Introduction to Intraoperative Neurophysiology

A presentation for HealthTrust members

October 6, 2020

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Speaker Disclosures

- The presenter is an employee of NeuroAlert.
- This program may contain the mention of drugs or brands presented in a case study or comparative format using evidence-based research. Such examples are intended for educational and informational purposes and should not be perceived as an endorsement of any particular supplier, brand or drug.

Learning Objectives

- Describe the origins and applications of modern day Intraoperative Neuromonitoring.

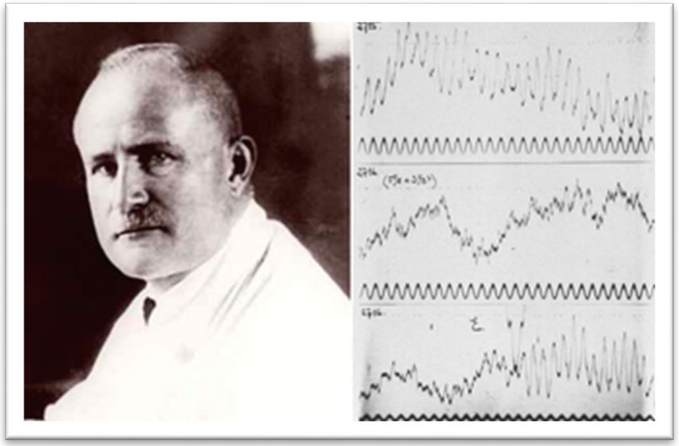
- Discuss types of surgeries during which Intraoperative Neurophysiologic Monitoring (IONM) is used, as well as well as the modalities that can be applied during various surgeries.

- Identify the effect of patient pathology and anesthetics on IONM, and how to best integrate with the surgical team for optimal outcome achievement

History of IONM

In 1875 Richard Caton reported to the British Medical Association in Edinburgh that he had used a galvanometer to observe electrical impulses from the surfaces of living brains in animal subjects.

Hans Berger cited Caton’s work in his 1929 discovery of alpha-frequency brain waves, the beginning of EEG



In the 1960s, advances in spinal instrumentation allowed for more aggressive surgical interventions in the treatment of deformities. This created the need for a means to evaluate spinal cord integrity (Stagnara and Vauzelle)

Sources: Hans Berger (1873–1941), Richard Caton (1842–1926), and electroencephalography, J Neurol Neurosurg Psychiatry. 2003 Jan; 74(1): 9, VAUZELLE C, STAGNARA P, JOUVINROUX P. Functional monitoring of spinal cord activity during spinal surgery. Clinical Orthopaedics 1973; 93: 173- 178.

Anesthesiologist Betty Grundy worked with Nash and Brown to develop a technique for monitoring cord function while under general anesthesia, the first *clinical* application of Somato-Sensory Evoked Potentials (SSEP)

At the same time, Tamaki (surgeon) and Shimoji (anesthesiologist) were developing an invasive cord monitoring technique in Japan

In 1977, Nash's group and Tamaki's group met for the 1st international spinal cord conference.

"It cannot be denied that against the historical backdrop of surgical technology development, including both electrical hardware and software, the evolution of anesthesiology has influenced and supported the development of IOM. This multidisciplinary support has made it possible not only to protect patients against catastrophic sequelae, but also to support new, aggressive and challenging surgical procedures." Tetsuya Tamaki

Source: GRUNDY Anesthesiology 1986 pp 211-230| Intraoperative Monitoring of Sensory Evoked Potentials

Robert Levine first reported intraoperative Brainstem Auditory Evoked Response (BAER) recordings in 1978

Patrick Merton and Burt Morton elicited the first transcranial Motor Evoked Potential (MEP)- 1980

However, this technique was not immediately applicable in the OR. The general technique at the time was N2O and Halogenated gas, which precluded the recording of MEP

Source: Levine RA, Montgomery WW, Ojemann RG, Pringer MFB. Evoked potential detection of hearing loss during acoustic neuroma surgery. Neurology 1978; 28:339, Hallett Transcranial Magnetic Stimulation: A Primer, Neuron Volume 55, Issue 2, 19 July 2007, Pages 187-199

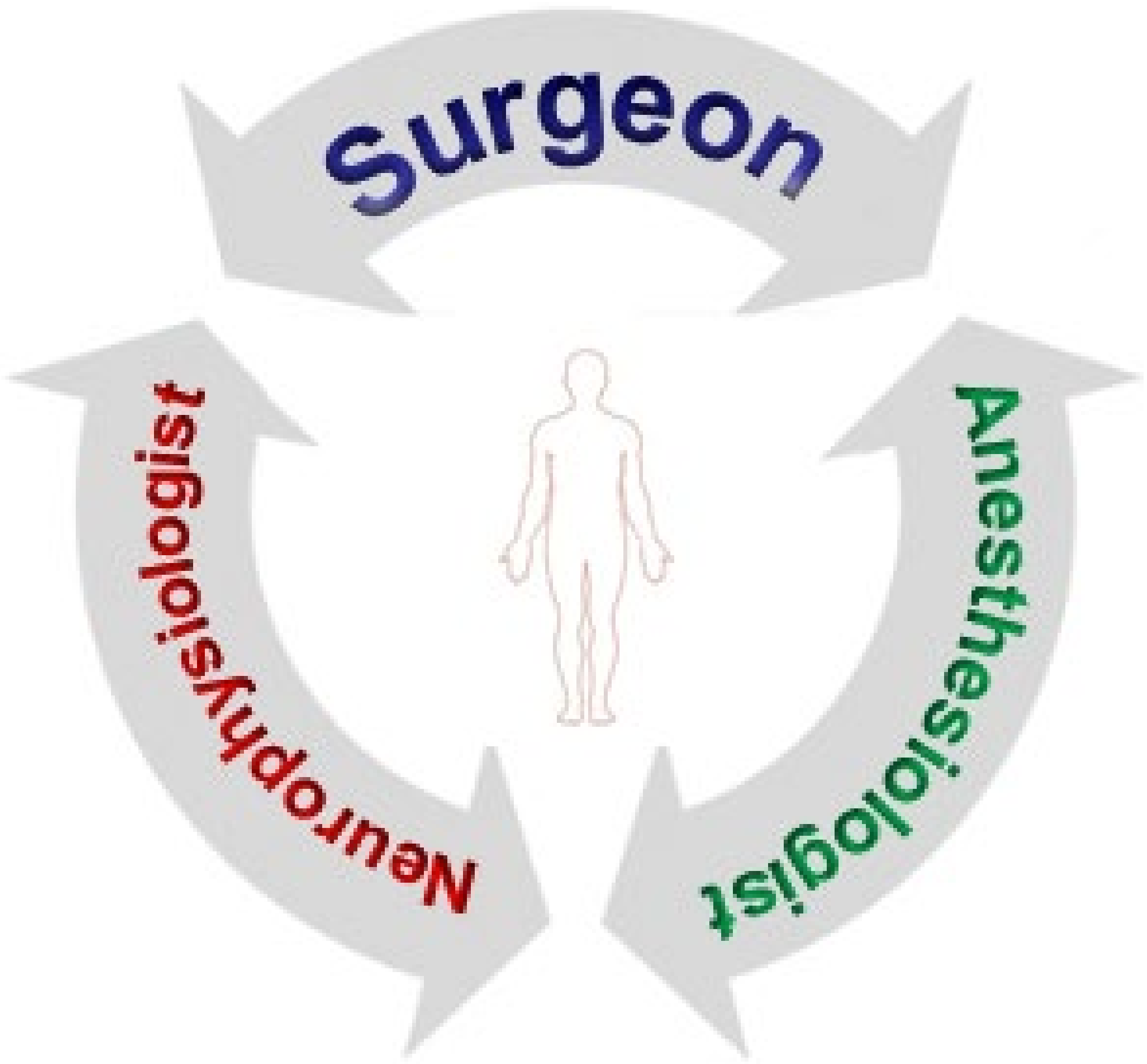
“Neurogenic” MEP (NMEP) were investigated in an attempt to avoid the pitfalls of the prevailing anesthetic techniques of the time

Meanwhile:

Jellinek D, Jewkes D, Symon L. Non-invasive intraoperative monitoring of motor evoked potentials under propofol anesthesia: effects of spinal surgery on the amplitude and latency of motor evoked potentials. Neurosurgery. 1991;29:551–557

Toleikis collision studies disproved NMEP as a pure motor response- 2000

The multi-modality technique that is today’s gold standard is of relatively recent vintage and continues to evolve


Surgeon
Neurophysiologist
Anesthesiologist

What is intraoperative neurophysiologic monitoring?

a.k.a.

- IONM
- IOM
- NIOM
- Evoked potentials
- Spinal cord monitoring
- Neurophysiology, etc

THE AMERICAN SOCIETY OF NEUROPHYSIOLOGICAL MONITORING

The American Society of Neurophysiological Monitoring

The American Society of Neurophysiological Monitoring was founded in 1990 to serve the emerging field of neurophysiologic monitoring. As defined by the Society, neurophysiologic monitoring includes any measure employed to assess the ongoing functional integrity of the central or peripheral nervous system in the operating theatre or other acute care setting.

Intraoperative neurophysiological monitoring (IONM) has evolved over the last several decades. Its mission is protection of the patient's nervous system. Neurophysiologic signals are monitored continuously during surgery for adverse changes, detection of which enables corrective action. Risk of postoperative neurological deficit, such as weakness, loss of sensation, hearing loss and impairment of other bodily functions is thereby reduced. In addition to detection of change, surgical guidance can be offered in specialized circumstances.

Members of the IONM team include but is not limited to: technologists, surgeons, nurses, anesthesiologists, neurophysiologists, and the supervising person. Team members are those who generate the setting & monitor the patient (technologists), identify the changes (technologists and monitoring personnel), institute management plans that involve surgical maneuvers (surgeons), physiological, pharmacological and anesthetic management (anesthesiologists), moving and repositioning of electrical equipment (nurses), and repositioning of the patient (surgeon, anesthesiologists, nurses).

The Society is dedicated to the advancement of quality neurophysiologic monitoring services for neuroprotection.

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Medicolegal Implications

Concerns

- 99% of US physicians in high-risk specialties will have a malpractice claim filed against them by the age of 65 (Jena et al., 2011)
  - Neurosurgeons lose in about 40% of cases- expertise had little mitigating effect
- IONM's explosive growth has attracted the attention of "entrepreneurial" lawyers
  - It's a complex system, more potential for failure in the system
- When neurosurgery is accompanied by IONM, it potentially *increases* legal exposure

SOURCE: Malpractice Risk According to Physician SpecialtyAnupam B. Jena, M.D., Ph.D., Seth Seabury, Ph.D., Darius Lakdawalla, Ph.D., Amitabh Chandra, Ph.D., N Engl J Med 2011; 365:629-636

Benefits

- The electronic trail that IONM creates can act as a deterrent to potential litigation
- IONM provides surgeons with documentary evidence of the condition of the patient’s neurological system during surgery
- If IONM has been properly performed and data evidencing neurological damage is absent, plaintiffs will be hard pressed to prevail in a case
- If monitoring is not performed, plaintiffs’ attorneys have recently been much more willing to argue that the failure to conduct IONM testing to ascertain if neurological compromise was occurring was a negligent action

Survey of 683 neurosurgeons

- asked if respondents were ever involved in a lawsuit where neuromonitoring was a claim
- whether the judgment favored the plaintiff
- what the allegation regarding neuromonitoring consisted of
- whether fear of litigation contributes to the use of neuromonitoring

SOURCE: UH Neurological Institute Journal Vol 7, No. 1
Intraoperative Spinal Neuromonitoring – Indications and Patterns of Usage Among Neurosurgeons, Tomei, Eccher, Bambakidis

Results

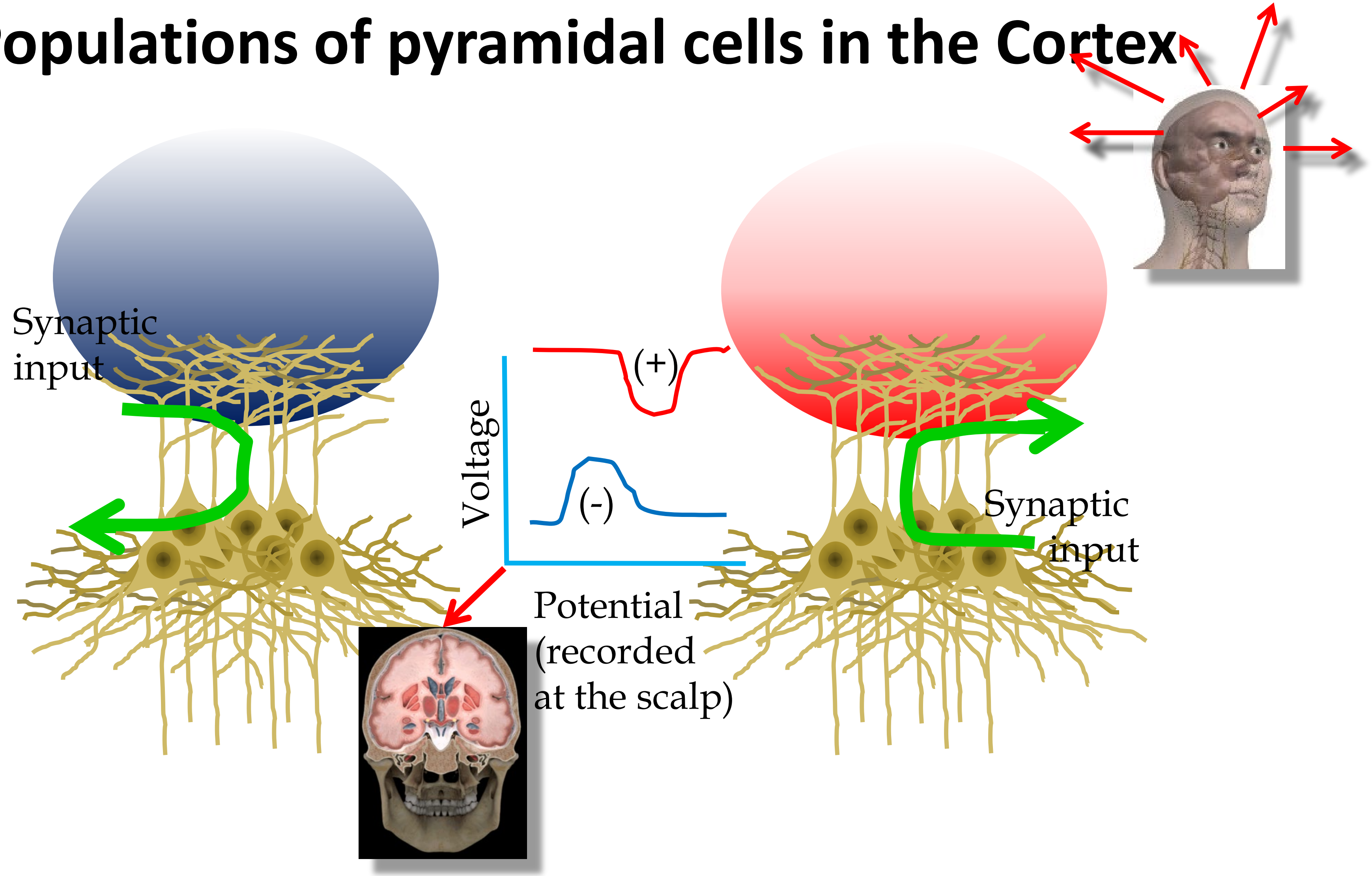
- Thirty-eight (6.3%) of respondents stated that they had a previous lawsuit where monitoring was a part of the claim
- 47.5% of the judgments favored the plaintiff
- The most frequent claim was lack of neuromonitoring in 13 judgments
- The second most frequent claim was failure to respond to changes in neuromonitoring in three judgments
- Fear of litigation contributed to use of monitoring according to 54.4% of respondents

No Monitoring is Better than Bad Monitoring

Anatomy Review

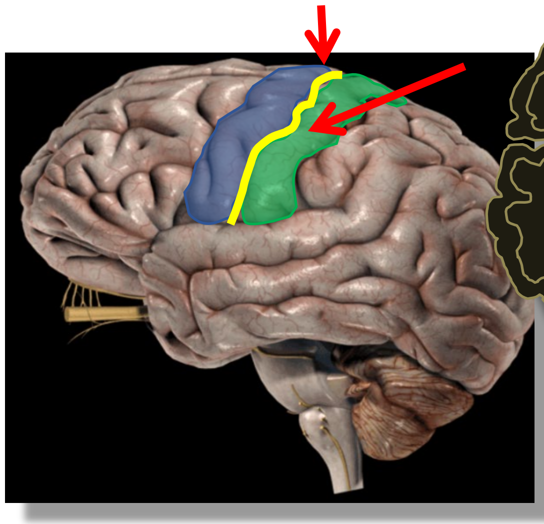
- Cerebral Cortex
- Sensory Pathways
- Motor Pathways
- Auditory Pathways

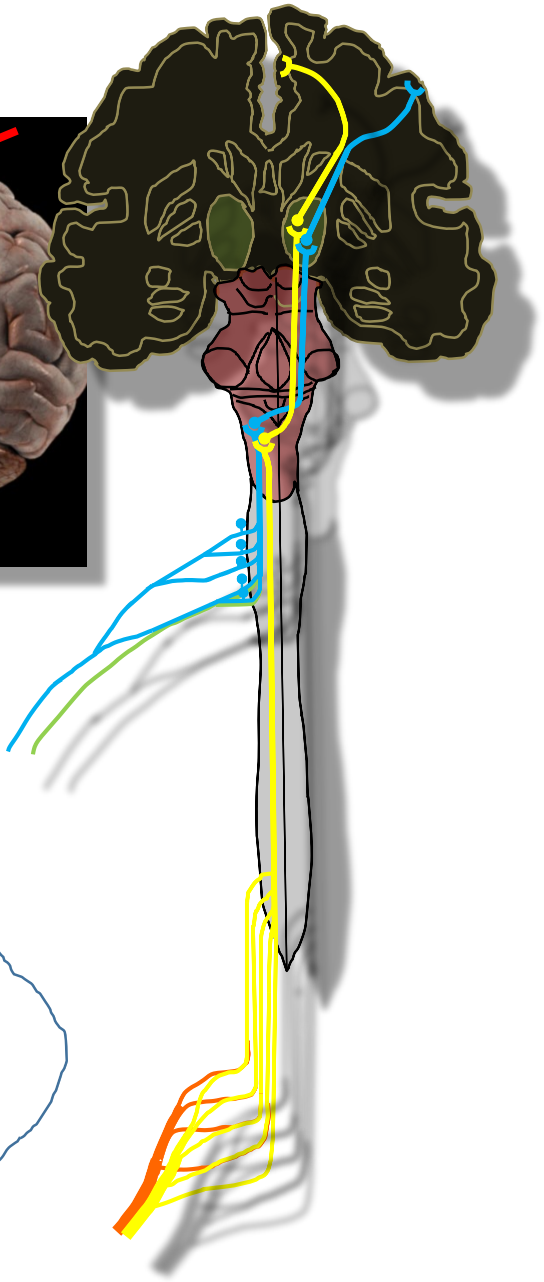
Populations of pyramidal cells in the Cortex

