NON-CORTICAL INTRAOPERATIVE MONITORING

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Workshop handouts are prepared as background didactic material to complement a hands-on workshop session. This workshop handout was originally prepared in September 2000 and was revised in September 2003 and October 2006. The idea and opinions in this publication are solely those of the author(s) and do not necessarily represent those of the AANEM.
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I. Introduction

A. Purpose of intraoperative monitoring
   1. Prevent damage to central and peripheral nervous systems
      a. Identify and locate important structures
      b. Measure modalities that reflect function of motor and sensory pathways
   2. Design and maintain a reliable monitoring system
      a. Ease of operation
      b. No added risk or interference with surgical procedure
      c. Reproducible and reliable recordings
         1) rapid acquisition with feedback of accurate relevant information
         2) identify and correct technical problems
            - Electrical noise
            - Muscle artifact
         3) identify and account for physiological variables that affect recordings
            - Age
            - Temperature
            - Blood pressure
            - Body position
            - Anesthetics and other drugs
      d. Reliably predict post-operative function
         1) permanent change in recording should correlate with neurologic deficit in appropriate
            system/pathway/level of the nervous system
         2) transient or reversible change not associated with deficit
         3) deficit should not occur without concurrent/predictive change in appropriate recording

B. Levels monitored

<table>
<thead>
<tr>
<th>Level</th>
<th>Technique</th>
<th>Surgery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brainstem, Cranial</td>
<td>SEP, VEP, AEP,</td>
<td>Intra- or Extra-axial tumors, AVM, MVD of</td>
</tr>
<tr>
<td>Nerves</td>
<td>EMG, CMAP, NAP</td>
<td>cranial nerves, Skull base, head and neck</td>
</tr>
<tr>
<td></td>
<td></td>
<td>surgery</td>
</tr>
<tr>
<td>Spinal Cord, Nerve</td>
<td>SEP, MEP, EMG,</td>
<td>Correction of spinal deformity, Decompression</td>
</tr>
<tr>
<td>Roots</td>
<td>CMAP, NAP</td>
<td>and/or fusion</td>
</tr>
</tbody>
</table>
H reflex, F wave | for degenerative disease, Tumors, Congenital malformations, AVM, Thoracoabdominal aneurysm repair
---|---
Plexus, Peripheral Nerve | SEP, EMG, MEP CMAP, NAP | Primary or metastatic tumors, Trauma, Entrapment

SEP- somatosensory evoked potential, VEP- visual evoked potential, AEP- auditory evoked potential, EMG- electromyography, CMAP- compound muscle action potential, NAP- nerve action potential, MEP- motor evoked potential AVM- arteriovenous malformation, MVD- microvascular decompression

**General principles**

1. Concept of “false positives and negatives” in surgical monitoring
   a. False positive is a change in a recorded potential that is not associated with a post-operative deficit
   b. False negative is a post-operative deficit that is not associated with an intraoperative change in the recorded potential
   c. The requirements for a true false positive and negative
      1) Deficit occurs in the pathway monitored by the potential
      2) Deficit occurs during the time that monitoring was employed
      3) Change in the recorded potential persists (transient changes don’t count as the recordings are a dynamic measure of function)
      4) Change is not related to technical problems or physiological variables that effect the recording
   d. General conclusions supported by extensive published data
      1) The recording modalities available accurately measure function in their respective pathways
      2) When changes occur, the first step should involve a search for technical problems
      3) Changes should then be interpreted in light of baseline variability created by the affects of disease, age, anesthetics, drugs, blood pressure, and noise
      4) Monitor as many pathways and levels of the nervous system that are at risk as possible during surgery
      5) Monitor throughout the period at risk, which in most cases, extends until the end of general anesthesia

2. Troubleshooting for how to prevent and detect technical problems
   a. Monitor pathways at multiple levels
   b. Monitor the same level of the nervous system with multiple modalities
   c. Establish baseline variability of signal under anesthesia but before critical stages of surgery have been undertaken
   d. Identify and remove sources of artifact early in the surgical procedure
   e. Understand the effects of physiological variables on the signals being monitored
II. Intraoperative monitoring techniques

A. Auditory evoked potentials
   a. Structures monitored – auditory (VIII) nerve and brain stem
   b. Surgical procedures – acoustic neuroma, other posterior fossa surgeries, and petrous bone lesions

