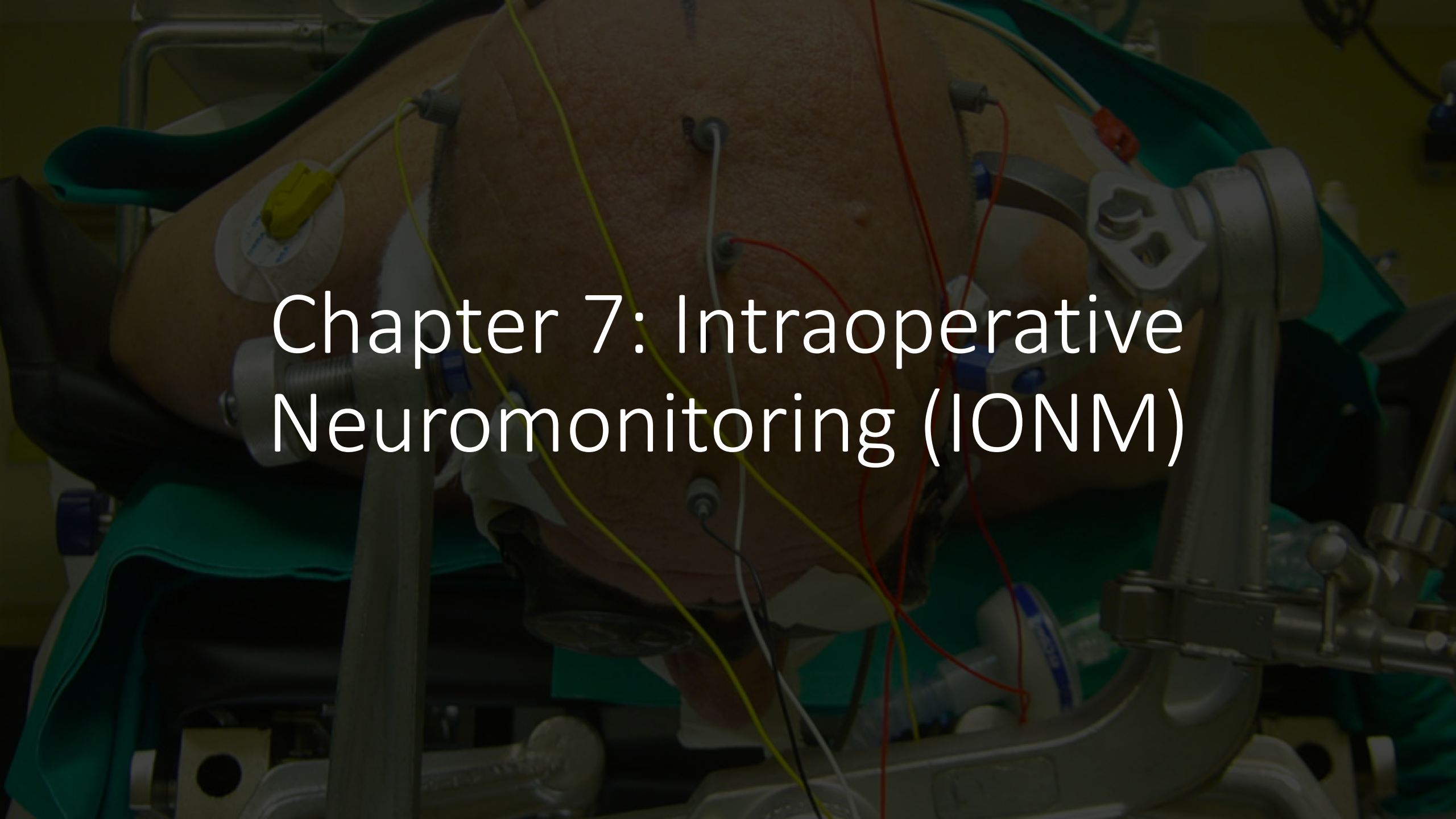


Chapter 7: Intraoperative Neuromonitoring (IONM)

Introduction

IONM is now an integral part of many surgical procedures

Minimize neurological damage during surgery

Identification of important neural structures

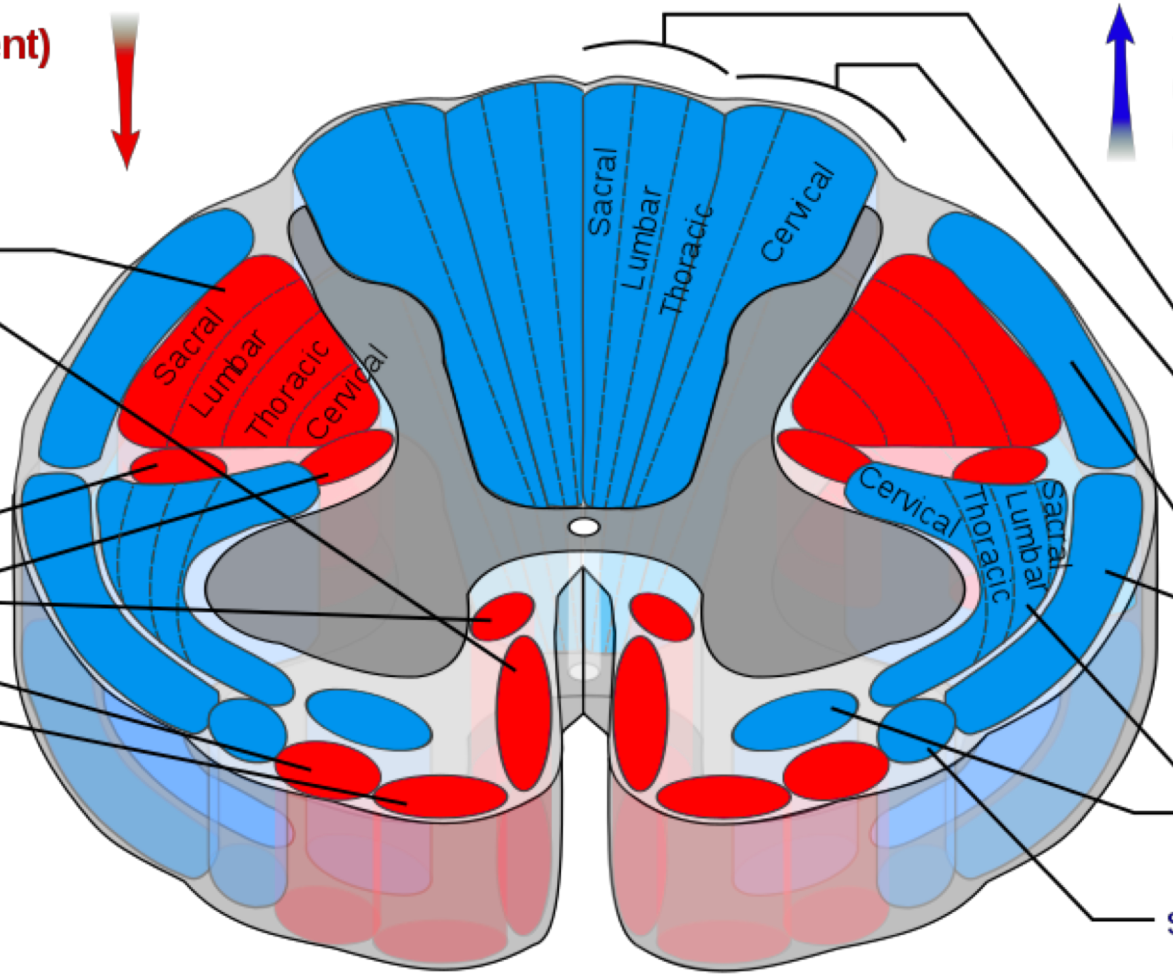
Motor and descending (efferent) pathways (red)

Pyramidal tracts

- Lateral corticospinal tract
- Anterior corticospinal tract

Extrapyramidal Tracts

- Rubrospinal tract
- Reticulospinal tracts
- Olivospinal tract
- Vestibulospinal tract



Sensory and ascending (afferent) pathways (blue)