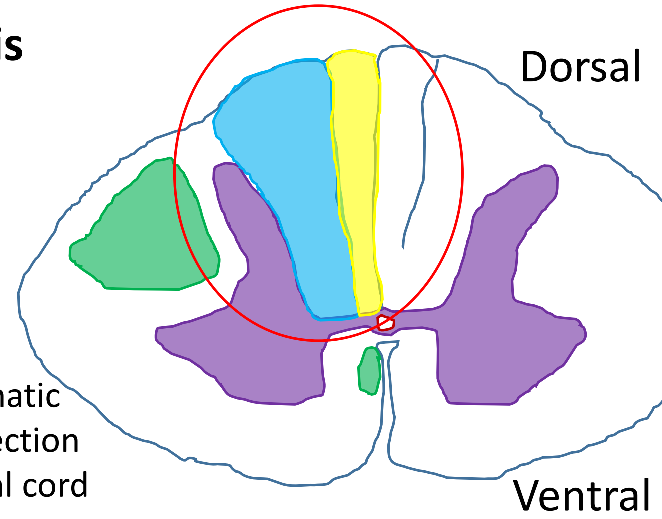


Sensory Path Anatomy

- Post Central Gyrus
  - Primary Somatosensory Cortex
- Internal Capsule – Radiations
- Thalamus
- Medial Lemniscus
- Medulla Dorsal Column Nuclei
  - Cuneatus and Gracilis
- Dorsal Column Fasciculi –
  - Cuneatus and Gracilis
- Dorsal Root Ganglia
- Nerve Roots
- Plexus
- Peripheral nerve
- Nerve endings

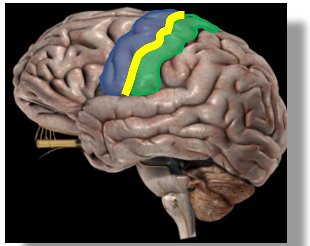


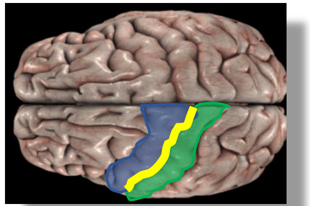


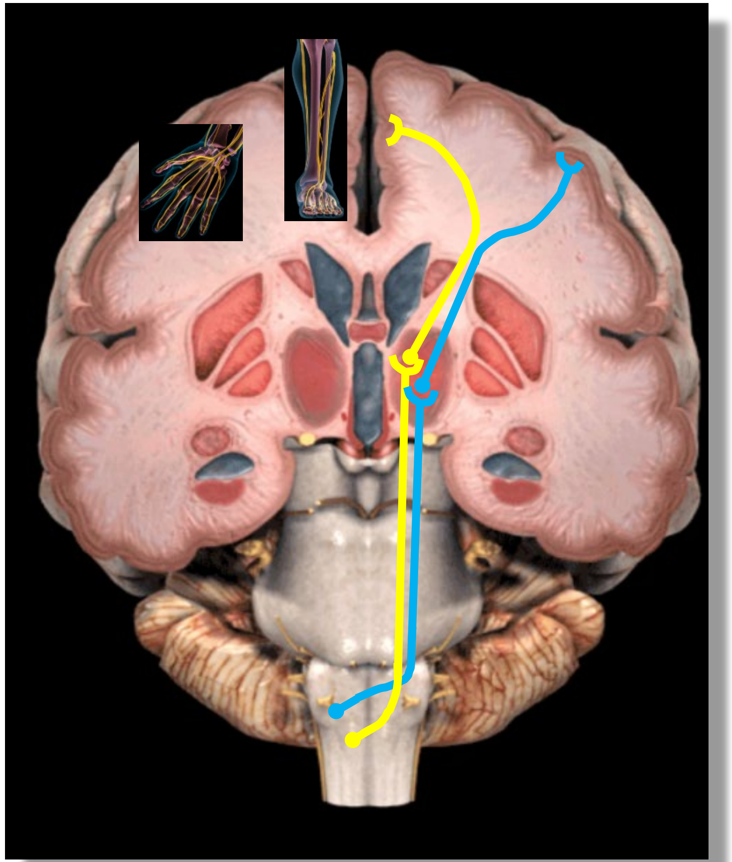


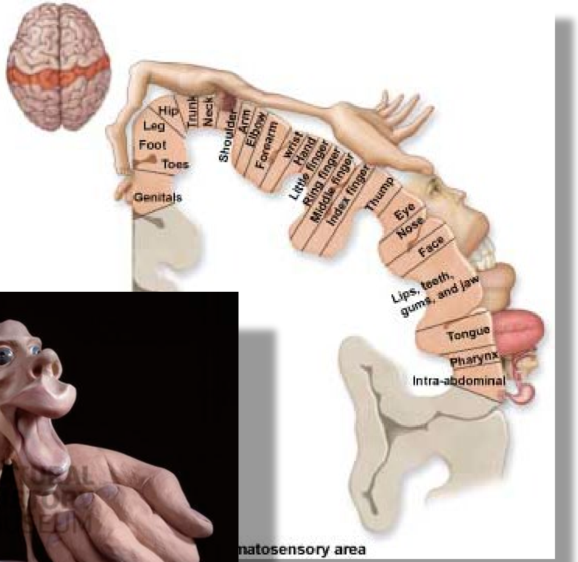
Schematic cross section of spinal cord

Somatotopic cortical representation

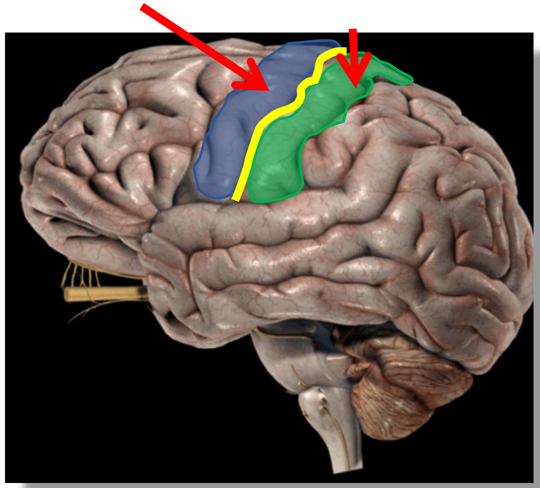


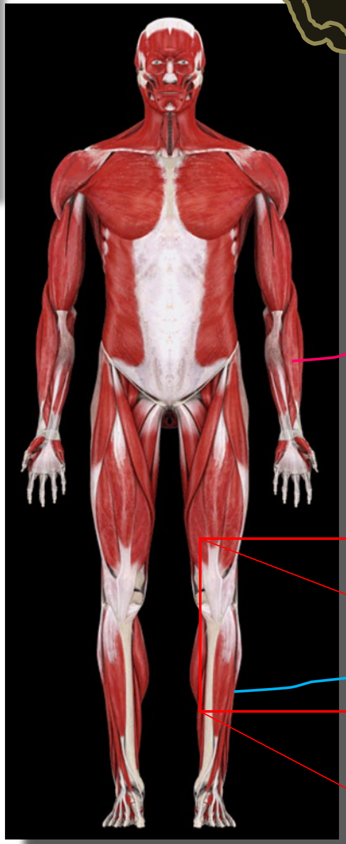


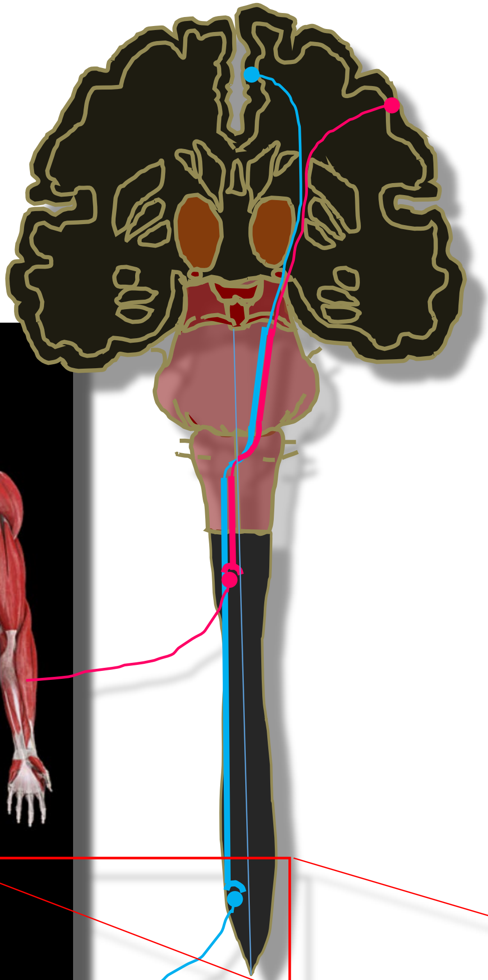


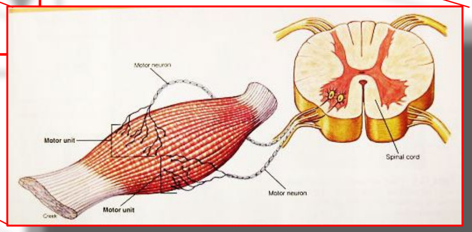


Motor Path Anatomy





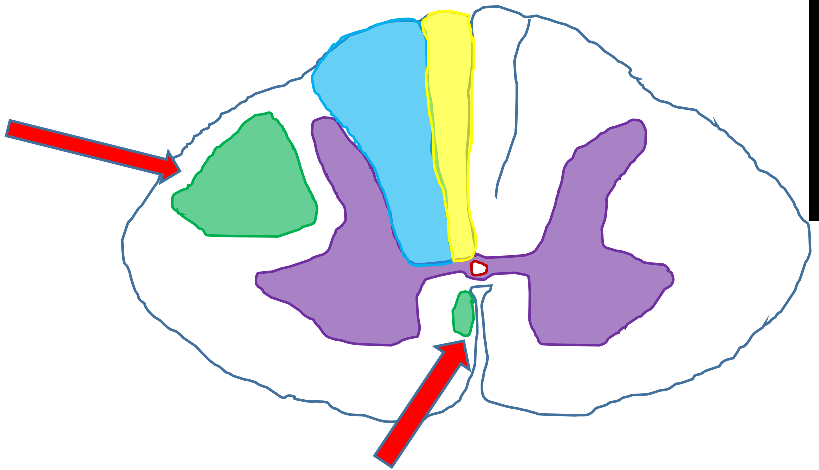


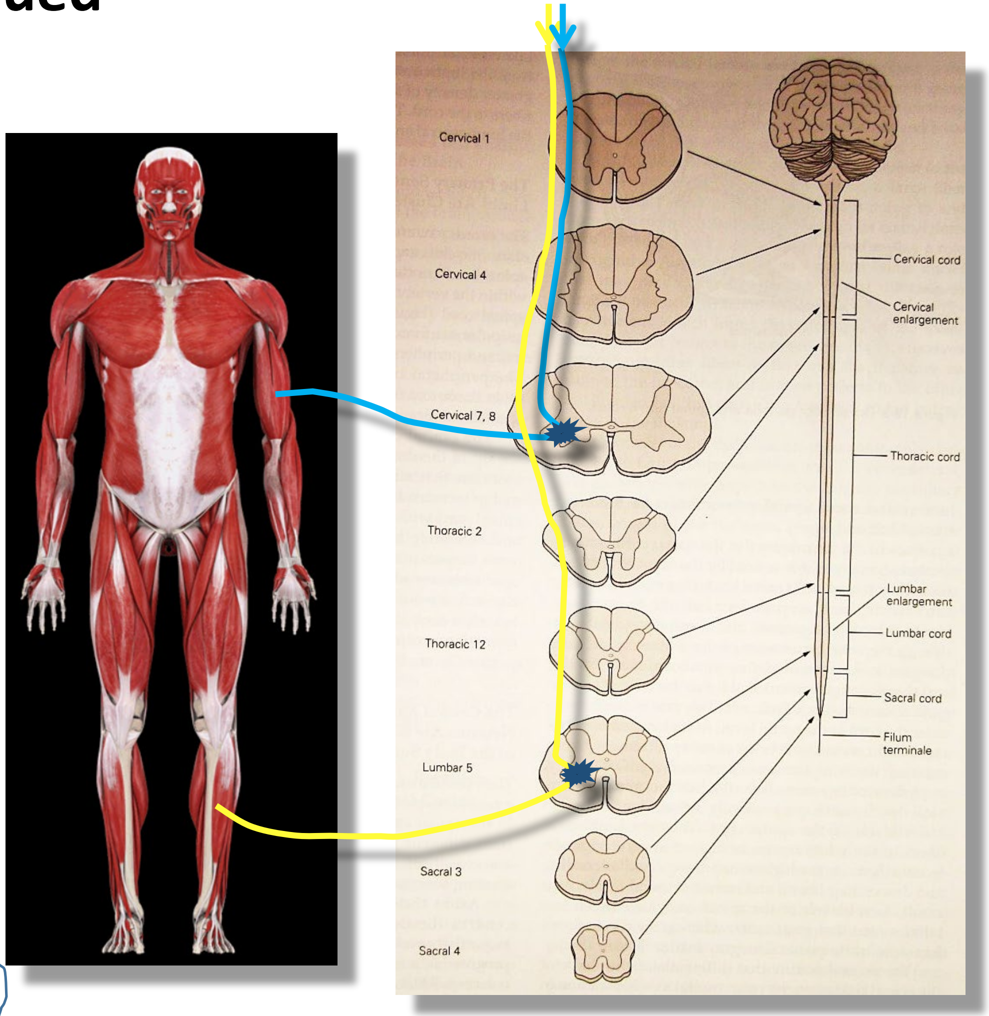


- Motor cortex – upper motor neuron
- Radiations
- Internal Capsule
- Pyramidal Decussation
- Corticospinal tract…

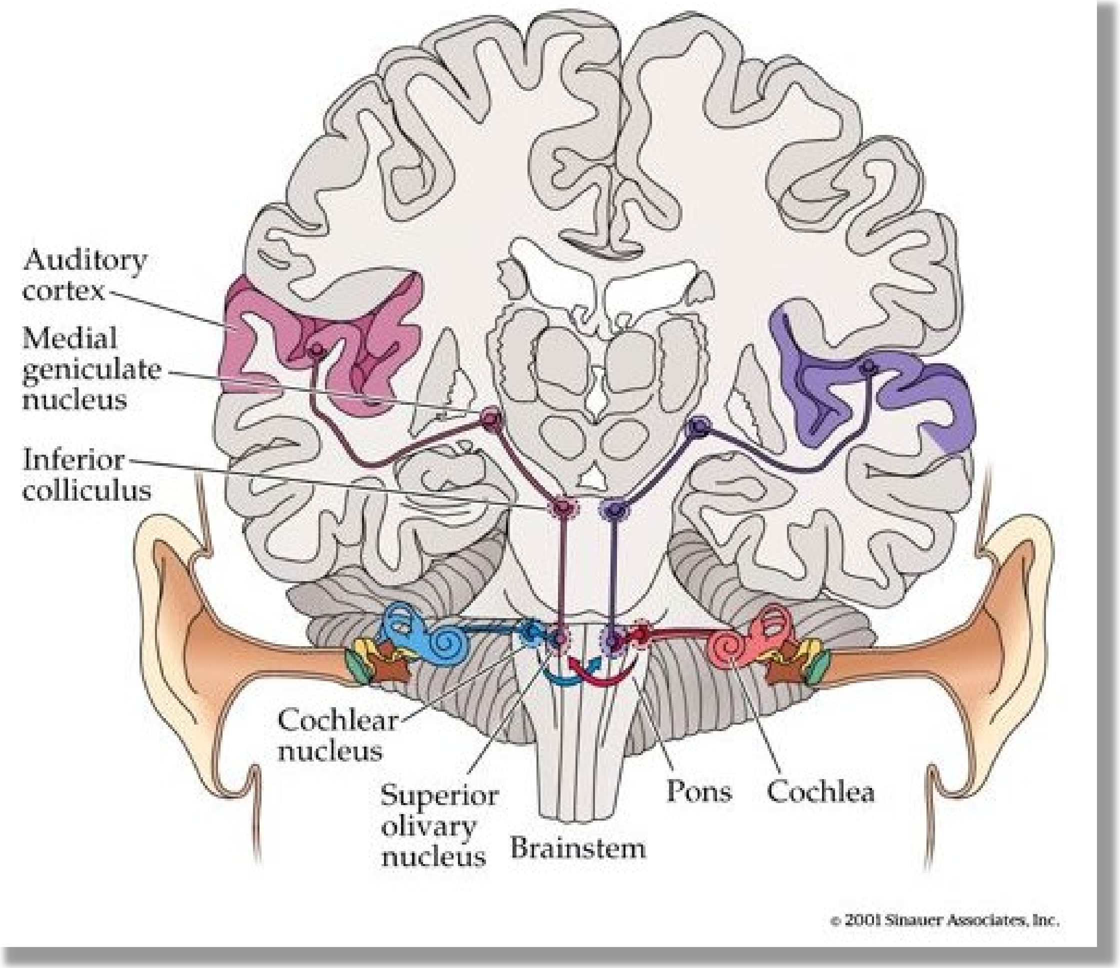
Motor Path Anatomy, continued

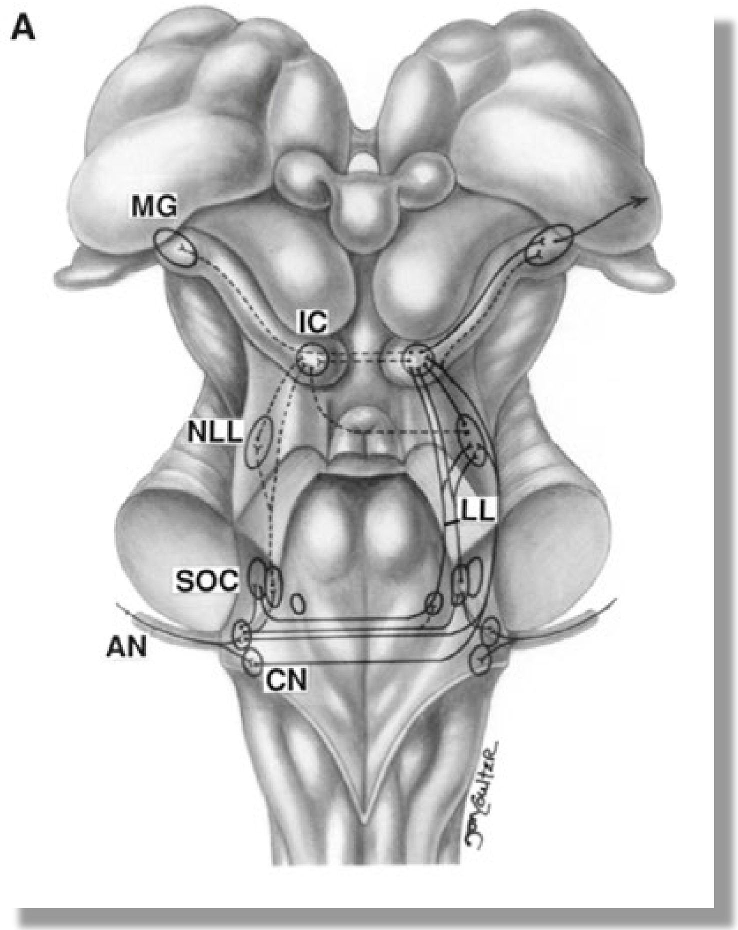
- …Corticospinal tract
- Spinal motor nuclei
- Alpha motor neuron (lower motor neuron)
- Ventral root to the muscle