1. Brainstem auditory evoked potential (BAER)

<table>
<thead>
<tr>
<th></th>
<th>Stimulation</th>
<th>Recording</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrodes</td>
<td>External ear canal- foam insert with extension tube to click generator</td>
<td>External ear canal- foil surrounding foam insert; sealed with bone wax, referred to Cz</td>
</tr>
<tr>
<td>Parameters</td>
<td>Rarefaction or alternating clicks- 100 to 200 ms duration</td>
<td>Filters- 30 to 3000 Hz</td>
</tr>
<tr>
<td></td>
<td>Intensity- 60 to 80 dB above threshold</td>
<td>Average- 500 traces</td>
</tr>
<tr>
<td></td>
<td>Frequency- 10.1 to 20.1 Hz</td>
<td>Key components- Wave I and Wave V</td>
</tr>
<tr>
<td></td>
<td>Masking noise contra ear = Ipsilateral – 40 dB</td>
<td></td>
</tr>
<tr>
<td>Technical Problems</td>
<td>Stimulator failure- troubleshoot components from machine to patient</td>
<td>Electrical noise- microscope and other equipment</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Electrode impedance</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ground</td>
</tr>
<tr>
<td>Effects of Physiologic Variables</td>
<td>Disease- often poorly defined in acoustic tumors</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Age- little to no effect</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Anesthetics/drugs- little to no effect</td>
<td></td>
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<tr>
<td></td>
<td>Blood pressure- little to no effect</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Temperature- exposure of auditory nerve to air when dura opened- increase Wave V latency by 1 to 2 ms</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Body position- little to no effect</td>
<td></td>
</tr>
<tr>
<td>Pathophysiological Correlation</td>
<td>Isolated increased latency Wave V- exposure to air, traction on auditory nerve</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Acute loss of Wave I and V- ischemia or avulsion of nerve/cochlea</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gradual loss of Wave V- traction or contusion of auditory nerve/brainstem</td>
<td></td>
</tr>
<tr>
<td>Advantages</td>
<td>Simple reliable technique</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Can monitor during the entire procedure</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Resistant to anesthetics</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Good correlation with post-operative hearing</td>
<td></td>
</tr>
<tr>
<td>Disadvantages</td>
<td>Response may be poorly defined in acoustic neuroma</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Poor correlation with post-operative brainstem function</td>
<td></td>
</tr>
</tbody>
</table>
2. Auditory nerve action potential

<table>
<thead>
<tr>
<th></th>
<th>Stimulation</th>
<th>Recording</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Electrodes</strong></td>
<td>External ear canal- foam insert with extension tube to click generator</td>
<td>Cotton wick/wire or ball electrode placed on auditory nerve in posterior fossa-referred to Cz</td>
</tr>
<tr>
<td><strong>Parameters</strong></td>
<td>Rarefaction or alternating clicks- 100 to 200 ms duration</td>
<td>Filters- same as BAER</td>
</tr>
<tr>
<td></td>
<td>Intensity- 60 to 80 dB above threshold</td>
<td>Average- 0 to 50 traces</td>
</tr>
<tr>
<td></td>
<td>Frequency- 10.1 to 20.1 Hz</td>
<td>Key components- Auditory NAP</td>
</tr>
<tr>
<td></td>
<td>Masking noise contra ear = Ipsi – 40 dB</td>
<td></td>
</tr>
<tr>
<td><strong>Technical Problems</strong></td>
<td>Stimulator failure- troubleshoot components from machine to patient</td>
<td>Electrical noise- microscope</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Electrode impedance- electrode moves, too much spinal fluid</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ground</td>
</tr>
<tr>
<td><strong>Effects of Physiologic Variables</strong></td>
<td>Disease- little to none</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Age- little to none</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Anesthetics/drugs- little to none</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Blood pressure- little to none</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Temperature- little to none</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Body position- little to none</td>
<td></td>
</tr>
<tr>
<td><strong>Pathophysiological Correlation</strong></td>
<td>Isolated increased latency NAP- decreased temperature of auditory nerve exposed to air, movement of recording electrode</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Acute loss of NAP- ischemia or disruption of auditory nerve</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gradual loss of NAP- contusion, traction of auditory nerve</td>
<td></td>
</tr>
<tr>
<td><strong>Advantages</strong></td>
<td>Simple, reliable technique but need cooperation of surgeon</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Resistant to anesthetics</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Good correlation with post-operative hearing</td>
<td></td>
</tr>
<tr>
<td><strong>Disadvantages</strong></td>
<td>Noise and electrode movement may produce fluctuation or loss of potential</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Can only record when nerve is exposed at time of surgery</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Poor correlation with post-operative brainstem function</td>
<td></td>
</tr>
</tbody>
</table>
B. Somatosensory evoked potentials (SEP)
   b. Surgical procedures: Spine surgery (scoliosis, tumor, trauma, degenerative spine disease), aortic aneurysm, posterior fossa mass lesions, cerebral tumors, cortical localization.

