Evoked Potentials

Last updated: August 8, 2020

Electrical brain activity is either ***spontaneous*** or ***event-related*** (i.e. elicited by stimulus).

EVOKED POTENTIAL (EP) - electrical response *recorded* from CNS, *elicited* by external stimulus.
synonyms: **EVENT-RELATED POTENTIAL (ERP)** or **EVENT-RELATED RESPONSE (ERR)**

CLINICAL USES

1. Assessing **functional integrity** (and detecting lesions) in afferent pathways under study.
   - most useful when identify subclinical abnormalities (esp. in multiple sclerosis) or confirm abnormalities corresponding to vague or equivocal symptoms.
   - may reveal abnormalities missed by MRI, and vice versa.
   - precise localization on basis of electrophysiological findings may not be possible (because generators of many components of EP are unknown).
   - changes produced by disease states:
     1) ***delayed responses*** - reflect conduction delays in responsible pathways.
     2) ***attenuation*** / ***loss of component waveforms*** – reflect conduction block or dysfunction of responsible generator.

2. **Cortical mapping** (accurate identification of speech, sensorimotor, visual cortex) – for preservation of functional cortex during resection of intracerebral tumors and vascular malformations.

3. Evaluating patients in **coma**, **suspected brain death** for BAER role - see p. Ear30 >>
   Somatosensory evoked potentials (SEPs) are most accurate in assessment of neurologic outcome:
   – patients with absent cortical SEPs bilaterally are unlikely to recover cognition (esp. bilateral loss of N20 response after median stimulation is associated with fatal outcome or development of persistent vegetative state).
   – presence of normal SEPs does not predict useful recovery.

4. Determining **completeness of lesion** in spinal cord injuries.
   – absence of any cortical response in acute stage doesn't mean that lesion is complete;
   – preserved responses (or their early return) indicate better prognosis.

5. Determining **auditory acuity** in patients whose age / mental state precludes their cooperation for behavioral testing. see p. Ear30 >>

6. **Intraoperative monitoring** *see below >>*

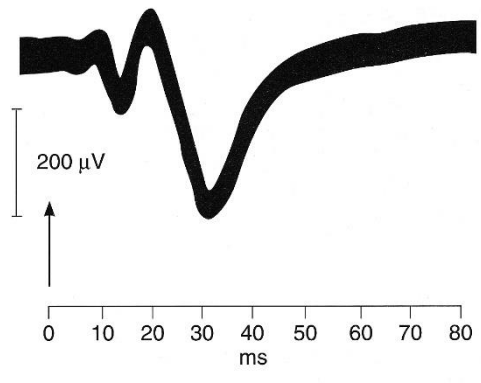
SOMATOSENSORY EVOKED POTENTIALS (SSEP)

Stimulation of sensory systems leads to generation of **CORTICAL EVOKED POTENTIALS** - can be recorded with exploring electrode (connected to another electrode at indifferent point some distance away):

a) over scalp (surface electrode)
b) over pial surface of cortex (samples activity to depth of only 0.3-0.6 mm)
c) microelectrode (inserted in layers 2-6 of underlying cortex)

- best seen in animals under barbiturate anesthesia (eliminates background electrical activity).
- in unanesthetized animals / humans, evoked potential is obscured by spontaneous brain activity (i.e. not apparent in ordinary EEG); evoked potential can be demonstrated by superimposing multiple traces - **signal averaging technique** (signals that are time locked to stimulus are enhanced, whereas background EEG activity is averaged out).

1. First positive-negative wave sequence is **PRIMARY EVOKED POTENTIAL**
   - latency 5-12 ms; latency and morphology depends on eliciting stimulus.
   - **highly specific in location** (can be observed only *over primary receiving area* for particular sense).
   - primary response is negative-positive when it is recorded with *microelectrode* (indicates depolarization on dendrites and somas in cortex, followed by hyperpolarization).



Response evoked in the contralateral sensory cortex by stimulation (at the arrow) of the sciatic nerve in a cat under barbiturate anesthesia. Upward deflection is surface-negative.

2. Second positive-negative wave sequence is **DIFFUSE SECONDARY RESPONSE**
   - larger, more prolonged; latency 20-80 ms.
   - **not highly localized** - appears at same time *over most of cortex* - due to activity in projections from midline and related thalamic nuclei (not due to lateral spread of primary potential!).

