Neurological Complications in EOS and Neuromonitoring Issues

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New Neurological Deficit (NND) Associated With Spine Surgery

1064 New Neurologic Deficits / 108,419 Procedures  1%

Revision cases 1.25%  Primary cases 0.89%
Pediatric cases 1.32%  Adult cases 0.83%

Neuromonitoring was used for 65% of cases

<table>
<thead>
<tr>
<th>Deficit</th>
<th>Number</th>
<th>IOM changes</th>
<th>Recovery</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>No recovery</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Partial</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Complete</td>
</tr>
<tr>
<td>Nerve Root</td>
<td>662</td>
<td>11%</td>
<td>4.7%</td>
</tr>
<tr>
<td>Cauda Equina</td>
<td>74</td>
<td>8%</td>
<td>9.6%</td>
</tr>
<tr>
<td>Spinal Cord</td>
<td>293</td>
<td>40%</td>
<td>10.6%</td>
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</tbody>
</table>

Kojo Hamilton and Al. Spine 2011
### New Neurological Deficit (NND) Associated With Spine Surgery

#### Type of Scoliosis

**Pediatric < 21 Y**

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Nerve Root</th>
<th>Cauda Equina</th>
<th>Spinal Cord</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Congenital</td>
<td>2045</td>
<td>0.98% (20)</td>
<td>0.05% (1)</td>
<td>0.98% (20)</td>
<td>2.00% (41)</td>
</tr>
<tr>
<td>Neuromuscular</td>
<td>4855</td>
<td>0.39% (19)</td>
<td>0.06% (3)</td>
<td>0.58% (28)</td>
<td>1.03% (50)</td>
</tr>
<tr>
<td>Idiopathic</td>
<td>11,741</td>
<td>0.31% (36)</td>
<td>0% (0)</td>
<td>0.43% (50)</td>
<td>0.73% (86)</td>
</tr>
</tbody>
</table>

Kojo Hamilton and Al. Spine 2011
**New Neurological Deficit (NND) Associated With Spine Surgery**

**Type of procedure in EOS**

- Mean age at initial implantation: 4.8 years
- Mean F.U.: 51 Months (24-117)
- 36 Children
- 3 patients IOM changes during surgery (8%)
- 2 Upper Extremity Motor Alerts for 2 VEPTR placements
- 1 VEPTR Removal
- Brachial plexus palsy
- recover in 10 weeks
- 2 Reducing VEPTR tension
- IOM normalized
- 1 Lower Extremity Motor Alerts for a VEPTR revision
- Wake-up test, neurologic deficit, implants revised, IOM improved
- Lower extremity weakness (2 additional procedures; partial revision then implant removal)
- Recover after 3 months

Wudbhav N. Sankar and Al. Spine 2010
New Neurological Deficit (NND) Associated With Spine Surgery

NND in EOS

30 patients underwent 180 cases

150 Cases monitored

14 spinal cord monitoring alerts

47% of the patient cohort

9.3% of the cases

No permanent neurologic deficit

Except a L5 nerve root traction injury with partial recovery

Jonathan H. Phillips  SRS  Lyon  2013
Intraoperative Neuro Monitoring

- **Purpose**
  - Prevent Neural Injury
  - Early Detection of Neural Injury
  - Early Treatment of Neural Injury
SomatoSensory Evoked Potentials (SSEP)

Assess the functional integrity of sensory pathways

Stimulation: 0.2ms, ~3Hz, ~25mA
Recording: 5Hz-1kHz, 10ms/div, 300 stimulations
Acquisition time ~ 1.5mn
SomatoSensory Evoked Potentials (SSEP)

**SSEP altered by**
- *Surgical manoeuvres* (mechanical, local ischemia)
- *Low blood pressure*
- Anesthesiologist +++
- Hypothermia
- Hematocrit decrease
- Volatile agents such as
  - Isoflurane
  - Halothane
  - Nitrous Oxyde