1. Lower extremity SEP (tibial > peroneal)

<table>
<thead>
<tr>
<th>Electrodes</th>
<th>Stimulation</th>
<th>Recording</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface electrodes- ankle, knee or buttock</td>
<td>Sciatic, spinal (needle, esophageal, direct), scalp (Cz to Fz, C3 to C4)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Stimulation</th>
<th>Recording</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2 ms duration, 50 to 90 mA, just above twitch threshold</td>
<td>Filters- 30 to 3000 Hz Average- 250 to 500 traces Key components- sciatic, spinal, cortical (P38)</td>
<td></td>
</tr>
<tr>
<td>Frequency- 1.9 to 3.9 Hz</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Technical Problems</th>
<th>Stimulation</th>
<th>Recording</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stimulator failure, peripheral ischemia- loss of all potentials</td>
<td>Electrical noise-microscope, blood warmer, cautery, etc. Electrode impedance Muscle noise- may eliminate spinal potentials Ground</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Effects of Physiologic Variables</th>
<th>Stimulation</th>
<th>Recording</th>
</tr>
</thead>
<tbody>
<tr>
<td>Disease- mild to severe abnormalities at all recording sites, depending on disease location and severity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age- children and adolescents- scalp potential very susceptible to general anesthetics</td>
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</tr>
<tr>
<td>Anesthetics/drugs- inhalation and induction agents all reduce scalp potential</td>
<td></td>
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</tr>
<tr>
<td>Blood pressure- mean BP &lt; 80 to 90 may reduce all potentials</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature- core temperature &lt; 27 C reduces to eliminates all potentials</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Body position- Subdural air accumulation in seated position (pick up with temporal electrodes)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pathophysiologcal Correlation</th>
<th>Stimulation</th>
<th>Recording</th>
</tr>
</thead>
<tbody>
<tr>
<td>Isolated increased latency- usually insignificant unless associated with amplitude change</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acute loss of cervical spine and scalp potentials- cord ischemia, contusion, compression (subdural hematoma, narrowing of canal)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gradual loss of cervical spinal and scalp potentials- cord traction, compression, accumulated contusions</td>
<td></td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Stimulation</th>
<th>Recording</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple, reliable technique</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Can monitor during the entire procedure (especially with electrodes outside the surgical field)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Good correlation with post-operative function (especially posterior columns but also anterior and lateral columns in most cases)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| Disadvantages | Response may be poorly defined in disease or with certain anesthetic regimens  
|               | Poor correlation with post-operative outcome in surgical procedures that cause isolated injury to anterior cord |
### 2. Upper extremity SEP (ulnar > median)

