Intraoperative Neurophysiological Monitoring

James Watt, BAS, CNIM

History of IOM

- 1970's - Intraoperative monitoring comes into general use
  - Somatosensory Evoked Potentials recorded for scoliosis correction
  - Electromyography to preserve facial nerve function for vestibular schwannoma
- 1980's - Commercial equipment becomes available and university and teaching hospital begin monitoring
- 1990's – Equipment manufacturers develop software enabling multimodality monitoring
- 2000's – Intraoperative neurophysiologic monitoring considered "standard of care"
- 2010 – Intraoperative Monitoring Specialty **IS** standard of care, in high demand with limited resources of trained specialists

Current State of IOM

- Simultaneous multimodality monitoring
  - EMG – spontaneous electromyography from skeletal muscles
    - CMAP - compound motor action potential
    - NAP - nerve action potential
  - EEG – electroencephalography
    - Analog display, compressed spectral array (CSA), electrocorticography
  - Evoked Potentials
    - SEP (upper and lower extremity)
      - Cortical mapping
    - TCeMEP -- Transcranial electrical Motor Evoked Potentials
    - AEP -- Auditory Evoked Potentials
      - electrocochleography
    - VEP -- Visual Evoked Potentials
- Each recording time-stamped with documentation of events
  - Hemodynamic status, physiologic changes, communication, anesthesia levels, oximetry, temperature, trends, etc.

Introduction

- Neurophysiologic Intraoperative Monitoring (NIOM) provides continuous information about the functional integrity of the central and/or peripheral nervous system.
  - Avert potential injuries
    - Misplaced instrumentation
    - Compression of neural structures
    - Decreases in blood perfusion
  - Identify neural structures
    - Cranial nerves distorted by pathology
    - Location of nerve roots
  - Imaging techniques are limited to identifying anatomic structures.

Benefits

- Reduced risk of neurologic deficits
- Surgeon has increased sense of security
- Decreased operating time
- Medicolegal
- Patients are asking for neuromonitoring

Skills

- Knowledge of
  - Medical terminology
  - Neuroanatomy and Physiology
  - Surgical procedure
  - Electrophysiology
  - Proper etiquette
  - OR policies and procedures
- Technical skills
- Adaptability to scheduling changes
- Good communication skills
- THICK SKIN!

Qualifications

- The American Board of Registration of Electroencephalographic and Evoked Potential Technologists (ABRET)
  - Certification in Neurophysiologic Intraoperative Monitoring (CNIM) Examination.
    - Demonstrates an advanced level of competence and knowledge of technical aspects of neuromonitoring
- Exam information
  - abret.org
  - ptcny.com
  - aset.org

CNIM Eligibility Requirements

- Documentation of 150 surgical cases monitored. The candidate must be present and an active participant in the set-up and monitoring of each case listed
- Provide evidence of at least ONE of the following
  - R. EEG T. - Registered Electroencephalographic Technologist
  - R. EP T. - Registered Evoked Potential Technologist
  - RET - Registered Electroencephalographic Technologist (Canada)
  - Bachelor's degree or 120 hours of college credit
- Path 1 - Registered Technologist (EEG/EP)
  - 200 questions based on CNIM Practice Analysis
- Path 2 - Bachelor's Degree
  - 250 questions - 200 questions based on CNIM Practice Analysis and 50 additional questions in EP

American Board of Neurophysiologic Monitoring – ABNM

- Diplomate Certification for professional level neuromonitorists
- D.ABNM
- 10 year certification

ABNM Requirements

A minimum of a doctorate degree in a physical science, life science or clinical allied health profession from an accredited institution.

At least three years experience in neurophysiologic monitoring.

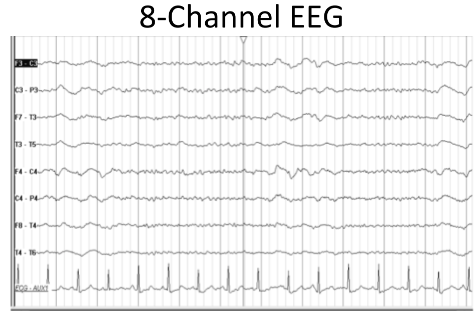
Primary responsibility for having monitored a minimum of 300 surgical procedures in person.

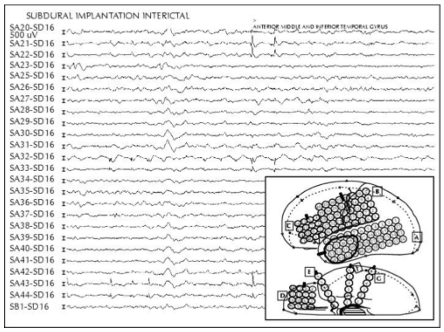
Graduate level coursework in neuroanatomy and neurophysiology.

