Montage, Review, and Analysis of High Density EEG

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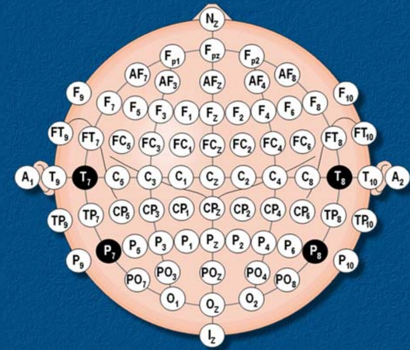
Modified Combinatorial Nomenclature



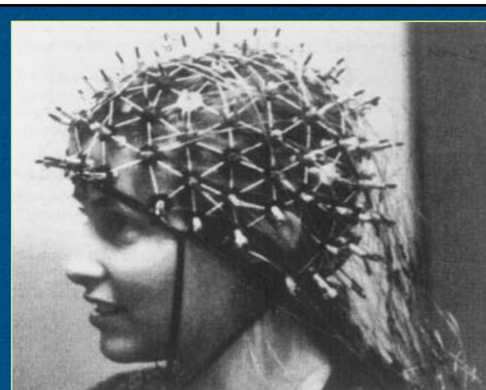
Disclosure

Relevant financial relationships

- None

Off-label/investigational uses

- None



Standard vs. High Density EEG

Standard EEG (10-20)

- Accuracy limited by large interelectrode spacing (6-7 cm for 10-20 system placement)
- May provide too low spatial resolution to determine localization and even lateralization of seizure generators (e.g., in medial frontal lobe epilepsy)

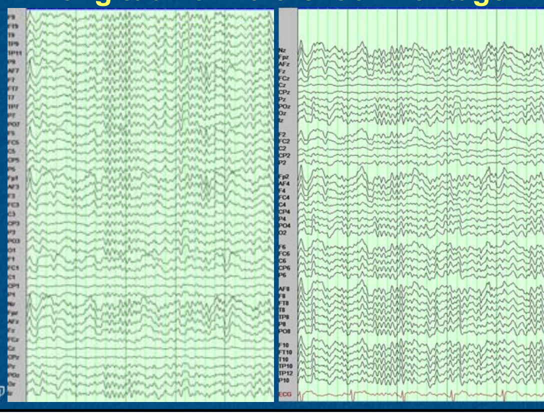
High Density EEG (10-10)

- Use of higher density electrode arrays (for example, 10-10 system) improves spatial resolution
- Improved spatial resolution may allow better localization of seizure generators for epilepsy surgery

High Density Montages

- Referential montages
  - Used as input for amplifier (often with Cz or CPz reference).
  - Also can use average ear or average mastoid reference.
- Bipolar montages
  - Longitudinal bipolar
  - Transverse bipolar

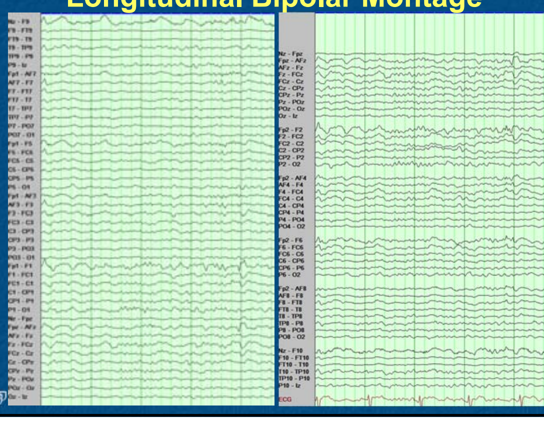
Longitudinal Referential Montage



Localization by Conventional EEG

- Requires no special equipment (readily available)
- Requires no models or assumptions about data, generators, or volume conducting medium
- Instrumental, external interference, and physiologic artifacts are relatively easy to recognize