Auditory Path Anatomy





Categories of IONM Signals (Modalities)

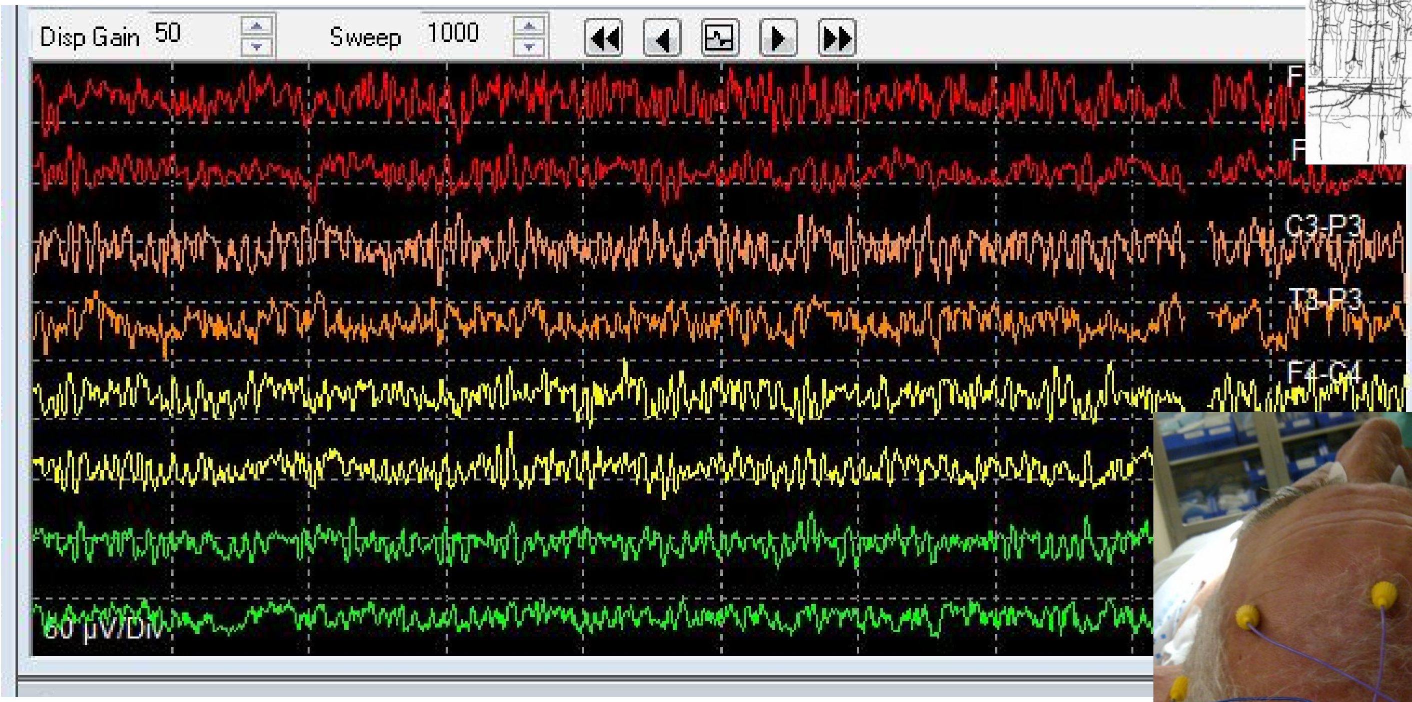
Spontaneous

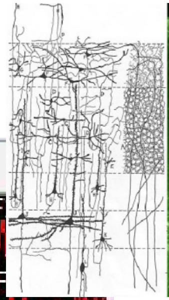
- Electroencephalography (EEG)
- Electrocorticography (ECOG)
- Electromyography (EMG)

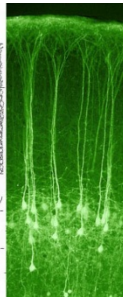
Stimulus Evoked

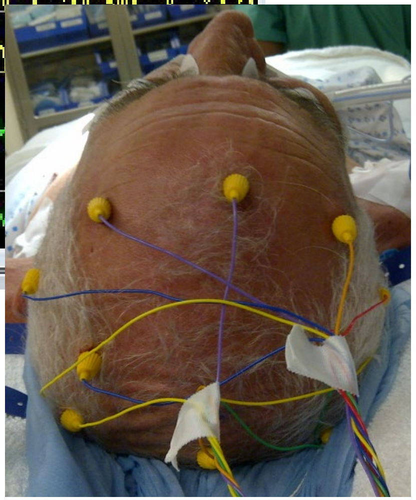
- Electromyography (EMG)
- Somatosensory Evoked Potentials (SSEP)
- Transcranial Motor Evoked Potentials (TCeMEP)
- Brainstem Auditory Potentials (BAPs, BAERs, ABRs)
- Visual Evoked Potentials (VEP)
- Compound Nerve Action Potentials (CNAP, NAP)
- Mapping of eloquent cortical tissue
- Direct Cortical Stimulation (DCS)
- Direct Spinal Cord Recordings/Stimulation (D waves, Dorsal Column Mapping, etc)

Electroencephalography









What is it?

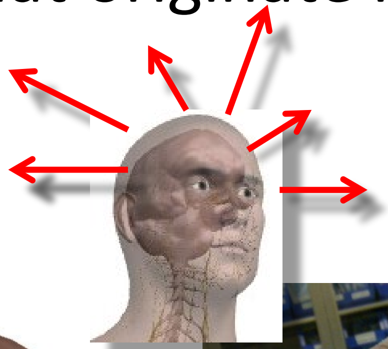
Brain activity is in the form of bioelectric signals originating from synaptic and action potentials (and even long-term depolarizations) that, because of volume conduction, can be observed using electrodes on/in the scalp.

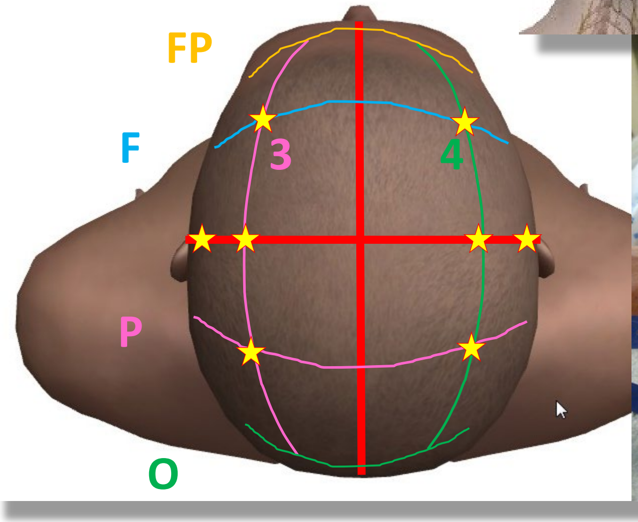
Electroencephalography, EEG, is the recording of these potentials at the scalp while Electrocorticography, ECOG, is the recording directly from the surface of the brain.

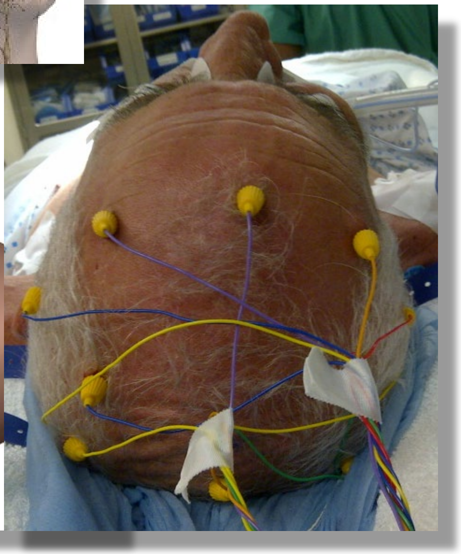
If we use the appropriate, focused recording parameters (e.g. filters) it becomes evident that there are underlying patterns of brain activity. These patterns of activity are the result of synchronous, coordinated activation of regions of cortical tissue - generators - and this activity is believed to be modulated primarily by subcortical structures such as the thalamus and by intrinsic cortical networks.

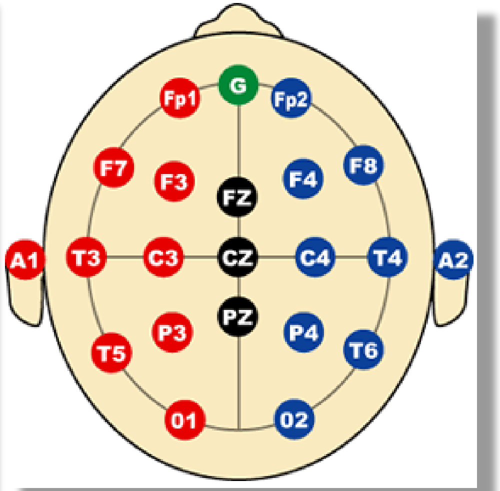
What is recorded and Recording sites

Small amplitude, volume-conducted voltage deflections that originate in the cerebral cortex.

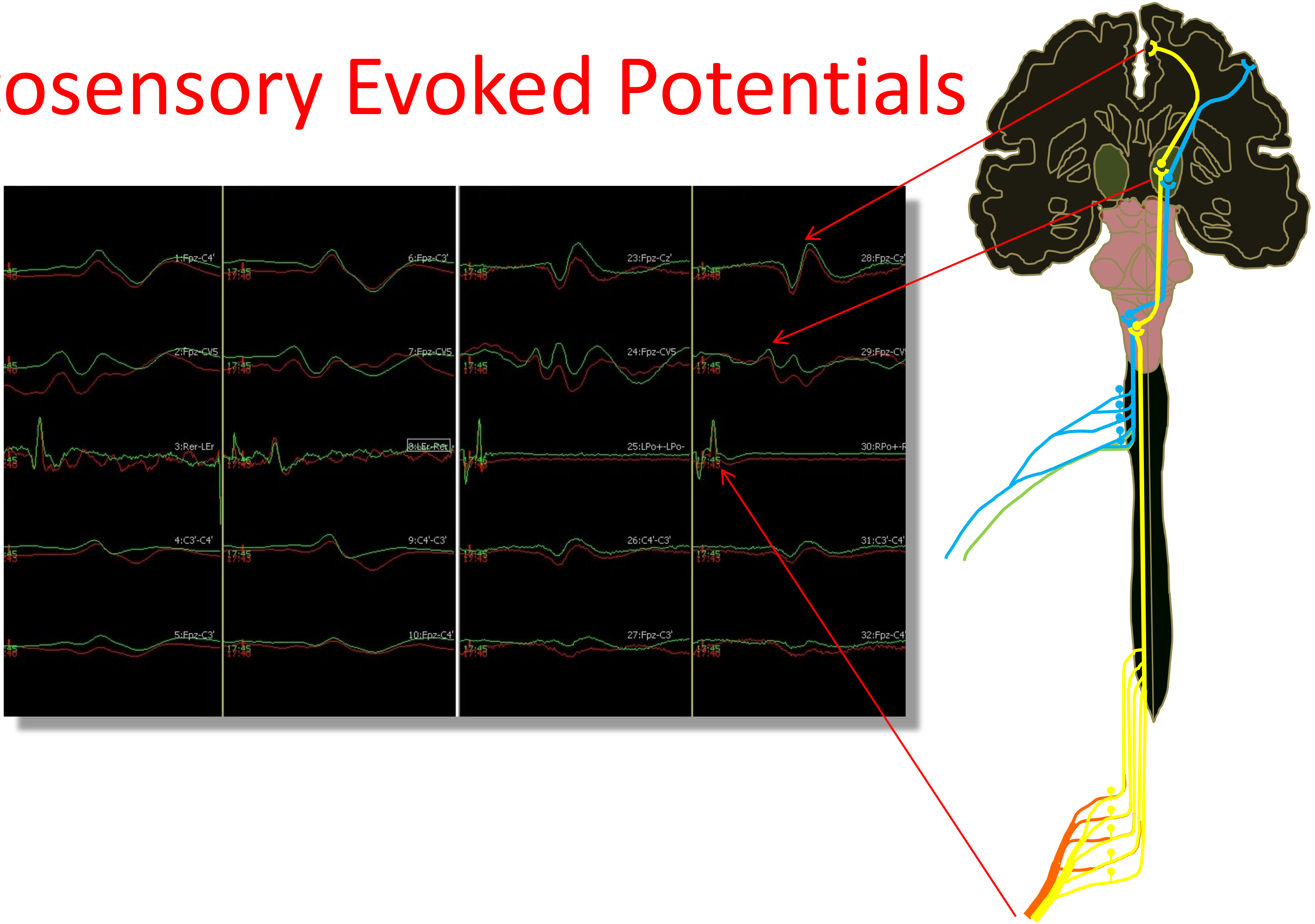








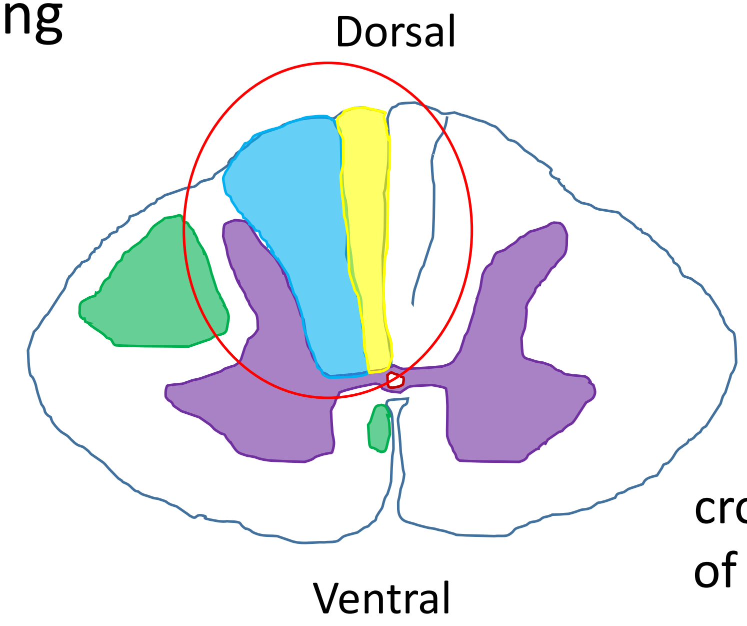
Somatosensory Evoked Potentials



What is it?

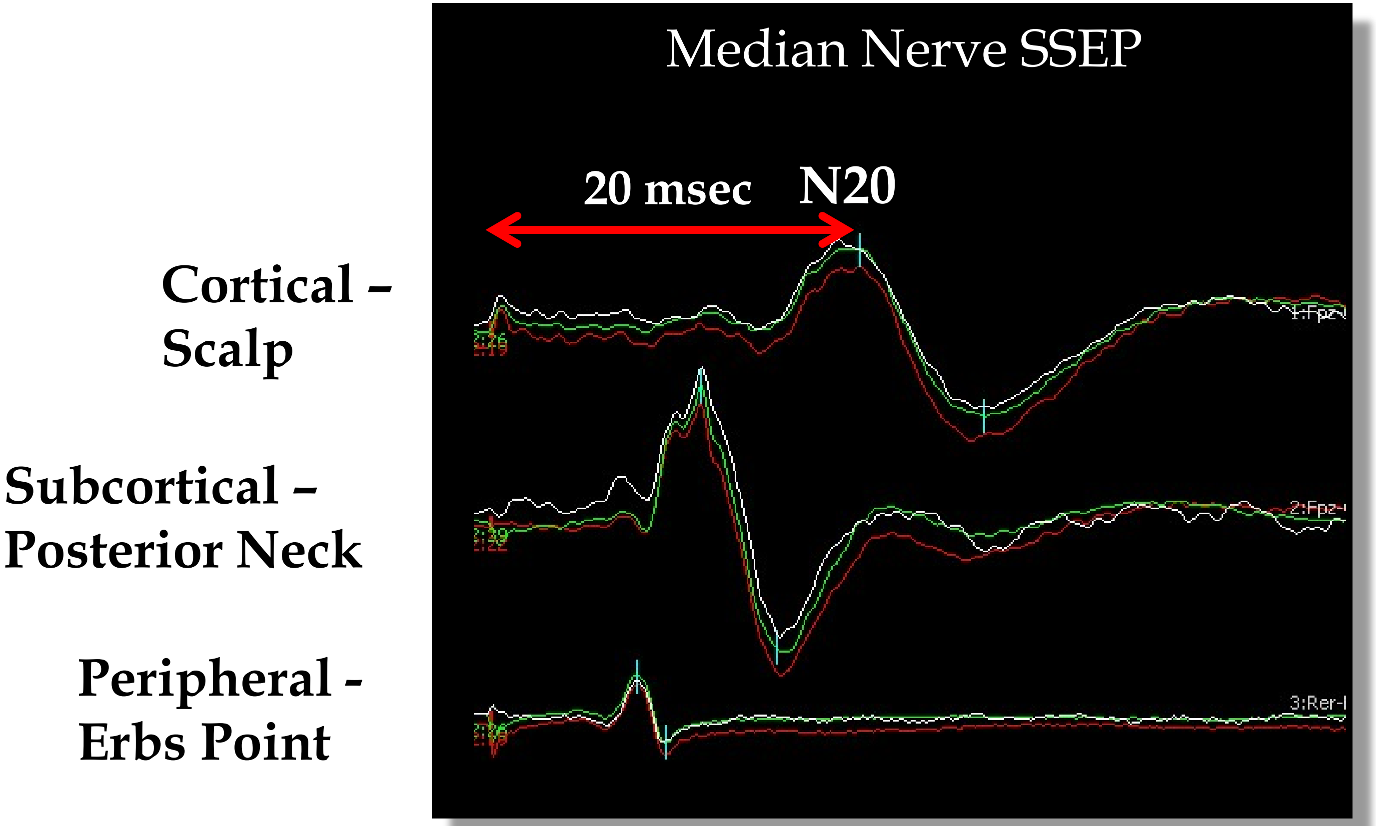
A somatosensory evoked potential (SSEP) is the recording, typically on the skin surface, of volume conducted bioelectric events originating in the ascending pathway of the nervous system. In IONM the SSEP corresponds predominantly to activity in the dorsal column-medial lemniscal pathway. The pathway is activated by electrical stimulation, most commonly at the wrist and ankle, of a peripheral nerve

and recordings are made along the pathway. Each voltage deflection corresponds to activity in a discrete site or portion of the pathway.