<table>
<thead>
<tr>
<th>Electrodes</th>
<th>Stimulation</th>
<th>Recording</th>
</tr>
</thead>
</table>
| Surface electrodes | Surface electrodes- wrist    | Spinal (needle, esophageal, direct), scalp (C3’ or C4’ to Fz, C3’ to C4’)
| Direct- brachial    | Direct- brachial plexus elements or roots (peripheral nerve surgery) |                                             |
| Parameters         | Surface- 0.2 ms duration, 50 to 90 mA, just above twitch threshold Direct- 0.05 ms, 1 to 20 mA Frequency- 1.9 to 3.9 Hz | Filters- 30 to 3000 Hz Average- 250 to 500 traces Key components- sciatic, spinal, cortical (P38) |
| Technical Problems | Stimulator failure, peripheral ischemia- loss of all potentials | Electrical noise- microscope, blood warmer, cautery, etc. Electrode impedance Muscle noise- may eliminate spinal potentials Ground |
| Effects of Physiologic Variables | Disease- mild to severe abnormalities at all recording sites depending on disease location and severity Age- children and adolescents- scalp potential very susceptible to general anesthetics Anesthetics/drugs- inhalation and induction agents all reduce scalp potential Blood pressure- mean BP < 80 to 90 may reduce all potentials Temperature- core temperature < 27 C reduces to eliminates all potentials Body position- subdural air accumulation in seated position (pick up with temporal electrodes) |
| Pathophysiological Correlation | Isolated increased latency- usually insignificant unless associated with amplitude change Acute loss of cervical spine and scalp potentials- cord ischemia, contusion, compression (subdural hematoma, narrowing of canal) Gradual loss of cervical spine and scalp potentials- cord traction, compression, accumulated contusions |
| Advantages         | Simple, reliable technique Can monitor during the entire procedure (especially with electrodes outside the surgical field) Good correlation with post-operative function (especially posterior columns but also anterior and lateral columns in most cases) |
| Disadvantages      | Response may be poorly defined in disease or with certain anesthetic regimens Poor correlation with post-operative outcome in surgical procedures that cause isolated injury to anterior cord |
3. Cranial nerve reflexes (lateral spread reflex)
   Structures monitored: Facial nerve
   Surgical procedure: microvascular decompression
   (Blink reflex is lost with most anesthetic agents, and is therefore seldom used)

<table>
<thead>
<tr>
<th>Stimulation</th>
<th>Recording</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrodes</td>
<td>Surface, subcutaneous or intramuscular needles/wires Orbicularis oculi, oris and/or mentalis</td>
</tr>
<tr>
<td>Parameters</td>
<td>Filters- 2 to 2000 Hz Average- none Key components- blink- R1 orb oculi, R1 synkinesis orb oris or mentalis, lateral spread- reflex response in oculi with mandibular stim or in oris/mentalis with zygomatic stimulation</td>
</tr>
</tbody>
</table>

| Technical Problems | Stimulus artifact- intensity of stimulus too high, change location/orientation of stimulating electrodes, electrode impedance Orientation of Cathode on lateral spread- should be proximal | Electrical noise- usually not a problem Electrode location Ground |

| Effects of Physiologic Variables | Disease- trigeminal, brainstem, facial (blink); facial, brainstem (lateral spread) Age- none Anesthetics/drugs- all eliminate blink except in some cases of hemifacial spasm (lateral spread only present in hemifacial spasm) Blood pressure- none Temperature- none Body position- none |

| Pathophysiologic Correlation | Isolated increased latency- no significance Acute loss of blink synkinesis or lateral spread reflex in hemifacial spasm patients indicates adequate decompression of facial nerve (microvascular decompression) |

| Advantages | Simple reliable technique Can monitor during the entire procedure Good correlation with post-operative outcome (elimination of hemifacial spasm) |

| Disadvantages | Response may be poorly defined in mild cases Response may not always be totally eliminated at the time of surgery despite good relief of spasm |
C. Motor evoked potentials (cerebral and spinal evoked)
   2. Surgical procedures: Spine surgery (scoliosis, tumor, trauma, degenerative spine disease),
      brachial plexus, aortic aneurysm, posterior fossa mass lesions, cerebral tumors, and cortical
      localization.
   3. Spinal evoked are used only for thoracic and lumbar surgery

