitoring of myogenic MEPs in select spine cases as an additional safety measure, even in very young patients.

Disclosure

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author contributions to the study and manuscript preparation include the following: Conception and design: Jea, Satyan. Acquisition of data: Fulkerson, Wilder, Riviello, Stayer, Whitehead, Curry, Dauser, Luerssen. Analysis and interpretation of data: Fulkerson, Satyan, Riviello. Drafting the article: Fulkerson, Stayer. Critically revising the article: Jea, Fulkerson. Reviewed final version of the manuscript and approved it for submission: all authors. Study supervision: Jea.

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References

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Address correspondence to: Andrew Jea, M.D., Texas Children’s Hospital, 6621 Fannin Street, CCC 1230.01, 12th Floor, Houston, Texas 77030. email: ajea@bcm.tmc.edu.