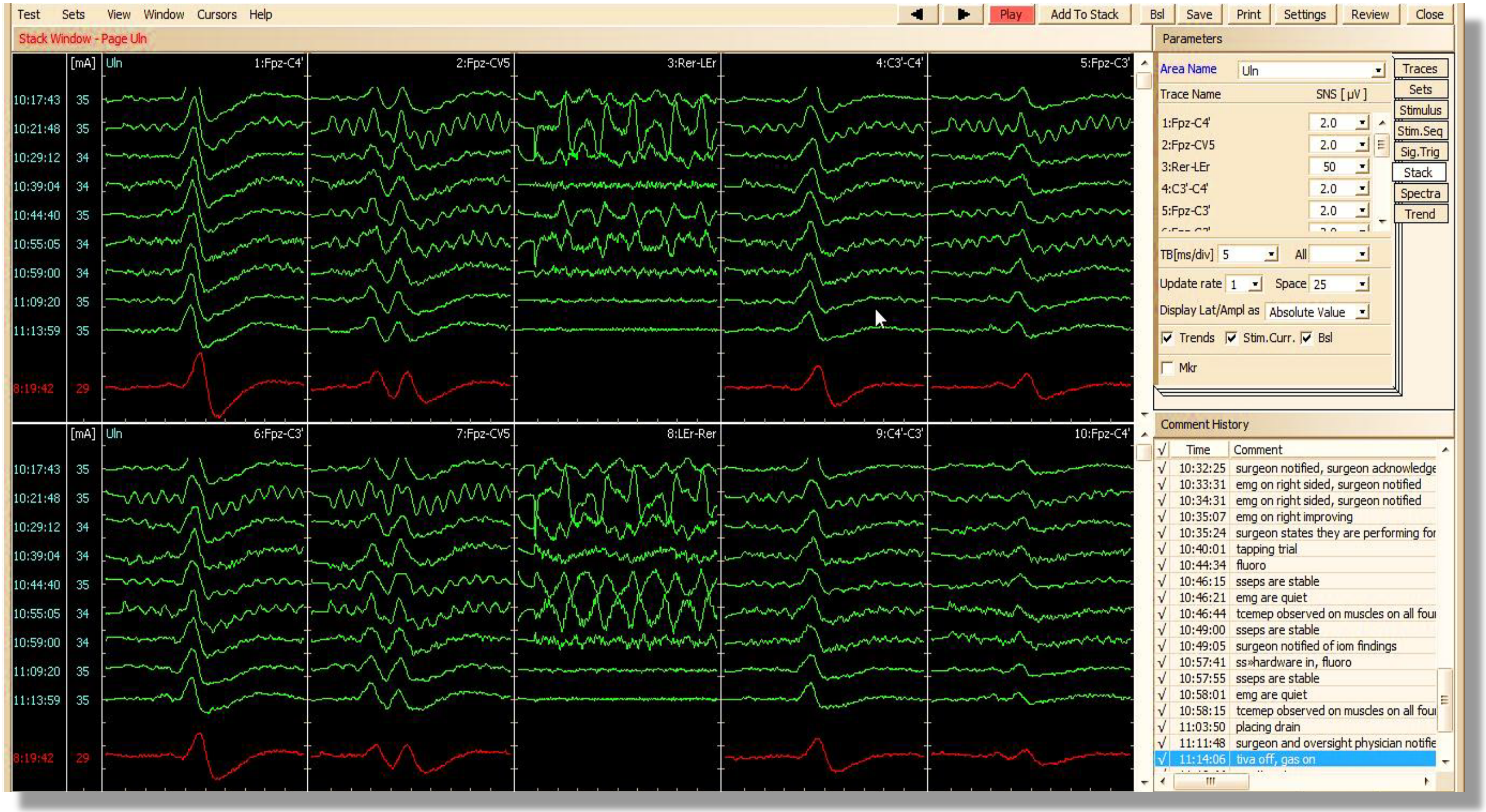
Schematic cross section of spinal cord

Characteristic and reproducible morphology and latency



Note that the convention, due to the orientation of the active and reference electrode in the differential amplifier, is that a **negative potential** read at the active electrode is **upward**, whereas a **positive potential** is **downward**.

Patient serves as their own control

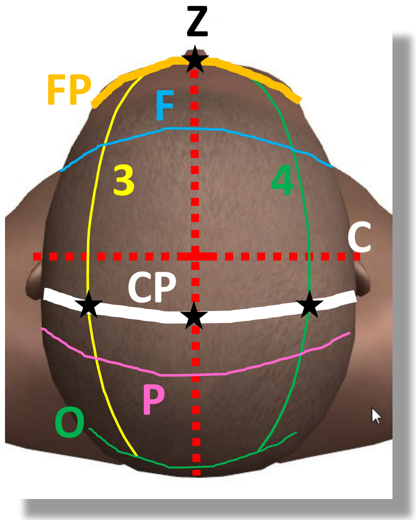


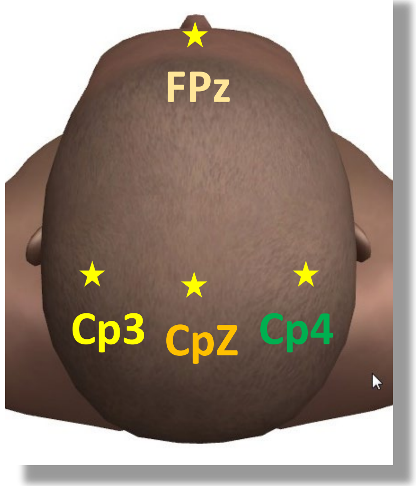
Recording Sites

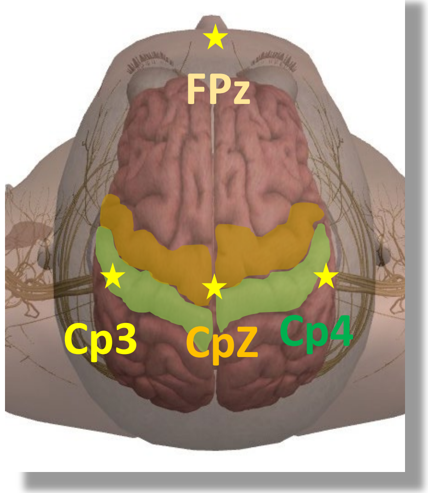
- The location of each recording site is based on what portion of the pathway is of interest, the presumed location of the generator and the ability to see activity from that generator at that location
- Typically
  - Cortical recordings
  - Subcortical recordings
  - Peripheral recordings
- Observation of a potential at each recording contributes to the interpretation of a change in data and it's presumed location

Cortical Recording Sites – Scalp Electrodes

- Approximate postcentral gyrus: 10-20 system
- Electrodes are placed at **CPZ, CP3, CP4, FPZ**



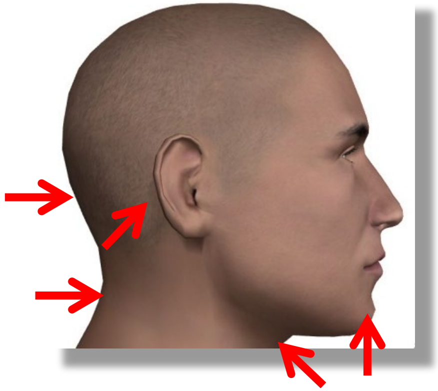


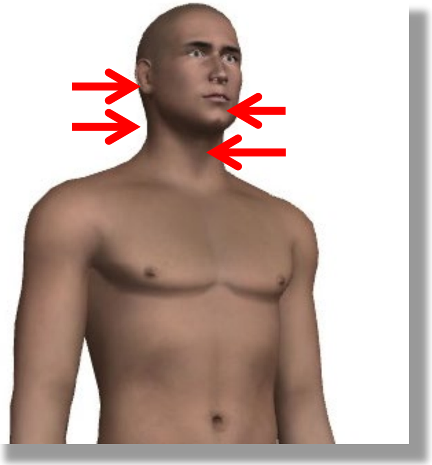


Subcortical Recording Sites

Head and Neck – one of the following:

- Posterior
  - Cervical levels 5 or 3 or 7
  - Inion
- Mastoid/ Double Mastoid
- Anterior neck
- Chin
- Usually named **CS5**

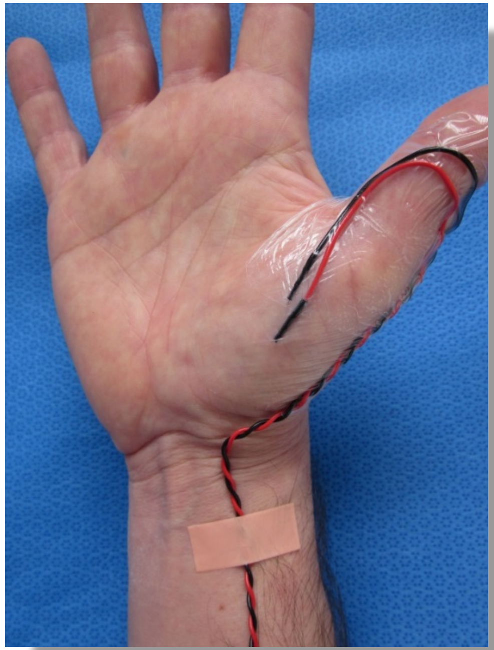


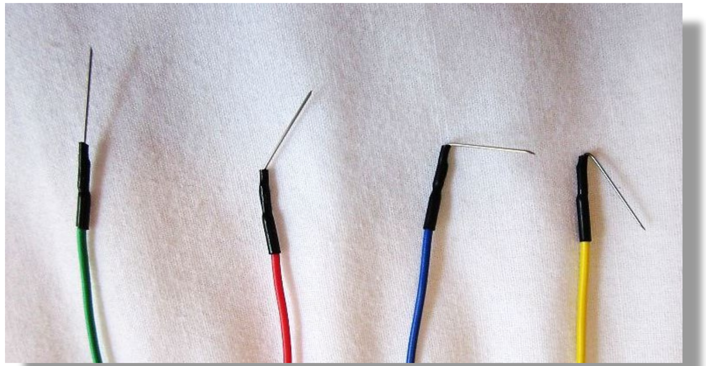


Video

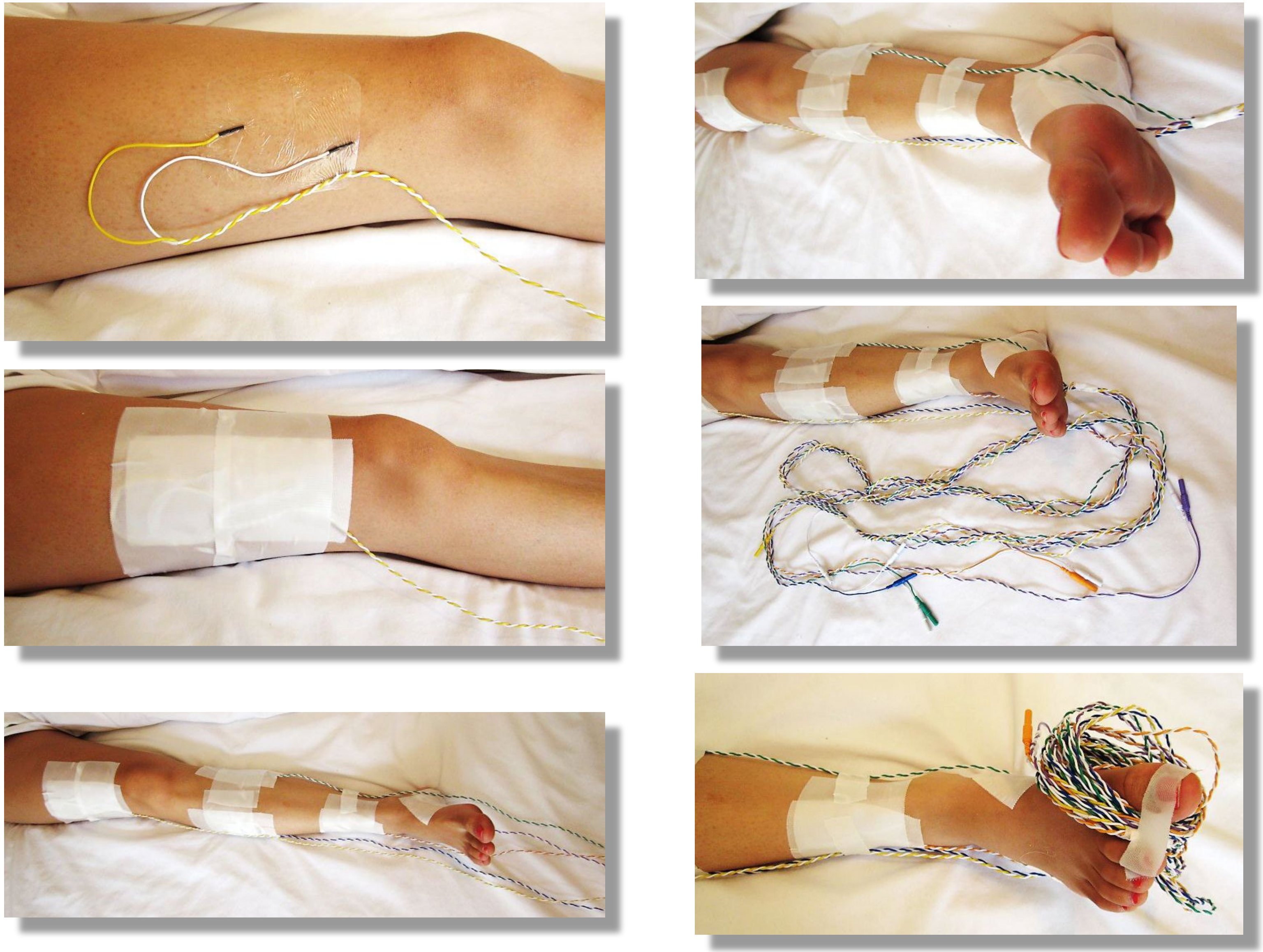
Patient Set-up

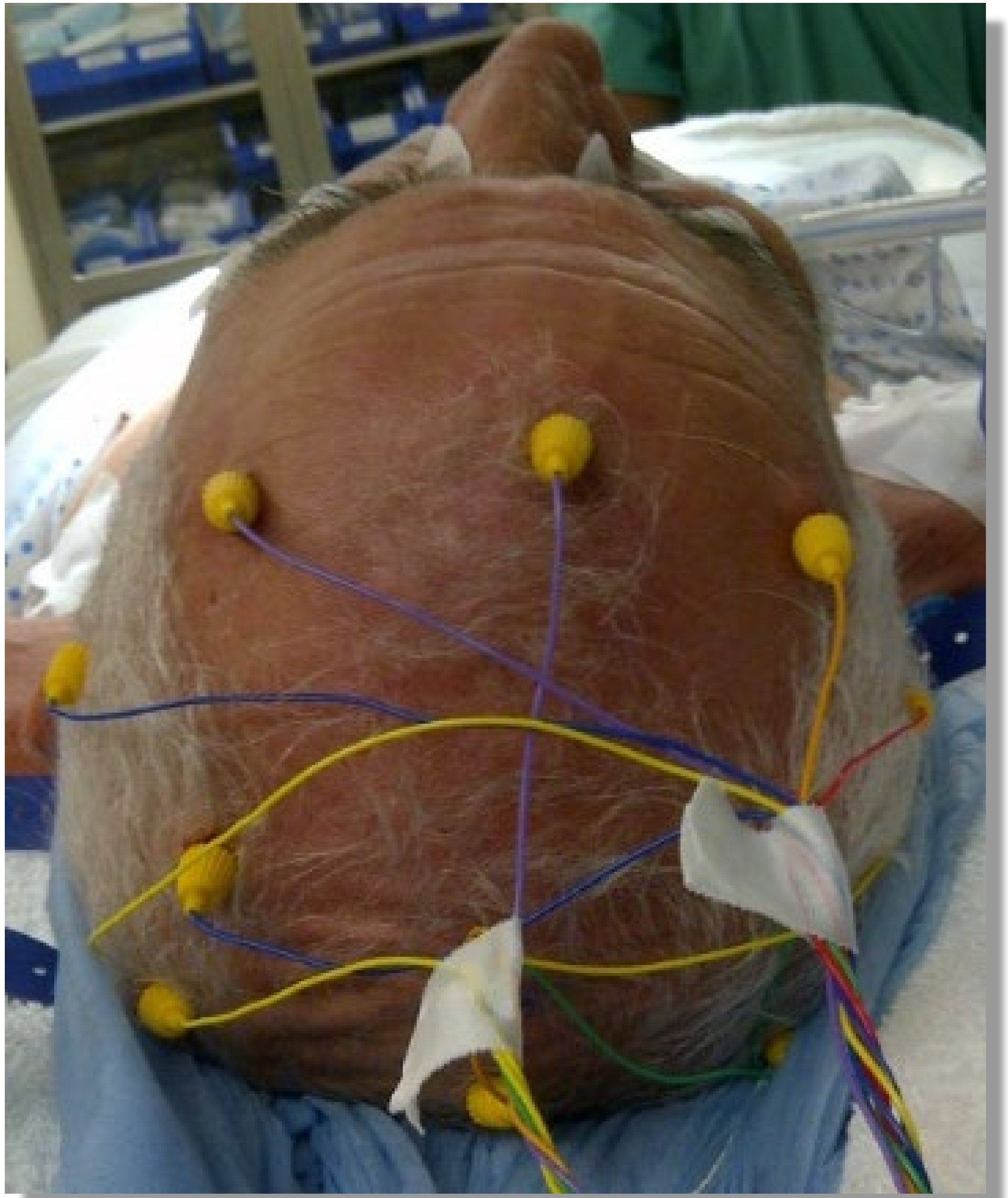
Subdermal or Intramuscular





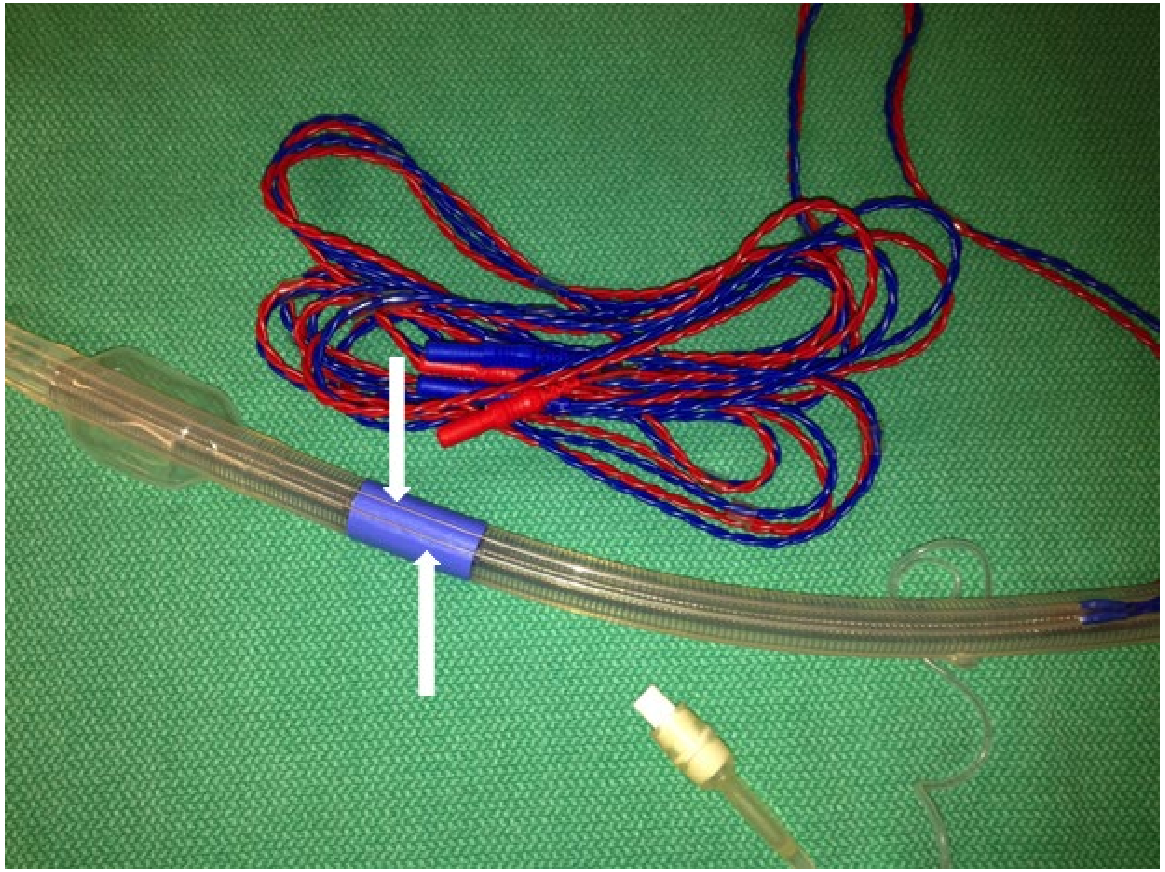

Surface
Subdermal





Sharing space?