Dorsal Column Medial Lemniscus System

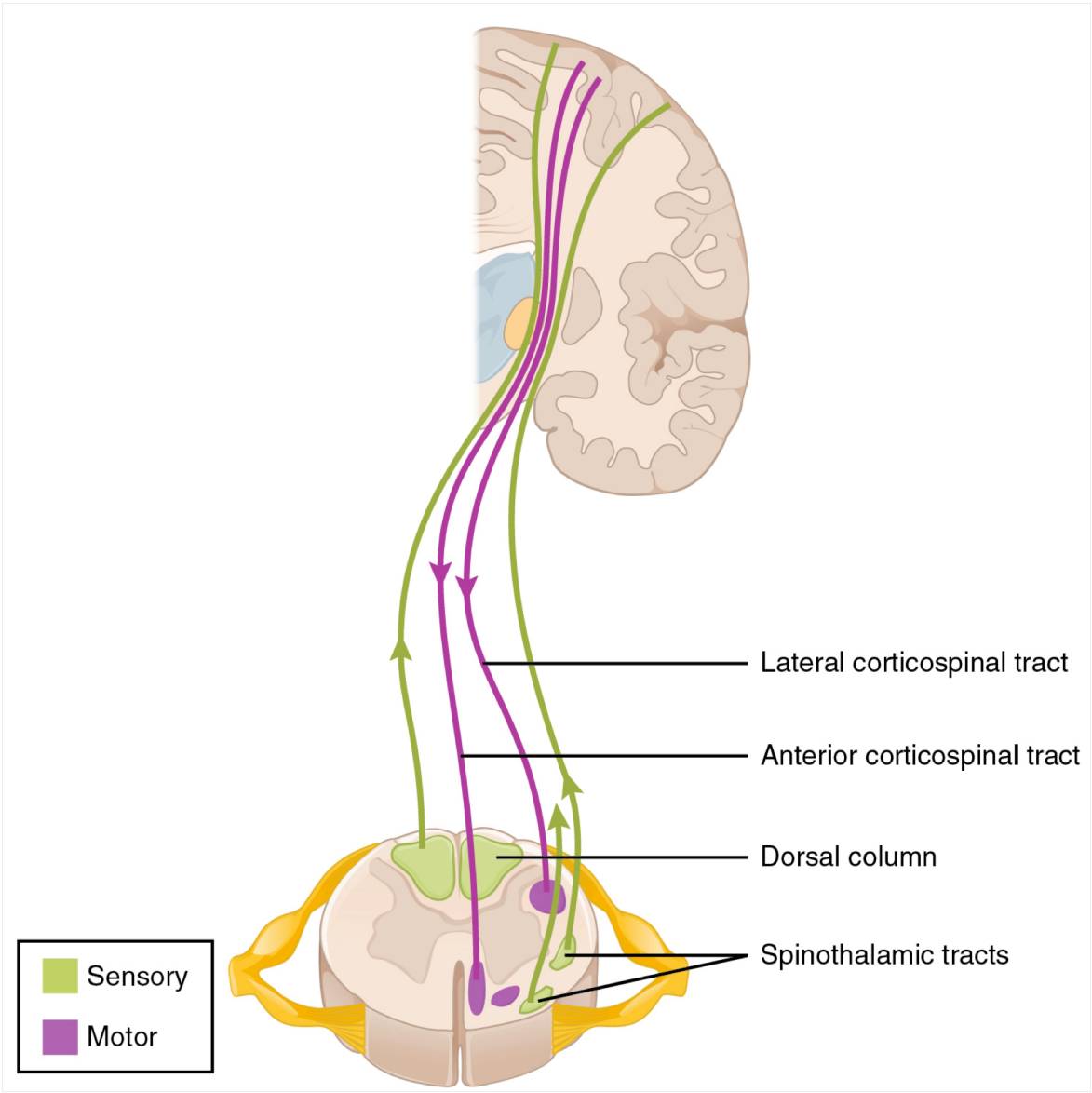
- Gracile fasciculus
- Cuneate fasciculus

Spinocerebellar Tracts

- Posterior spinocerebellar tract
- Anterior spinocerebellar tract

Anterolateral System

- Lateral spinothalamic tract
- Anterior spinothalamic tract
- Spino-olivary fibers


Lateral corticospinal tract
Anterior corticospinal tract
Dorsal column
Spinothalamic tracts
Sensory
Motor

Intraoperative Neuromonitoring (IOMN)

Patient’s latencies preoperatively serve as baseline

Evoked Responses

- SSEP
- MEP
- BAEP
- VEP

Spontaneous

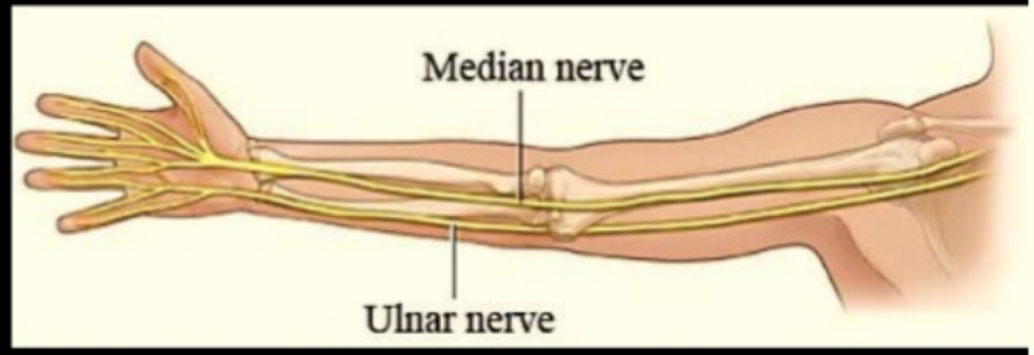
- EMG
- EEG

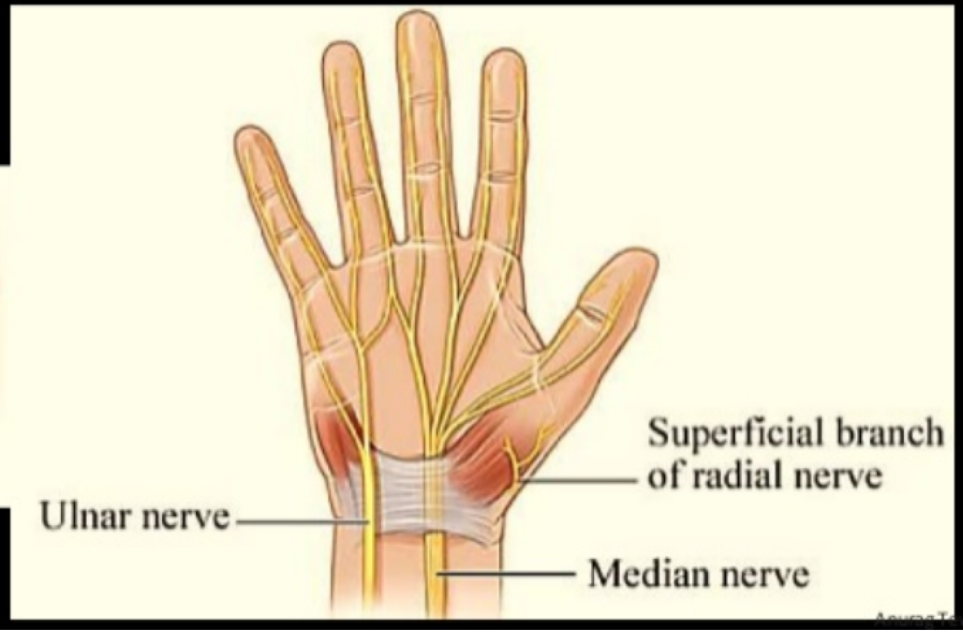
Somatosensory Potentials (SSEP)

- Presynaptic and postsynaptic responses recorded over the limbs, spine, and scalp following stimulation of peripheral nerves, trunks or cutaneous nerves

How are Upper SSEPs Generated?

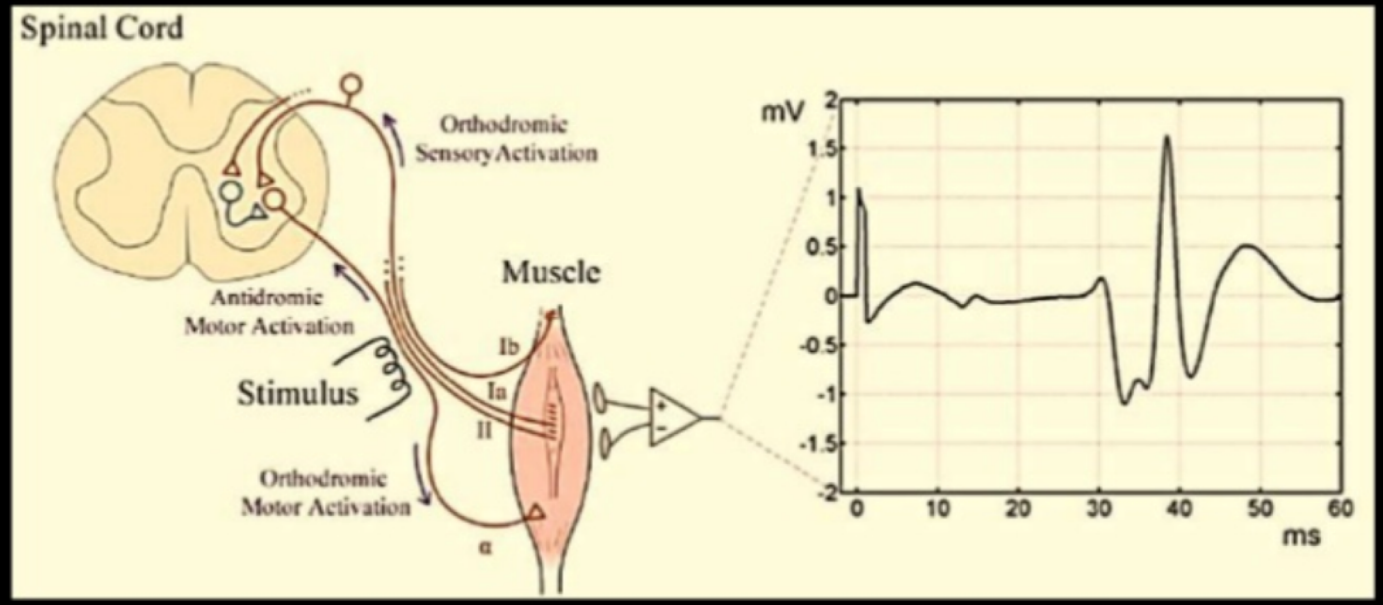
- SSEPs are elicited by stimulation of somatic sensory nerves
- In IONM the most common stimulus used is an electrical pulse
- It is delivered to a peripheral nerve which is a large mixed motor and sensory nerves such as
  - **Median nerve**
  - **Ulnar nerve**





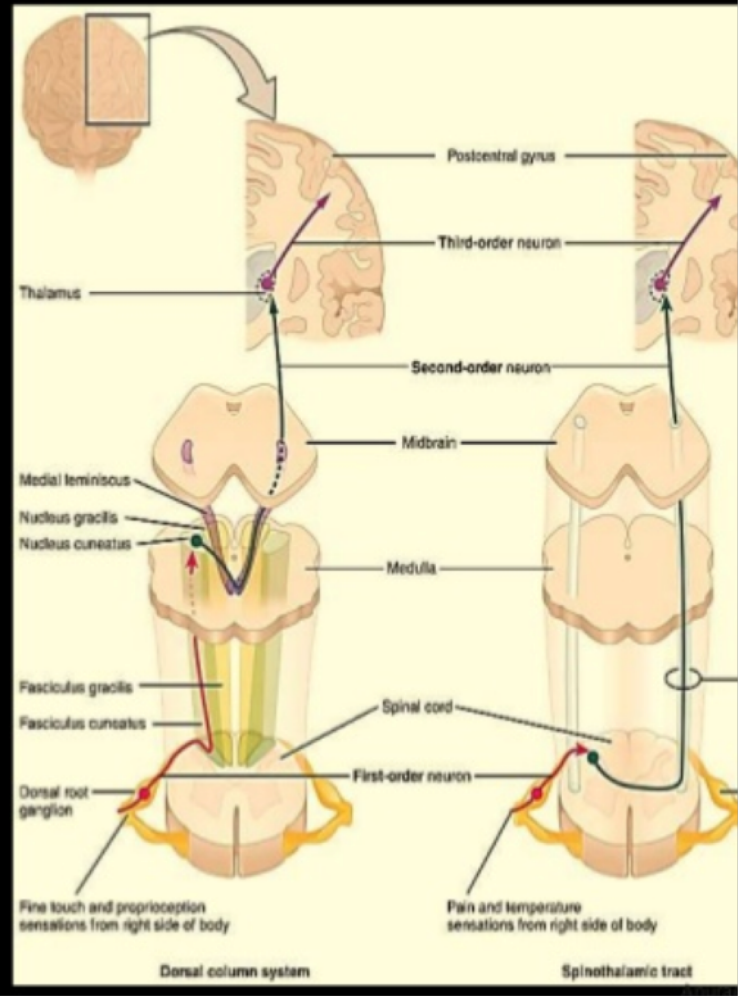
How are Upper SSEPs Generated?

