SEP Monitoring of Cord Function

- Uses dorsal column function as a surrogate for global cord function
- Works because:
  - cord compression
  - blunt trauma
  - ischemia
  - usually affect both sensory and motor systems

SEP Monitoring can “Fail”

- SEPs not monitorable at baseline
- Technical – instrumental
- Inherent limitation of test:
  - SEPs inadequate surrogate
MEP + SEP → Parallel Redundancy

SEP

MEP

SEPs not monitorable
14 year old with Friedreich's Ataxia, scoliosis correction

Absent SEPs at Baseline

Normal, Easily Monitored MEPs

18 y/o Spinal Fracture - Fusion / Instrumentation
LE Sensory deficit / Motor 4/5

SEPs not monitorable
SEPs become unmonitorable

Initial dorsal myelotomy may disturb dorsal column function sufficiently to make SEPs unmonitorable.

Anterior Spinal Fusion Complicated by Paraplegia
A Case Report of a False-negative Somatosensory-evoked Potential

BRUCE BENOVID, MD, GLENN HALLER, MD, and PETER TAYLOR, MD

SPINE • VOLUME 12 • NUMBER 5 • 1987

Caval tear → prolonged MAP 40-45
Transient loss of SEP, Paraplegia

Distinct Pathways
Distinct Circulations

Tenuous Anterior Supply

Posterior spinal artery
Anterior spinal artery
Anterior
Lateral corticospinal tract
Watershed Areas
Adamkiewicz Area
Spinal deformity correction
Derotation may injure major radicular artery

Thoracoabdominal aortic aneurysm surgery
Cross clamping aorta
Sacrifice of significant segmental arteries

Embolization of vascular malformations
Abnormal vasculature
Territory perfused unpredictable
Modality lost on test injection unpredictable

False Start: Direct Spinal Cord Stimulation
Record form peripheral nerve: Neurogenic "MEPs"

Largely Antidromic Sensory Signals
NOT Motor EPs!
Neurogenic “MEP”

Two false negative cases:

Unchanged neurogenic “MEP” + motor deficit
Minahan et al, J Clin NP 2001

However

Are quicker and easier than SEPs
Do provide instrumental redundancy

Intervening synapses prevent simultaneous activation of spinal cord sensory pathways

Stimulation of the cerebral cortex in the intact human subject

P. A. Merton & H. B. Morton
The National Hospital, Queen Square, London WC1N 3BG, UK

To stimulate, a 0.1-μF condenser charged to up to ~2,000 V was discharged through the electrodes using a Morse key. The electrode over the motor area was the positive. A shunt resistance of 100 Ω ensured that the time constant of discharge was less than 10 μs.
Spinal Cord D-Wave Monitoring

D-wave Monitoring
- Compatible with complete NM blockade
- Compatible with volatile anesthetics
- May permit more aggressive intramedullary resection
  - D wave > 50% + Muscle MEP Lost → only transient deficit (Kothbauer 1998)
- Unilateral lesions hard to detect
- Can’t monitor lower cord, cauda, or roots
- Can’t detect spinal motor neuron ischemia
- Technically difficult to position recording electrodes
Cord Position Change → Spurious D-wave Change
5% false positive (>50% ↓) in scoliosis surgery
(18% had >20% but <50% ↓)

Derotation → change in proximity of motor tract to epidural electrode

For Muscle MEP Monitoring, Must Fire α Motor Neuron

Stimulus Trains For Muscle MEPs

Propofol / opioid anesthesia
MEPs Exhibit Trial to Trial Variability
Spontaneous Fluctuation of Motor Pool Excitability

Dual Train Facilitation
Segmental & Suprasegmental

Facilitation Depends on Inter-train Interval

Each train:
4 stim.
20 msec
100 usec
105 V
Record ADM

Absolute Inhibition 35 – 130 msec
Facilitation Depends on Inter-train Interval

Stimulus train
Threshold Fluctuates

Stimulus
Train
Train
MEP
MEP
20 msec

Journee HL. Clinical Neurophysiology. 2007;37:423-430. Fig 3
Spatial Facilitation: Medial Plantar Arch