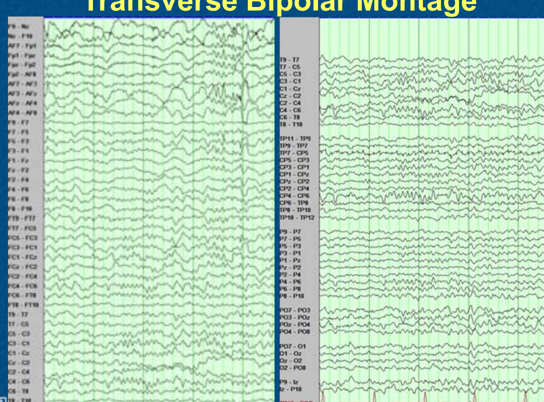
Longitudinal Bipolar Montage



Localization by Processed EEG/MEG

- Requires special equipment (computer software or MEG unit)
- May require models or assumptions about data, generators, or volume conducting medium
- Instrumental, external interference, and physiologic artifacts may be difficult to recognize after processing

Transverse Bipolar Montage

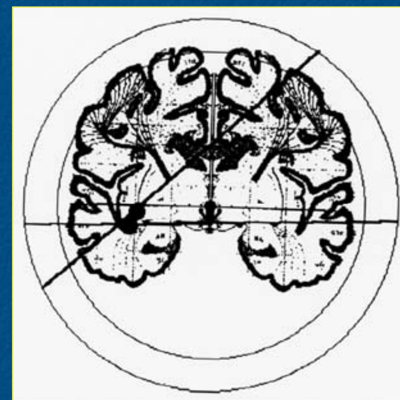


Localization by Conventional EEG

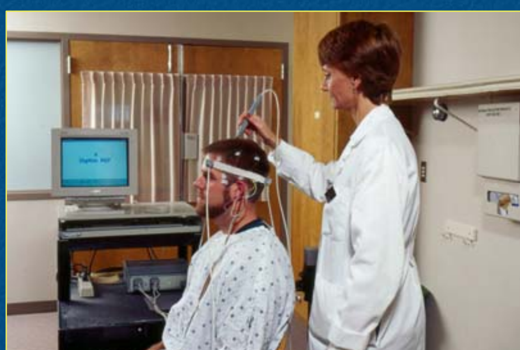
- Spatial distributions of waveforms or features difficult to visualize in time-series displays
- Interpretation may be confused by reference electrode activity
- Accuracy limited by smearing of potentials by volume conducting medium (especially skull)
- Risks to patient are associated with recording from invasive intracranial electrodes and such electrodes only sample brain areas in the immediate vicinity

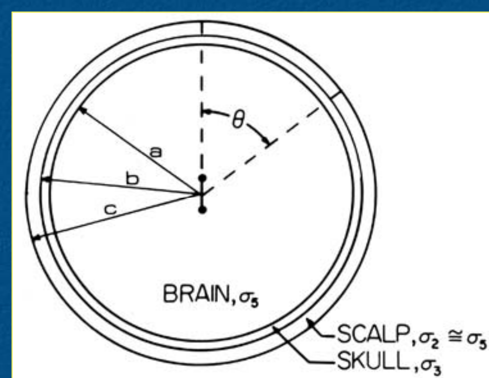
Localization by Processed EEG

- Topographic displays make distribution of waveforms or features easier to visualize
- Reference-independent methods eliminate active reference problems
- Processing may reduce smearing of potentials by volume conductor, enhancing spatial resolution
- Cortical projection methods estimate cortical potentials without placing electrodes intracranially