<table>
<thead>
<tr>
<th></th>
<th>Stimulation</th>
<th>Recording</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Electrodes</strong></td>
<td>Spinal- percutaneous or direct with laminar needles (referred to other needle or esophageal electrode)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Transcortical electrical</td>
<td>Muscles in upper and/or lower limbs- surface or intramuscular electrodes Nerve action potentials</td>
</tr>
<tr>
<td><strong>Parameters</strong></td>
<td>Spinal - Electrical- single or train of 2 to 4 stimuli at 2 to 3 ms intervals.</td>
<td>Filters- 20 to 2000 Hz Average- none Key components- compound muscle action potentials (recorded with titrated continuous infusion of n to mm blocker)</td>
</tr>
<tr>
<td></td>
<td>1 ms duration; 100 mA</td>
<td>CMAP with surface or subdermal NAP with hook electrodes</td>
</tr>
<tr>
<td></td>
<td>Cortical – Electrical – C3-C4 subdermal needles, 2-4 pulses. Up to 1000volts @ 0.05 msec</td>
<td></td>
</tr>
<tr>
<td><strong>Technical Problems</strong></td>
<td>Stimulator failure, movement of stimulation electrodes</td>
<td>Too much or too little neuromuscular blockade, peripheral nerve ischemia</td>
</tr>
<tr>
<td><strong>Effects of Physiologic Variables</strong></td>
<td>Disease- mild to severe abnormalities depending on disease location and severity</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Age- none</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Anesthetics/drugs- inhalation and induction agents all eliminate potentials; best recorded with IV Fentanyl anesthetic regimen</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Blood pressure- mean BP &lt; 80 to 90 may reduce all potentials</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Temperature- core temperature &lt; 27 C reduces to eliminates all potentials</td>
<td></td>
</tr>
<tr>
<td><strong>Pathophysiological Correlation</strong></td>
<td>Isolated increased latency- usually insignificant unless associated with amplitude change</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Acute loss of muscle potentials- cord ischemia, contusion, compression (subdural hematoma, narrowing of canal); recordings made before and after critical stages of procedure; gradual or partial loss of potentials usually not observed</td>
<td></td>
</tr>
<tr>
<td><strong>Advantages</strong></td>
<td>Monitors entire motor system (and only the motor system)</td>
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<tr>
<td></td>
<td>Can monitor during the entire procedure (especially with electrodes outside the surgical field)</td>
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</tr>
<tr>
<td></td>
<td>Good correlation with post-operative function (especially anterior columns but also anterior horn cells)</td>
<td></td>
</tr>
</tbody>
</table>
| Disadvantages                       | Requires special anesthetic regimen  
|                                   | Response may be poorly defined in disease or with certain anesthetic regimens  
|                                   | Poor correlation with post-operative outcome in surgical procedures that cause isolated injury to posterior cord |
D. Compound muscle and nerve action potentials (CMAP and NAP)

**Structures monitored:** peripheral motor nerves and cranial motor nerves

**Surgical procedures:** Parotid tumor; thyroid carcinoma; ulnar neuropathy; peripheral nerve tumor and peripheral nerve reconstruction; spine hardware placement

<table>
<thead>
<tr>
<th>Electrodes</th>
<th>Direct stimulation with probe, hook or plate electrodes- size and shape determined by nerve</th>
<th>CMAP- surface, subcutaneous or intramuscular electrode NAP- subcutaneous or direct with probe, hook, plate electrodes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameters</td>
<td>Direct- 0.05 ms, 1 to 20 mA Frequency- single stimulus or 1.9 to 3.9 Hz</td>
<td>Filters- 30 to 3000 Hz Average- 0 to 50 traces</td>
</tr>
<tr>
<td>Technical Problems</td>
<td>Stimulator failure- especially electrode orientation, location and impedance Over-stimulation- stimulate wrong nerve Stimulus artifact Peripheral ischemia (tourniquet)</td>
<td>Electrical noise- microscope, blood warmer, cautery, etc. Electrode impedance Volume conducted muscle response Ground</td>
</tr>
<tr>
<td>Effects of Physiologic Variables</td>
<td>Disease- mild to severe abnormalities at all recording sites depending on disease location and severity Age- none Anesthetics/drugs- none except neuromuscular blocking agents and CMAPs Blood pressure- none Temperature- no significant change</td>
<td></td>
</tr>
<tr>
<td>Pathophysiological Correlation</td>
<td>Increased latency- significant if distance and stimulus intensity tightly controlled Acute or gradual loss of amplitude correlates with loss of function if stimulation done proximal to site of injury (cranial nerve surgery) Focal conduction block significant for localization in peripheral nerve surgery NAP across injury site assist in confirming regeneration Stimulation/recording used to identify nerves when anatomy distorted and viable fascicles when feasible to spare them</td>
<td></td>
</tr>
<tr>
<td>Advantages</td>
<td>Adds significant localization and regeneration information to preoperative studies. Helps preserve function Correlates with post-operative function (e.g. facial nerve in acoustic neuroma surgery)</td>
<td></td>
</tr>
<tr>
<td>Disadvantages</td>
<td>Many technical problems impair reliability</td>
<td></td>
</tr>
</tbody>
</table>
E. Electromyography

Structures monitored: peripheral motor nerves, cranial motor nerves, nerve roots, cauda equina
Surgical procedures: Acoustic neuroma; parotid tumor, cervical and spinal spondylosis, intrinsic cord lesions; peripheral nerve surgery.