Signals Recorded - Brain

- Electroencephalography - EEG
  - Summated pyramidal cell postsynaptic potentials
    - Amplitude, frequency, and symmetry
      - Carotid Endarterectomy, cerebral aneurysm, Cerebral AVM
- Electrocorticography
  - Epilepsy surgery

8-Channel EEG



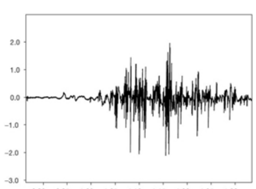


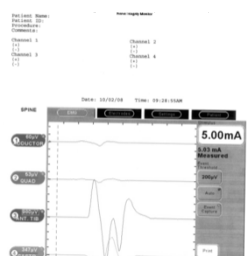
Signals Recorded – Peripheral Nervous System

- Electromyography – EMG
  - Spontaneous/Free Run
  - Triggered
    - Compound Motor Action Potential – CMAP
      - Action Potential recorded from a muscle triggered by electrical stimuli
- Nerve Action Potential – NAP
  - Action Potential recorded directly from nerve/spinal cord

EMG

Spontaneous EMG

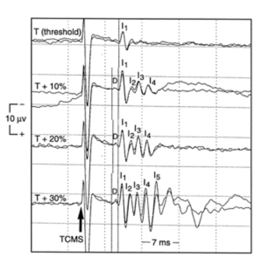


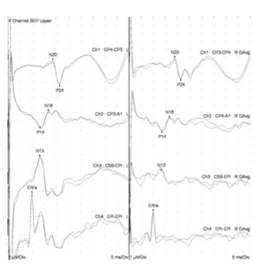


Signals Recorded

- Evoked Potentials
  - Somatosensory Evoked Potential (SSEP)
    - Electrical stimulus is delivered peripherally (nerve), recorded centrally (brain, spinal cord)
  - Transcranial Electrical Motor Evoked Potential (TCeMEP)
    - Electrical or magnetic stimulus is delivered centrally (brain), recorded peripherally (muscles).
  - Auditory Evoked Potential – AEP
    - Clicking noise stimuli
  - Visual Evoked Potential – VEP
    - Flashes of light via LED goggles

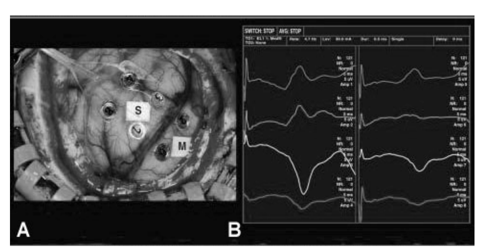
Evoked Potentials

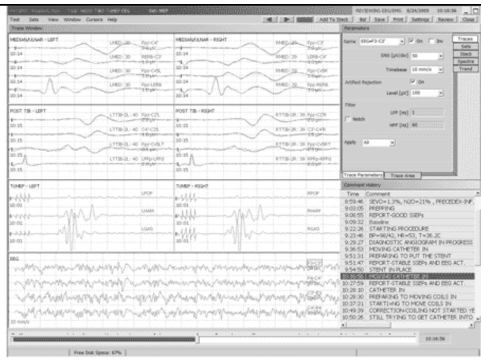




Somatosensory Evoked Potential – SEP

Cortical Mapping





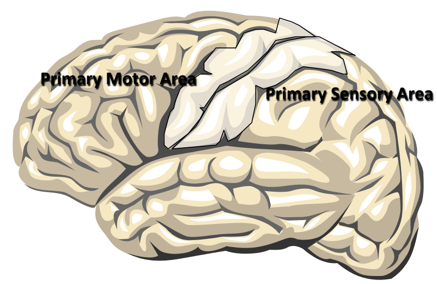
Cortical Mapping

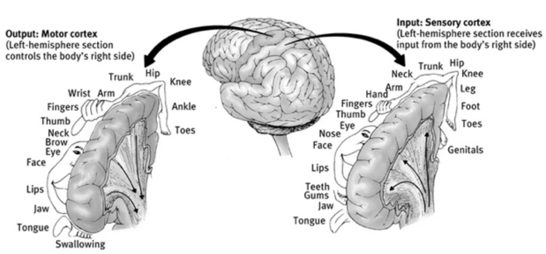
Goal of Cortical Mapping

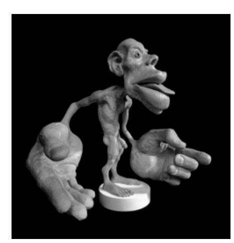
- Location of functional motor cortical surfaces with direct cortical stimulation
- Location of the primary sensory cortex with direct cortically recorded SSEPs (Phase Reversal)
- Location of eloquent speech centers through direct cortical stimulation
- Localization of epileptic foci using electrocorticography

- To avoid these areas during tumor resection
- To identify and remove epileptic foci

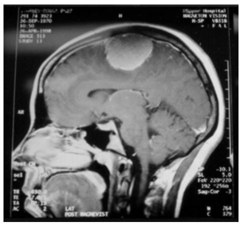
Functional Anatomy



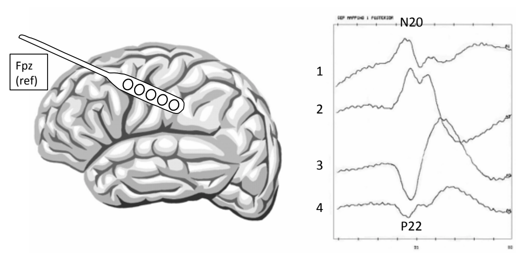


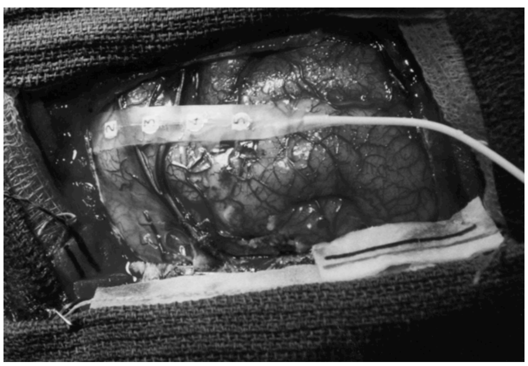


Tumors can often distort the cortical anatomy



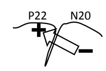
Phase Reversal to Locate Central Sulcus



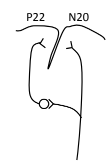


Theories for Phase Reversal

- Dipole Theory
  - Due to the folding of the cortex in the central sulcus the cortical response generator (post-central gyrus) produces a positive-negative dipole across the central sulcus