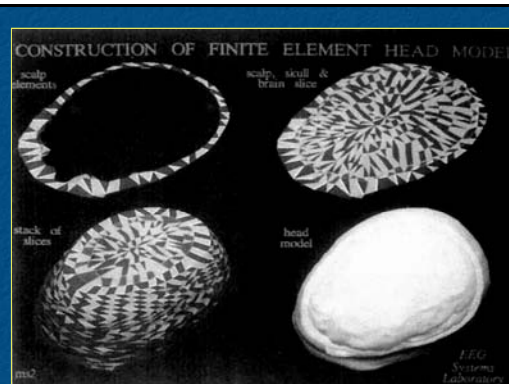
Digitizing electrode positions





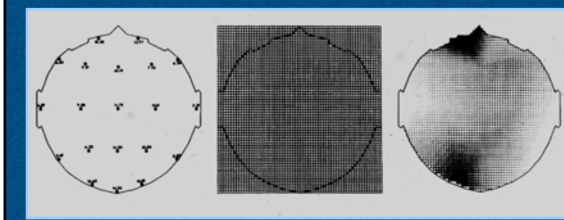
Types of Head Models Used for EEG/MEG

- Homogeneous Sphere Model (CIT, some dipole localization methods)
- Three-concentric sphere model (spatial deconvolution, spherical harmonic expansion, most dipole localization methods)
- Finite element model based on MRI images (deblurring method, some dipole localization methods)



Model Independent Methods

- No assumptions about generator number, type, or configuration
- Topographic display methods show EEG scalp potential distribution after interpolation (rely on visual interpretation alone)
- Laplacian methods show scalp radial current density which is related to underlying generators
- Cortical projection methods estimate cortical surface potentials



Topographic Displays

Generate a “picture” of the distribution of electrical activity over the head

Since potentials at points other than those occupied by electrodes are **not known**, need to interpolate the available EEG data to intermediate points on the head

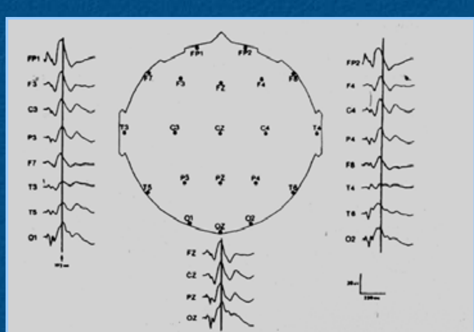
Types of Topographic Display

Classified by domain

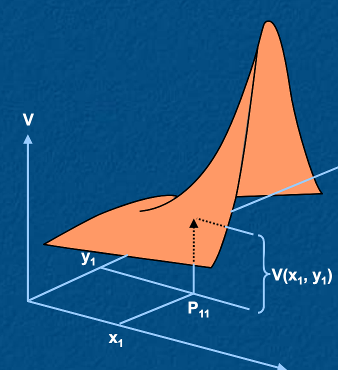
- Time domain (“snap shot” of potential distribution at one instant of time)
- Frequency domain (shows distribution of power in a given range or band of frequencies)

Classified by display method

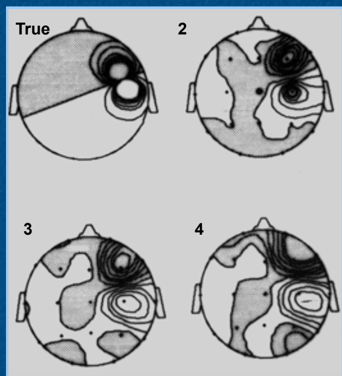
- 3-dimensional plots
- Contour plots
- Grey scale intensity plots
- Color plots



3-Dimensional Plot



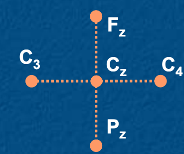
Contour Plot



Laplacian Montage

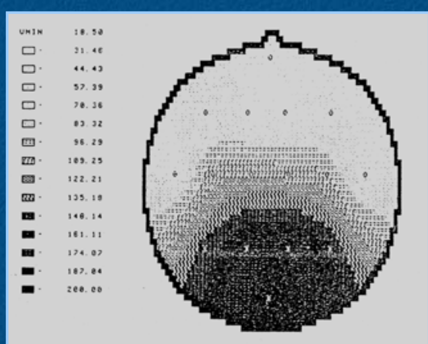
Approximation of the Laplacian

The Laplacian of the EEG at any electrode can be approximated as the difference between the EEG signal at that electrode and the average signal at the 4 surrounding electrodes (anterior, posterior, left and right)