- The peripheral nerve stimulation activates
  - The large diameter fast conducting **Ia** muscle afferent
  - **Group II** cutaneous nerve fibers



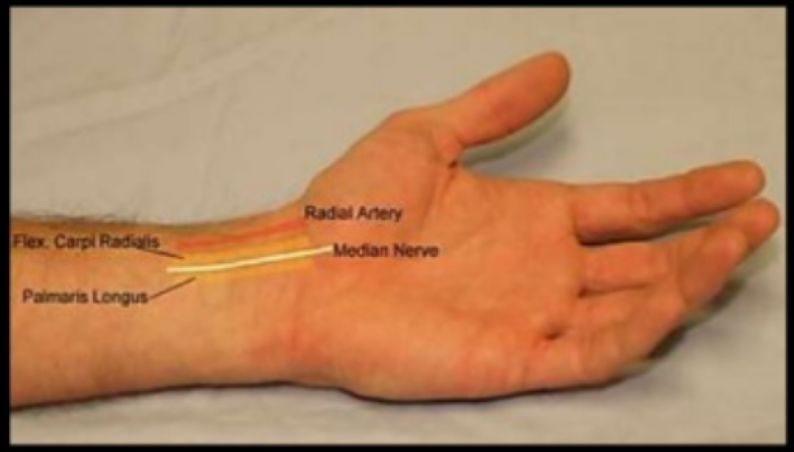
How are Upper SSEPs Generated?

- The incoming volley of neural activity from stimulation represents primarily the pathway of proprioception and vibration that ascends the ipsilateral dorsal column synapsing in the **dorsal column nuclei, nucleus cuneatus** (**first order fibers**)
- It then decussates near the **cervico-medullary junction** ascending via the **contralateral medial lemniscus** (**second order fibers**)
- A second synapse occurs in the ventro-posterolateral nucleus of the thalamus
- The **third order fibers** from the thalamus project to the **frontoparietal sensory motor cortex**



Obtaining Upper SSEP

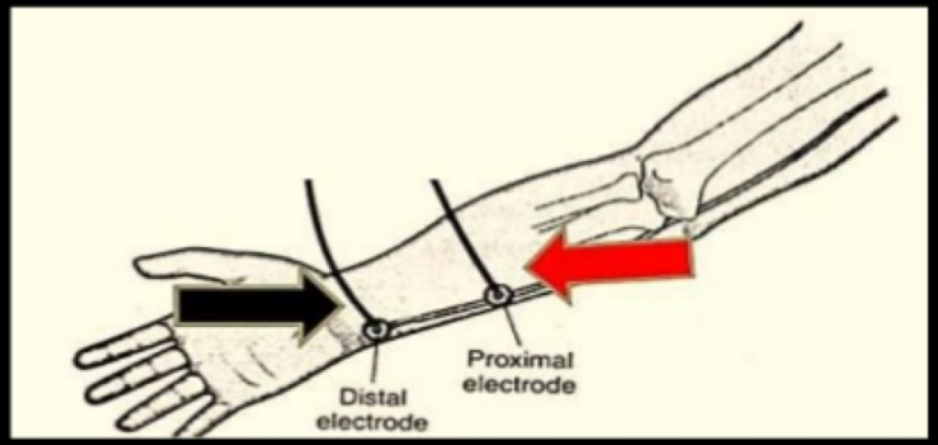
- **Median Nerve Stimulation**
  - 2 cm from wrist crease
  - In between the tendons of **Palmaris Longus** and **Flexor Carpi Radialis**

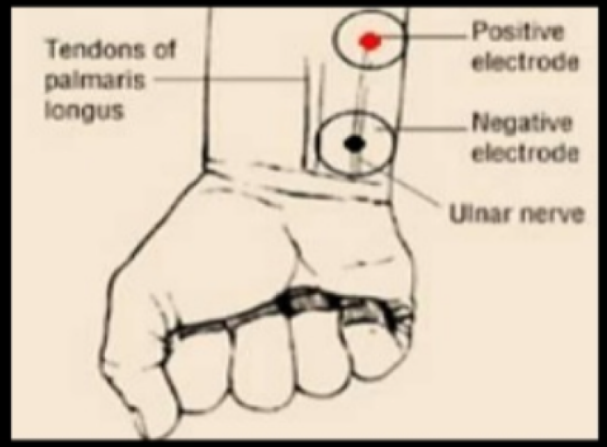


- Stimulation should produce a clearly visible muscle twitch causing **Abduction Of The Thumb**

Obtaining Upper SSEP

- **Ulnar Nerve Stimulation**
  - 2 cm from wrist crease
  - In line with the smallest digit