- Carotid Endarterectomy
- A-line
- Place on side contralateral to surgery?
- Move to ulnar groove?



- Recurrent Laryngeal Nerve
    - Thyroid
    - ACDF
    - Large vestibular schwannoma
- Electrode-implanted Endotracheal tube
    - Multiple sizes
    - Who supplies?
- Midline placement critical for IOM utility

Bite Blocks

The incidence of bite injuries associated with transcranial motor-evoked potential monitoring

- 17,273 consecutive surgical procedures
- Reviewed for type and number of bite blocks, positioning, anesthesia, and stimulus variables
- 111 bite injuries in 109 patients for a total incidence of 0.63%
- 88 (79.3%) tongue injuries, 22 (19.8%) lip injuries, and 1 (0.9%) broken incisor
    - 25 patients required sutures
- All but 2 patients had some form of bite block used
- In 22 cases, displacement of bite block or of the tongue was documented
- Future study is needed to determine optimal bite block configuration

SOURCE: Tamkus A, Rice K. Anesth Analg. 2012 Sep;115(3):663-7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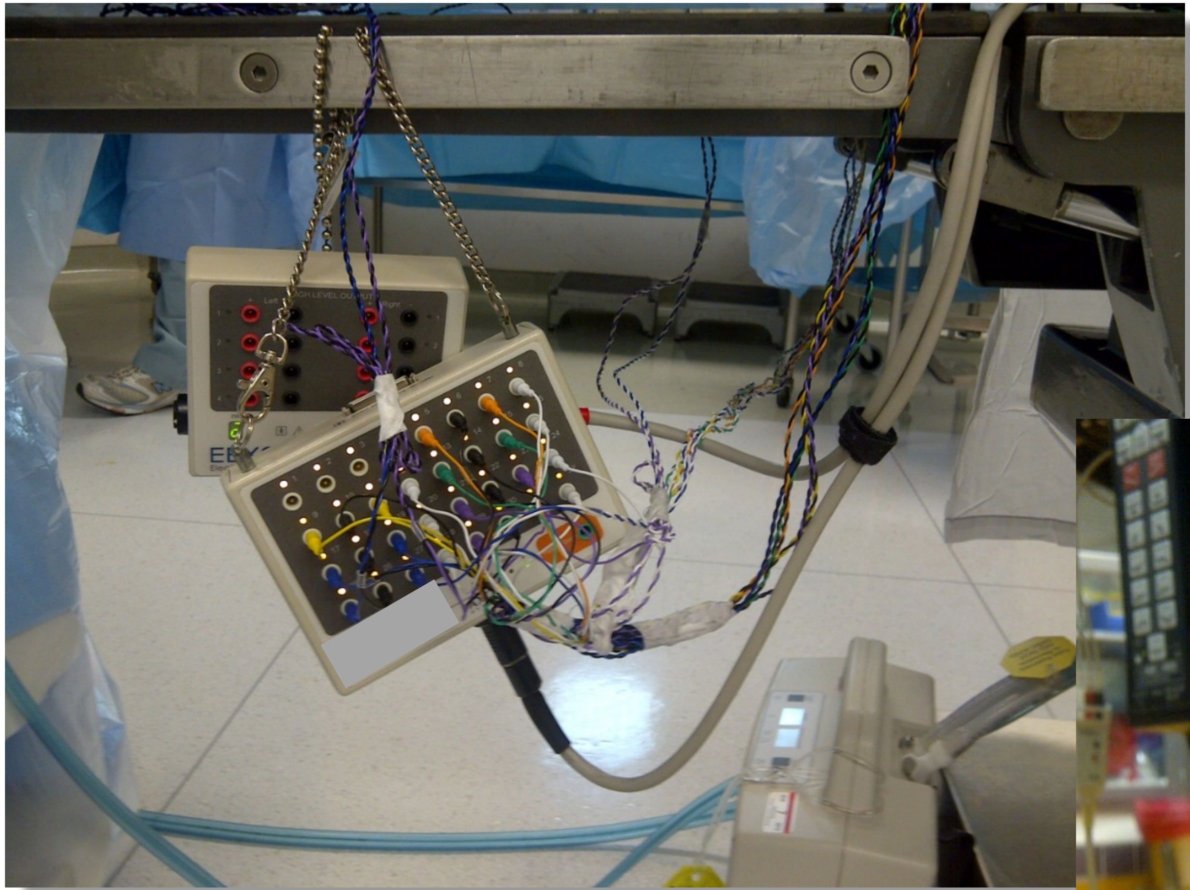
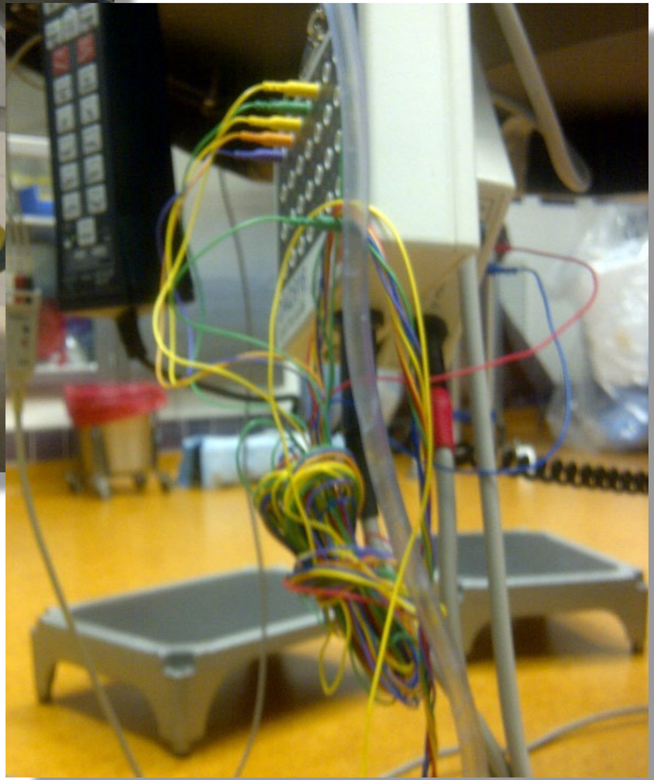
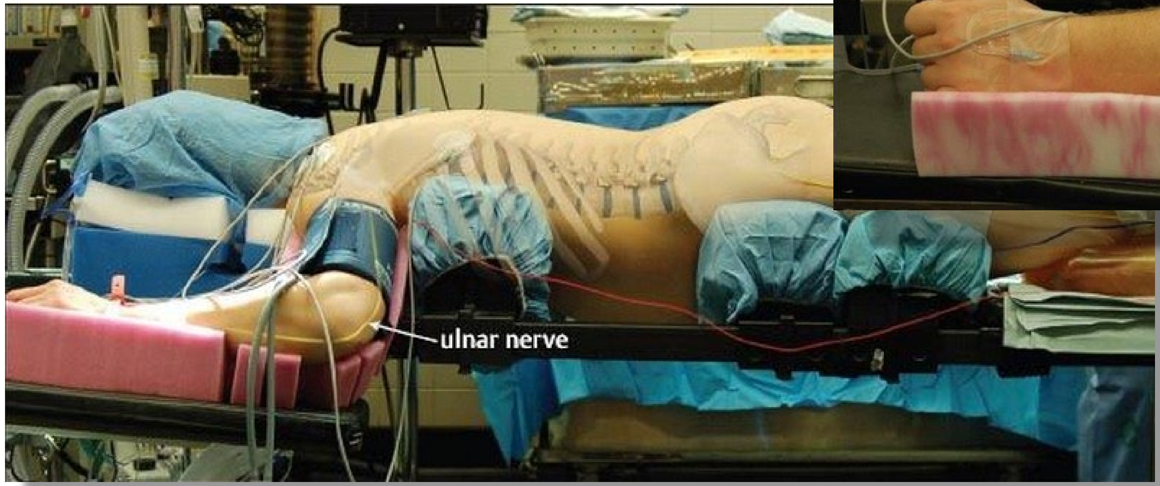
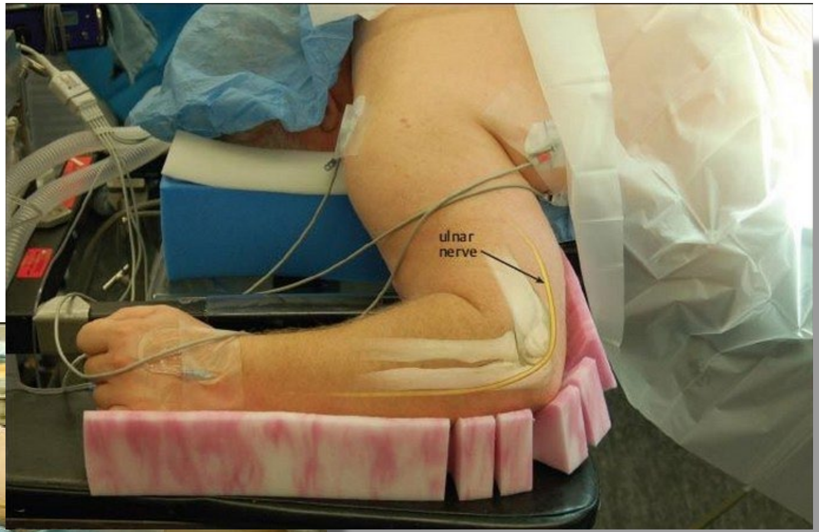
▲19

At the Table

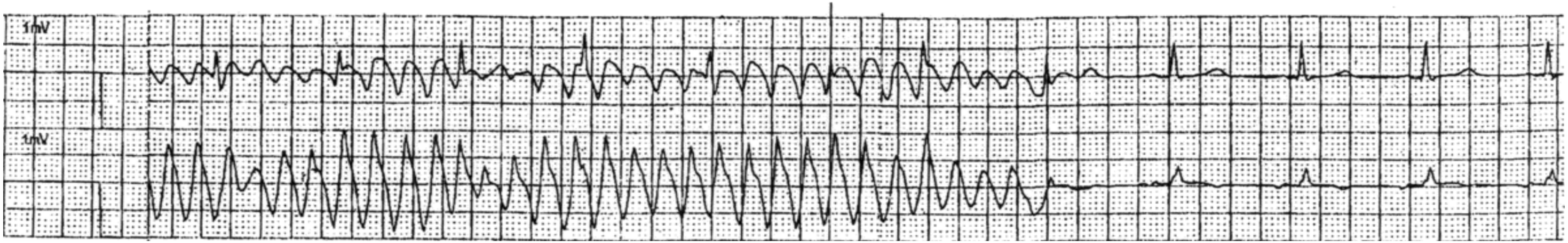
Patient Positioning



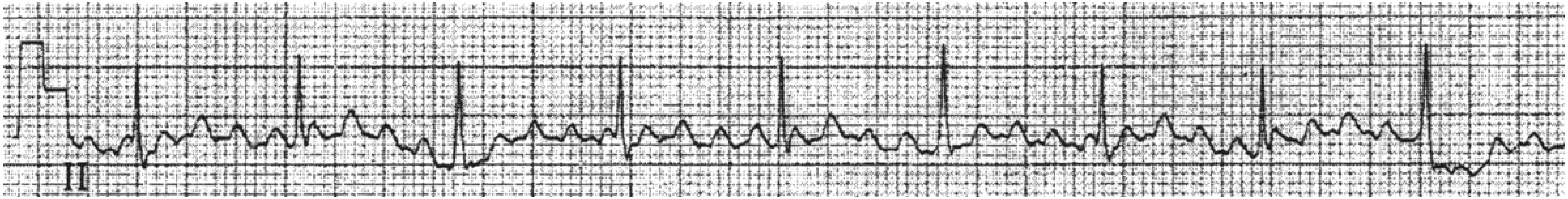


Detection of positional neuropathy

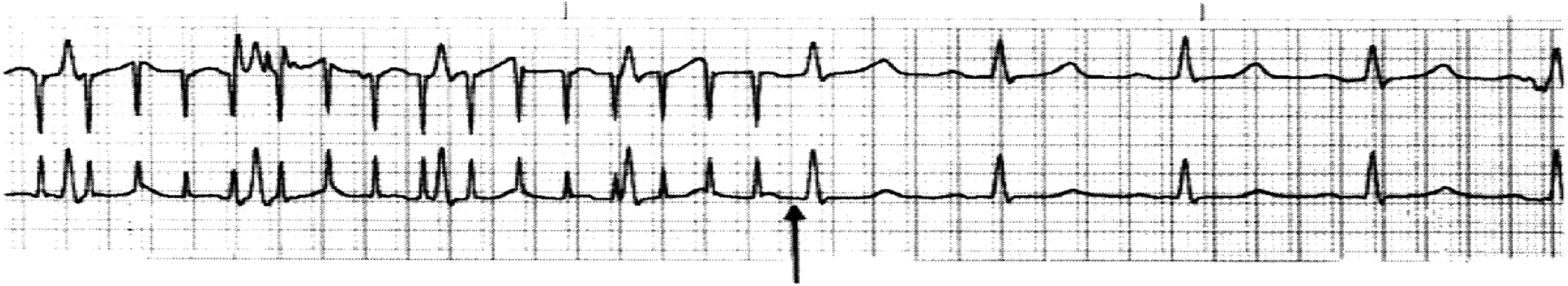
Ventricular Tachycardia



Atrial Flutter

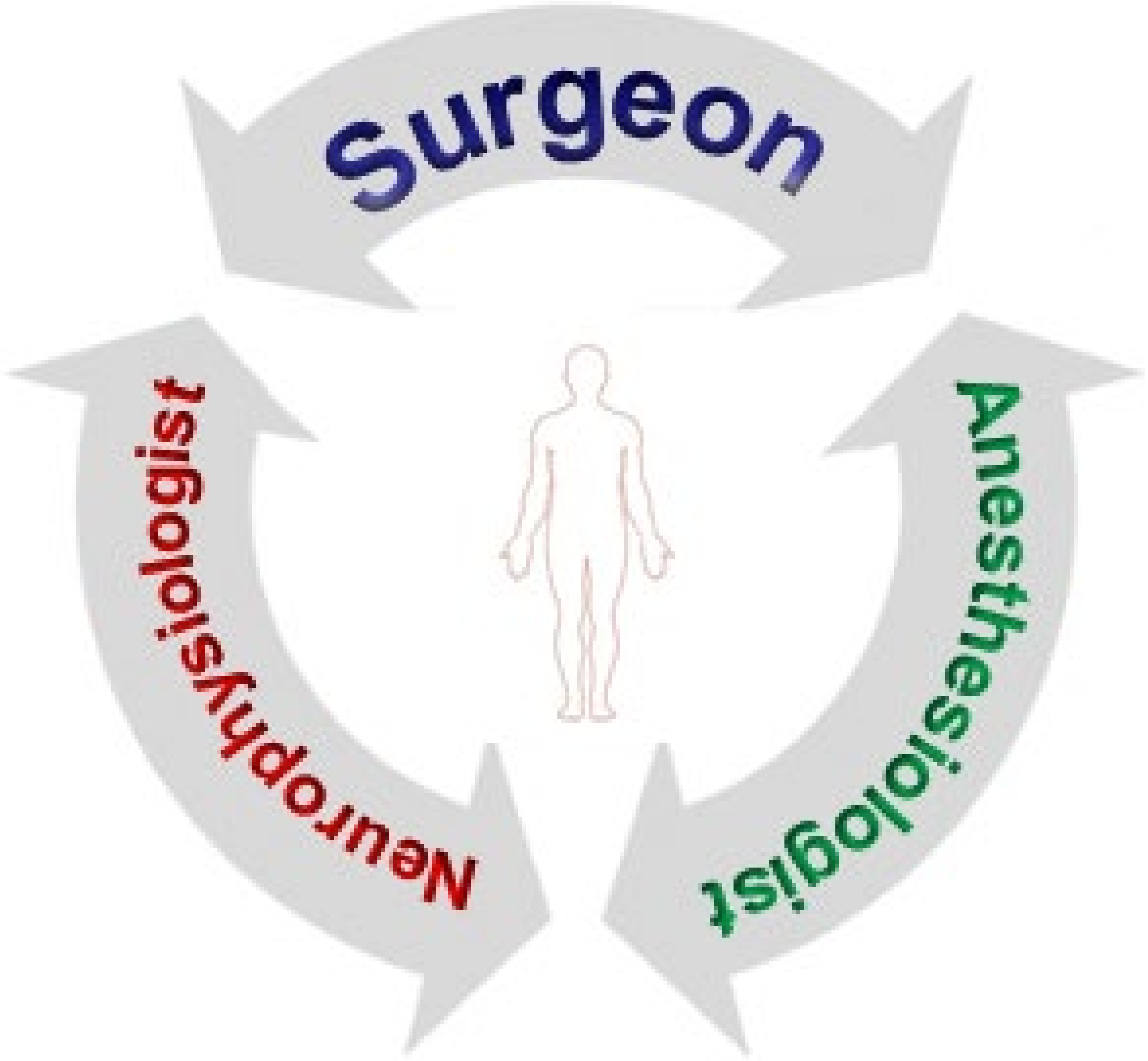


Narrow complex supraventricular tachycardia




HR
/min
92
ECG
PVC
0 /min
ST
mm
I
0.3
II
0.4
V1
0.4
II
0.4
160
80
0
P1 Art
mmHg
113/77 (88)
SpO2
%
90 OFF
100
PR
178 /min
mmHg
Adult
Sys 40 200
Sys
Dia
92/50
Mean
(65)
30 min
T1 & T2
°C
No sensor detected
T1
36.0
T2