**Warning signals:**
Decrease in amplitude > 50%  
and/or  
Increase in latencies > 10%
### SomatoSensory Evoked Potentials (SSEP)

<table>
<thead>
<tr>
<th>Disadvantages</th>
<th>Advantages</th>
</tr>
</thead>
</table>
| • Assess only the functional integrity of spinal cord dorsal column | • **Nuwer 1995** 51263 interventions
  92% sensitivity (417 True +, 34 False -)
  98% specificity |
| • Few cases of Post Op. paraplegia with preserved intraoperative SSEPs have been reported | • Easy to implement |
| • Sensitive to anesthetics  
  Avoid Halogenated gases | • No contraindications |
| • Acquisition time > 1mn | • Cervical spine monitoring is possible |
| | • Can be combined with other techniques |
The morphology of SSEP is different in young children.

The amplitude of cortical SSEP can decrease during the averaging in young children.

Warning signals are thus more difficult to detect in young children compared to adolescents.
Motor Evoked Potentials (MEP)

Assess the functional integrity of motor pathways

Spinal cord is the target

Stimulation: 5-7 pulses, Intensity 250-750 V
Duration of each pulse 0.5ms
Interval inter stimuli 2-4ms
Recording: Lower Limb muscles
**Motor Evoked Potentials (MEP)**

**Spinal cord is the target**

- **C1 C2 Electrical Cortical Stimulation**
- **Peripheral Recordings**

**Assess the functional integrity of motor pathways**

**Advantages**
- Selective and specific of motor pathway
- Lateralization
- No need for averaging

**Disadvantages**
- Curarization has to be interrupted
- Adverse effects
- Difficult in children under age 4
Motor Evoked Potentials (MEP)

Assess the functional integrity of motor pathways

Spinal cord is the target

C1 C2 Electrical Cortical Stimulation

Peripheral Recordings

Adverse effects
- Tongue or lip laceration: 29/15,000
- Mandibular fracture: 1/15,000
- Cardiac arrhythmia: 5/15,000
- Epileptic seizures: 5/15,000
- Scalp burn: 2/15,000
- Intraoperative awareness: 1/15,000

Difficult because incomplete maturation of motor pathways
Response facilitation methods are currently being developed

Increase in the threshold voltage for sufficient MEP response.
Longer stimulating pulse trains
Greater need to adjust stimulating scalp electrodes.
Limitation of depressant anesthetics

MEP Before the age of 4Y

Temporal facilitation

Train-of-five pulse, 400–700 V; time constant 100s; interstimulus interval 2 ms

The anode was placed at the Cz position and a ring of 4 cathodes approximately 6 cm apart.

MEPs were recorded with needle electrodes from the left and right tibialis anterior muscles.

An electrical stimulus to the medial border of the foot is applied 60 ms before the transcranial electrical stimulus.

**MEP Before the age of 4Y**

**Overall Series**

Temporal facilitation alone, reliable MEPs: 78% (105 of 134)
Temporal and spatial facilitation, reliable MEPs in Frei FJ and Al.: **96% (129 of 134)**

**Age Under 6**

Reliable MEPs were documented in **86% (18 of 21)** in children < 6 Y

Neurogenic Mixed Evoked Potentials (NMEP)

Spinal cord is the target

Stimulation: 20-50 mA, duration 1 ms, frequency 4.1 Hz
Recording: 20 Hz – 3 KHz, 8 ms/div, 1 µV/div, 20-50 stimulations
Require patient curarization

Spinal electrodes inserted by the surgeon
Neurogenic Mixed Evoked Potentials (NMEP)

Stimulation: 20-50 mA, duration 1 ms, frequency 4.1 Hz
Recording: 20 Hz – 3 KHz, 8 ms/div, 1 µV/div, 20-50 stimulations
Require patient curarization

Spinal cord is the target

Spinal electrodes inserted by the surgeon

Advantages
- Fast and easy to implement
- Resistant to most anesthetics
- Sensitive
- Determination of lesional level

Disadvantages
- Relative specificity
- Require curarization
- Terminal medullary conus not monitored
Neurogenic Mixed Evoked Potentials (NMEP) in EOS

Easy to perform in children before the age of 4

But

- NMEP are not specific of motor pathways
- NMEP do not allow to monitor the conus terminalis.