Transcranial Electrical Stimulation

60 msec

Sim Medial Plantar Arch
10 pulses 20-60 mA
0.5 msec ISI

Record MEP AH

Transcranial Electrical MEPs

Anodal stimulation

C1 “anterior” – C2 “anterior”
   Target LEs
   May be less effective

C3 “anterior” – C4 “anterior”
   May be more effective for both UE and LE

Transcranial Electrical Simulation

Special purpose constant voltage, capacitive coupled stimulator
   Or
   Standard, constant current, SEP type stimulator

Both work well; special purpose stimulators provide more rapid charge delivery and lower total charge.
Include Distal Muscles
AH / APB ADM

Muscle MEP Monitoring
Anesthetic Effects

- Cortex
  - I-wave suppression
  - D-waves spared
- Depress spinal motor neuron

Muscle MEP Monitoring
Anesthetics

- Inhalational agents (N₂O, halogenated) attenuate MEPs most
- Intravenous anesthesia (propofol, dex, opioid) attenuate MEPs less
- Ketamine may be help, especially < 6 y/o (Frei, Spine 2007)
11 y/o AIS
Ketamine, Propofol
ISO 0.6%, No NMB
Obese, Labile BP

Dual Train Adds Resilience To Anesthetic Effects

12 y/o AIS
Ketamine, Propofol
ISO 0.6%, No NMB
Obese, Labile BP

Dual Train Adds Resilience To Anesthetic Effects

MEPs More Difficult in Young Children

Lieberman JA. Anesth Analg. 2006;103:316-321. Fig 5
"Anesthetic Fade"
Threshold increases with duration of anesthesia
Independent of dose dependent depressant effects
Lipid soluble and insoluble agents

Neuromuscular blockade
- Attenuates MEPs
- Most centers avoid NMB (4 of 25 peds centers use, Sloan 2010)
- Improve SEPs, especially brainstem
- Reduce patient movement
- Reduces tongue bite incidence / severity

- Constant controlled infusion
- 3-4 twitches TOF
- Avoid Boluses!

No NMB
Vecuronium Infusion
3/4 Twitches
SEPs Improved
MEPs Still Robust
**Partial NMB Does Not Interfere with MEP Monitoring**

14 y/o AIS  PSF Instrumentation T2-L2

- Propofol
- Ketamine
- Lidocaine
- Isoflurane 0.4%
- Vecuronium
  
  1 mg/hr

3 / 4 twitches

Partial NMB Does Not Interfere with MEP Monitoring

**Small Vecuronium Bolus Transiently Abolishes MEP**

13 y/o AIS  PSF T4 – L1

- Propofol
- Ketamine
- Fentanyl
- N2O 50%
- ISO 45%

8:35 6 MG VEC Induction

4/4 Twitches

Small Vecuronium Bolus Transiently Abolishes MEP

**Interpretative Criteria**
Identical stimuli produce variable Muscle MEPs!

N₂O, narcotic, propofol

Muscle MEPs are Quite Sensitive Indicators of Cord Function
MEP Lost @ 33% D-wave Decrease
Ependymoma T6-T6

Modified from Sala Clin Neurophysiol 2008;119:248-264

Relationship Between D-Wave, Muscle MEP and Outcome

<table>
<thead>
<tr>
<th>D wave</th>
<th>Muscle MEP⁴</th>
<th>Motor status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unchanged or 30-50% decrease</td>
<td>Preserved</td>
<td>Unchanged</td>
</tr>
<tr>
<td>Unchanged or 50% decrease</td>
<td>Lost uni- or bilaterally</td>
<td>Transient motor deficit</td>
</tr>
<tr>
<td>&gt;50% Decrease</td>
<td>Lost bilaterally</td>
<td>Long term motor deficit</td>
</tr>
</tbody>
</table>

⁴ In the tibial anterior muscles.
Proposed “Alarm Criteria”

- Complete loss
- % amplitude decrease (75 – 90)
- Stimulus threshold criteria
- Waveform complexity criteria
- Combination \( \text{Amplitude} \times \text{Area} \times \text{Duration} \times \text{Phase/Latency} \)

Notify surgeon when baseline variability is exceeded.