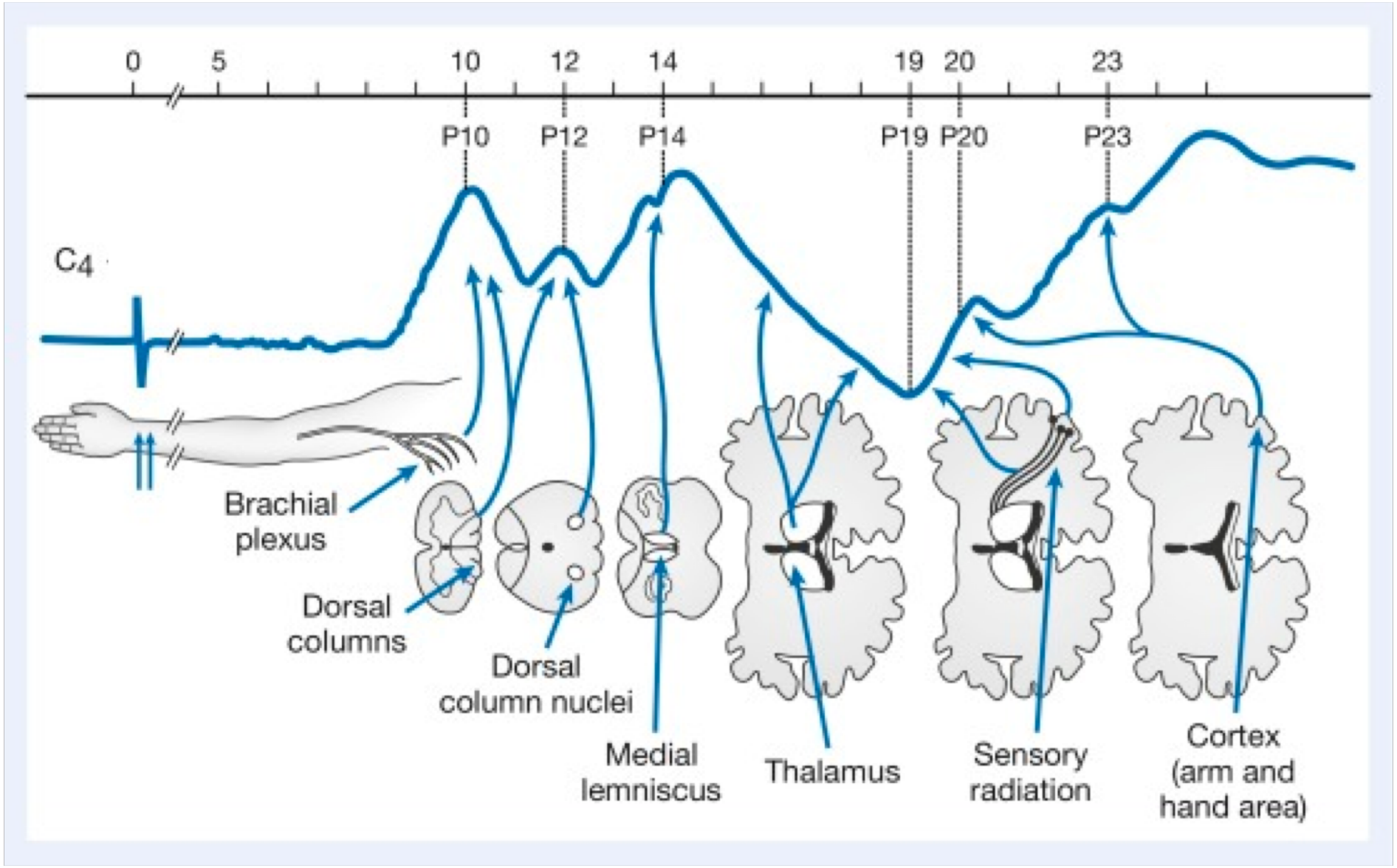


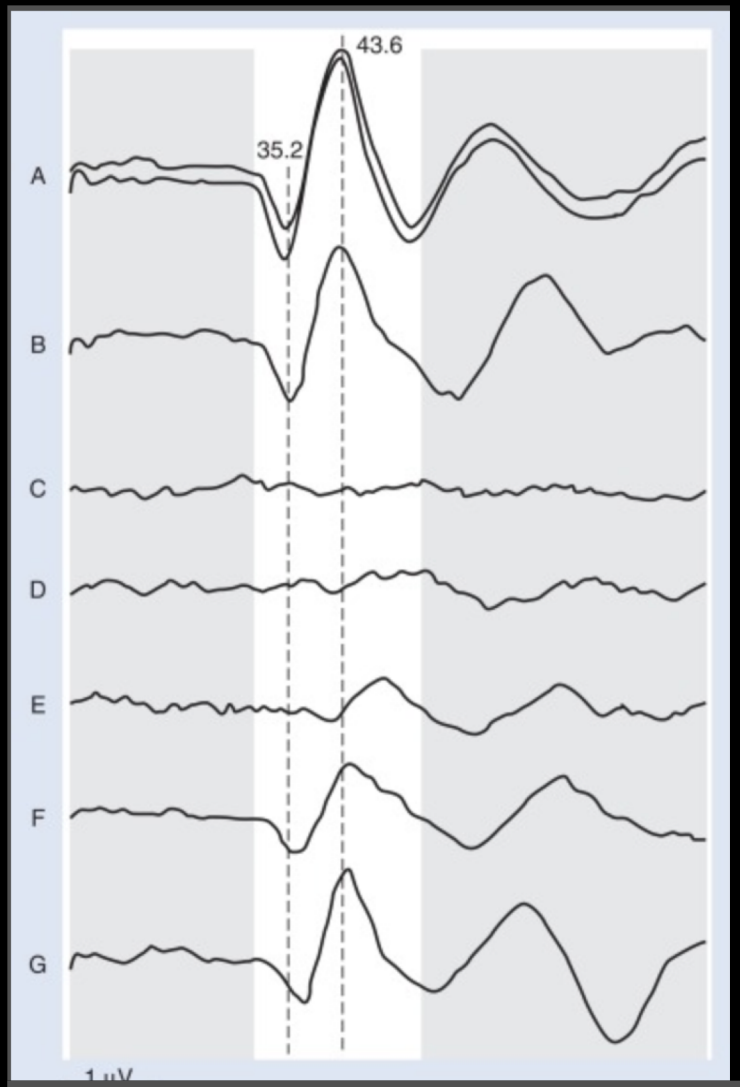
- **Stimulation should produce a FLEXION of ulnar half of digits, or the 4th and 5th digits**

- General Principles of SSEP
  - Large diameter fibers have highest contribution to potentials
  - Lesions of the posterior column have biggest impact on SSEPs
  - Highest amplitude SSEPs are obtained after stimulation of ulnar and median nerves

- SSEPs - subject variables
  - Age
  - Height
  - Limb temperature
  - Neuropathy
  - Body habitus
  - Depth of anesthesia

- SSEP – limitation and averaging
  - SSEP amplitude is low compared to noise of motor activity, movement artifact, ECG, EEG, and electromagnetic activity in the environment
  - Averaging summates activity that is time locked to the stimulus trigger while subtracting background noise
  - Most artifacts can be eliminated by averages rejecting sweeps that contain waveforms exceeding fixed maximal amplitudes
  - FIGURE OF EEG WITH EVOKED POTENTIAL AND NO AVERAGING WITH n4 n16 n64 and they can see how the thing emerges


0
5
10
12
14
19
20
23
P10
P12
P14
P19
P20
P23
C4
Brachial plexus
Dorsal columns
Dorsal column nuclei
Medial lemniscus
Thalamus
Sensory radiation
Cortex (arm and hand area)

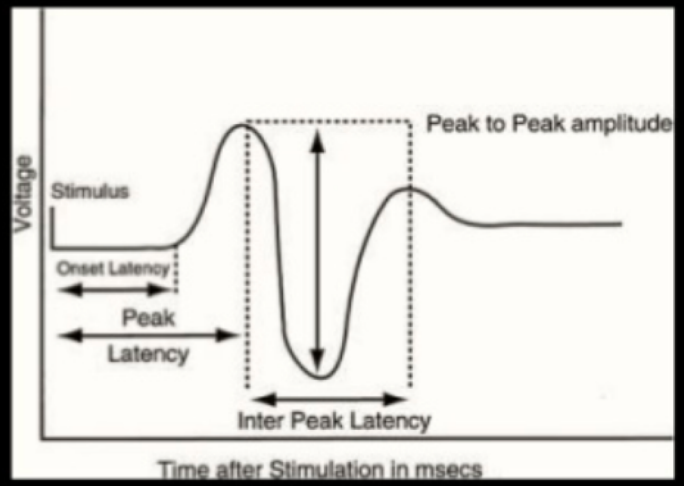


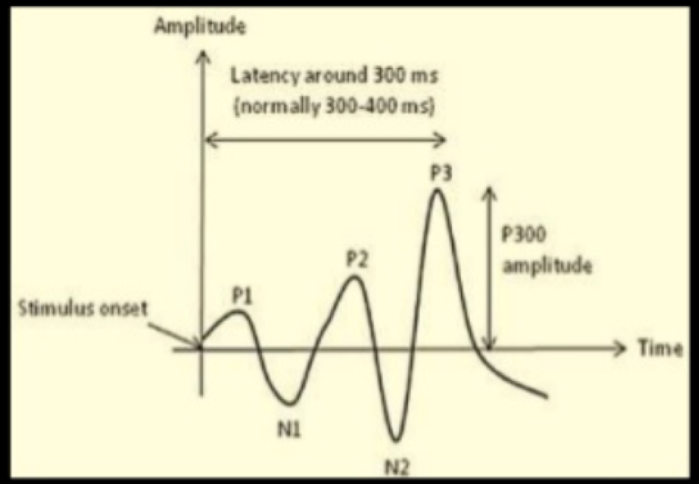
Example of somatosensory evoked potential monitoring for a patient undergoing surgery. Baseline recordings the afternoon prior to operation were normal **(A)** . **B** shows recordings after the induction of anesthesia. Responses were abolished after passing sublaminar wires around the laminae **(C)** . The wake-up test showed inability to move the legs **(D)** . After 15 minutes, the poorly defined potentials reappeared **(E)** . After closure of the wound, evoked potentials showed a little increased latency **(F)** , with normal overall waveform **(G)** .

Upper SSEPs Waveform

Nomenclature

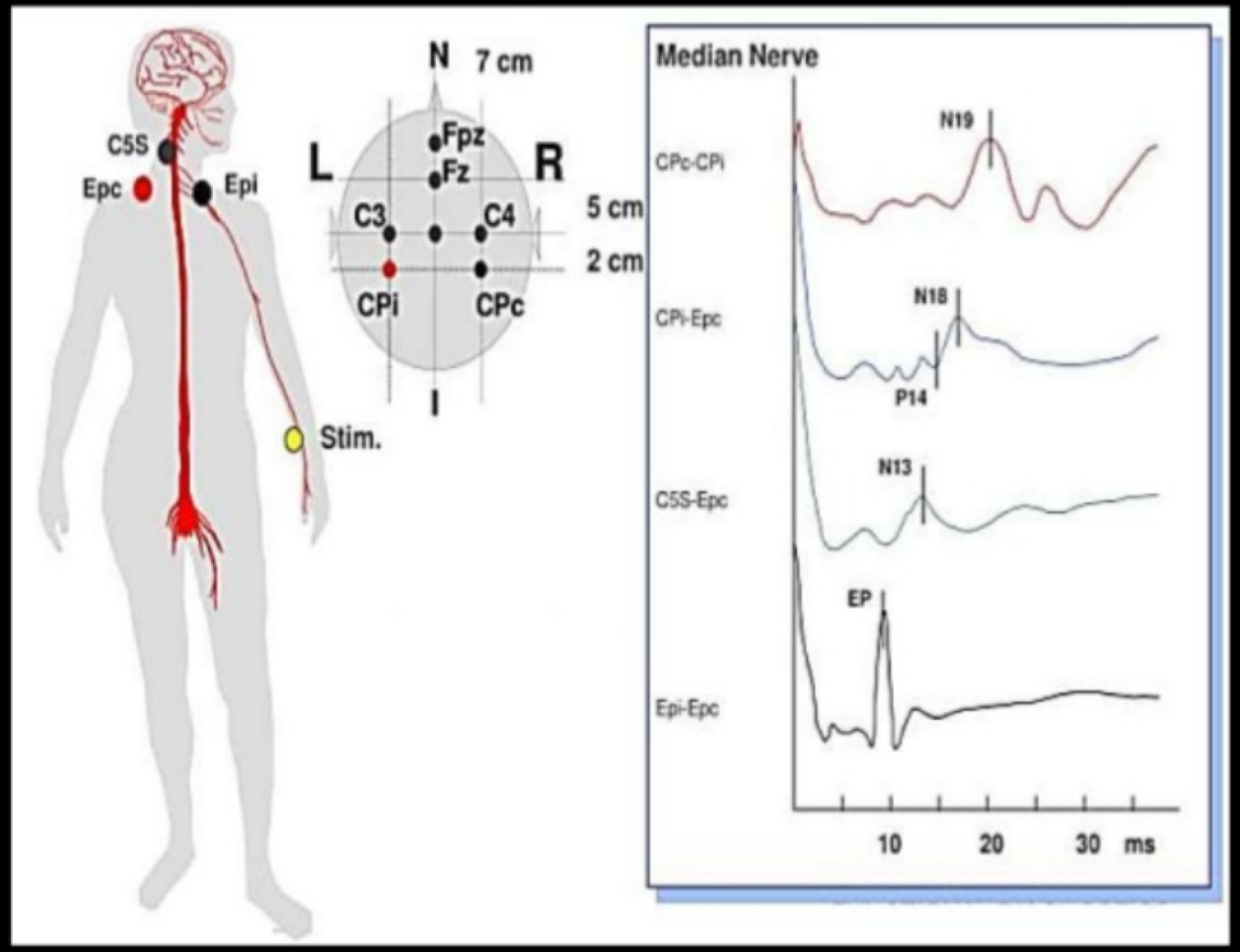
- N = Negative
  - Peak
- P = Positive
  - Valley
- Number represents Latency
- Amplitude from peak to valley
- Time of slope is the duration