<table>
<thead>
<tr>
<th></th>
<th>Stimulation</th>
<th>Recording</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrodes</td>
<td>Generally recording responses triggered by mechanical irritation.</td>
<td>Intramuscular wire electrodes Spontaneous activity- fibrillation potentials, MUPs with light anesthesia; neurotonic discharges (MUP 100 to 200 Hz triggered by mechanical or metabolic stimuli</td>
</tr>
<tr>
<td>Parameters</td>
<td>Direct- 0.05 ms, 1 to 20 mA Frequency- single stim or 1.9 to 3.9 Hz</td>
<td>Filters- 30 to 3000 Hz Sweep-10 to 200 ms/cm</td>
</tr>
<tr>
<td>Technical Problems</td>
<td>Stimulator failure- especially electrode orientation, location and impedance</td>
<td>Electrical noise, volume conducted muscle response- same as CMAP and NAP recordings</td>
</tr>
<tr>
<td></td>
<td>Over-stimulation- stimulate wrong nerve</td>
<td>Movement artifact, cautery are sources of noise when monitoring for neurotonic discharges</td>
</tr>
<tr>
<td></td>
<td>Stimulus artifact</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Peripheral ischemia (tourniquet)</td>
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<tr>
<td>Effects of Physiologic Variables</td>
<td>Disease- a diseased nerve is less likely to produce neurotonic discharges than a healthy one</td>
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<td></td>
<td>Age- none</td>
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<td></td>
<td>Anesthetics/drugs- none except neuromuscular blocking agents (can still record under partial block)</td>
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<td></td>
<td>Blood pressure- none</td>
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<td></td>
<td>Temperature- no significant change</td>
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<tr>
<td>Pathophysiological Correlation</td>
<td>Neurotonic discharges are induced by mechanical stimulation of nerve, saline irrigation, and possibly ischemia</td>
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<td></td>
<td>Discharges are less likely to be induced in diseased nerves (fewer axons to stimulate) and may not occur with sharp injury to axons</td>
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<td></td>
<td>Discharges may also be induced by stimulation of the distal segment of a severed nerve for several hours to days</td>
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<tr>
<td>Advantages</td>
<td>Simple technique</td>
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<tr>
<td></td>
<td>Neurotonic discharges- provides immediate feedback that nerve is being stimulated. Mechanical stimulation correlates with potential injury to nerve, but stimulation with saline irrigation does not</td>
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<tr>
<td>Disadvantages</td>
<td>See pathophysiological correlation</td>
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</tr>
</tbody>
</table>
### III. Applications of intraoperative monitoring

#### A. Spine surgery

<table>
<thead>
<tr>
<th>Surgery Type</th>
<th>Monitoring Protocol</th>
<th>Findings and Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cervical Spine Surgery</strong></td>
<td>Ulnar and tibial SEPs recording sciatic, cervical spine (nasopharyngeal), scalp EMG- multiple upper limb muscles when roots/AHC at risk MEP- occasionally used-requires high cord or transcranial stimulation</td>
<td>Many documented cases- 1) persistent change in SEP = neurologic deficit 2) change in SEP that resolves after surgical or anesthetic intervention = low risk of deficit 3) preserved SEP and MEP at end of surgery = no risk of spinal cord deficit EMG- neurotonic discharges = mechanical or ischemic injury to AHC or spinal roots</td>
</tr>
<tr>
<td><strong>Thoracic Spine Surgery</strong></td>
<td>Tibial SEPs (median or ulnar SEP used as control) recording sciatic, cervical spine (laminar needle), scalp MEP- most common application especially in high risk fusion and TAA repair; transcortical or cervical spine stimulation recording over lower limb muscles</td>
<td>Many documented cases- 1) persistent change in SEP = neurologic deficit (&gt;50% reduction) 2) change in SEP that resolves after surgical or anesthetic intervention = low risk of deficit 3) persistent change (usually complete loss) in MEP = severe motor deficit 4) preserved SEP and MEP at end of surgery = no risk of spinal cord deficit</td>
</tr>
<tr>
<td><strong>Lumbosacral Spine Surgery</strong></td>
<td>Tibial SEP recording sciatic, cervical spine (laminar needle), scalp CMAP- stimulation of roots recording from intramuscular wires or surface EMG- multiple lower limb and/or anal sphincter muscles when roots/ conus at risk</td>
<td>SEP changes less sensitive to root/cauda injury, more sensitive to conus injury CMAP recordings used to identify roots when anatomy is distorted Pedicle screw hole stimulation used to prevent root injury (0.05 ms duration, &lt; 20 mA threshold) EMG sensitive to AHC or root injury</td>
</tr>
</tbody>
</table>
### B. Posterior fossa surgery