$$\text{Laplacian at } C_z = C_z - \frac{F_z + P_z + C_3 + C_4}{4}$$

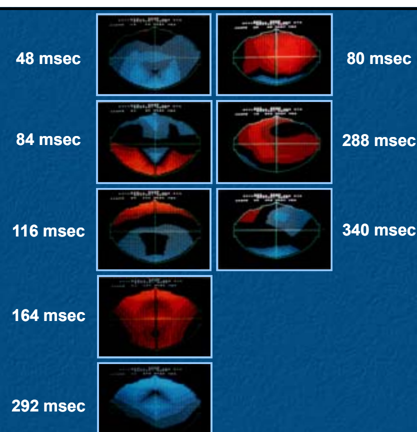
Grey-Scale Plot



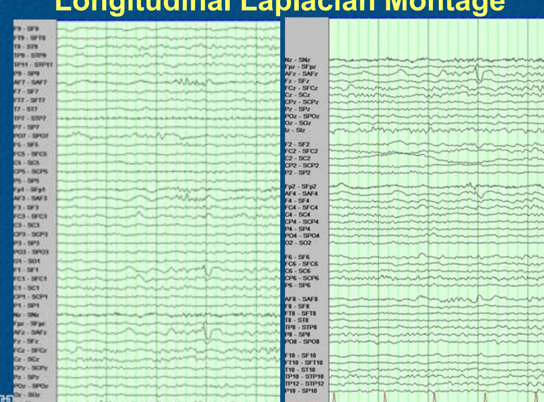
Methods for Calculating Laplacian

- Nearest neighbor inverse distance weighted (Taylor's series)
- Rectangular surface splines
- Rectangular 3-D splines projected onto spherical surface
- Rectangular 3-D splines projected onto elliptical surface
- Spherical surface splines
- Spherical harmonic expansion

Color Plots



Longitudinal Laplacian Montage

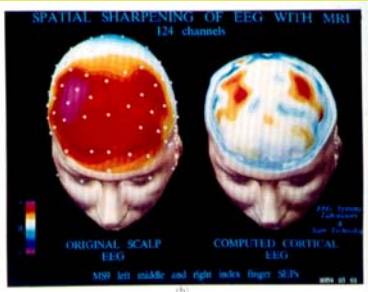


Estimation of Cortical Activity

- The "inverse problem" does not have a unique solution; the "inward continuation problem" does
- Can uniquely calculate the potential at all points on a surface inside the head (e.g., cortical surface) from the scalp surface potential, if no intervening generators exist
- Does not require knowledge of location or number of generators, only knowledge of electrical properties of intervening tissues

Linear Dipole Analysis Methods

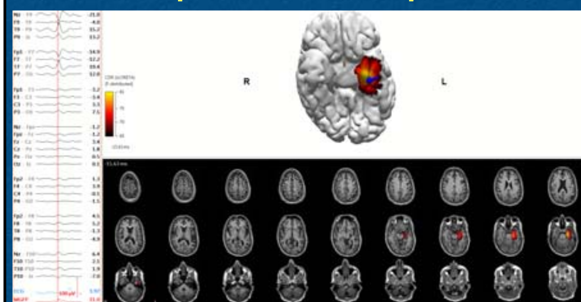
- Assume a large set of dipoles with known locations; find strength of each source to best match actual recorded scalp EEG or MEG by linear regression techniques
- Can fill entire brain volume with dipoles, or can use MRI to determine cortical surface and constrain dipoles to this surface
- Involve forming linear combinations of multiple channels of EEG/MEG data at each instant of time
- May display dipole strengths in time-series or topographic format, or mapped on MRI image slices or rendered cortical surface



(b)

Fig. 7. (a) Deblurred steady-state evoked potentials (EP's) elicited by 14.92-Hz stimulation (with occasional missing stimuli) of left middle, right middle and right index fingers of a normal subject (MS9). All three cases show the expected contralateral maximum in activity. (b) Original (left) and deblurred (right) EP's of subject MS9 in response to 14.92-Hz stimulation of left middle and right index fingers. The white dots on the left represent the 124 scalp EEG recording positions. The increase in spatial detail produced by the Deblurring procedure is apparent.