- Independent Generator Theory
  - Separate sensory and motor generators exist as a result of ascending thalamocortical fibers activating motor cortex via a synapse



Direct Cortical SSEP Parameters

- Stimulating:
  - Contralateral Median nerve and Posterior tibial nerve
  - Rep rate 4.47/sec
    - Can be increased to 9.23/sec
  - 200 uS pulse
  - Supramaximal stim
- Recording:
  - Grid contacts referenced to Fpz
  - 10-1000 Hz
  - 50-100 msec sweep
    - 100 mS may be superior
  - Sensitivity at 1 – 20 uV/div
  - Average as needed (usually <100)

Anesthesia for sensory-motor mapping

- Desire 0.5 MAC Inhalational Agent or less
- 4/4 twitches
- Narcotics as needed
- Supplemental propofol infusion as necessary
- Dexmetitomidine (Precedex) is also acceptable

Motor Cortex Mapping

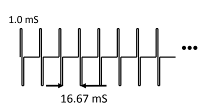
- Purpose:
  - To positively identify cortical tissue essential to motor function.
- Method:
  - Stimulate the cortex.
  - Record muscle potentials in the periphery.
  - Label the cortex.

Two techniques of cortical stimulation for motor mapping

- "Ojemann" technique
  - Long pulse train, low frequency
- Short Pulse Train
  - High frequency train similar to TCMEP
  - Described by Tanaguchi 1993

Ojemann Technique

- Long pulse train (1-4 seconds)
- Biphasic pulses (to minimize deposition of toxic metal salts) of 1 mS duration
- 50-60 Hz
- 1-20 mA peak-to-peak intensity



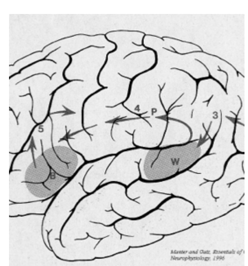
Ojemann Stimulator

- Delivers constant current biphasic pulses 0-10 mA range (20 mA peak-to-peak)
- Runs on four 9-volt batteries (have an extra set handy!)
- Can control frequency, duration and intensity
- Probe uses banana plug connectors

If the Patient has a Seizure…

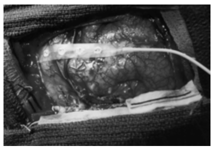
- Ice-cold irrigation (preferably <4° C) of the exposed cortex will stop the electrical activity (without harm) and allow mapping to continue
- Irrigation should be applied for 5-10 seconds
- Pharmaceutical intervention (barbiturates or paralytics) will delay mapping and may reduce reliability

Cortical Language Function



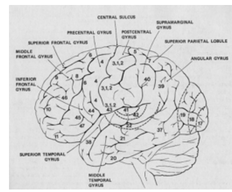
- Wernicke's area.
- Broca's area.
- Parietal operculum.

Direct Cortical EEG Recording Methods



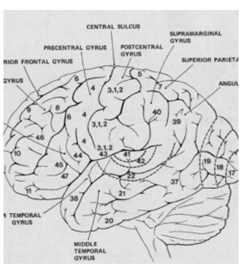
- Minimum 4 channels
- 1 –70 Hz (No 60 Hz notch)
- 30 uV/mm
- 30 mm/sec

Wernicke's Area



- Responsible for recognition of the words we see and hear.
- Lesions of Wernicke's area:
  - Fluent speech and grammatical construction.
  - Inability to find the correct words.
  - May omit words, substitute words or use words without precise meanings.

Broca's Area



- Responsible for production of the words we speak.
- Lesions of Broca's area:
  - Good comprehension.
  - Difficulty producing spoken language.
  - Executive aphasia.
  - Many prepositions, nouns and verbs are deleted.

Variability of Language Sites

- Patients will typically have 2-3 cortical sites essential to language function; some will have several
- Considerable variation in the location of areas important to language has been described
- Patients with a non-English primary language will have separate language areas and should be mapped in both languages

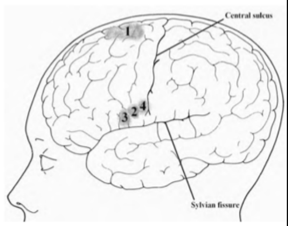
Hemisphere Dominance for Language

- 95% of the population is left-hemisphere dominant.
- Essentially all right-handed people (90%) have left-hemisphere language dominance.
- ½ Of the left-handed people (10%) have left-hemisphere language dominance.

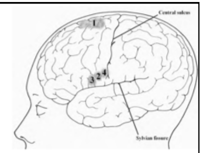
Broca's Mapping Under General Anesthesia

Anatomy

- (4) Primary motor cortex for oro-pharyngeal-laryngeal muscles
- (2) Primary negative motor speech area
- (1) Supplementary negative motor area
- (3)Broca area – posterior part of the inferior frontal gyrus

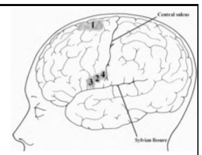


Speech arrest during a counting task – Clinical features



- Broca area (3); Speech arrest **without simultaneous motor responses in oro- pharyngeal-laryngeal muscle** group. During speech arrest the subject **is able to execute voluntary tongue movement (i.e. wiggling** from side to side).
- Negative motor areas (1,2); Speech arrest **without simultaneous motor responses in oro- pharyngeal-laryngeal** muscle group. During speech arrest the subject is **not able to execute voluntary tongue movement (i.e.** wiggling from side to side).
- Primary motor cortex (M1) for oro-pharyngeal-laryngeal muscles; Speech arrest **with simultaneous** motor response in oro-pharyngeal-laryngeal muscle group. During speech arrest the subject is **not able to** execute voluntary tongue movement (i.e. wiggling from side to side).