The spinal electrode has to be above the vertebral level T8 ++++
Controversies

*Anterior spinal cord injury with preserved neurogenic evoked potentials*
*R E Minahan and Al. Clinical Neurophysiology 2001*

*Combined spinal cord monitoring using neurogenic mixed evoked potentials and collision techniques*
*Y Pereon and Al. Spine 2002*
**D Waves**

Stimulation: 80-100 mA, durée 0.5-1 ms, frequency 0.8 Hz
Recording: 5 Hz – 3 KHz, 3 ms/div, 20 µV/div, 5-10 stimulations
Patient curarisé

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**Spinal cord is the target**

Transcranial electrical stimulation

**Distal spinal cord recording T11**

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**Advantages**
- Very rapid acquisition
- Specific of motor pathway
- Determination of lesional level
- Pronostic value

**Disadvantages**
- Electrode in the surgical field
- Laterality cannot be distinguished
- Curarization
- Cannot be used < 4 years of age
D Waves
In EOS

Obtained after 4 Years of age

In our experience:
Unobtained in 4 very young child (21 M, 22 M, 30 M, 36 M)

Obtained in one child 25 months old

Maturation steps are variable

→ Difficult for the neurophysiologist to know before the surgery if he will be able to test selectively the motor pathways in a child before the age of 4 using D Waves (or using MEP, even with facilitation procedures).
Pedicle screws testing

Stimulation: 5 à 30 mA, duration 0.2 ms, frequency 0.8 Hz
Recording: 20 Hz – 3 KHz, 5 ms/div, 50 µV/div
No averaging
Neuromuscular blockades are prohibited

Nerve root is the target

Advantages
- Fast and easy to implement
- No curarization

Disadvantages
- Surgeon duty
- Sensitive to a large number of anesthetics
- Less sensitive for thoracic compared to lumbar pedicle screws
Pedicle screws testing

Stimulation of Pedicle Screw between 2 mA and 30 mA

< 5 mA = very likely screw contact with exiting root

5-10 mA = possible pedicle breach

>15 mA = no inferomedial breach (98% confidence level*)

*Glassman et al. 1995
Pedicle screws testing

In EOS

No data before age 4

Values are certainly different

Bone conductivity values vary especially during childhood

Gonçalvez and Al, 2003
Continuous Electromyography (EMG)

**Nerve root is the target**

- No stimulation
- Continuous recording: 20 Hz – 3 KHz, 5 ms/div, 50 µV/div,
- Search for abnormal discharges of rhythmic motor unit potentials
- No curarization

**Advantages**
- Multiple pathway recordings
- Immediate information

**Disadvantages**
- Poor Sensibility
- Poor Specificity
- Information not retroactive

Muscular recording
### Failure of Intra Operative Monitoring

**False Negative** to Detect Post operative Neurologic Deficit

12,375 Patients

Multi modal Intra Operative Monitoring including:

<table>
<thead>
<tr>
<th>Method</th>
<th>Count</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSEP</td>
<td>4</td>
<td>8.9%</td>
</tr>
<tr>
<td>Descending Neurogenic Evoked Potential (DNEP)</td>
<td>4</td>
<td>8.9%</td>
</tr>
<tr>
<td>Trans Cranial Motor Evoked Potential (MEP)</td>
<td>4</td>
<td>8.9%</td>
</tr>
<tr>
<td>Dermatomal somatosensory evoked potential (DSEP)</td>
<td>7</td>
<td>15.6%</td>
</tr>
<tr>
<td>Triggered EMG</td>
<td>9</td>
<td>20%</td>
</tr>
<tr>
<td>Spontaneous EMG</td>
<td>25</td>
<td>55.6%</td>
</tr>
</tbody>
</table>