<table>
<thead>
<tr>
<th>Surgery Type</th>
<th>Monitoring Protocol</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Acoustic neuroma, other mass lesions, IV ventricular lesions,</td>
<td>Median, tibial SEP</td>
<td>Loss of response</td>
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</table>

### C. Cranial nerve surgery

<table>
<thead>
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</thead>
<tbody>
<tr>
<td>Middle Cranial Fossa-Lesions of Orbit, Sphenoid Ridge, Cavernous Sinus Cranial Nerves 3, 4, 5, 6</td>
<td>EMG and CMAP-intramuscular electrodes in extraocular muscles</td>
<td>EMG sensitive to cranial nerve manipulation/injury CMAP recordings used to identify cranial nerves when anatomy is distorted</td>
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<tr>
<td>Posterior Cranial Fossa-Lesions of the Cerebellopontine Angle (CPA), Brain Stem (especially 4th ventricle) or Cerebellum Cranial Nerves-5, 7, 8- Upper CPA 5, 6, 7, 8 - 4th Ventricle 10, 11, 12- Lower CPA or Brain Stem</td>
<td>EMG and CMAP-intramuscular electrodes in trigeminal muscles (masseter, sometimes pterygoids), facial muscles (oculi, oris &gt;&gt; mentalis, frontalis), and/or lower cranial muscles (vocal cord, cricothyroid, sternocleidomastoid, trapezius, genioglossus) CMAP with surface electrodes over facial muscles (nasalis, mentalis) BAER</td>
<td>EMG sensitive to cranial nerve manipulation/injury CMAP recordings used to identify cranial nerves when anatomy is distorted Facial CMAP used to quantitate loss of facial function during course of CP angle surgery Lateral spread reflex- used to monitor ephaptic transmission between facial axons in MVD for hemifacial spasm Greater than 50% reduction of waveform I or/and V, Latency change &gt; 1 msec</td>
</tr>
<tr>
<td>Extracranial Surgery- Parotidectomy, Neck Dissection, Thyroidectomy, Carotid Endarterectomy</td>
<td>EMG and CMAP-intramuscular electrodes in facial muscles and lower cranial muscles (as per posterior cranial fossa)</td>
<td>EMG sensitive to cranial nerve manipulation/injury CMAP recordings used to identify cranial nerves when anatomy is distorted</td>
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</tbody>
</table>

### D. Peripheral nerve surgery

<table>
<thead>
<tr>
<th>Surgery Type</th>
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</thead>
<tbody>
<tr>
<td>Mononeuropathies (Ulnar, Median, Radial, Peroneal, Tibial, Sciatic Most Common)-Entrapment, Traumatic Injury, Tumor, total hip replacement</td>
<td>Tailored to individual case- 1) EMG- recorded from intramuscular electrodes; neurotonic discharges 2) CMAP- recorded from surface or subcutaneous electrodes, short segmental stimulation 3) NAP- recorded from</td>
<td>EMG sensitive to manipulation/injury of functioning nerve fascicles CMAP and NAP recordings may help “fine tune” localization of pre-operative NCS and EMG NAP recordings can detect early proximal</td>
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<tr>
<td>Hooked electrodes, short segmental stimulation</td>
<td>Reinnervation before it reaches target muscle</td>
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<tr>
<td>Brachial Plexopathy</td>
<td>Same as mononeuropathy, In addition: SEP- stimulate individual roots, trunks, cords, nerves; record over spine and/or scalp with averaging MEP- Trancortical recorded over roots, peripheral nerve or muscle</td>
<td>Same as mononeuropathy including- SEP helps detect proximal continuity of sensory axons Presence of response confirms continuity of root</td>
</tr>
</tbody>
</table>

E. Vascular surgery – aortic aneurysms

<table>
<thead>
<tr>
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<th>Monitoring protocol</th>
<th>Findings &amp; significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thoraco-abdominal aneurysm</td>
<td>SEP, MEP</td>
<td>Rapid loss of responses is highly likely due to severe ischemic damage with paraplegia as a common problem subsequently.</td>
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NON-CORTICAL INTRAOPERATIVE
MONITORING

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