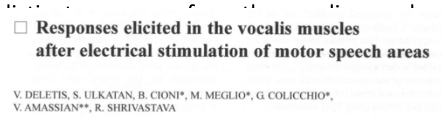
Speech arrest during a counting task – Neurophysiologic features



- Broca area; Speech arrest with presence of long latency response in laryngeal muscles (Deletis et al., 2008)
- Negative motor areas; Speech arrest with electrical silence in laryngeal muscles
- Primary motor cortex (M1) for oro-pharyngeal-laryngeal muscles; Speech arrest with a short latency response in laryngeal muscles (Amassian et al., 1987; Ertekin et al., 2001; Rödel et. al., 2004; Deletis et al., 2009).

New neurophysiologic marker for Broca's area and methodology for identifying Broca's under general anesthesia

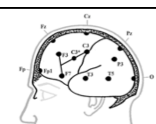
- Deletis demonstrated that stimulation of the Broca area versus primary motor cortex for oro-pharyngeal-laryngeal muscles produced

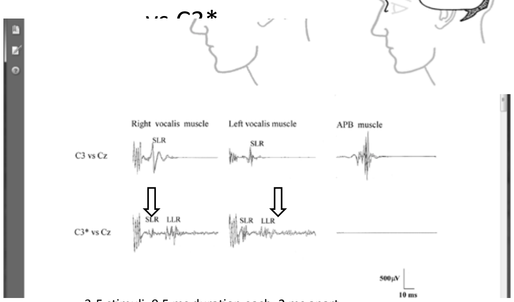

Responses elicited in the vocalis muscles after electrical stimulation of motor speech areas

V. DELETIS, S. ULKATAN, B. CIONI*, M. MEGLIO*, G. COLICCHIO*, V. AMASSIAN**, R. SHRIVASTAVA

Deletis, V., Ulkatan, S., Cioni, B., Meglio, M., Colicchio, G., Amassian, V., Shrivastava, R. (2008). Responses elicited in the vocalis muscles after electrical stimulation of motor speech areas. Rivista Medica. 14:159-165.

Transcranial stimulation at C3 vs C3*





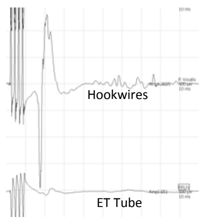
3-5 stimuli, 0.5 ms duration each, 2 ms apart, train repetition rate of 2 Hz and intensity up to 120 mA

Recording from Vocalis Muscle

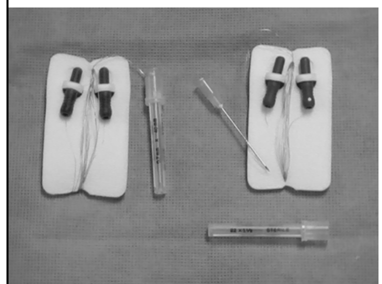
- Two hook wire electrodes, each consisting of teflon coated wire of 76 µm in diameter passing through 27 gauge needles (hook wire electrode, specially modified, Viasys Healthcare WI, MA).
- The recording wires have a stripped teflon isolation of 2 mm at their tip and are bended to form the hook for anchoring them. Impedances of electrodes were around 20 K Ohm.
- After the patient is intubated, two electrodes are inserted in each vocalis muscle through the rigid laryngoscope. After the wire insertion in the vocalis muscles, needles are withdrawn, wires are twisted and needles are covered to protect patients from accidental injury.
- For recording the electrical activity from both hand muscles and abductor pollicis brevis (APB), twisted pair needle electrodes are inserted in the muscle belly.

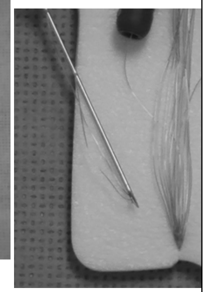
Why use hookwires instead of endotracheal tube electrodes?

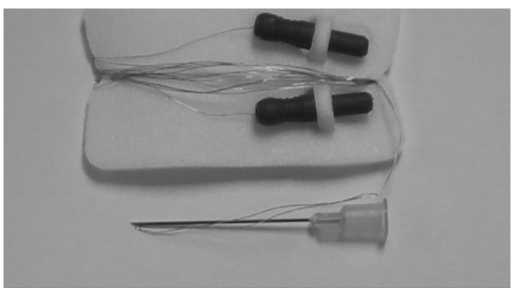
- Because the response amplitudes from the hookwires are larger by an order of magnitude (Bigelow 2002)
- The closely spaced bipolar hookwires will be less susceptible to picking up far-field responses from adjacent neck muscles