- 3-5 Hz ELECTRICAL STIMULATION of peripheral nerve:
  a) sufficient to produce ***slight muscle twitch*** (when mixed nerve is stimulated)
  b) sufficient to generate ***sensory nerve action potential that is ≈ 50% of maximum*** (when sensory nerve is stimulated).
- best recorded with SURFACE ELECTRODES:

a) **bipolar derivation** (both recording electrodes placed on scalp - over posterior and lateral regions);
b) **referential derivation** involving noncephalic reference electrode:
   – over cervical spine, Erb point (for median nerve stimulation at wrist);
   – over lumbar spine, popliteal fossa (for peroneal or posterior tibial nerve stimulation at ankle).

- response is small - necessary to average ***2000 responses in arm*** or ***4000 responses in leg***.

N.B. *physiological transmission* must be distinguished from *electrical conduction*!

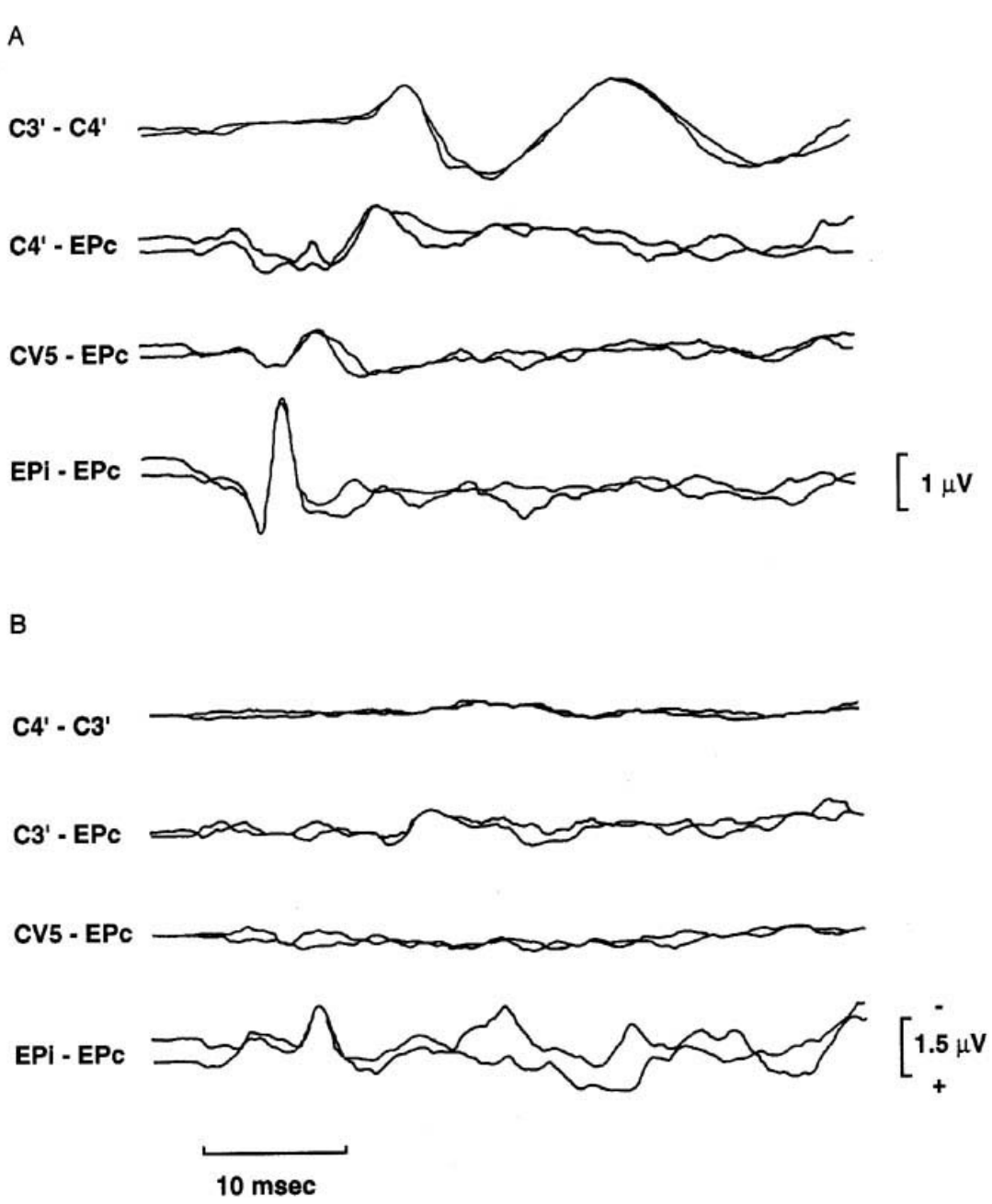
SEP components are defined by **polarity** (P/N) and **latency** (number); obligate components:
in arm nerve stimulation:
P9 - activity at or just beyond brachial plexus.
P13-P14 - activity in medial lemniscus (P13 in cervical cord, P14 in lower brain stem).
N18 - rostral brain stem.
N20 - primary somatosensory cortex.
in tibial nerve stimulation at ankle:
P38 - primary somatosensory cortex.