Timers
Countdown
00:00:00
Elapsed
00:00:00


Surgeon
Neurophysiologist
Anesthesiologist

Case Reports

Example 1: Carotid Endarterectomy (CEA)

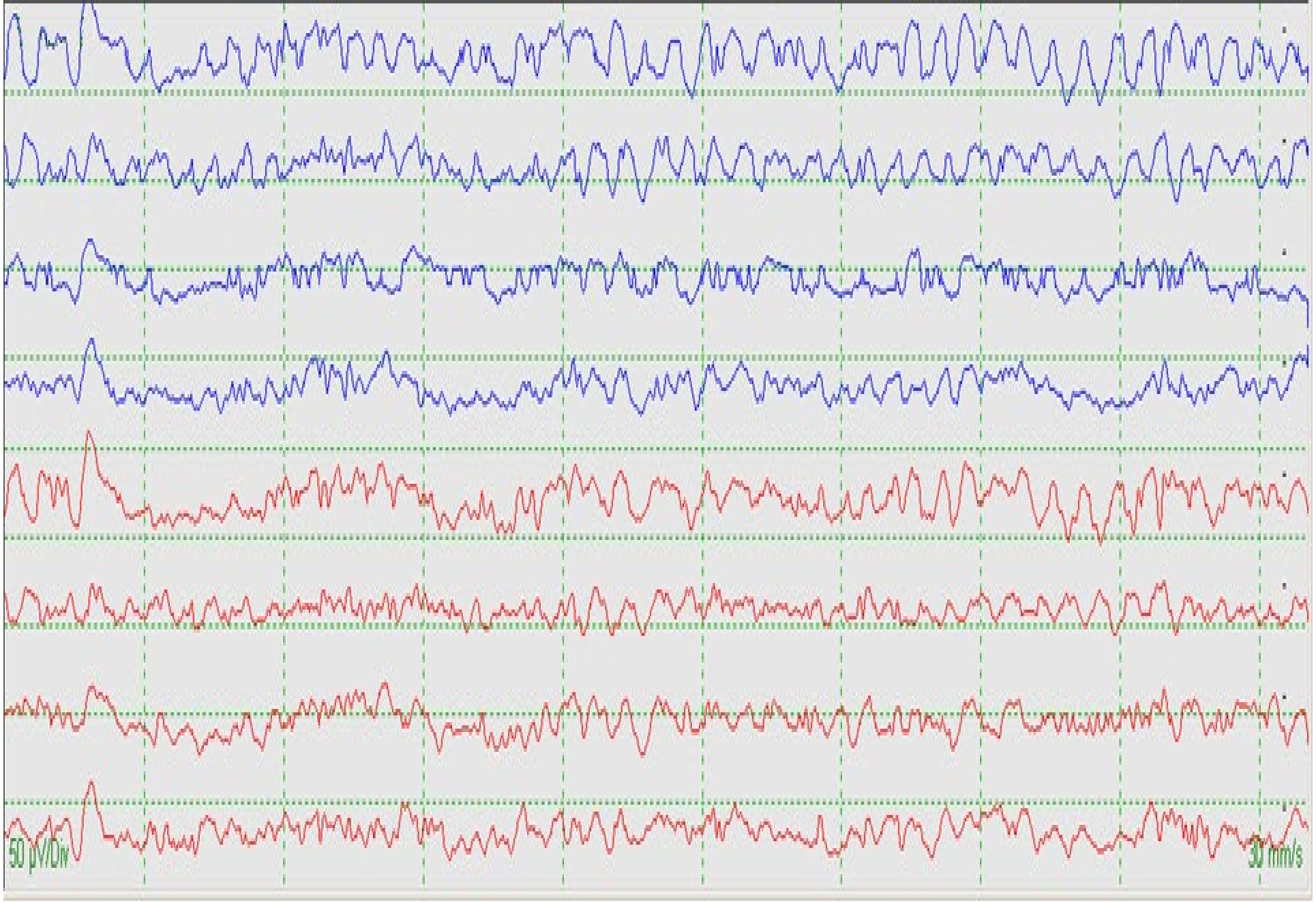
- 67 y/o male
- Significant cerebrovascular disease
- All four vessels are significantly stenosed
- Right Carotid supplies most of the posterior circulation via a large Posterior Cerebral Artery
- Significant left carotid disease 80-90% stenosis
- Right carotid chosen since it supplies the right hemisphere and posterior circulation

Example 1: CEA

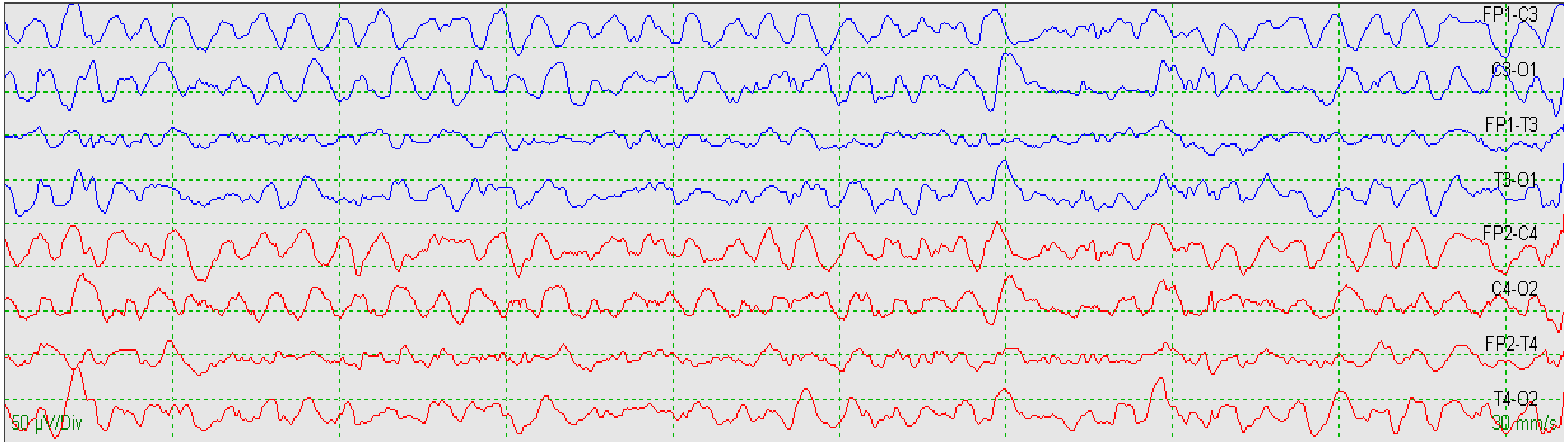
Example 1: Carotid Endarterectomy

Anesthetic Regimen:

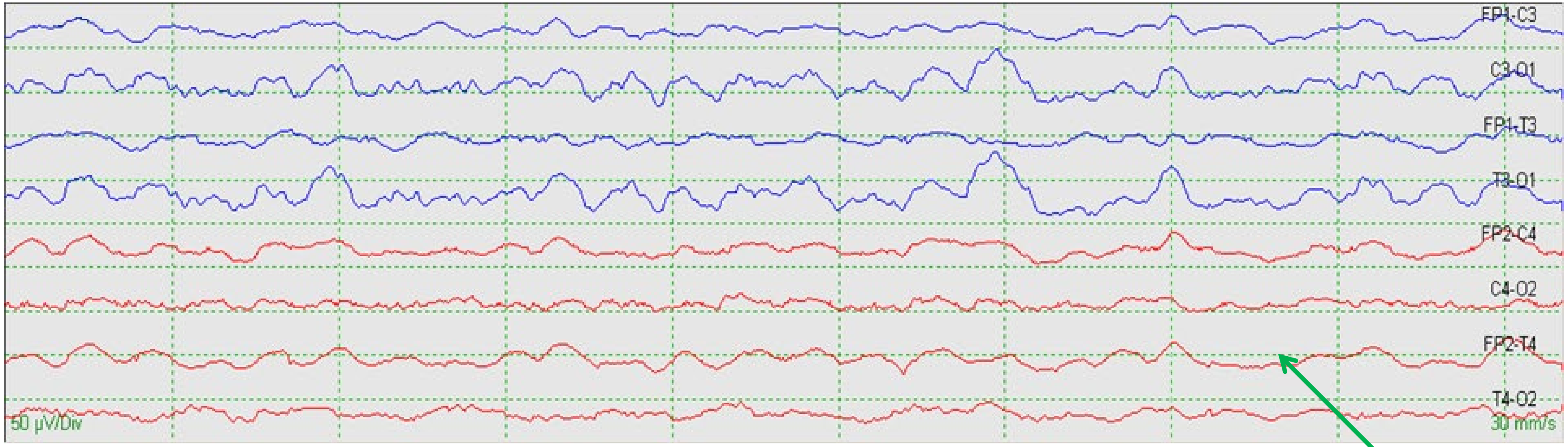
- Neuromuscular block
- 1.5 Mac Sevoflurane
- 50% N_2O



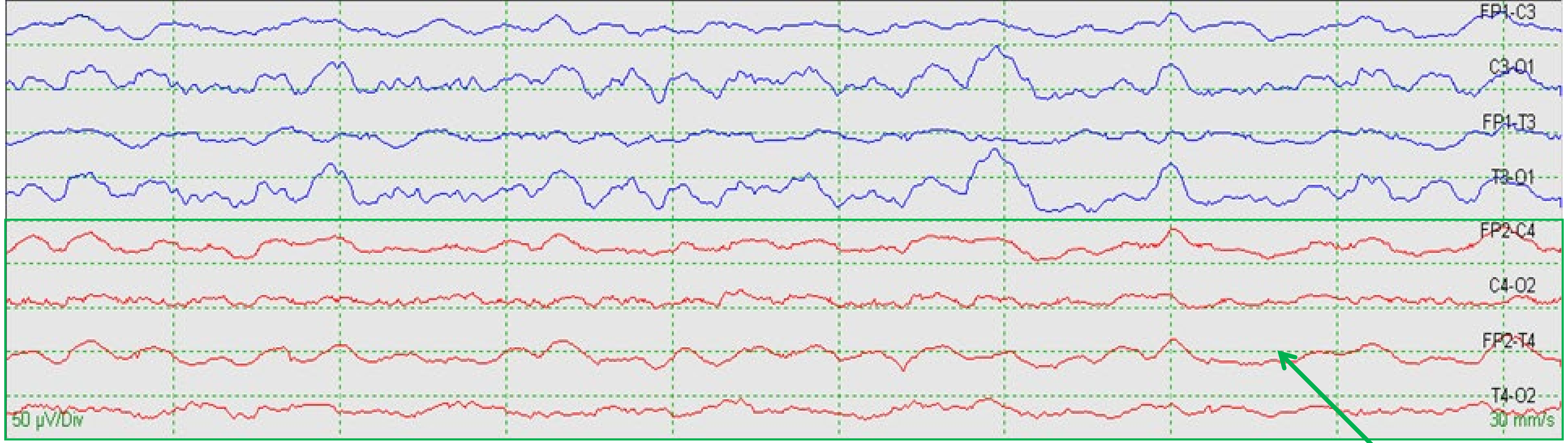
Baseline EEG: Sevo. = 1.15 mac / N_2O=50%, MAP=82



Pre-Clamp: Sevo. = 1.25 mac / N_2O=50%, MAP=85

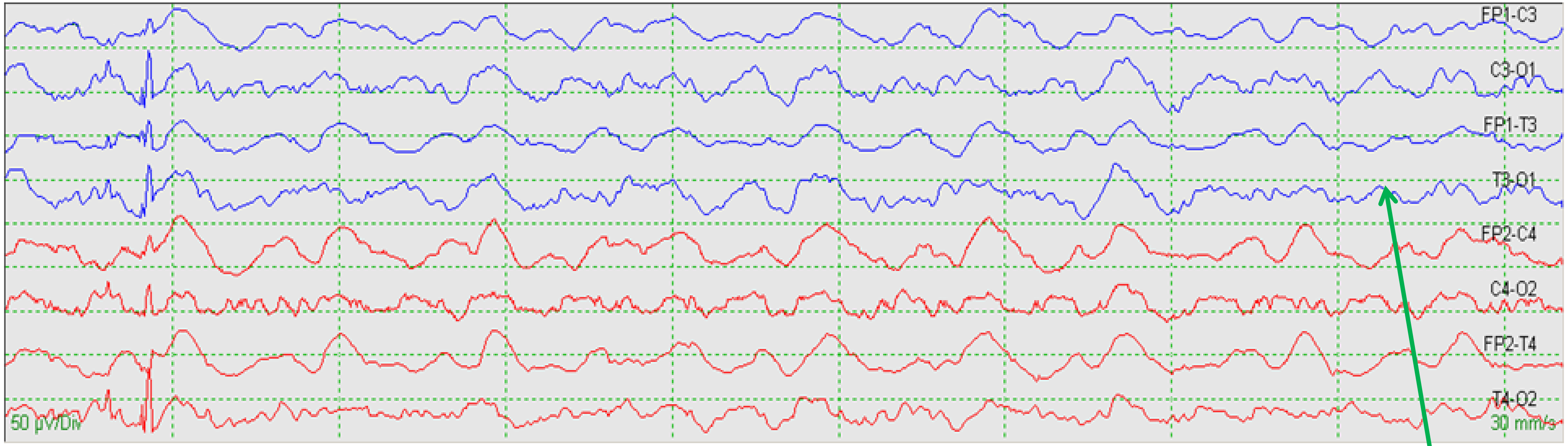


20 Sec. Post Clamp: Sevo. = 1.25 mac / N_2O=50%



20 Sec. Post Clamp: Sevo. = 1.25 mac / N_2O=50%

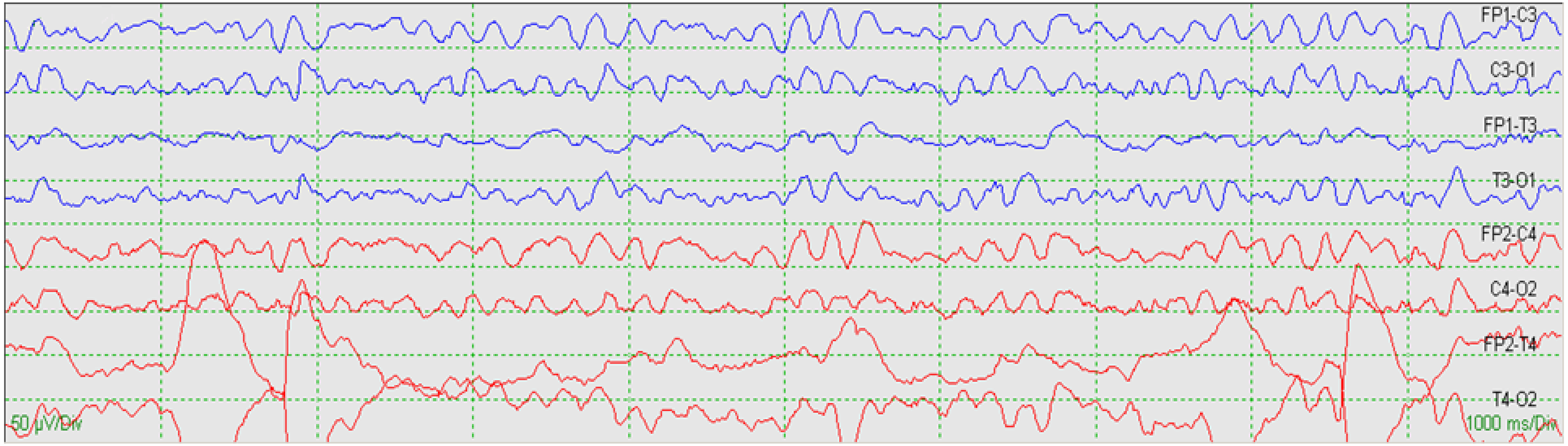
Unilateral Change – decreased amplitude on right



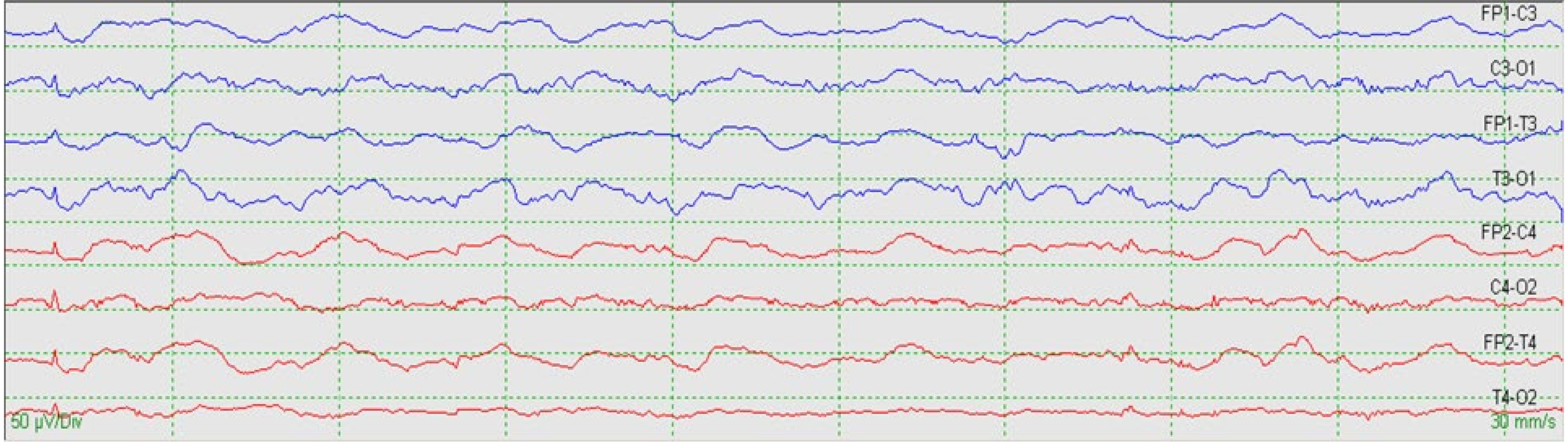
10 Sec. Post Shunt: Sevo. = 1.25 mac / N_2O=50%, MAP=102