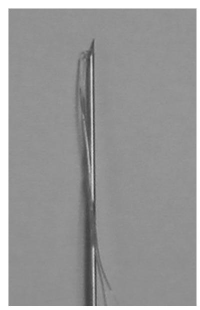


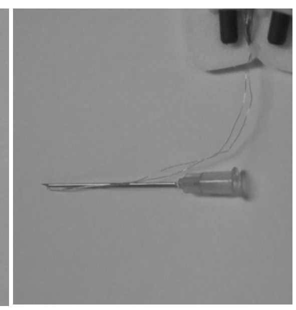
Paired Hookwires



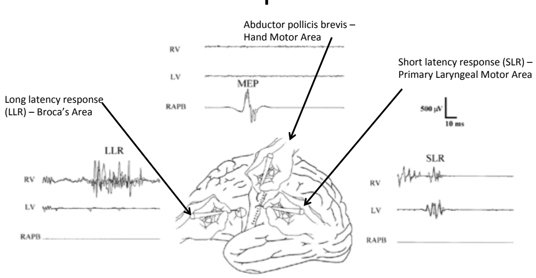






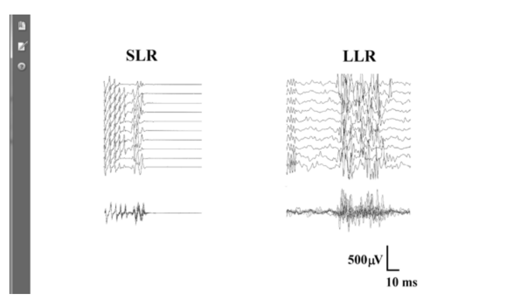


Three distinct responses identified



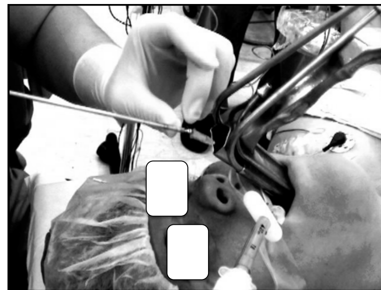
SLR and LLR elicited by TES and DCS had similar latency; SLR had latency of 10-12 ms while LLR had latency of 35-50 ms and their amplitude was higher when elicited by DCS than by TES. SLR was well synchronized, and short duration, while LLR was desynchronized and of the long duration.

Reproducibility of Vocalis responses

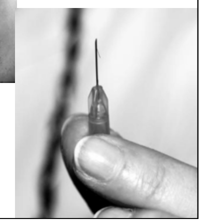


Primary motor vs Broca's

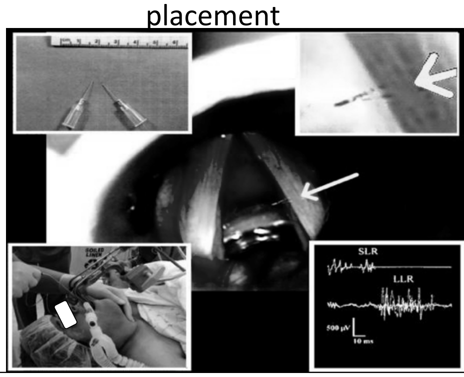
- Stimulation of the lower part of precentral gyrus, laterally to the point which elicits response in contra lateral APB muscle, elicit SLR in both vocalis muscles
  - This corresponds to the area of primary motor cortex for the oropharyngeal muscles
- Stimulation of a very restricted region of the lower frontal gyrus, posterior, approximately 10x10 mm, elicit only LLR in either the ipsilateral or contralateral vocalis muscle



Placement of hookwires is performed by an ENT specialist

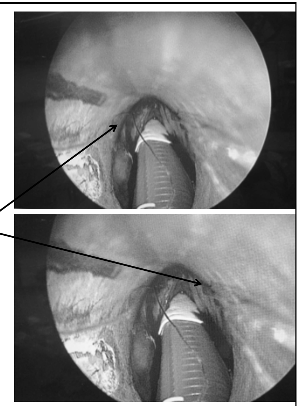


Laryngoscopic view of hookwire placement

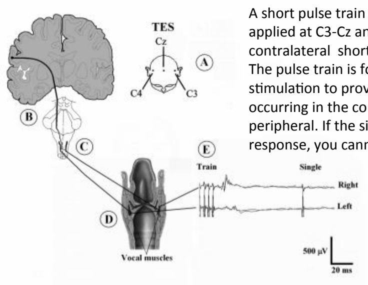


Laryngoscopic view of hookwires

- Paired hookwires are in each vocalis muscle

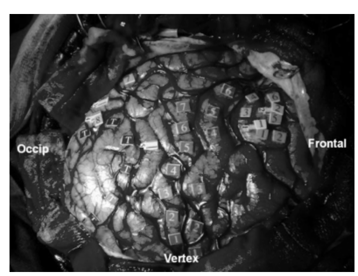


Utilizing transcranial stimulation to monitor corticobulbar path, vagus nerve and recurrent laryngeal nerve

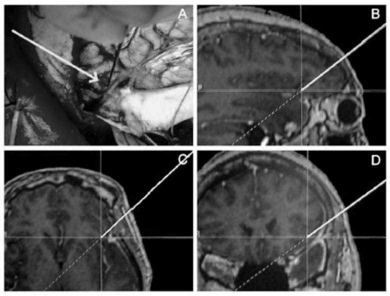


A short pulse train (4-5 pulses at 500 Hz) is applied at C3-Cz and C4-Cz to elicit contralateral short-latency vocalis responses. The pulse train is followed by a single pulse stimulation to prove that activation is occurring in the corticobulbar tract and not peripheral. If the single pulse produces a response, you cannot make this claim.