Most important features:
1) ***presence or absence*** of obligate components; amplitude size is not so important.
2) ***absolute and interpeak latencies*** of components (N.B. absolute latency of individual components, but not interpeak latency, varies with limb length!).

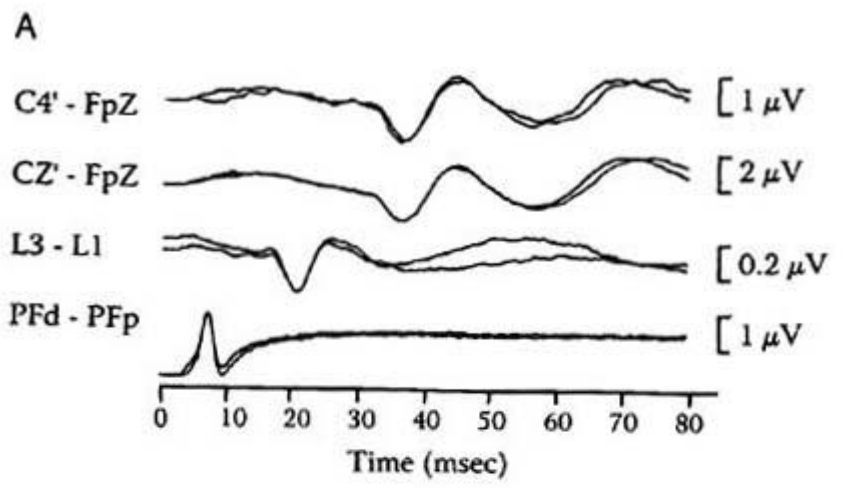
CLINICAL USES

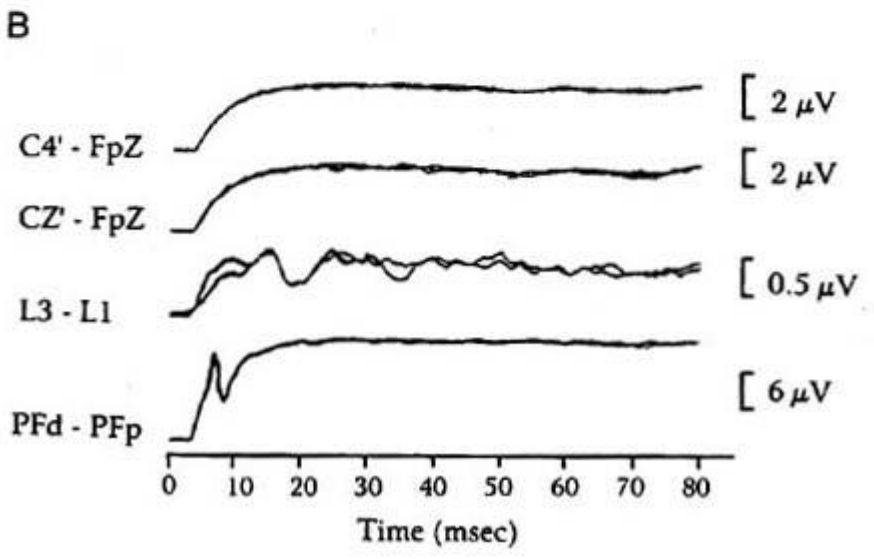
1. **Intraoperative monitoring** *see below >>*
2. Detecting lesions of **somatosensory pathways within CNS** (esp. dorsal column-medial-lemniscal system).
   – SEP is abnormal in *multiple sclerosis* (≈ 80%) - loss (or marked attenuation) of cervical response after median stimulation, increase in central conduction time.
   – ***abnormally large amplitude SEP*** (enhanced cortical excitability) are seen in progressive myoclonus epilepsy, photosensitive epilepsy, late infantile ceroid lipofuscinosis.
3. Little value in evaluating **peripheral nervous system** (except functional integrity of nerves that are not easily accessible for conventional nerve conduction studies); e.g. SEPs to evaluate *radiculopathies*;
   – stimulation of polysegmental nerve trunk would not cause abnormal SEP in isolated root lesions;
   – cutaneous nerve or dermatomal stimulation gives conflicting results.

