EEG Localization

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Electrical Principles (Slide 2)

Surface electrodes are applied to the scalp to record the underlying cortical activity. Each electrode records the synchronized electrical activity arising from a population of neurons in an area of cortex in an angle subtended by the surface electrode of approximately 6 cm^2, slightly more than the surface area of a quarter.

(Slide 3)

Since most of the neurons in the cerebral cortex are radially oriented, the synaptic events in the area just under the surface of the scalp tend to be negative in polarity, reflecting the electrical activity in the extracellular space around apical dendrites as positive ions rush into the cell during excitation. Electrical activity surrounding the soma is generally positive in polarity, but due to its depth, is not typically recorded by surface electrodes

Electrode Placement (Slide 4)

The surface electrodes are placed on the scalp in a systematic manner that standardizes their position in relation to underlying brain regions and ensures a reproducible study between patients or for an individual patient across multiple recordings.

International 10-20 Electrode Placement System

EEG electrodes are placed according to an internationally agreed-upon system called the International 10-20 System established by the American Clinical Neurophysiology Society. This system is based on measurements of the head that are divided into 10% and 20% fractions of the total circumference of the head, the ear to ear measurement and the anterior-posterior measurement from the nasion to the inion.

The electrodes are named based on convention, with letters that represent particular cerebral regions (**F**rontal, **T**emporal, **C**entral, **P**arietal, **O**ccipital), and numbers that represent sidedness. Odd numbered electrodes are on the left, even numbered on the right, and electrodes with a “z” designation at the midline.

Recording and display conventions (Slide 5)

The EEG machine is a *differential amplifier*. It takes the electrical information from one signal source or electrode and compares it to another source, rejecting any common features (*common mode rejection*). The resulting signal reflects a measurement of the net difference in voltage between the two electrodes (here designated as gridpoints **G1** and **G2**) over time. In this way the EEG displays a continuous tracing of the electrical activity from a particular region of the cortex in relationship to another cortical region or in relationship to a non-brain reference.

(Slide 6)
By convention, the tracing for each *channel* of the EEG reflects the electrical activity of the first electrode or gridpoint (**G1**) in reference to the second (**G2**). Again by convention, each derivation or channel displays a waveform with an upward deflection when the net difference of the voltage between the two electrodes is negative (G1-G2<0). If G1 is positive or less negative than G2 (G1-G2>0), then the waveform has a downward deflection. Thus there are two possible interpretations for the waveform produced by each derivation pair. For example, if G1 is more negative than G2 or G2 is more positive than G1, then the waveform points upwards.

There is a rational basis for the convention of displaying electrically negative events as an upward deflection on the EEG. Epileptic discharges result in a paroxysmal negative charge at the surface of the cortex, and on conventional EEG tracings produce a rapid upward deflection often described as a sharp wave or spike. This is why a transient negative potential at any given electrode is described as a *surface negative* event. Vice versa, a transient positive potential is described as a *surface positive* event.

Montages: (Slide 7)

A *montage* is the arrangement of channels on the EEG display or tracing, and each channel consists of paired signal sources. When channel derivations are arranged into montages their sequence provides information that identifies the polarity and location of the cortical activity of interest. Montages can be created in any array, though the most useful ones will be those that allow for rapid visual interpretation of the EEG signals. There are two types of montages: *bipolar* and *referential*. The rules for interpretation for each type of montage are different based on the way they display the information.

Bipolar montages (Slide 8)

Bipolar montages are created by making *chains* of sequential channels where each channel consists of a pair of individual electrodes. In order to convey spatial resolution, the chains of sequential channels can be arranged in anatomically relevant directions. A new chain starts when the sequence begins in a new location. The chains can run in an anterior to posterior direction (AP Bipolar Montage also called the double banana), or in a transverse direction across the head; whatever manner that gives useful localizing information.

(Slide 9)
Rule for interpretation of a bipolar montage: A *phase reversal* in a chain identifies an area where the changes in electrical potential are maximal relative to the surrounding signals. Phase reversals can either be positive or negative in polarity. When there is a negative phase reversal, the waveforms appear to point toward each other; when there is a positive phase reversal the waveforms appear to point away

from each other. Phase reversals often indicate a region of interest electrophysiologically, showing a particular spatial point on the EEG where voltage changes are maximal and/or the spatial extent of voltage changes that surround it, its *field*.

(Slide 10)
In this hypothetical *bipolar* example, systematically evaluating each channel will allow us to make an interpretation of the entire chain and by using the polarity conventions of EEG display, localize electrical events in space.

- In the first channel where **a** is compared to **b**, there is no large net difference in their electrical potentials so the display shows a relatively flat line.
- When **b** is compared to **c**, there is a small downward deflection. This finding suggests that either b is slightly more positive than c or c is more negative than b.
- When **c** is compared to **d**, there is another small deflection downwards also suggesting that c is slightly more positive than d or that d is more negative than c.
- There is a large deflection upwards when **d** is compared to **e**. In this case, d is either much more negative than e or e is much more positive than d.
- When **e** is compared to **f**, there is a small upward deflection suggesting e is either slightly more negative than f or f is slightly more positive than e.
- Finally, in the last channel **f** and **g** are equipotential and the tracing appears relatively flat.