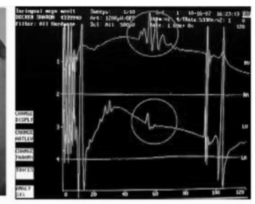
A mapped cortex



Monopolar anodal stimulation of Broca's area



For transcranial stimulation the C3* and C4* can be mapped with surface monopolar transcranial stimulation



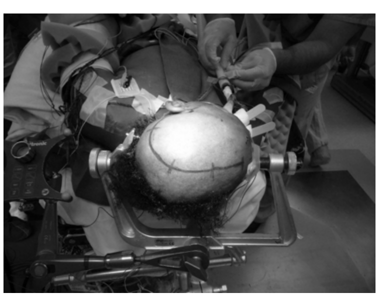
Anesthesia

- Anesthesia was maintained with Propofol (100-150 µg/kg/min) and Fentanyl (1-1.5 µg/kg/hour). A short-acting muscle relaxant (Rocuronium 50 mg/kg) was administered for intubation purposes only. The anesthesia regimen, blood pressure and temperature were kept constant throughout the surgery.
- Recovery from muscle relaxation was monitored by the train-of-four technique and recorded from the abductor pollicis brevis muscle after stimulation of the median nerve at the wrist.

Is TIVA necessary?

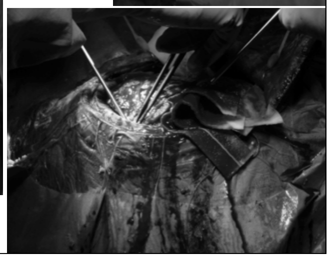
- Yes!
- The pathway of Broca's to Primary motor cortex is set back by at least one synapse; thus, we are essentially activating the Broca's response via I-waves rather than D-waves!
- Remember, I-waves are quite sensitive to anesthesia although they can be facilitated by a train

Incision Site



Exposing the Cranium and Creating Burr holes

Peeling off the skull plate and performing hemostasis



Dura is peeled away and
The Cortex Revealed

Placement of 1x4 cortical strip

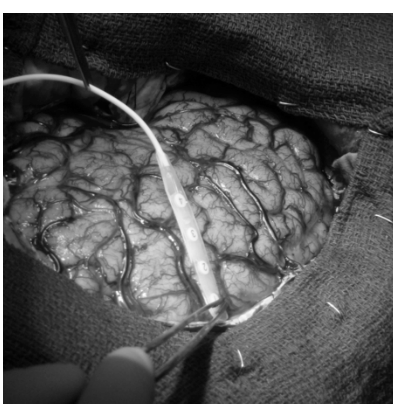
11:13

Cortical strip placed across the sulcus and covered by a saline soaked cottonoid

11:16

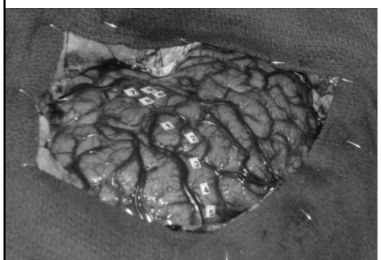
11:17

Strip placed over motor cortex



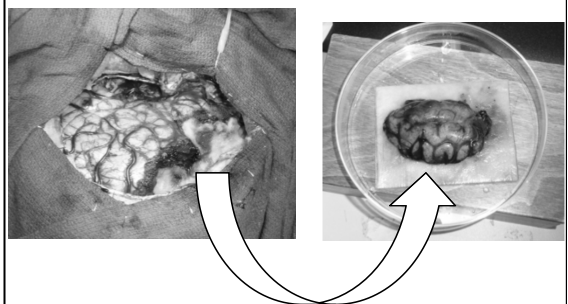
Monopolar anodal stimulation

Mapping Results

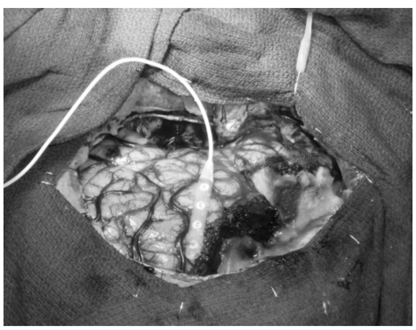


6,7,8,9 = Oris and Right Vocalis (SLR&LLR)
1 = Oculi/Oris
2,3 = Hand
4,5 = Arm/Shoulder

Frontal Brain Resection Subtemporal cortex/hippocampus also resected

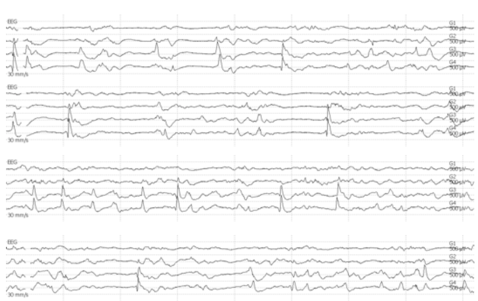


Final Motor Evaluation

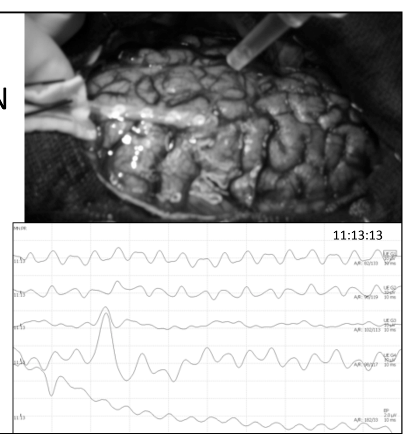


Phase Reversal Data

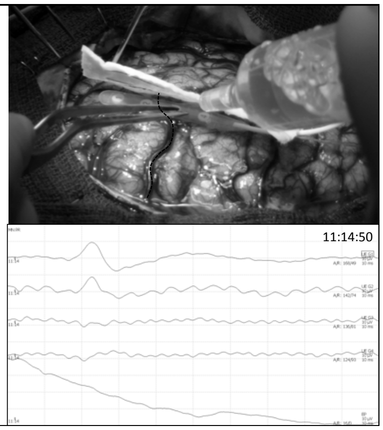
ECoG from 1x4 (500 uV/div)