Median-elicited SEP
(EP - Erb's point; CV5 - 5th cervical spine; i - ipsilateral; c - contralateral):
A. Normal subject.
B. Multiple sclerosis (Erb point potential is present but responses over cervical spine and scalp are absent).



Tibial-elicited SEP
(PF - popliteal fossa; L1 - 1st lumbar spine; L3 - 3rd lumbar spine; d - distal; p - proximal):
A. Normal subject.
B. Multiple sclerosis (no response over scalp).

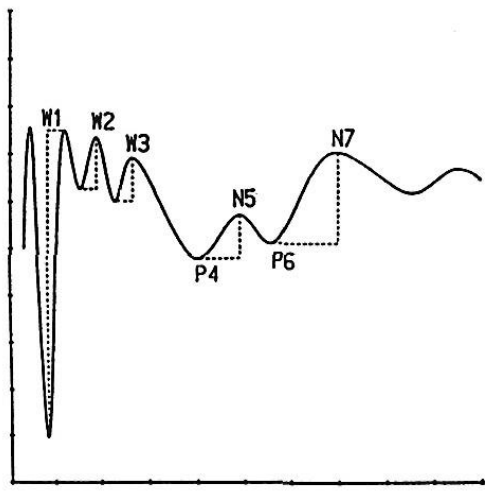


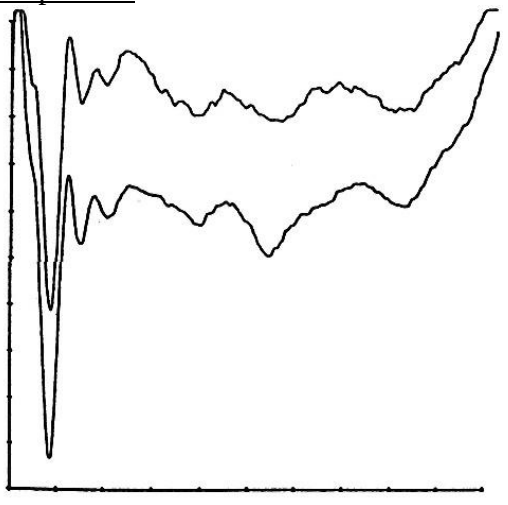


TRIGEMINAL EVOKED RESPONSES

- **infraorbital nerve** is stimulated with electrode inserted into infraorbital foramen.
- recording electrodes are placed at Cz with reference to C7 vertebral spinous process (Cv7).
- bilateral studies provide opportunity for evaluation of control and determination of symmetry.
- **waves 1** (entrance of maxillary division into gasserian ganglion), **2** (root entry zone into pons), and **3** (trigeminal tract within pons) have latencies of 0.88, 1.80, and 2.44 ms, respectively.
- interwave latencies 1-2 and 2-3 are 0.90 and 1.55 ms, respectively; increase in wave 1 latency > 0.32 ms (when compared to normal side) is considered abnormal.
- absence of waves 2 and 3 is after successful surgery for trigeminal neuralgia.
- evoked responses may also be obtained from stimulation of **supraorbital nerve** (harder to obtain, need to anesthetize scalp).

<u>Stylized and actual normal trigeminal evoked responses:</u>





MAGNETIC STIMULATION, MOTOR EVOKED POTENTIALS (MEP)

Magnetic stimulation of brain / spine elicits **motor evoked potentials** (i.e. compound muscle action potential over appropriate target muscle).

- assesses descending motor pathways!

Magnetic stimulation of peripheral nerves elicits **somatosensory evoked potentials**.

- assesses ascending sensory pathways!

- magnetic stimulation *effects* are similar to electrical stimulation.
- magnetic impulses travel through tissues painlessly and without attenuation* (vs. electrical impulses).

  *but magnetic impulses decrease in relation to inverse square of distance from stimulator coil
- procedure is noninvasive (!), painless and apparently safe.
- *latency of motor responses* can be measured.
- ***central conduction time*** can be estimated by comparing latency of cerebral and spinal stimulation.

  motor latencies↑↑↑ - in MS, cervical myelopathy, cervical spondylosis, spinal cord trauma, hemiplegia, hereditary spastic paraparesis, etc.
- clinical utility is investigational.
- with development of accurate focal stimulation, cortical mapping could be done noninvasively!

Electrical stimulation (painful in alert patients) may be preferable for intraoperative monitoring where patient is anesthetized and paralyzed, since equipment is less complicated to organize in operating room environment;

- response is best recorded from peripheral nerves, using needle electrodes.