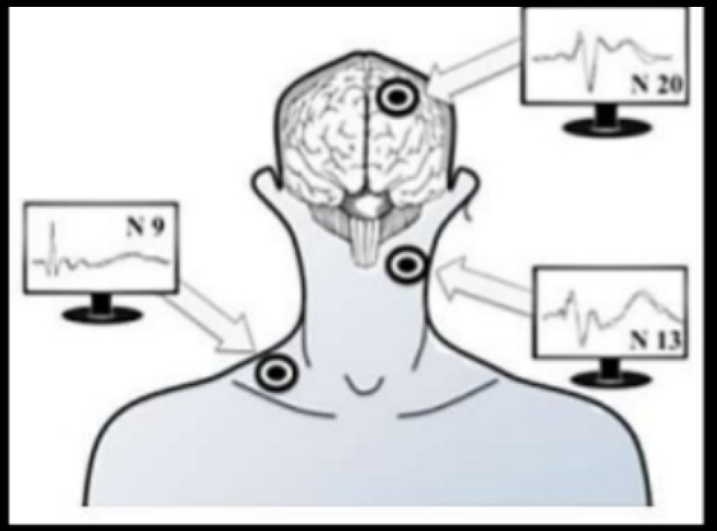


Minimal Montage for Upper SSEP

- Montage
  - **Channel I: Epi - Epc**
  - **Channel 2: CSp5-Reference**
  - **Channel 3: CPi-Reference**
  - **Channel 4: CPc-CPi**



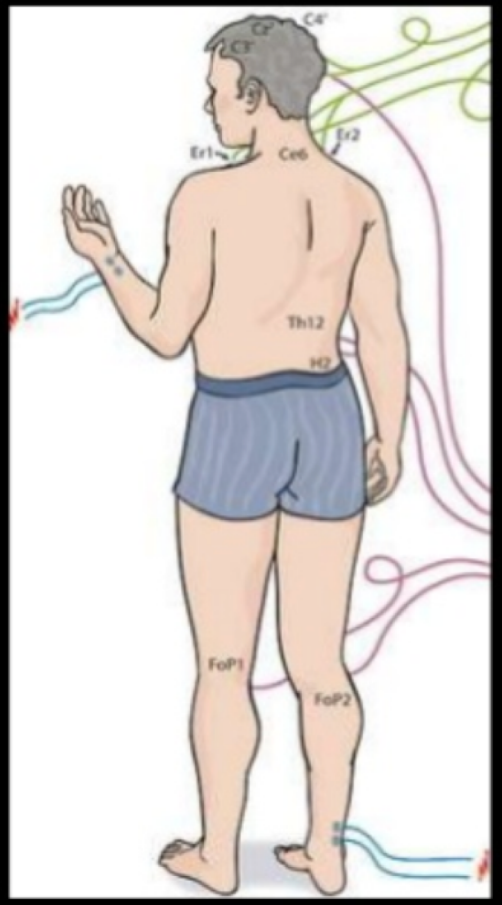
Electrode Placement



- Erb's point on each side (EP)
- Over the second or fifth cervical spine process (CSp2 or CSp5)
- Scalp over the contralateral cortex (CPc) and ipsilateral cortex (CPi)
- Non-cephalic electrode (Ref)

Upper SSEPs Recording Parameters

- **Pulse Width** = 100-300microseconds
- **Stimulation Intensity** = 30-40 mA
  - Till EP amplitude no longer increases in size
  - Twice motor threshold (around 6-10mA)
- **Impedance** < 5 Kilo Ohms
  - for both Stimulating and Recording electrodes
- **Monophasic rectangular pulses**



Neural Generator for Median Nerve SSEP

Label	Generator	Montage Used	Alternate Label
N9	Brachial Plexus	EPi – EPc	Erb's
N13a	Dorsal Horn Interneuron	CSp6 – Fpz	Cervical/Subcortical
N13b	Dorsal Column	CSp2 – Fpz	Cervical/Subcortical
P13	Spino-medullary Junction	CSp – Fpz, Mast – Fpz	Cervical/Subcortical
P14	Lemniscal pathway/Cuneatus Nuclei	CSp – Fpz, Mast – Fpz	Cervical/Subcortical
N19	Primary Sensory Cortex	Cc – Fz, Cc – Ci	N20, Cortical

Cc: C3' or C4', which ever is contralateral Ci: ipsilateral C3' or C4', which ever is ipsilateral

Localization of Neural Functions based on pattern of SSEP changes

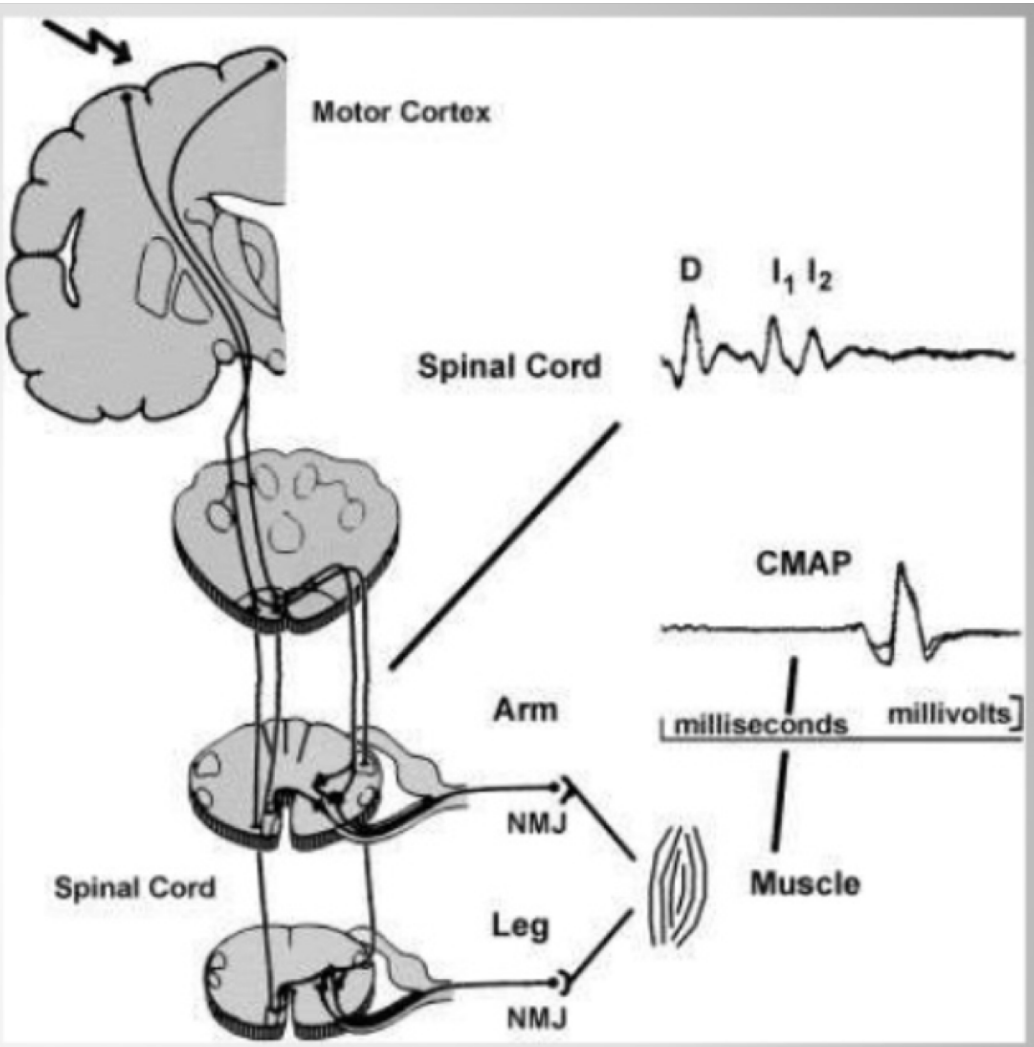
Locus of Neural Insult	Associated Pattern of SSEP Degradation
Spinal Cord Dysfunction	Loss of subcortical and cortical signals, Erb's point intact
Limb Malposition	Unilateral loss of Erb's point, subcortical and cortical signals
Cerebral Ischemia	Unilateral cortical loss, intact subcortical signal
Anesthetic effect	Global cortical loss, intact subcortical signals