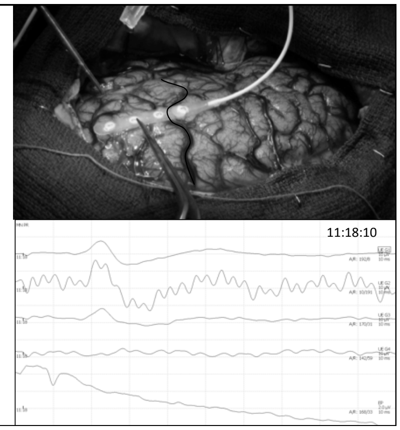
Initial MN Phase reversal



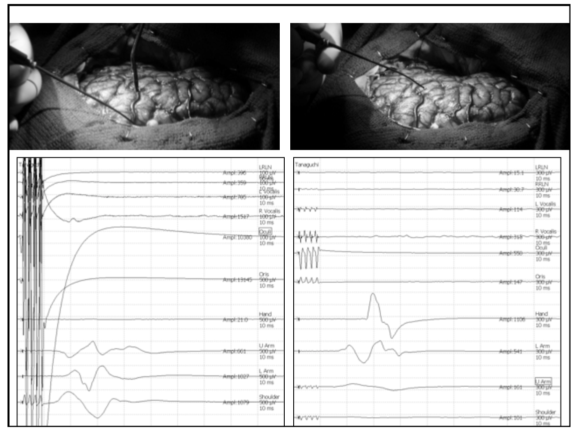
MN Phase Reversal #2

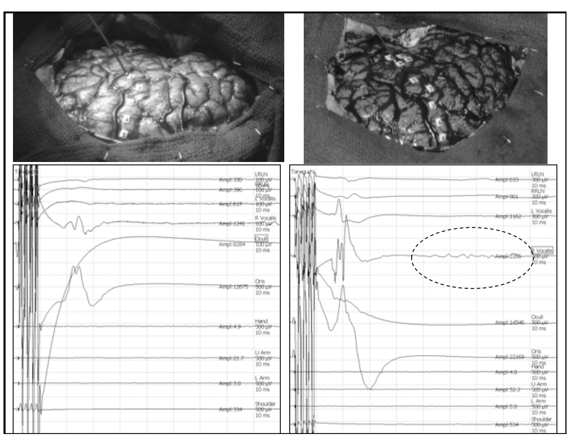


Final MN Phase Reversal

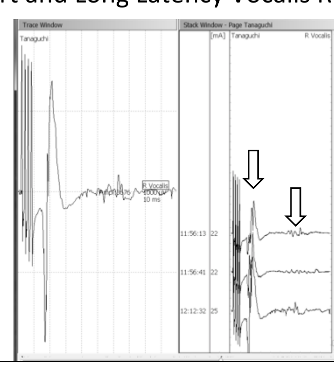


Motor Cortex Stimulation

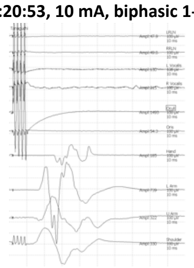




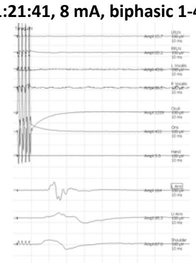
Short and Long Latency Vocalis Responses