COGNITIVE EVOKED POTENTIALS

- evoked potential components depending upon **mental attention of subject** and setting in which stimulus occurs (rather than on physical characteristics of stimulus), i.e. such endogenous "event-related" potentials (ERP) are related to ***cognitive aspects*** of distinguishing infrequently occurring target stimulus from other stimuli occurring more frequently (usually randomly alternating low and high pitch auditory stimuli).

- most important is **P3 component** (s. **P300 component** - because of 300 ms latency after auditory target stimulus).
- P3 latency is prolonged in ***dementia***.
- P3 is normal in depression or other psychiatric disorders (that might be mistaken for dementia).

INTRAOPERATIVE MONITORING (IOM)

IOMs can reliably detect and predict neurological damage but there are 2 major problems:

a) it is ***too late*** (damage is done)
b) IOM is not useful if ***corrective action is not available***

- when evoked potential abnormality occurs during surgical procedure, it is hoped that alteration / reversal of procedure will minimize damage; examples:
  - monitoring *CN2* (visual evoked potentials) during transsphenoidal removal of pituitary tumor.
  - monitoring *CN7 and CN8* (brain stem auditory evoked potentials) during posterior fossa surgery.
  - monitoring *spinal cord* (somatosensory evoked potentials, motor evoked potentials) during scoliosis* / myelomeningocele / intramedullary tumor / degenerative** cervical spine surgery, repair of coarctation of aorta.

*reduces complications rate 10-fold (because effective corrective action exists if IOM signal changes – popping rod)

**most likely no benefit at all (studies show, IOM does not prevent complications)

- for kids < 4 years old, white matter long tracts are immature – motor evoked potentials, SSEP are unreliable.

INDICATIONS

Spine surgery:

1) severe spinal cord compression
2) deformity correction
3) intradural tumor / vascular malformation removal

Avoid use for simpler surgeries (e.g. ACDF without myelopathy, lumbar microdiscectomy).

W.S. James "A socioeconomic analysis of intraoperative neurophysiological monitoring during spine surgery: national use, regional variation, and patient outcomes" Neurosurgical Focus Nov 2014 / Vol. 37 / No. 5 / Page E10
Use of IONM did not strongly correlate with improved patient independence at discharge or prevention of iatrogenic nerve or spinal cord injury.

ANESTHESIA CONSIDERATIONS

- all ***volatile anesthetics*** produce dose-dependent reduction in SSEP peak amplitude and increase in peak latency; adding nitrous oxide increases this sensitivity to anesthetic agents.
- helpful anesthesia measures:
  - minimize pentothal dose during induction (produces 30 minutes of suppression of EPs), or use ETOMIDATE (which increases both SSEP amplitude and latency)
  - total intravenous anesthesia is ideal; nitrous/narcotic technique is a second choice
  - if inhalational anesthetic agents are required:
    - use < 1 MAC (maximal allowable concentration), ideally < 0.5 MAC
    - avoid older agents such as Halothane
- ***nondepolarizing muscle relaxants*** have little effect on EP (in monkeys).
- long-acting paralytic agents blunt MEPs.
- gases (nitrous oxide) blunt SSEPs
- **TIVA (TOTAL INTRAVENOUS ANESTHESIA)** - propofol, fentanyl, and etomidate - causes less decline in MEP than inhalational agents at the same depth of anesthesia.
- ***benzodiazepines*** have a mild-to-moderate depressant effect on EPs
- continuous infusion of anesthetic drugs is preferred over intermittent boluses
- ***hypocapnia*** (down to end tidal CO_2 = 21) causes minimal reduction in peak latencies
- ***antiepileptic drugs*** (phenytoin, carbamazepine, phenobarbital) do not affect SSEP.
- run baseline before and after patient positioning (thus, will know if there is a technical problem with wires or baseline patient pathology).

PROTOCOL

- induce anesthesia by using propofol (2 to 3 mg/kg) along with a short-acting or medium-acting paralytic (rocuronium).
- maintain a propofol infusion throughout the case.
- after induction, use 50% of the minimum alveolar concentration of vapor (i.e., isoflurane) and remifentanil (0.1 to 0.25 mg/kg/min) as a narcotic infusion - this combination is least likely to affect SSEPs and MEPs.
- use an arterial line and keep the MAP > 85-90 mm Hg to prevent spinal cord ischemia.

MEP

N.B. **MEP (motor evoked potentials)** is gold standard but are highly affected by anesthesia and muscle relaxation in particular

- checking MEP causes patient motion - need to pause surgery to run stimulation (bite block is necessary!) – gives warning to surgeon too late!