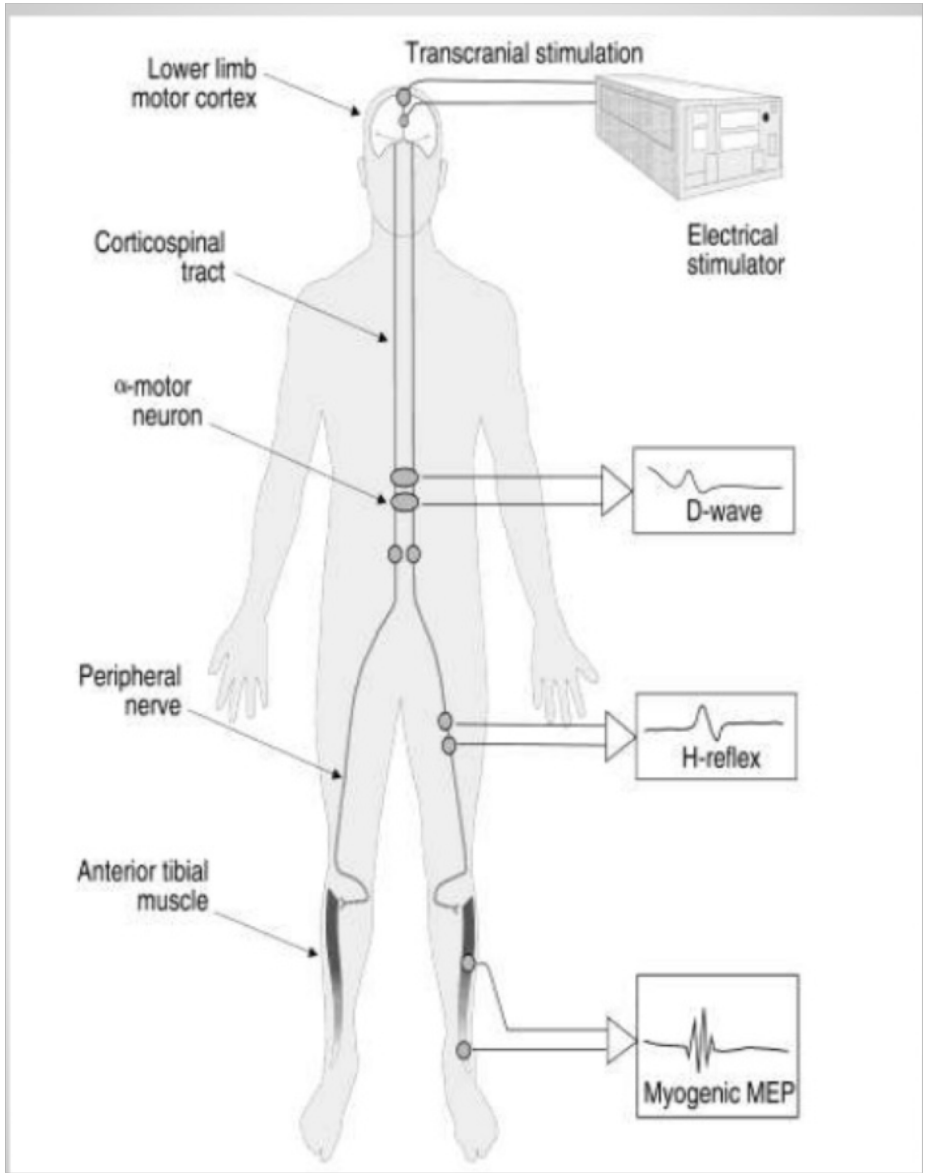
Motor Evoked Potentials (MEP)

- MEPs are recorded from muscles following direct stimulation of exposed motor cortex, or transcranial stimulation of motor cortex, either magnetic or electrical

Transcranial electrical MEP monitoring

- Stimulating electrodes placed on scalp overlying motor cortex.
- Application of electrical current produces MEP.
- Stimulus propagated through descending motor pathways.




Transcranial stimulation
Lower limb motor cortex
Electrical stimulator
Corticospinal tract
α-motor neuron
D-wave
Peripheral nerve
H-reflex
Anterior tibial muscle
Myogenic MEP

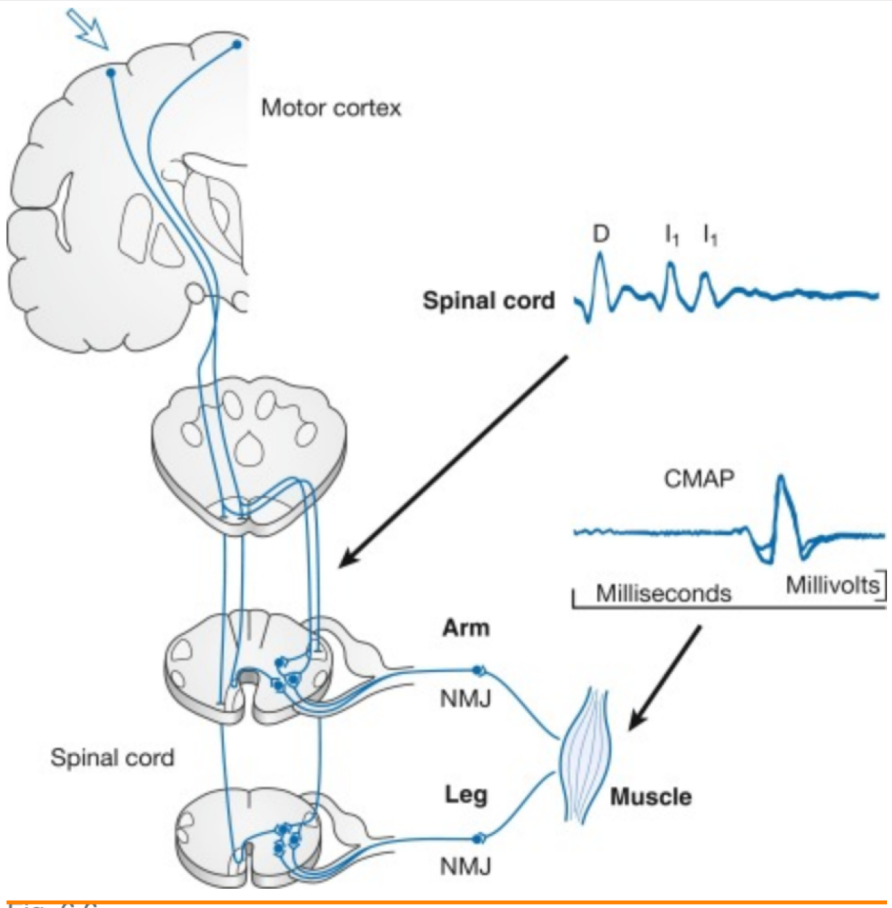


Fig. 6.6

Motor evoked potentials are produced by stimulation of the motor cortex (arrow). The response can be recorded epidurally over the spinal column as a D wave followed by a series of I waves. The pathway synapses in the anterior horn of the spinal cord and the response travels to the muscle through the neuromuscular junction (NMJ). The response is typically recorded in the muscle as a compound muscle action potential (CMAP).

Once the electrical activity reaches the periphery, intramuscular needle electrodes are used to record muscle contractions, which are called Compound Muscle Action Potentials (CMAPs). These "myogenic" MEPs are complex and polyphasic.

- Muscle MEPs are not averaged.
- Rather, the CMAP is a single recording following stimulus delivery.
- This is a real time measure of motor function, but movement may limit the frequency with which you can test motor function, so MEPs really represent a snapshot of motor function during a very small window of time.

MEP Variables

Amplitude

Measured peak-to-peak in microvolts

Neural transmission altered by low temp, nerve compression, injury

Decreased amplitude can indicate evolving injury

Presence/Absence

Myogenic MEP amplitudes vary, concern is whether or not MEP is present at all

50% decrease in amplitude in baseline is considered significant, alert surgeon

Threshold

Minimum voltage necessary to trigger a CMAP with amplitude > 0 microvolts

If significant increases in voltage are required to generate MEPs (100V) this can indicate evolving injury

Brainstem Auditory Evoked Potentials (BAEP)

- BAEPs are elicited by auditory stimulation and represent activity generated by CN VIII and brainstem
- Useful for posterior fossa surgeries:
  - Vestibular schwannoma
  - Vertebrobasilar aneurysms
  - Vascular malformation repairs
  - Microvascular cranial nerve decompressions
  - Skull based, CPA tumor resections
- Intra-operative BAEP loss or post-operative deafness is due to interruption of blood supply or traumatic transection to the auditory nerve or cochlea

- Latency increases of 1– 1.5 ms or amplitude decrement of 50% require notification of the surgeon

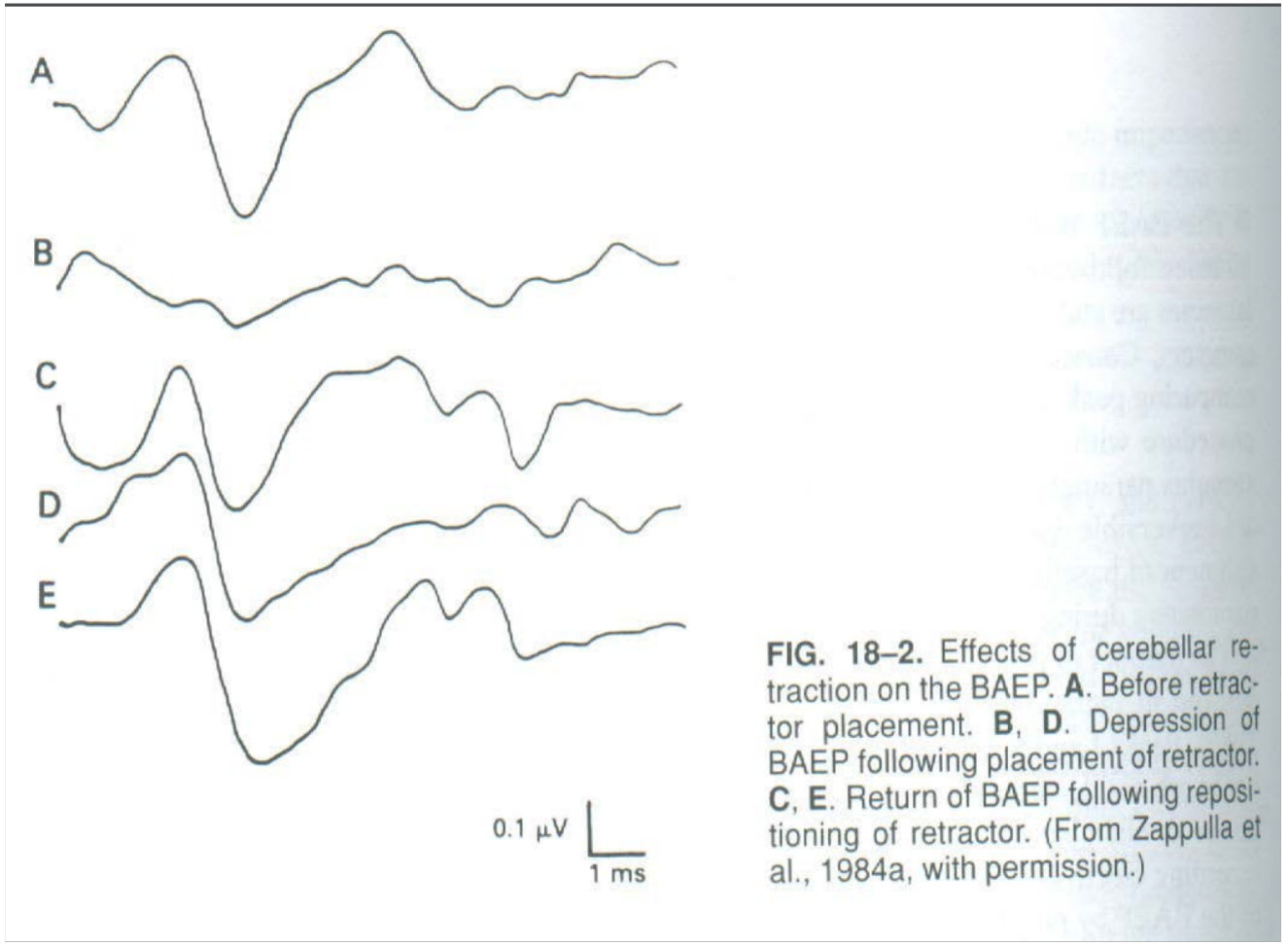


FIG. 18–2. Effects of cerebellar retraction on the BAEP. **A**. Before retractor placement. **B**, **D**. Depression of BAEP following placement of retractor. **C**, **E**. Return of BAEP following repositioning of retractor. (From Zappulla et al., 1984a, with permission.)