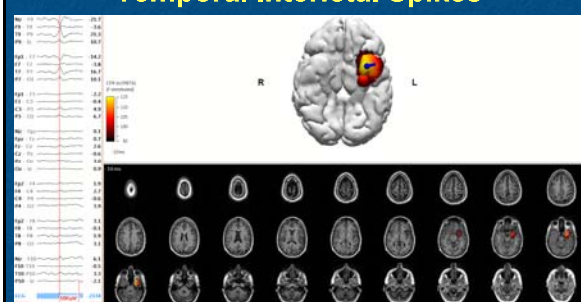
sLORETA Map of Averaged Left Temporal Interictal Spikes



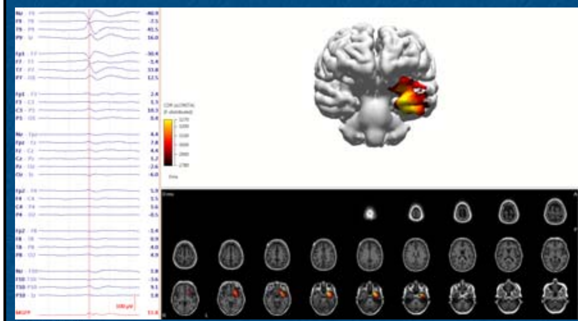
Model Dependent Methods

- Attempt to solve the <u>Inverse Problem</u>: find the intracranial sources generating a known distribution of scalp potentials or magnetic fields
- The general <u>Inverse Problem</u> has no unique solution
- Most approaches assume that EEG or MEG is generated by intracranial dipoles
- This assumption most useful for small generators, e.g. generators of certain evoked potential peaks, or of epileptic spikes
- Many generators are <u>not</u> small, but involve widespread cortical areas
- Nonlinear methods very sensitive to initial estimates of dipole locations; also computationally demanding

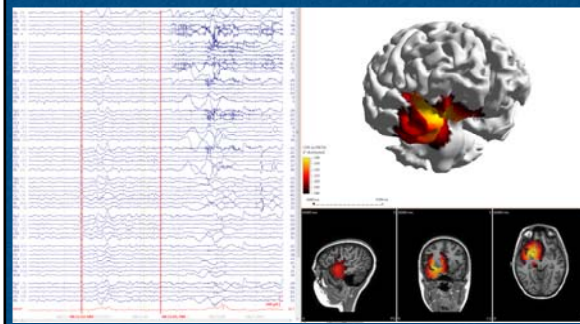
sLORETA Map of Averaged Left Temporal Interictal Spikes



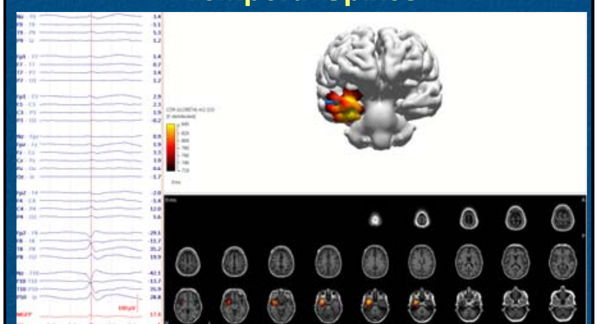
sLORETA Map of Averaged Left Temporal Interictal Spikes



