Motor Evoked Potential
Intraoperative Monitoring

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

Absent SEPs at Baseline

Normal, Easily Monitored MEPs
SEPs not monitorable
18 y/o Spinal Fracture - Fusion / Instrumentation
LE Sensory deficit / Motor 4/5
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 BEN-DAVID, MD, GLENN HALLER, MD, and PETER TAYLOR, MD

SPINE • VOLUME 12 • NUMBER 6 • 1987

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

Posterior spinal artery
Anterior spinal artery
Lateral corticospinal tract

Watershed Areas

Tenuous Anterior Supply

Adamkiewicz Artery
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!

Sciatic n. record ~ scoliosis surgery

Pereon Y. Electroencephalogr Clin Neurophysiol, 108:17, 1988 Fig. 6
Neurogenic “MEP”

Two false negative cases:

Unchanged *neurogenic “MEP”* + motor deficit

However

Are quicker and easier than SEPs

Do provide *instrumental redundancy*
Intervening synapses prevent simultaneous activation of spinal cord sensory pathways
D-Wave

I-Waves
Spinal Cord D-Wave Monitoring

Courtesy Eva Ritzl

Morota N. Neurosurgery 1997;41:1327-1336 Fig. 1
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 $\rightarrow$ Spurious D-wave Change

5% false positive ($>50\% \downarrow$) in scoliosis surgery

(18% had $>20\%$ but $<50\% \downarrow$)

Derotation $\rightarrow$ change in proximity of motor tract to epidural electrode

Ulkantan S. Clinical Neurophysiology 2006;117: 2093–2101 Fig. 5
For Muscle MEP Monitoring, Must Fire α Motor Neuron

After Phillips and Porter, Prog Brain Res ’64
Baboon α Motor Neuron
MEPs Exhibit Trial to Trial Variability
Spontaneous Fluctuation of Motor Pool Excitability

Stimulus train

Threshold Fluctuates

Spinal Cord α Motor Neuron

EPSP

After Phillips and Porter, Prog Brain Res ’64

Infrequent Testing

© RGE

10 Msec

30 uV
Dual Train Facilitation
Segmental & Suprassegmental

Stimulus

Train

Train

MEP

MEP

20 msec
Facilitation Depends on Inter-train Interval

Each train:
4 stims
ISI 2 msec
100 usec
125 V

Record ADM

Absolute Inhibition 35 – 130 msec
Spatial Facilitation: Medial Plantar Arch

- Transcranial Electrical Stimulation
- Stim Medial Plantar Arch: 10 pulses 20-60 mA 0.5 msec ISI
- Record MEP AH

60 msec
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)
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

12 y/o AIS
Ketamine, Propofol
ISO 0.6%, No NMB
Obese, Labile BP
MEPs More Difficult in Young Children

**Figure 5**

Graph showing MEP threshold voltage vs. age with the equation:

\[ y = -14.2x + 451 \]

\[ R^2 = 0.53, P < 0.0001 \]
“Anesthetic Fade”
Threshold increases with duration of anesthesia
Independent of dose dependent depressant effects
Lipid soluble and insoluble agents

Desflorane / Propofol
Desflorane / N₂O
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!
Vecuronium Infusion
3/4 Twitches

No NMB

SEPs Improved
MEPs Still Robust
Partial NMB Does Not Interfere with MEP Monitoring

14 y/o AIS    PSF Instrumentation T2-L2

12:30

C3′ - C4′  Cz′ - C4′  Fpz – SC5  Cz′ - SC5

14:00

L Tibial SEP

3 uV/div  10 msec/div

L TA

500 uV/div
2000 uV/Div

L AH

2000 uV/Div 10 msec/div

L APB

Vecuronium
1 mg/hr
3 / 4 twitches

Propofol
Ketamine
Lidocaine
Isoflurane 0.4%
Small Vecuronium Bolus Transiently Abolishes MEP

13 y/o AIS   PSF T4 – L1

Propofol Ketamine Fentanyl N20 50% ISO 45%

8:35 6 MG VEC Induction

4/4 Twitches

BOLUS 1 MG VEC

200 uV, 10 msec / div
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 MEP&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Motor status (postoperatively)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unchanged or 30–50% decrease</td>
<td>Preserved</td>
<td>Unchanged</td>
</tr>
<tr>
<td>Unchanged or 30–50% 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>

<sup>a</sup> In the tibial anterior muscle(s).
Proposed “Alarm Criteria”

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

Notify surgeon when baseline variability is exceeded.
Transient MEP enhancement & EMG injury activity
Porcine Thermal Cord Injury Model
Injury may open “leakage conductance” channels

Tce-MEP Safety

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 bradyarrhythmia)
1 Intraoperative Awareness
A couple cases ........
12 y/o Neuromuscular Scoliosis

14:45 PM
Screw placement complete
begin rod placement

TIVA / Partial NMB
16:05PM
2nd Rod being positioned.