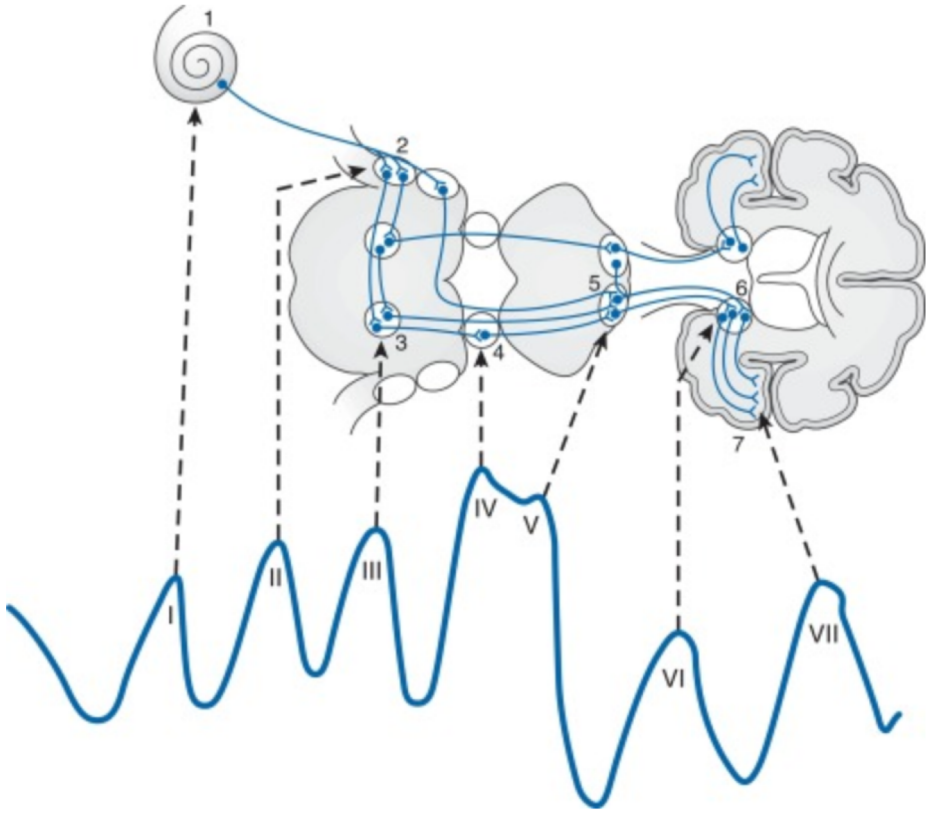


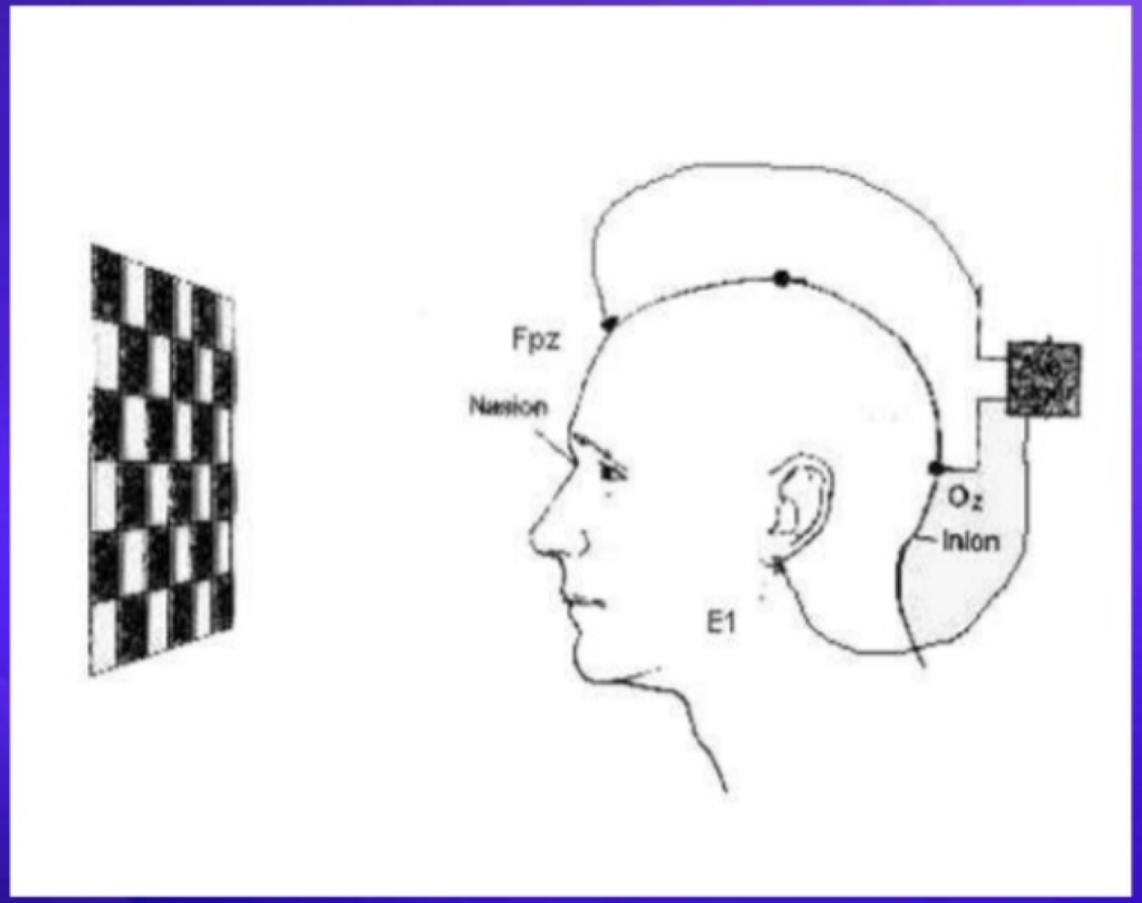
Fig. 6.4

Normal auditory brainstem response tracing and corresponding region of brainstem generating the response peaks (labeled by Roman numerals by convention). **I.** organ of Corti and extracranial cranial nerve VII; **II.** cochlear nucleus; **III.** superior olivary complex; **IV.** lateral lemniscus; **V.** inferior colliculus; **VI.** medial geniculate body; **VII.** auditory radiation.

(From Aravabhumi S, Izzo KL, Bakst BL, et al: Brainstem auditory evoked potentials: Intraoperative monitoring technique in surgery of posterior fossa tumors. Arch Phys Med Rehabil 1987;68:142.)

Visual Evoked Potentials (VEP)

- Record of gross electrical signal generated at the occipital cortex in response to visual stimulation
- VEP is the only objective technique available to assess the functional state of the visual system beyond the retinal ganglion cells
- Used in transphenoidal surgery, aneurysm clipping of posterior circulation, and removal of tumors near optic radiation



- Visual stimulus producing device
- Scalp electrodes
- Amplifier
- Computer and read out systems