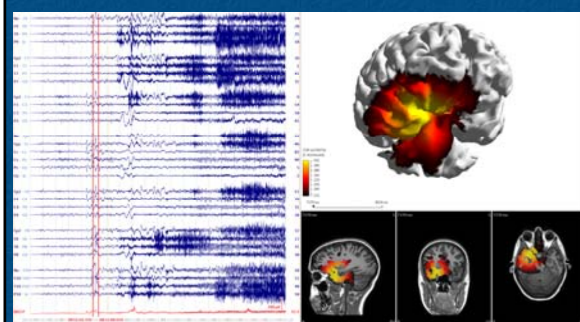
sLORETA Map of Right Temporal Onset Seizure



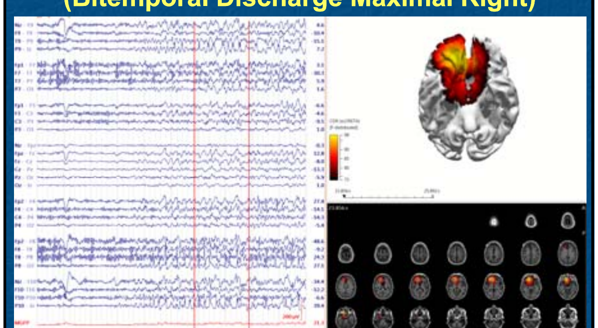
sLORETA Map of Averaged Right Temporal Spikes



sLORETA Map of Sentinal Sharp Wave Before Right Temporal Seizure

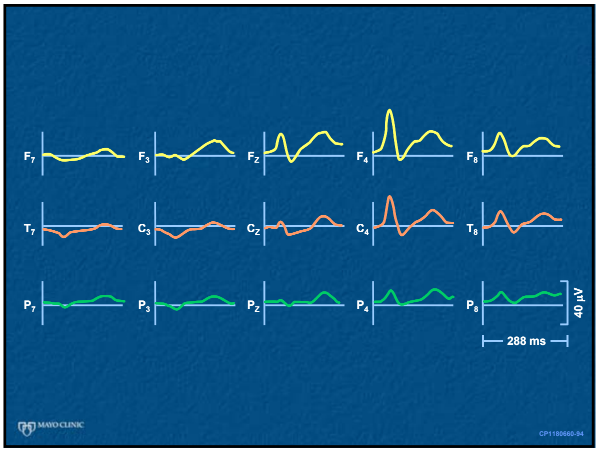


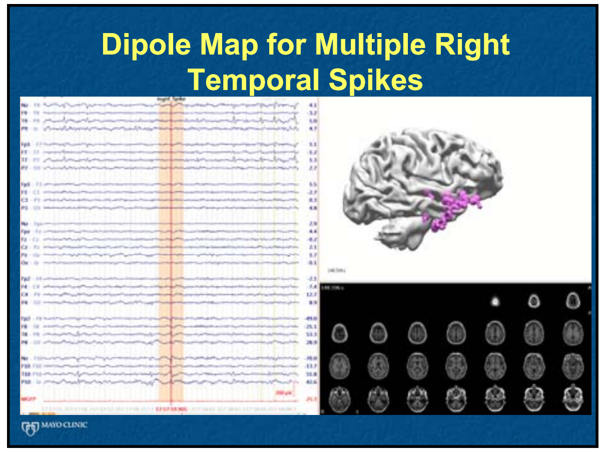
sLORETA Map of Seizure Onset (Bitemporal Discharge Maximal Right)



Nonlinear Dipole Analysis Methods

- One dipole method: tries to find the location, orientation, and strength of 1 dipole which best accounts for the recorded EEG or MEG (requires 6-parameter nonlinear fit to data)
- Two (or more) dipole method: after finding first best-fit dipole, its contribution to scalp EEG or MEG is subtracted and the residual is fit to a 2nd dipole, etc.
- Constrained radial/tangential dipole method: assumes two dipoles with fixed orientations but unknown location and strengths (requires 5-parameter nonlinear fit to data)
- Rotating dipole method: assumes locations of dipoles stay constant during epoch of EEG or MEG and only orientation and strength varies over time (requires 3-parameter nonlinear fit to data)