D-WAVE

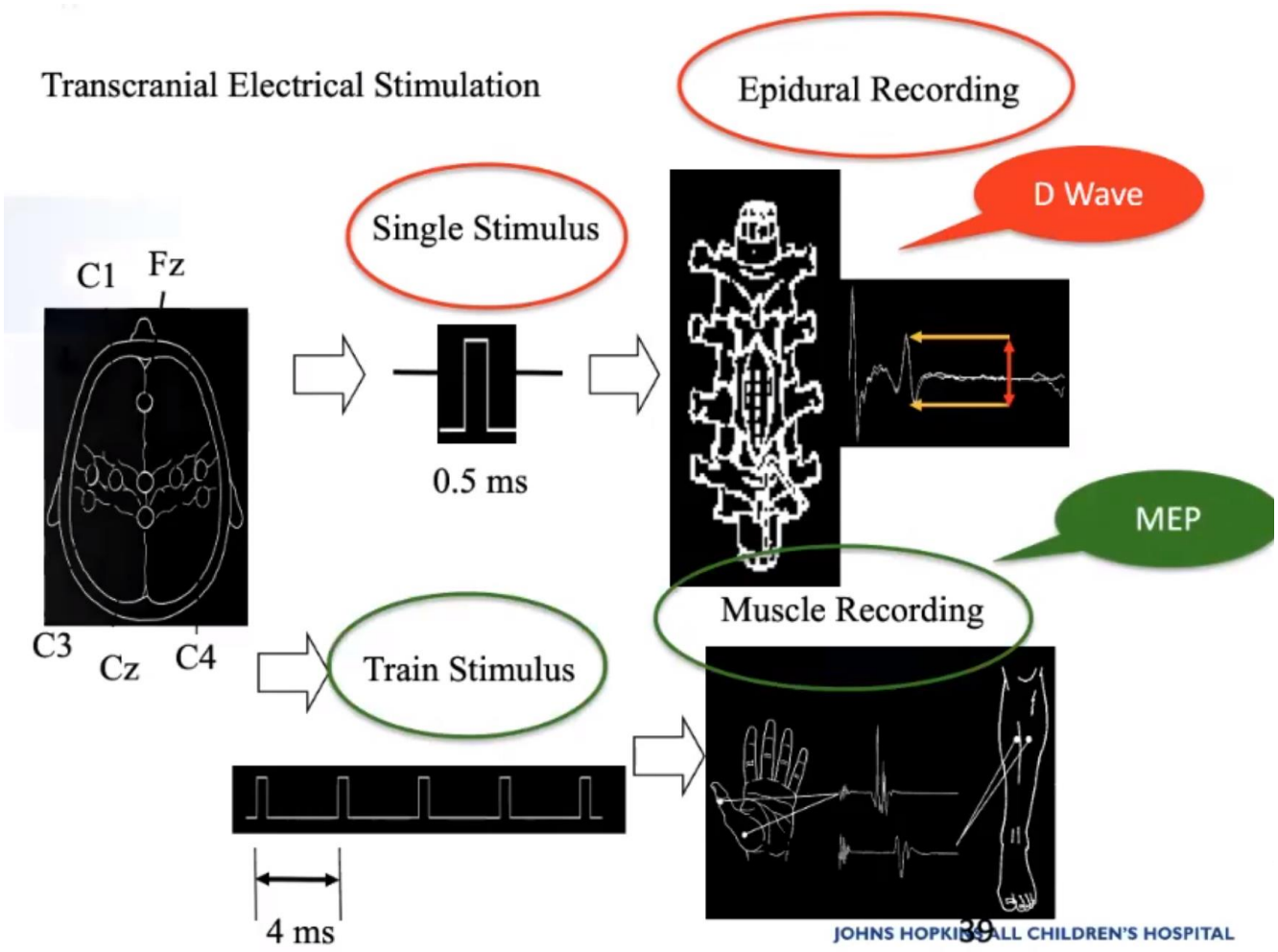
The direct (D) wave is a direct measure of the number of functioning fast-conducting fibers in the corticospinal tract (CST).

The use of D waves is limited in the cord up to T10–11 (fibers numerically decrease craniocaudally and are absent in the lumbosacral region)

In contrast to mMEPs and SSEPs, the **D wave is not in influenced by blood pressure, heart rate, temperature, and anesthesia drugs**

D wave monitoring needs midline recording.