Transient MEP enhancement & EMG injury activity
Porcine Thermal Cord Injury Model
Injury may open “leakage conductance” channels

Charge density
- 10,000,000 * < histological damage
- 1000 * < used for cortical functional localization

15,000 published & unpublished cases
McDonald JCN 2002

- 27 Bite injuries (lip/tongue) – Bite Block
- 1 Mandibular fracture
- 5 Seizures (? Coincidental)
- 5 Arrhythmias (?) Coincidental
  (we observed one additional related bradycardia/bradynthias)
- 1 Intraoperative Awareness

Tce-MEP Safety
A couple cases ........
Return of MEPs and SSEPs with increased blood pressure

14:37
12 y/o AIS, Posterior Fusion, screws placed
Propofol/Narcotic, MAP 65 mmHg

Left SEP | Right SEP | MEP

10 ms | 0.5 uV | 50 uV

©RGE

14:47
First Rod Place, Correction

Left SEP | Right SEP | MEP

©RGE
21
What happened to SEPs between ’95 and ’07?

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>Multicenter Retrospective Survey</td>
<td>91 cases</td>
<td>100 cases</td>
<td>207 cases</td>
<td>1121 cases</td>
</tr>
<tr>
<td>False Negative</td>
<td>0.13%</td>
<td>0%</td>
<td>1.4%*</td>
<td>0%</td>
</tr>
<tr>
<td>True Positive</td>
<td>0.42%</td>
<td>3.6%</td>
<td>2.8%</td>
<td>0.8%</td>
</tr>
<tr>
<td>False Positive</td>
<td>1.5%</td>
<td>6.5%</td>
<td>4.3%</td>
<td>5.2%</td>
</tr>
<tr>
<td>Motor Deficits Detected by SEP</td>
<td>100%</td>
<td>100%</td>
<td>50%</td>
<td>43%</td>
</tr>
<tr>
<td>Motor Deficits Detected MEP</td>
<td>N/A</td>
<td>N/A</td>
<td>100% (4)</td>
<td>100% (7)</td>
</tr>
</tbody>
</table>

* 2 radiculopathies, 1 delayed paraparesis

172 spinal deformity cases (144 patients)
3 procedures (2 patients) had no MEPs

Sensitivity = 100%
Specificity = 0.97 (5 false +)
Concurrent use of SSEPs & MEPs

Parallel Redundancy
Each is a surrogate for global cord function

Complimentary
MEPs – intermittent, but fast and very sensitive
SEPs – continuous, but respond slower and less sensitive

MEPs to Detect Root Injury??

Despite Multi-segmental Innervation
There’s Usually a Dominant Root

Reduction of tcMEP Amplitude After Root Ligation in Pig

<table>
<thead>
<tr>
<th>Root</th>
<th>Muscle</th>
<th>Mean Reduction</th>
<th>95% Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>L3</td>
<td>Rectus Femoris</td>
<td>48%</td>
<td>23 – 73%</td>
</tr>
<tr>
<td>L4</td>
<td>Vastus Lateralis</td>
<td>40%</td>
<td>24 – 56%</td>
</tr>
<tr>
<td>L5</td>
<td>Tibialis Anterior</td>
<td>67%</td>
<td>57 – 78%</td>
</tr>
</tbody>
</table>
INCREASES IN VOLUME MAY PRODUCE FALSE-NEGATIVES WHEN USING TRANSCRANIAL MOTOR EVOKED POTENTIALS TO DETECT AN ISOLATED NERVE ROOT INJURY

Lyon R J Clin Mon Comput 2010;24:411-448

Both Cases Foot Drop Post OP

Effect of increase stimulation voltage on TA amplitude
Following ligation of dominant root (L4, 5, or 6) in pig.

Lyon R J Clin Mon Comput 2010