Global Delta

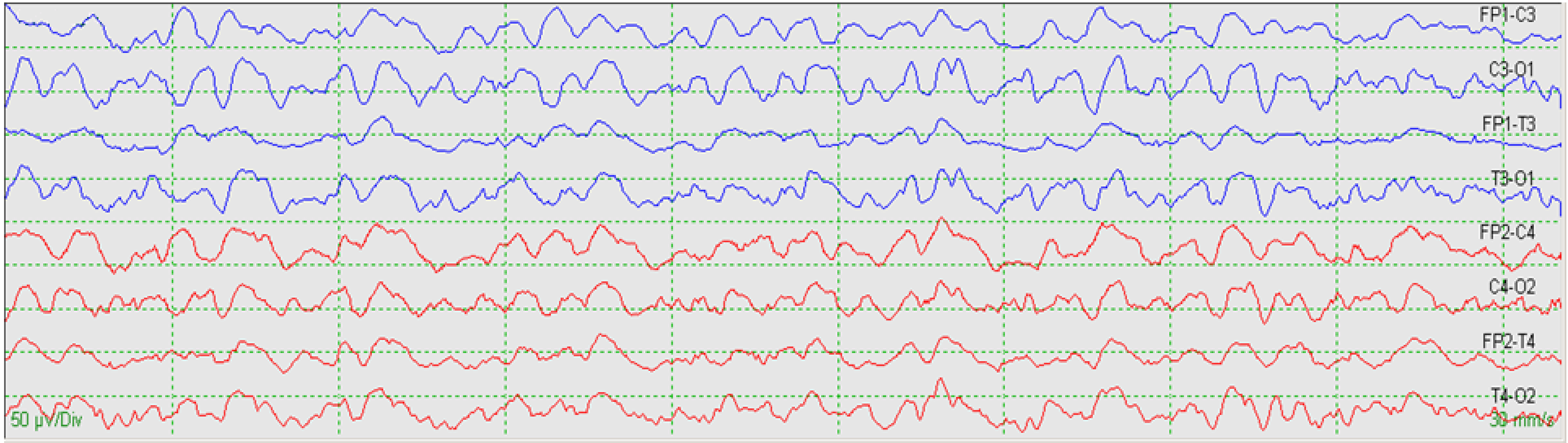
Back to General Theta



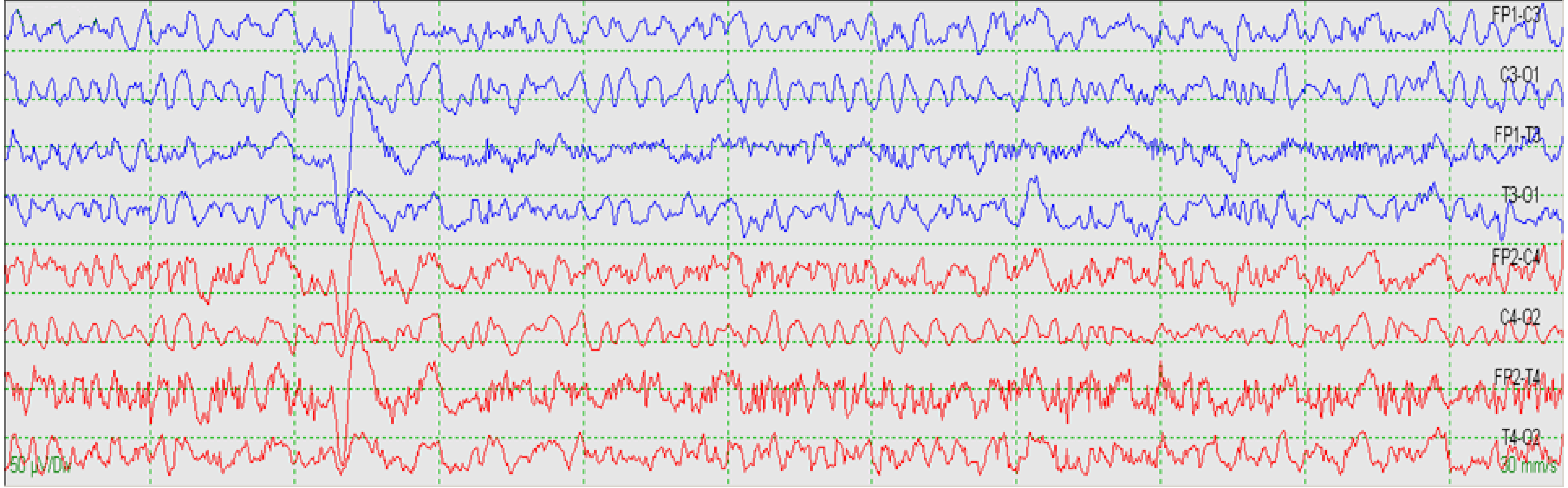
2 min. 15 Sec. Post Shunt: Sevo. = 1.25 mac / N_2O=50%, MAP=102
Almost back to baseline



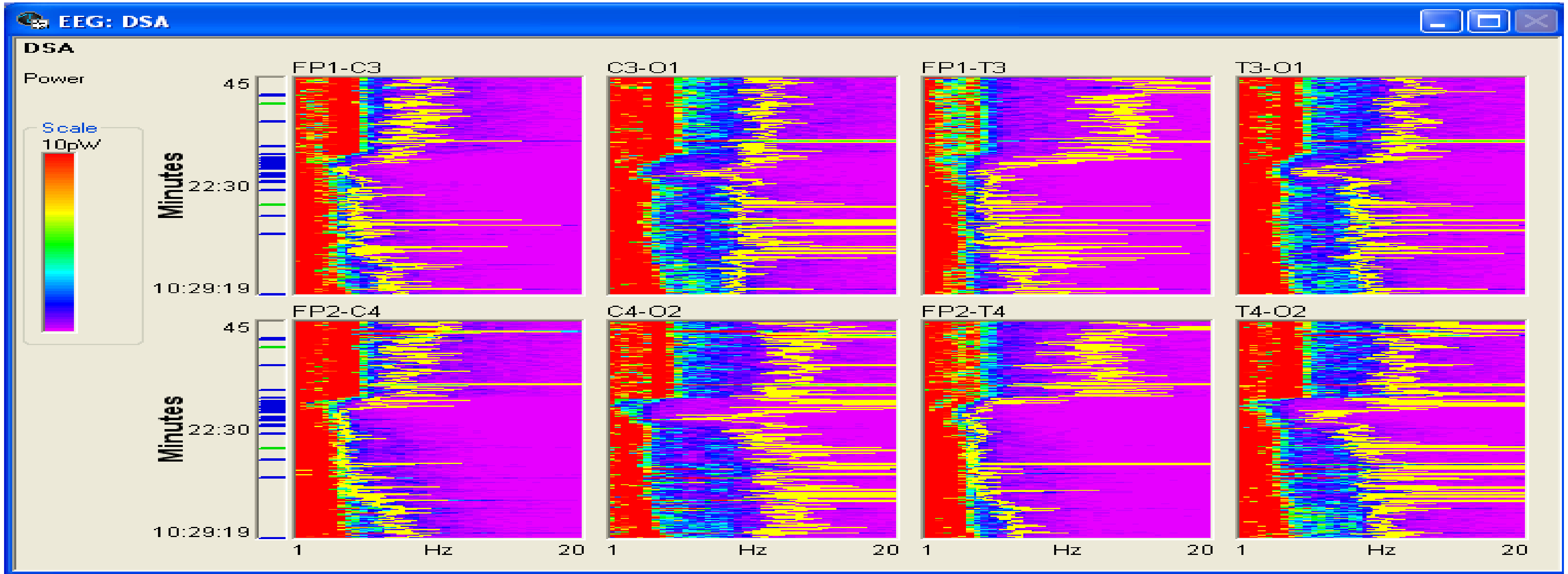
Clamp for Shunt Release: Sevo. = 1.25 mac / N_2O=50%



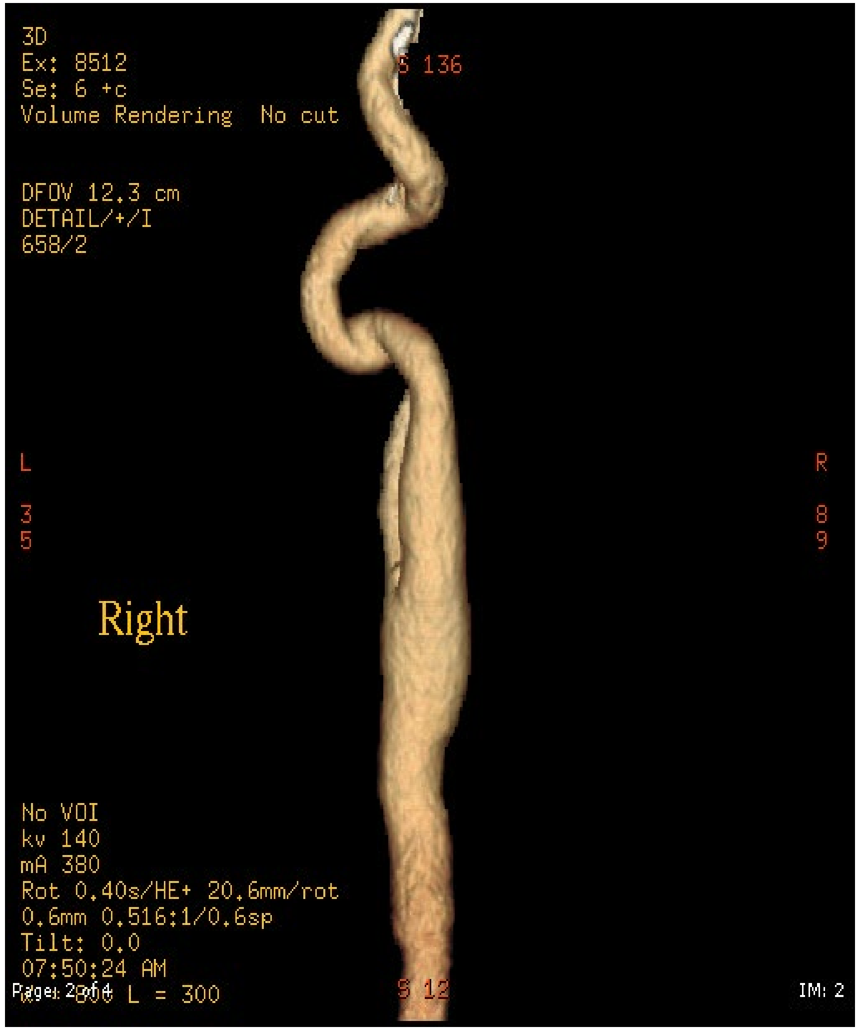
Clamp off: Sevo. = 1.25 mac / N_2O=50%



Closing: MAP=91



Left still abnormal

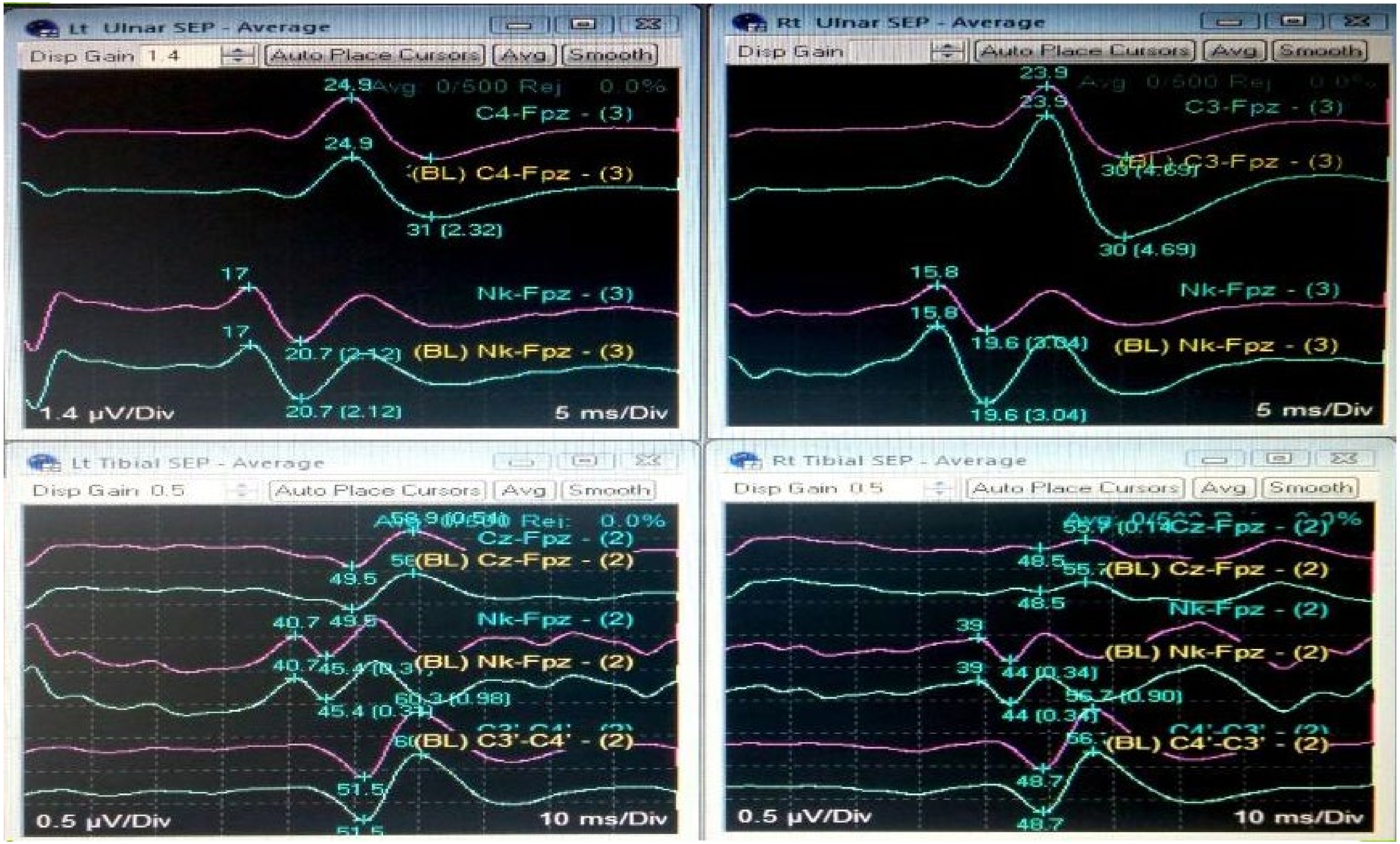


Right Repaired

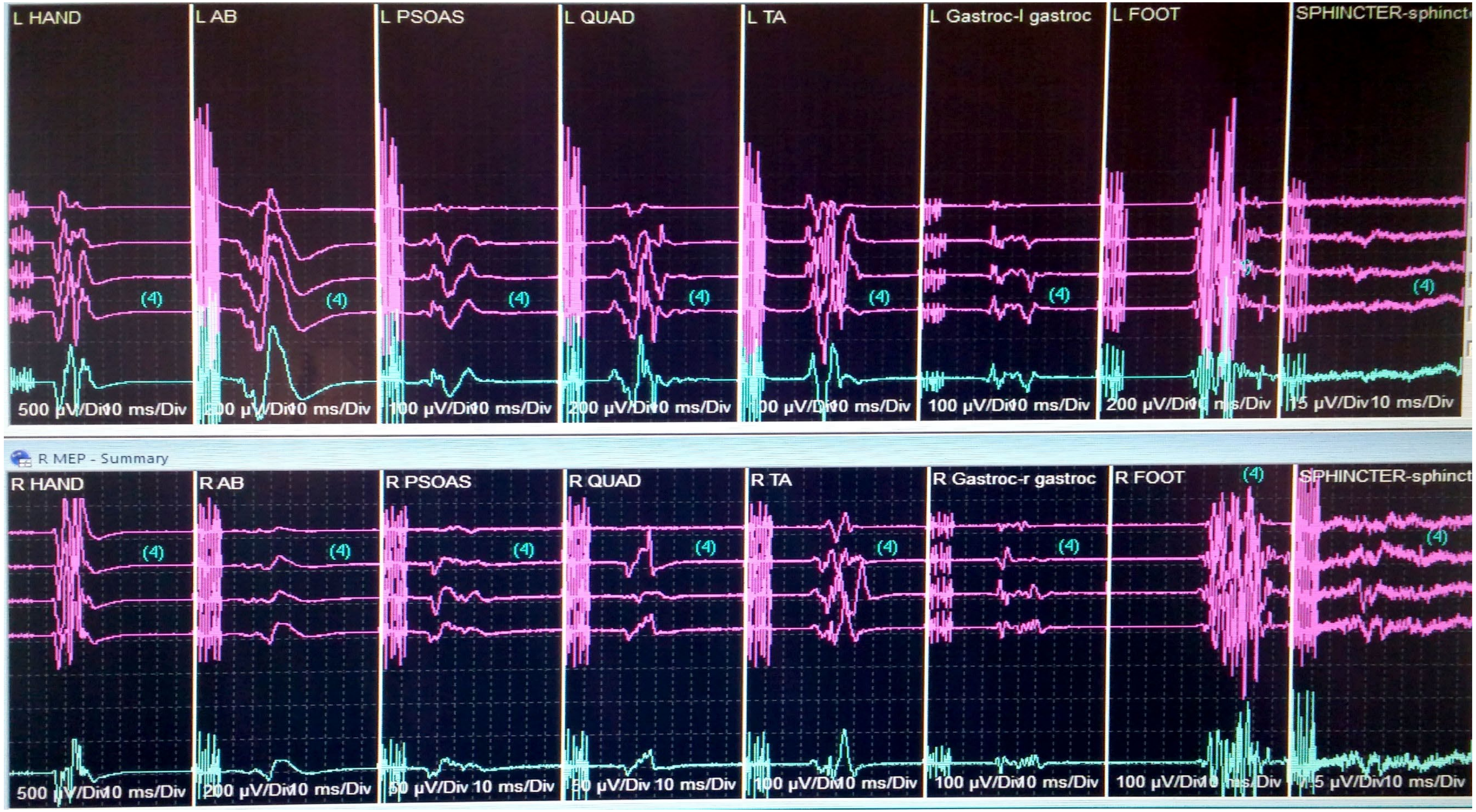
Example 2: Spinal Fusion

- 66 year old female. Height: 5'10 Weight: 190 lbs. Procedure: Fusion T10-Sacrum.
- Pt has metal implants in thoracic and lumbar spine from 10 previous back procedures. Pt had lower back and leg pain with numbness. Symptoms worse on left side.