45 / 12,375 i.e. 0.36% Post. Op. Deficits not Identified by IOM

37 Nerve Roots 6 Permanent Deficits
8 Spinal Cord 2 Permanent Deficits

Barry L Raynor and Al
48Th SRS Meeting Lyon 2013
Failure of Intra Operative Monitoring

False Positive

70 Patients
Mean Age: 4Y

<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>9 Neuromuscular</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>27 Congenital</td>
<td>8</td>
<td>0</td>
</tr>
<tr>
<td>32 Idiopathic</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>32 cases monitored with SSEPs and MEPs</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>38 cases monitored with SSEPs alone</td>
<td>5</td>
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</tbody>
</table>

Rib Based Distraction and IOM

Methods

Simulated VEPTR procedure on 8 fresh cadaveric specimens
Manometric measurements in 3 anatomic regions
Results

20% increase in pressure in the costoclavicular space of the thoracic outlet

![Graph showing pressure in the costoclavicular space before and after expansion and scapular reapproximation. The graph indicates a statistically significant increase with p=0.0032.](image)
Controversies

CWSDSG database from 2004-2013
524 Patients treated with rib based distraction
223 Congenital, 163 Neuromuscular, 67 Idiopathic, 63 Syndromic, 8 Unknown

9 Neurologic injuries = 1.7%
(7 congenital, 2 Idiopathic)

5 Brachial plexus → 2 residual upper limb weakness injuries
4 Partial Spinal Cord → Full resolution injuries

No injuries during routine lengthening surgery
Luke Gauthier And Al.

95 Patients underwent 635 rib based expansions and 90 exchange procedures
No neurologic deficit

Neuromonitoring may be not necessary in routine exchange and lengthening procedures
John T. Smith And Al.

Submitted as free papers at the ICEOS meeting San Diego 2013
# Controversies

1736 consecutive VEPTR procedures

<table>
<thead>
<tr>
<th></th>
<th>Neurol. Inj.</th>
<th>IOM Changes</th>
<th>SSEP</th>
<th>MEP</th>
<th>Up</th>
<th>Low</th>
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</thead>
<tbody>
<tr>
<td><strong>327</strong> Primary Device Implantation</td>
<td>5</td>
<td>5</td>
<td>3</td>
<td>1</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>224</strong> Device Exchange</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2 without IOM</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>1736</strong> Device Lengthening</td>
<td>0</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

- **8 Neurologic Injuries**
  - 6 upper extremity → 1 permanent
  - 2 lower extremity → resolved

Upper and lower limbs neuromonitoring could be not mandatory during routine lengthening of a rib based construct but still mandatory during primary implantation as well as device exchange

NMEP alert, child 25 months-old Thoraco-lombar kyphosis

SSEP and NMEP with a spinal electrode at the level of T6

- D-wave was present

NMEP alert during the instrumentation while SSEP remain unchanged

With a lesser correction, NMEP were re-establishe and D-waves were present

No neurologic deficit
NMEP & SSEP alerts / child 9 months-old
Congenital dislocation of the spine

11h50: Intra-operative NMEP & SSEP alert
Loss of amplitudes > 50%
Step of the surgery: dural traction

Release
→ Resolution of this monitoring alert
Normal post-operative neurologic examination
The multimodal intraoperative monitoring has to be adapted according to:
- the level of the surgery
- the structures at risk
- the age of the child
- the patient’s medical history
- and the neurophysiologist’s experience

Few data in the literature before the age of 4 years
(Helmers & Hall, 1994; Wilson-Holden et al, 1999; Gavaret et al, 2011)
Message to take home

Intra operative neuromonitoring in EOS patients

The motor pathways are difficult to selectively assess in young children.

SSEP alone may have false negative

Question remains to use SSEP alone or associated with

MEP with facilitation procedures or

NMEP associated with D waves