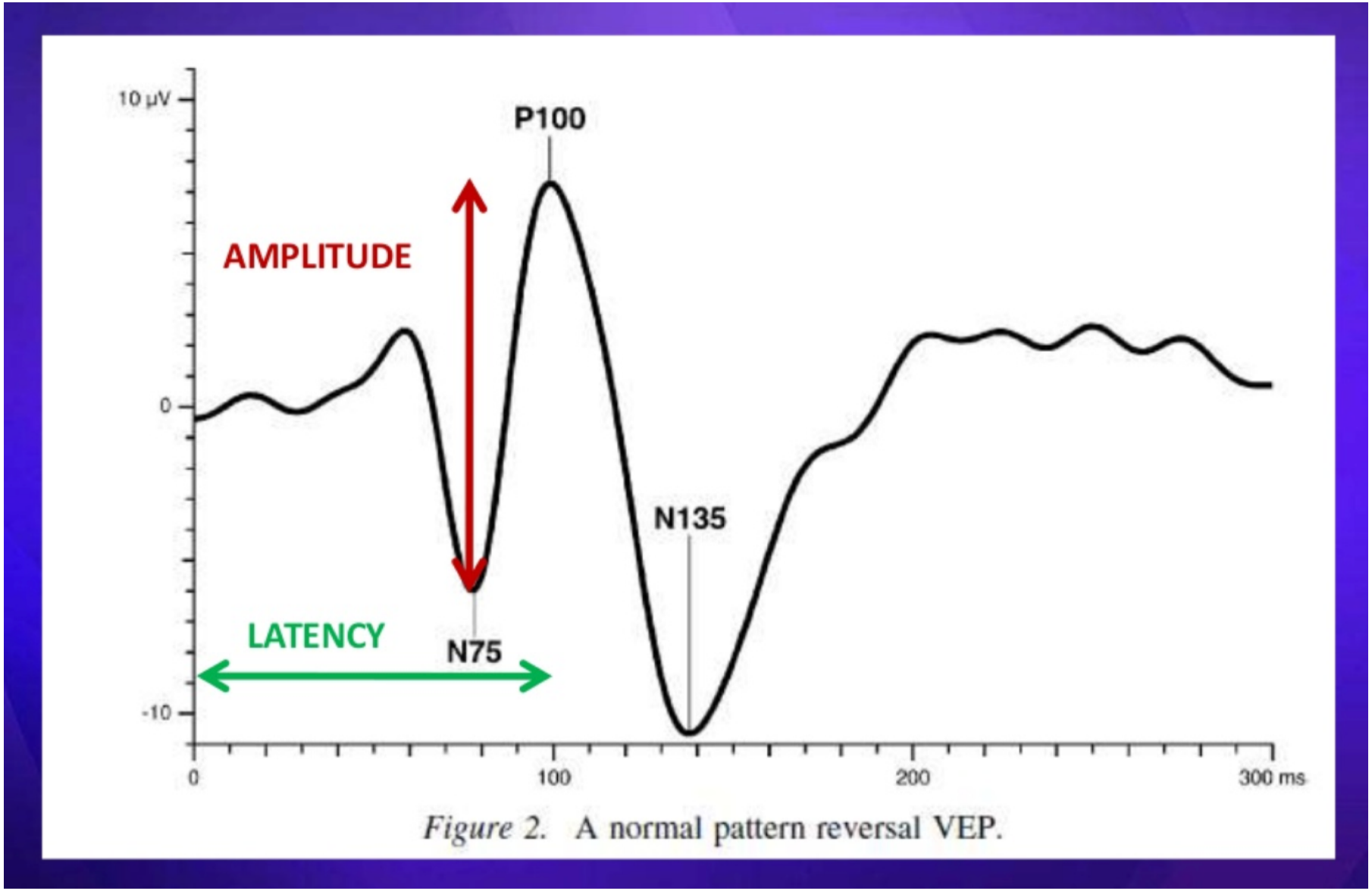


Figure 2. A normal pattern reversal VEP.

- If **acuity** of the patient is in question , the **amplitude** is more important
- If detection of a **lesion in visual pathway** is in question , **latency** is more important

EEG

- Records electrical activity from the scalp
- First adapted for IONM in 1960’s for CEA, still widely used for assessing degree of cerebral perfusion during vascular surgery and for monitoring depth of anesthesia

EMG

- Enables recording of electrical activity produced by skeletal muscles
  - Free-running EMG
  - Stimulated EMG
- Free-running EMG detects mechanical and/or metabolic irritation fo the nerve
  - Tonic Discharge – repetitive and steady episodes of activity from grouped motor units, observed in ischemia due to traction, heat, or saline irrigation
  - Phasic Discharge – short, synchronous burst of motor unit potentials, associated with blunt mechanical trauma
- Stimulated EMG – electrical stimulation of nerves and recording muscle action potentials in innervated muscle, used for nerve conduction assessment

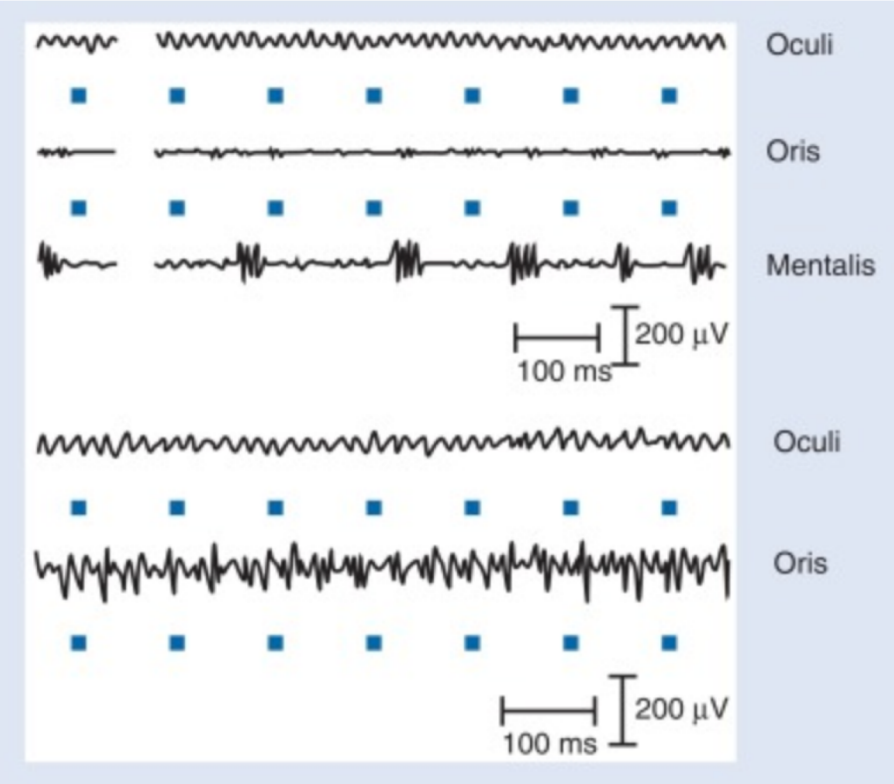


Fig. 6.5

Examples of continuously recorded muscle potentials during posterior fossa surgery. Responses are recorded from the orbicularis oculi, orbicularis oris, and mentalis muscles. *Top* , Multiple short responses (neurotonic bursts) in the mentalis muscle from dissection near the fifth cranial nerve. *Bottom,* Prolonged neurotonic discharges in the other muscles after irrigation with cool fluids.

(From Cheek JC: Posterior fossa intraoperative monitoring. J Clin Neurophysiol 1993;10:412.)

Monitoring of Cranial Nerves

Cranial Nerve		Monitoring Site or Method *
I	Olfactory	No monitoring technique
II	Optic	Visual evoked potentials
III	Oculomotor	Inferior rectus muscle
IV	Trochlear	Superior oblique muscle
V	Trigeminal	Masseter muscle and/or temporalis muscle (sensory responses can also be monitored)
VI	Abducens	Lateral rectus muscle
VII	Facial	Orbicularis oculi and/or orbicularis oris muscles
VIII	Auditory	Auditory brainstem responses
IX	Glossopharyngeal	Stylopharyngeus muscle (posterior soft palate)
X	Vagus	Vocal folds, cricothyroid muscle
XI	Spinal accessory	Sternocleidomastoid and/or trapezius muscles
XII	Hypoglossal	Genioglossus muscle (tongue)

Table 6.3 **Recommended Monitoring Modalities and Anesthetic Regimens for Surgical Procedures**

Type of Procedure	Monitoring Modalities					Anesthetic Recommendation	
			Electromyography				
	Somatosensory Evoked Potentials	*Transcranial Motor Evoked Potentials*	*Free Run*	*Stimulated*	*Auditory Brainstem Responses*	*Volatile (Inhalational Anesthetics)*	*Total Intravenous Anesthesia*
Spine Skeletal							
Cervical	•	•	•	•			
Thoracic	•	•	•	•	•		
Lumbar instrumentation	•	•	•	•			
Lumbar disc	•	•	•				
Head and Neck							
Parotid	•	•	•				
Radical neck	•	•	•				
Thyroid	•	•	•				
Cochlear implant	•	•	•				
Mastoid	•	•	•				
Neurosurgery							
Spine							
Vascular	•	•	•				
Tumor	•	•	•				
Posterior Fossa							
Acoustic neuroma	•	•	•	•			
Cerebellopontine	•	±	•	•	±	•	
Vascular	•	•	•	±	•		
Supratentorial							
Middle cerebral artery aneurysm	•	•					
Tumor in motor cortex	•	•	•				

Questions

Question 1

- SSEPs test the integrity of:
  A. Corticospinal tract
  B. Spinothalamic tract
  C. Posterior columns
  D. Spinocerebellar tract

Question 2

- The N11-13 complex corresponds to:
  A. Brachial plexus
  B. Cauda equina
  C. Cervicomedullary junction
  D. Thalamus

Question 3

- The first sign of ischemia on EEG during IOM
  A. Decrease in amplitude
  B. Loss of high frequency waveforms
  C. Loss of occipital rhythm
  D. All of the above

Question 4

- The chemical transmitter that mediates between sympathetic postganglionic fibers and the end organ is:
- a. norepinephrine
- b. acetylcholine
- c. adrenaline
- d. epinephrine

Question 5

- There is a greater amount of somatotopical representation in the motor cortex for the:
- a. arm
- b. legs
- c. erector spinae
- d. fingers

Question 6

- Which of the following is most closely associated with language comprehension?
- a. agnosia
- b. Broca’s area
- c. Wernicke’s area
- d. arcuate fasciculus

Question 7

- What is the typical threshold for the recurrent laryngeal nerve on stimulation, and what is the typical max response stimulated at?
- a. 1.0mA, 3.0mA
- b. 0.05mA, 0.1mA
- c. 6mA, 10mA
- d. 0.4mA, 0.8mA

Question 8

- What is the frequency of EMG activity that is a cause for concern?
- a. <20 Hz
- b. >20 Hz
- c. >60 Hz
- d. >120 Hz

Question 9

- What does cerebral oximetry measure?
- a. oxygenation of venous blood in the brain.
- b oxygenation of arterial blood in the brain.
- c. blood flow velocity
- d. blood flow volume

Question 10

- In BAERs, conductive losses affect all the following except:
- a. amplitudes
- b. interpeak latencies
- c. amplitudes and interpeak latencies
- d. none of the above

Question 11

- What are significant changes in VEP?
- a. all-or-none amplitude loss
- b. 50% change in amplitude
- c. latency shift of 40-50 msec
- d. both b and c