SSEP Baselines

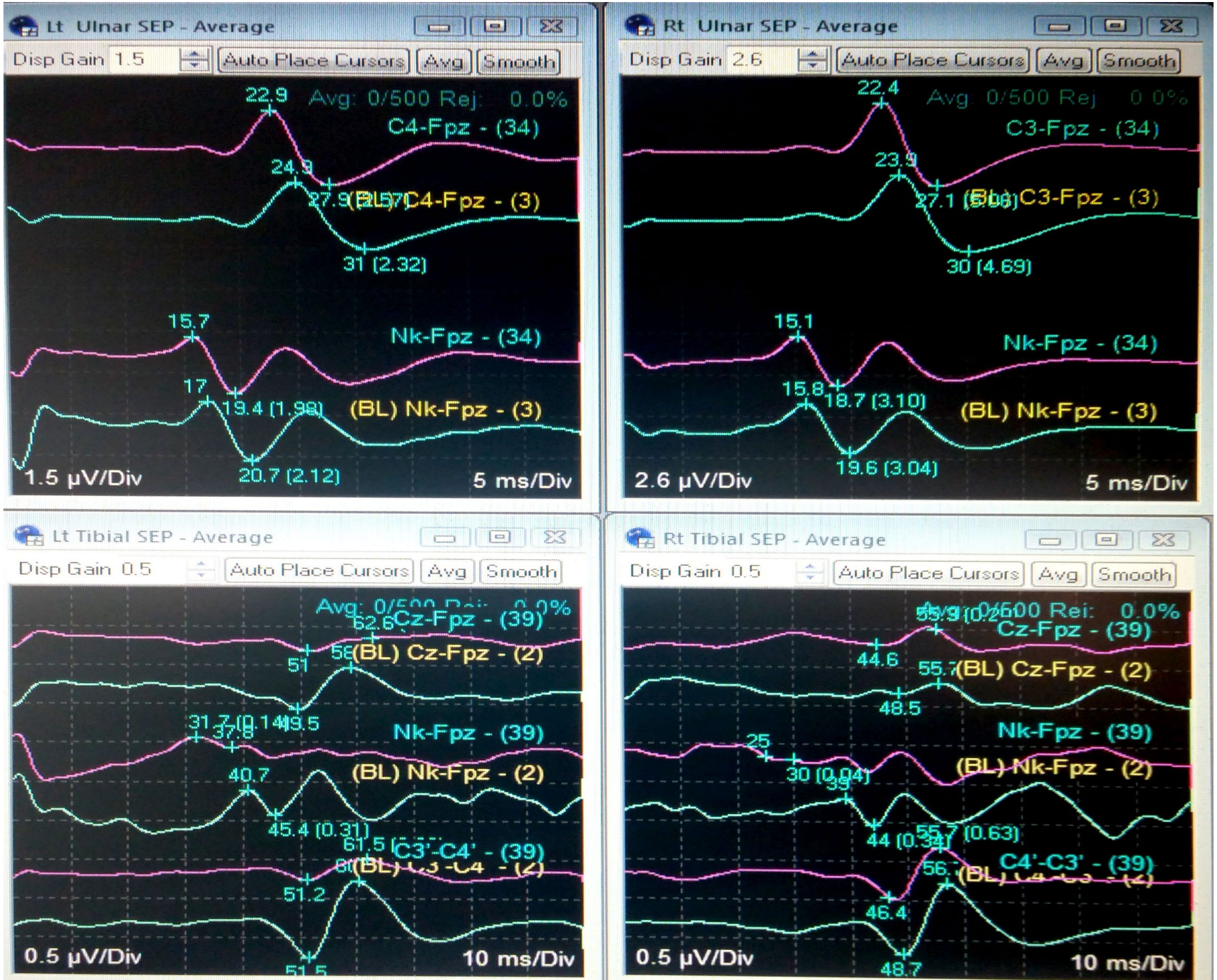


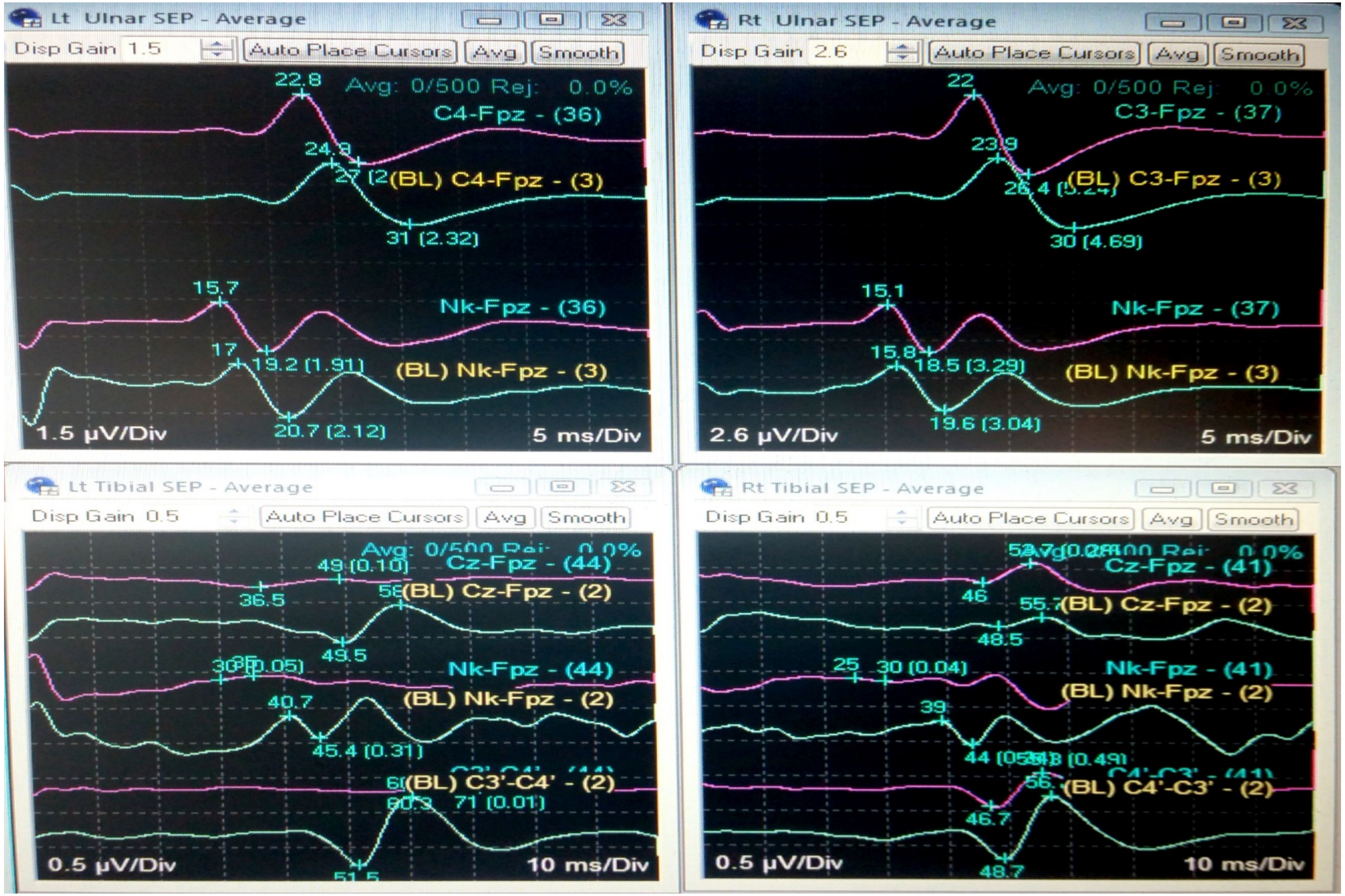
MEP Baselines



Surgical course

- BP 99/53(MAP 69), 0.8% Sevo, Prop 150 mcg/k/m
- Incision/Exposure
- EMG became valid at 10:40 am.
- 11:17 Surgeons began removing previous hardware and replacing as they went. (BP122/77(MAP 94) Prop 150 mcg/k/m, Remi 0.25 mcg/k/m, Sevo 0.75%
- 11:52 am Left PTN SEP Cortical and Transcortical signals began to decrease in amplitude.


Lt Ulnar SEP - Average
Disp Gain 1.5
Auto Place Cursors
Avg
Smooth
Avg: 0/500 Rej: 0.0%
22.9
C4-Fpz - (34)
24.9
27.9
(BL) C4-Fpz - (3)
31 (2.32)
15.7
Nk-Fpz - (34)
17
19.4 (1.98)
(BL) Nk-Fpz - (3)
20.7 (2.12)
1.5 μV/Div
5 ms/Div
Rt Ulnar SEP - Average
Disp Gain 2.6
Auto Place Cursors
Avg
Smooth
Avg: 0/500 Rej: 0.0%
22.4
C3-Fpz - (34)
23.9
27.1
(BL) C3-Fpz - (3)
30 (4.69)
15.1
Nk-Fpz - (34)
15.8
18.7 (3.10)
(BL) Nk-Fpz - (3)
19.6 (3.04)
2.6 μV/Div
5 ms/Div
Lt Tibial SEP - Average
Disp Gain 0.5
Auto Place Cursors
Avg
Smooth
Cz-Fpz - (39)
62.6
51
(BL) Cz-Fpz - (2)
49.5
31.7
37.8
Nk-Fpz - (39)
40.7
(BL) Nk-Fpz - (2)
45.4 (0.31)
61.5
C3'-C4' - (39)
51.2
0.5 μV/Div
10 ms/Div
Rt Tibial SEP - Average
Disp Gain 0.5
Auto Place Cursors
Avg
Smooth
Avg: 0/500 Rej: 0.0%
55.9
Cz-Fpz - (39)
44.6
55.7
(BL) Cz-Fpz - (2)
48.5
Nk-Fpz - (39)
25
30 (0.04)
(BL) Nk-Fpz - (2)
44 (0.34)
55.7 (0.63)
C4'-C3' - (39)
56.7
46.4
48.7
0.5 μV/Div
10 ms/Div



- After determining this was not a technical issue Surgeon was informed of this change and he asked that an MEP be ran.

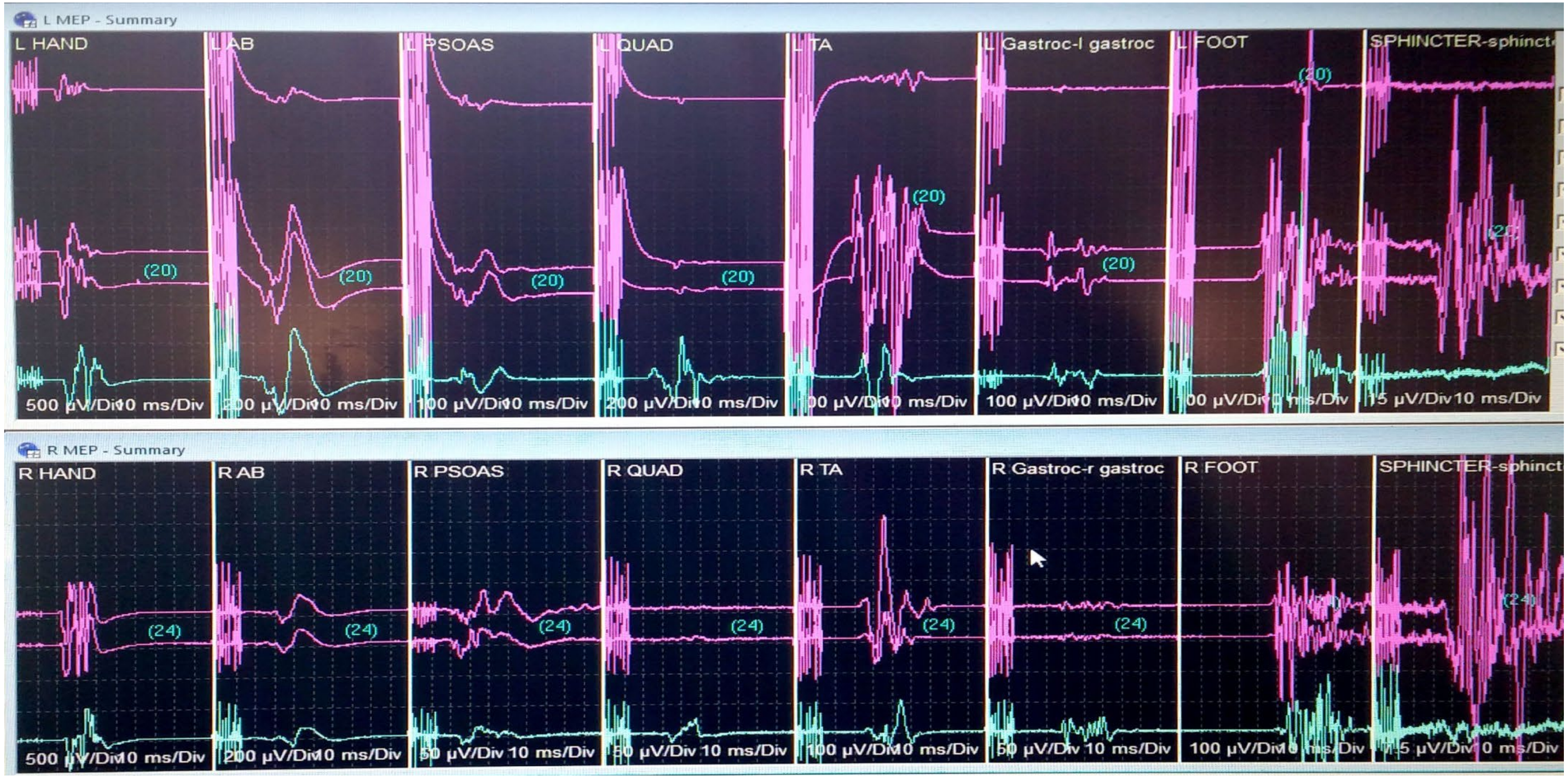
Gastrocnemius and Abductor Hallucis responses absent

Possible Reasons?

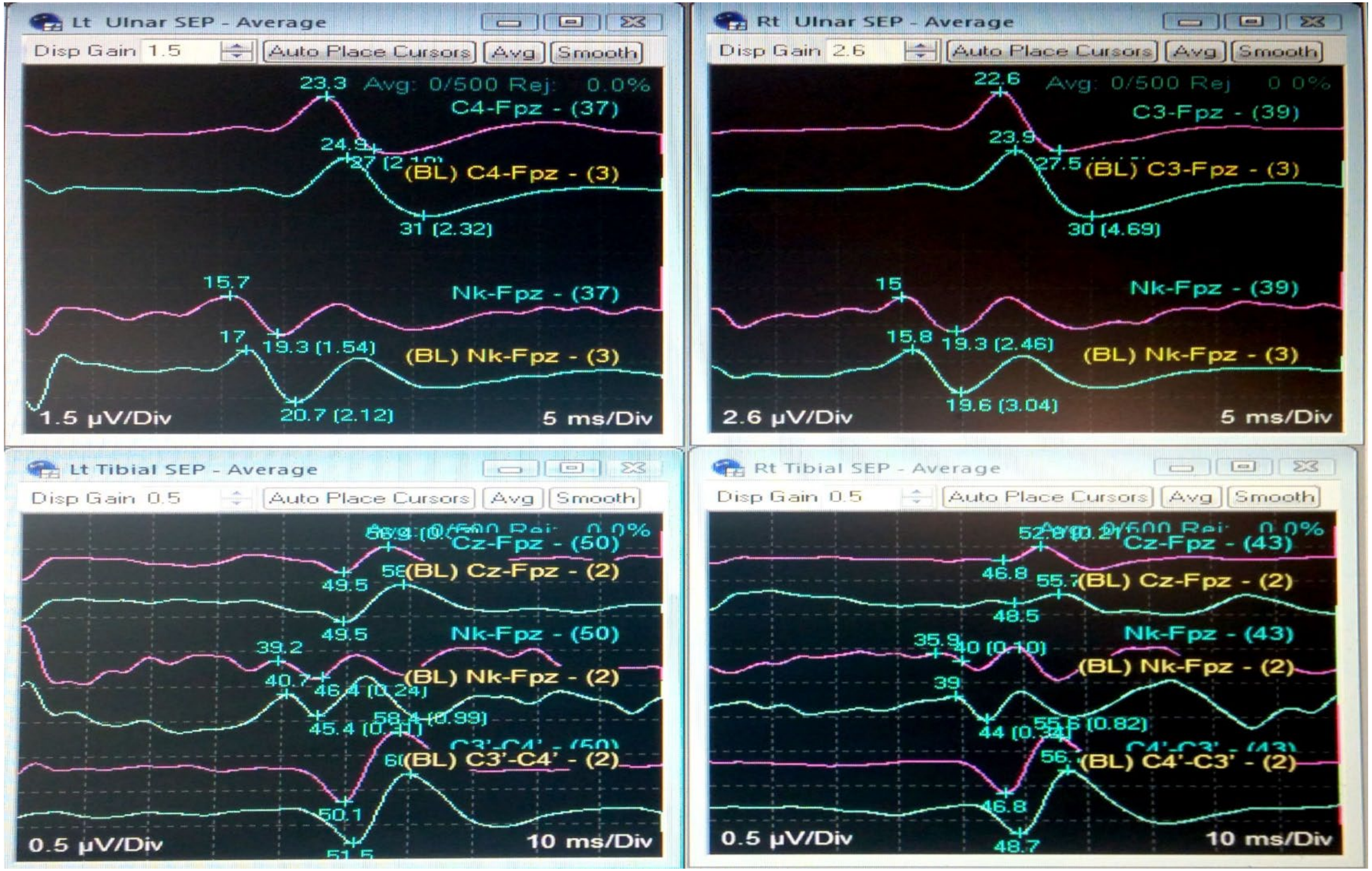
- Technical? (All stimulating and recording electrodes checked and were making good contact)
- Anesthesia? (Anesthesia had remained pretty stable up to this point in procedure MAP= 91 Propofol 150 µ/k/m, Remi= 0.25 µ/k/m, Sevo 0.7%)
- Increased Stimulation on MEPs from 350 to 800 to see if we could get Gastroc and Foot at high intensity. Still unable to acquire those signals.

Problem in Surgical Field

- After ruling out technical issues and anesthesia, we were confident that changes were the result of something that occurred in surgical field.
- Surgeon did not agree and wanted to do a Wake-Up Test.(Thought issue was technical)
- Assistant surgeon convinced him to explore the surgical field before doing so. (12:38 PM)



- After exploring area (12:54 PM) surgeon asked us to update MEPs and Gastroc and AH responses had returned bilaterally.



- By 1:01 PM the Left Tibial SSEP had returned to baseline strength, surgeon was informed.

Discussion

- The Surgeon explained that during hardware removal one of the facet joints became lodged in the canal. He stated that it was compressing 30% of the cord. Also stated that this was not easily visible and would not have been caught had the signals not changed.

Conclusion

- IONM has evolved and improved over time, with Anesthesia teams being essential in this development
- IONM interrogates the sensory and motor pathways of the nervous system during surgeries where clinical evaluation is not possible
- Detection of significant changes in IONM data can alert the surgical or anesthesia teams of the need for an intervention
- Communication and teamwork among all members is critical to providing the patient with the best care

. . .Thank you. . .

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