A warning is a decrease of more than 50% of the baseline amplitude



Interpretation of D-wave:

D Wave	Muscle MEP		Expected Outcome
↓ < 50%	No Change	→	No Change
↓ < 50%	↓ Unilateral or Bilateral	→	Transient motor deficit
↓↓ > 50%	Bilateral loss	→	Prolonged or permanent motor deficit

SSEP

- use dorsal column pathway to assess somatosensory cortex noninvasively.

- frequent* stimulation of bilateral **median** or **posterior tibial** nerves → response measurement via contralateral cortical electrodes.

*averages signal over several minutes – gives warning too late

- changes in latency or amplitude of SSEP waveforms indicate disruption of somatosensory pathway.

What changes in SSEP should trigger concern:

a) increased signal LATENCY (typically **> 10% prolongation**)
b) decreased signal AMPLITUDE (typically **> 50% reduction**)

- change is called ***irreversible*** when it fails to return to baseline before end of procedure.

False-positive SSEP signal change may be caused by:

1) blood pressure (mean and diastolic)
   – amplitudes of SSEPs are very sensitive to changes in ***mean arterial pressure***, making them useful for detecting ischemia!
2) heart rate
3) temperature
4) partial pressure of alveolar carbon dioxide
5) anesthetic drugs

SENSITIVITY, SPECIFICITY

– SSEP sensitivity 99%, specificity only 27%.
– MEP sensitivity 90-100%, specificity 90-100%.
– combined SSEP+MEP: sensitivity 83% and specificity 99%

STAGNARA TEST

– awakening patient during surgery (e.g. under remifentanil balanced anaesthesia) and performing neuro exam.

PROTOCOL FOR ALTERATIONS IN EVOKED POTENTIALS

- prompt cessation of dissection (until potentials recover) - changes are mostly transient and are not predictive for postoperative neurologic outcome.
- cord irrigated with warm normal saline ± papaverine.
- any retractors should be loosened; look at the entire operative field to verify that there are no impinging factors on the spinal cord.
- increase blood pressure (MAP > 90)
- verify the depth of anesthesia, presence of hypotension or hypothermia.
- transfuse blood if needed.
- give additional steroids (may start Bracken protocol)
- if nothing helps, do **Stagnara wake up test** or **terminate surgery** (consider expansile duraplasty + additional decompression to allow for cord swelling).

From Dr. George Jallo webinar:

"‥ Changes in SSEPs related to traction followed a predictable pattern of three changes, or "strikes," in our series. Each strike appeared to result in an increased recovery time".

"‥Traction-related SSEP changes could be tolerated in children up to a point of 3 strikes‥"

"blunt dissection plus traction lead to less bad results than dissectio with an aspirator for tumor removal"

All patients with decreased waveform complexity experienced at least a 1-point decrease in motor score in the immediate postoperative period, with good recovery on subsequent follow-up