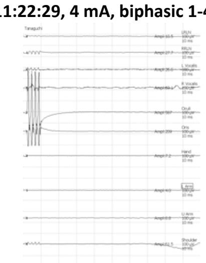
11:20:53, 10 mA, biphasic 1-4



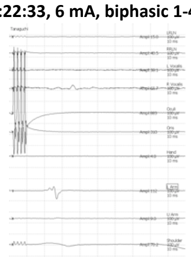
11:21:41, 8 mA, biphasic 1-4



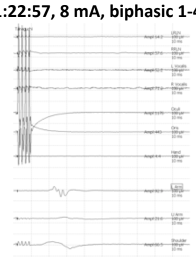
11:22:29, 4 mA, biphasic 1-4



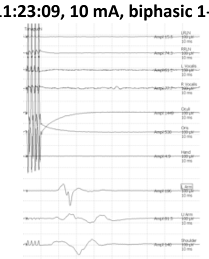
11:22:33, 6 mA, biphasic 1-4



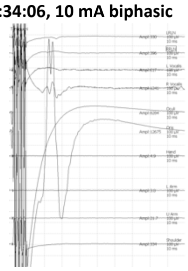
11:22:57, 8 mA, biphasic 1-4



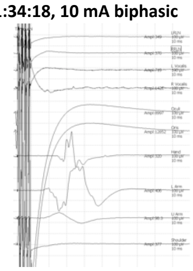
11:23:09, 10 mA, biphasic 1-4



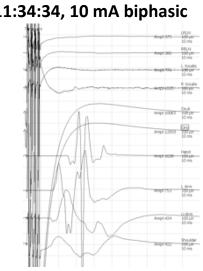
11:34:06, 10 mA biphasic



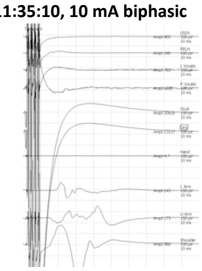
11:34:18, 10 mA biphasic



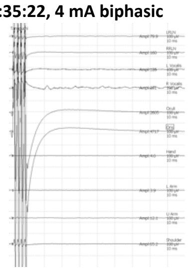
11:34:34, 10 mA biphasic



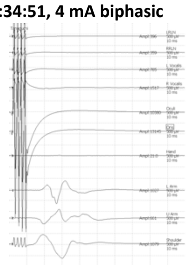
11:35:10, 10 mA biphasic



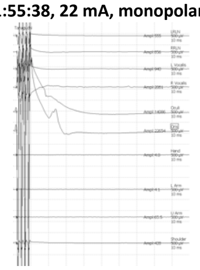
11:35:22, 4 mA biphasic



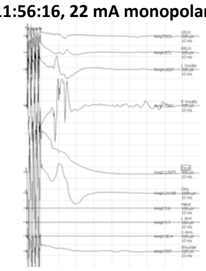
11:34:51, 4 mA biphasic



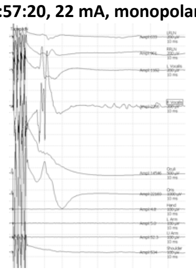
11:55:38, 22 mA, monopolar



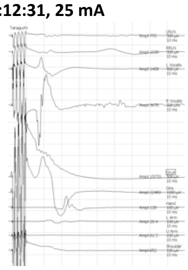
11:56:16, 22 mA monopolar



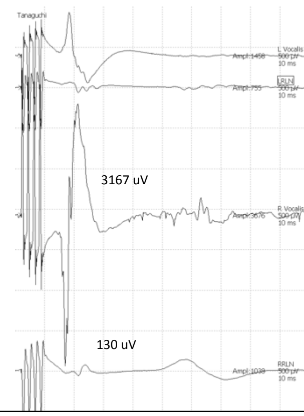
11:57:20, 22 mA, monopolar



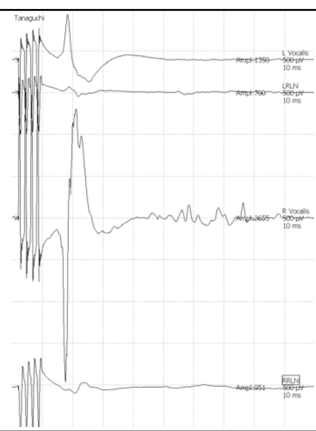
12:12:31, 25 mA



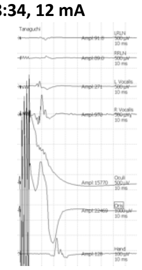
Comparison of Hookwires to Endotracheal tube recording 12:12:31 25 mA



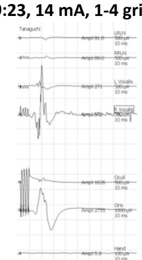
12:22:27 Another comparison



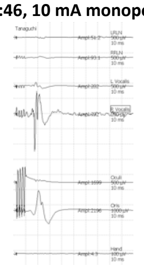
13:38:34, 12 mA



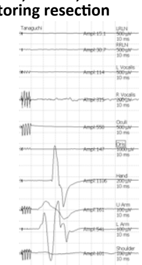
13:39:23, 14 mA, 1-4 grid



13:38:46, 10 mA monopolar



13:45:14, 12 mA, Grid 1-4 for monitoring resection



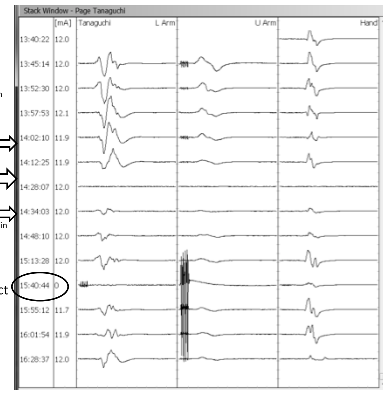
Direct cortical MEPs during brain resection

Propofol 50 mcg/kg/min
Fentanyl 1.5 mcg/kg/hr
TO4: 4/4
BP 133/55 (107)
BT 35.2 C

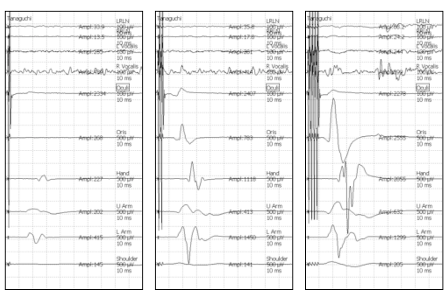
Patient Moving
Isoflurane 3.3/3.0%
Propofol 160 mcg/kg/min
Fentanyl 1.5 mcg/kg/hr
TO4: 4/4
BP 186/91 (119)
BT 35.5 C

Propofol 160 mcg/kg/min
Fentanyl 1.0 mcg/kg/hr
TO4: 4/4
BP 136/72 (90)
BT 35.6 C

Grid making poor contact

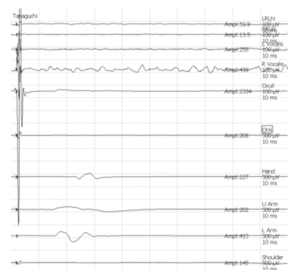


12 mA biphasic, 1 – 4 grid

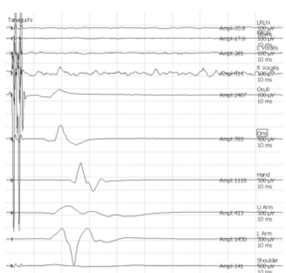


2 Pulses 3 Pulses 5 Pulses

2 Pulses, 12 mA biphasic 1-4 grid



3 Pulses, 12 mA biphasic 1-4 grid



5 Pulses, 12 mA biphasic 1-4 grid