**Surgeon alerted to decrement fo MEPs**
16:10PM
Surgeon removing both rods

complete loss MEPs
Decrement of SEPs

16:13 PM Surgeon removing rods
16:43PM
Surgeons repositioning rods
16:49PM
Rods repositioned

****Surgeons alerted to MEP loss
stable SEPs

17:18
Surgeons reinsert 1st rod, less correction

stable MEPs
stable SEPs

17:27
2nd rod being positioned, less correction

stable MEPs
<table>
<thead>
<tr>
<th>Left SEP</th>
<th>Right SEP</th>
<th>MEP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post Op Exam: No Deficits</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

18:30 Final Closing
Return of MEPs and SSEPs with increased blood pressure
14:37
Screws Placed
Propofol/Narcotic
MAP 65 mmHg

12 y/o AIS  Posterior Fusion

Left SEP
Right SEP
MEP

CP3 - CP4
CP3 - FPZ
CPZ - FPZ
CPZ - CHIN
FPZ - CHIN
Lpop - Lpop2

CP4 - CP3
CP4 - FPZ
CPZ - FPZ
CPZ - CHIN
FPZ - CHIN
Rpop - Rpop2

LTID - L REF
LGast - L REF
LAH - L REF
RTH - R REF
RGast - R REF
RAH - R REF

0.5 uV
50 uV
10 ms
First Rod Place, Correction

<table>
<thead>
<tr>
<th>Left SEP</th>
<th>Right SEP</th>
<th>MEP</th>
</tr>
</thead>
<tbody>
<tr>
<td>CP3 - CP4</td>
<td>CP4 - CP3</td>
<td>L Tib - L REF</td>
</tr>
<tr>
<td>CP3 - FPZ</td>
<td>CP4 - FPZ</td>
<td>L Gast - L REF</td>
</tr>
<tr>
<td>CPZ - FPZ</td>
<td>CPZ - FPZ</td>
<td>LAH - L REF</td>
</tr>
<tr>
<td>CPZ - CHIN</td>
<td>CPZ - CHIN</td>
<td>RTIB - R REF</td>
</tr>
<tr>
<td>FPZ - CHIN</td>
<td>FPZ - CHIN</td>
<td>RGast - R REF</td>
</tr>
<tr>
<td>Lpop - Lpop2</td>
<td>Rpop - Rpop2</td>
<td>RAH - R REF</td>
</tr>
</tbody>
</table>

10 ms
0.5 uV
50 uV
14:55

MAP ↑ 95 mmHg

Left SEP

Right SEP

MEP

©RGE
Second Rod Placed

15:09
### What happened to SEPs between ’95 and ’07?

<table>
<thead>
<tr>
<th></th>
<th><strong>Nuwer 1995</strong></th>
<th><strong>Forbes 1991</strong></th>
<th><strong>MacDonald 2007</strong></th>
<th><strong>Schwartz 2007</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Study Type</td>
<td>Multicenter Retrospective Survey</td>
<td>Royal Ortho Hospital Consec Retro</td>
<td>Mixed spinal Instrumentation</td>
<td>CHOP, RWJ St. Chris Consec Retro</td>
</tr>
<tr>
<td>Instrumentation</td>
<td>Mixed spinal instrumentation</td>
<td>Mixed spinal instrumentation</td>
<td>Mixed spinal Instrumentation</td>
<td>AIS Only</td>
</tr>
<tr>
<td>No. Cases</td>
<td>51,263</td>
<td>1168</td>
<td>207</td>
<td>1121</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 paraparasis

Brian Hsu, MBBS, FRACS,* Andrew K. Cree, MBBS, FRACS,*
Jim Lagopoulos, BSc, MBiomedE, PhD, FAINM,† and John L. Cummine, MBBS, FRACS*

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>

After Mok JM Spine 2008;33:E465-E473  Table 1
INCRESSES IN VOLTAGE MAY PRODUCE FALSE-NEGATIVES WHEN USING TRANSCRANIAL MOTOR EVOKED POTENTIALS TO DETECT AN ISOLATED NERVE ROOT INJURY

Russ Lyon, MS, DABNM\textsuperscript{1}, Anthony Gibson, MBBS\textsuperscript{2}, Shane Burch, MD\textsuperscript{2} and Jeremy Lieberman, MD\textsuperscript{3}

L4-5 TLIF

Pre-injury

Post-injury

\[ \uparrow \ 26 \ v \]

\[ \uparrow \ 54 \ v \]

L5 pedicle subtraction osteotomy

Pre-injury

Post-injury

\[ \uparrow \ 20 \ v \]

\[ \uparrow \ 50 \ v \]

Both Cases Foot Drop Post OP

Lyon J Clin Mon Comput 2010
INCREASES IN VOLTAGE MAY PRODUCE FALSE-NEGATIVES WHEN USING TRANSCRANIAL MOTOR EVOKED POTENTIALS TO DETECT AN ISOLATED NERVE ROOT INJURY

Russ Lyon, MS, DABNM¹, Anthony Gibson, MBBS², Shane Burch, MD² and Jeremy Lieberman, MD³

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;24:411-448  Fig 3