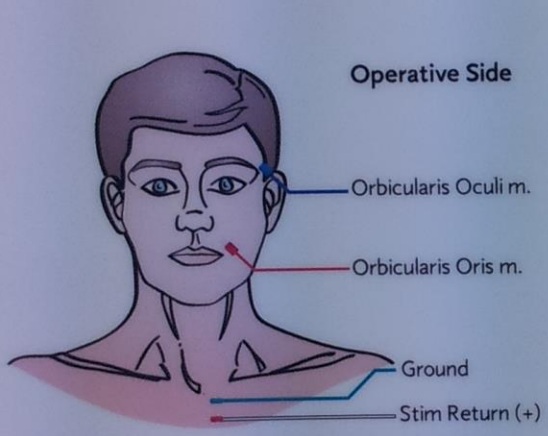
CN3-7, 10 MONITORING

NIM-RESPONSE® 2.0

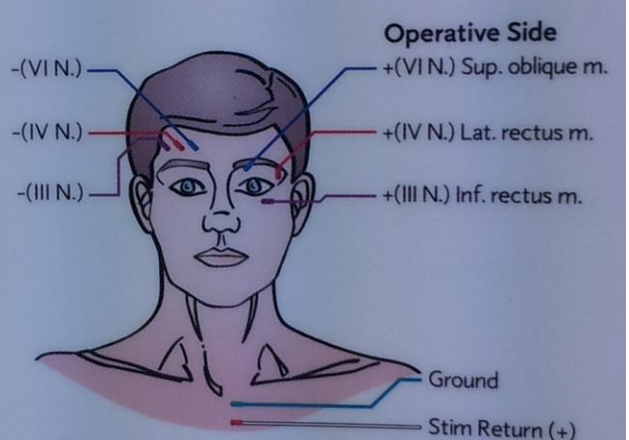
Quick Start Guide

Set up in 10 easy steps

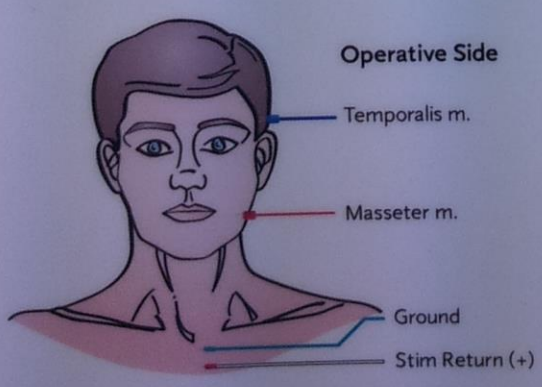
1. Place the NIM-Response® 2.0 system away from the electrocautery unit. **Proper grounding of electrocautery is essential.**
2. Do not use long-term paralyzing anesthetics.
3. Prep skin and place electrodes. (See diagram below.)



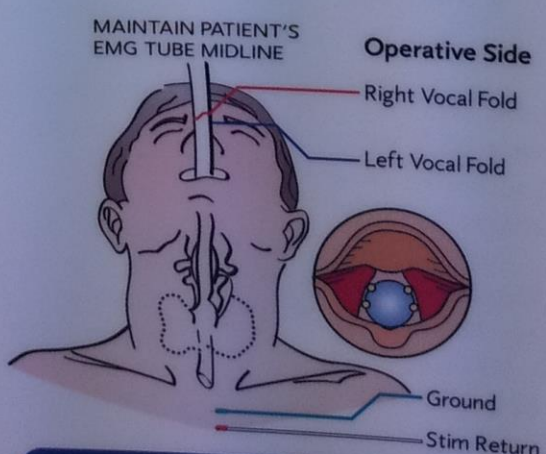
VII CRANIAL NERVE



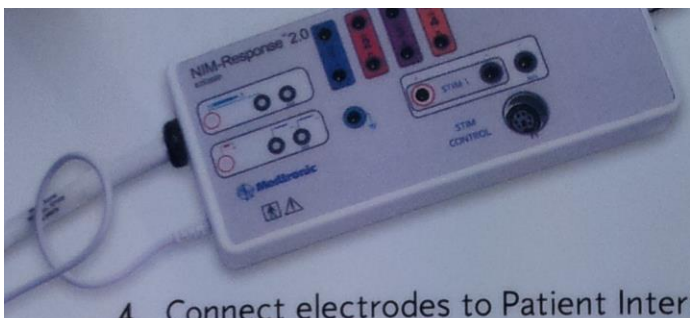
III, IV, AND VI CRANIAL NERVES



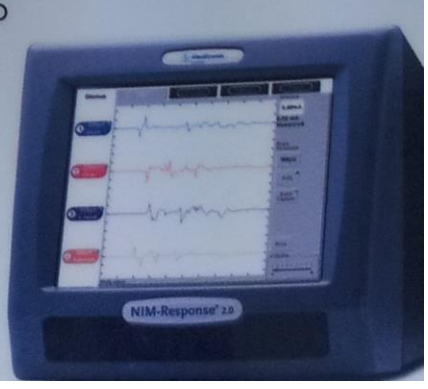
V CRANIAL NERVE



X CRANIAL NERVE



4. Connect electrodes to Patient Interface. Avoid entwining anode return (white) with other electrodes. Attach Patient Interface to the NIM-Response 2.0.
5. Plug in power cord and attach to the NIM-Response 2.0. Turn unit on. Confirm the NIM-Response 2.0 test results. **Pass, Pass, Pass**
6. Select physician setting from Quick Start menu. Verify the Stimulus setting is what the surgeon has requested.
7. Check baseline. **Peak values = 5-15uV.**
8. Press "ELECTRODES" tab to check Impedance and Difference. Reposition if necessary. Press "EMG" tab to return to monitoring.
9. Clip Muting Detector to ESU. For bipolar ESU, route single conductor cable through the clamp. Do not include grounding pad. Plug into Muting Probe Input jack #3 on rear panel of unit.
10. Connect the Prass Monopolar Stimulating Probe to the black (-) Stim 1 jack of the Patient Interface.



Please refer to the NIM-Response 2.0 User's Guide (8250651) for complete operating instructions. For technical questions or guidance through OR protocol with the NIM-Response 2.0, call the NIM™ Helpline or Medtronic ENT Customer Service at 1-800-874-5797 or 904-296-9600. For general information, you may also visit our website at www.MedtronicENT.com.

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