F7
F3
Fz
F4
F8
T7
C3
Cz
C4
T8
P7
P3
Pz
P4
P8
40 µV
288 ms
MAYO CLINIC


Dipole Map for Multiple Right Temporal Spikes
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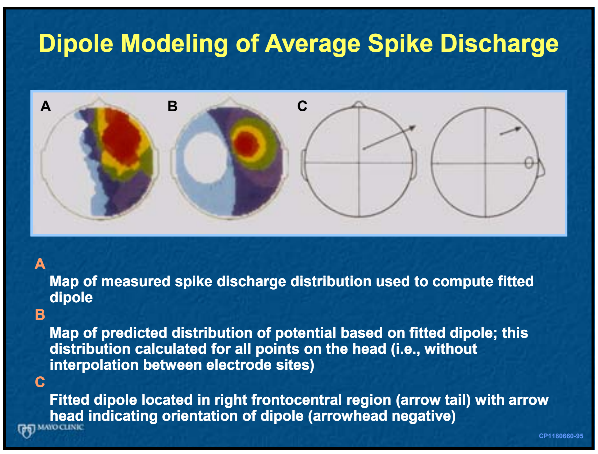
Dipole Modeling of Average Spike Discharge
A
B
C
A
Map of measured spike discharge distribution used to compute fitted dipole
B
Map of predicted distribution of potential based on fitted dipole; this distribution calculated for all points on the head (i.e., without interpolation between electrode sites)
C
Fitted dipole located in right frontocentral region (arrow tail) with arrow head indicating orientation of dipole (arrowhead negative)
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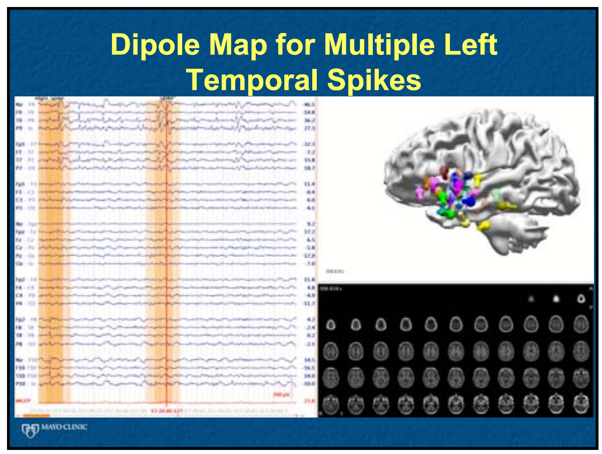
Dipole Map for Multiple Left Temporal Spikes
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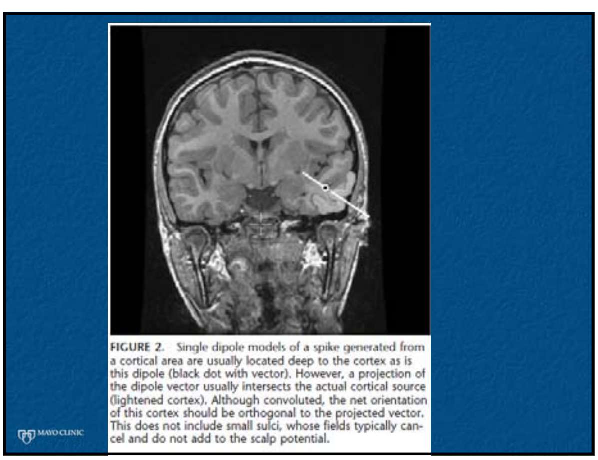
FIGURE 2. Single dipole models of a spike generated from a cortical area are usually located deep to the cortex as is this dipole (black dot with vector). However, a projection of the dipole vector usually intersects the actual cortical source (lightened cortex). Although convoluted, the net orientation of this cortex should be orthogonal to the projected vector. This does not include small sulci, whose fields typically cancel and do not add to the scalp potential.
MAYO CLINIC