The conclusion from this analysis suggests that either there are two positive generators on either side of the chain or electrode *d* is the region of maximum negativity and the potential of interest. Considering that most cortical events of interest are negative in potential, this finding would be the most logical conclusion. The deflections between channels c-d and d-e represent a *negative phase reversal*.

End of Chain phenomenon (Slide 11)
In this different hypothetical *bipolar* example, systematically evaluating each channel will allow us to make an interpretation of the entire chain and by using the polarity conventions of EEG display, localize electrical events in space.

- In the first channel where **a** is compared to **b**, there is no large net difference in their electrical potentials so the display shows a relatively flat line.
- When **b** is compared to **c**, there is still no large net difference in their electrical potentials so the display shows a relatively flat line.
- When **c** is compared to **d**, there is still no large net difference in their electrical potentials so the display shows a relatively flat line.
- When **d** is compared to **e** there is still no large net difference in their electrical potentials so the display shows a relatively flat line.
- There is a slight downward deflection when **e** is compared to **f**, there is a small downward deflection suggesting e is either slightly more positive than f or f is slightly more negative than e.
- Finally, there is a larger deflection in the last channel **f** and **g.** There is a prominent downward deflection suggesting f is either more positive than g or g is slightly more negative than f.

- Since g is the last in the chain and there is not another electrode on the other side of g to note whether g is positive or negative. The conclusion suggests that a-e are equally positive or that the maximal negative electrical activity may occur at the end of the chain at the electrode array at g.

Referential montages (Slide 12)

Referential montages give the same electrophysiological information but present the information in a slightly different format. The voltage at each electrode is compared to a common or neutral electrode or to mathematical average of a group of electrodes. In a referential montage, the area of highest amplitude is of the most interest because it represents the region most negative or positive in polarity. If there is an apparent "phase reversal" there are two potential interpretations: 1) The reference electrode is active or is involved in the area of interest, or 2) there is a horizontal dipole and that both ends of the dipole are apparent on the montage.

Common referential montages (Slide 13)

<u>Ipsilateral ear reference</u> – Each electrode over the left hemisphere is compared to the left ear electrode; each electrode over the right hemisphere is compared to the right ear electrode.

<u>Contralateral ear reference</u> – Each electrode over one hemisphere is compared to the contralateral ear electrode.

<u>A1-A2 reference</u> – Each electrode is compared to an average of the A1 and A2 electrodes

<u>Cz Reference</u> – each electrode is compared to Cz

<u>Average reference</u> – Each electrode is compared to the average signal of a group of electrodes (usually those least affected by eye movement or muscle artifact

<u>Laplacian anatomic average reference</u> – Each electrode is compared to a weighted average of an immediately surrounding set of electrodes.

(Slide 14)

In this hypothetical referential example (which shows the same electrical event as the first bipolar example), systematically evaluating each channel will allow us to make an interpretation of the entire EEG.

- In the first channel when **a** is compared with the reference electrode, there is no net difference in the electrical potentials so the display shows a relatively flat line.
- When **b** is compared to the reference electrode, there is also little net difference in the electrical potentials so the display also appears as a flat line. These findings suggests that neither a nor b is involved in the discharge of interest.
- When **c** is compared to the reference, there is a small deflection upwards, thus suggesting that c is slightly more negative than the neutral reference.
- There is a large deflection upwards when **d** is compared to the reference. This finding suggests that d is much more negative than the reference.

- When **e** is compared to the reference, there is a small upward deflection suggesting that e is slightly more negative that the reference.
- Finally, the last channel **f** is again equipotential to the reference.

The conclusion from this analysis suggests that electrode *d* is the maximally negative electrode with a field that extends to the surrounding electrodes *c* and to a lesser extent *e*. This analysis of the same set of electrodes draws us to the same conclusion as when we the bipolar montage was analyzed systematically. A referential display also allows quantification of the events recorded since the voltage of each channel is being compared to a common reference.

Horizontal (Tangential) Dipoles (Slide 15)
This type of discharge is often seen in the centrotemporal region near the Rolandic sulcus where the superior temporal bank of the temporal lobe is relatively perpendicular to the scalp surface. Classically there will be a *horizontal dipole* because of this localization. A negative charge is recorded from the central or temporal region with a simultaneous positive charge in the frontal region. Due to the orientation of the discharge, the EEG will be able to pick up both ends of the dipole. This is in contrast to typical discharges arising from the convexity when only the negativity is recorded and the positivity is buried deep within the brain (radially oriented dipole).

In this new hypothetical example, systematically evaluating each channel will allow us to make an interpretation of the entire EEG first in a bipolar montage and then in a referential montage.
Bipolar Montage

- In the first channel where **a** is compared to **b**, there is no large net difference in their electrical potentials so the display shows a relatively flat line.
- When **b** is compared to **c**, there is no large net difference in their electrical potentials so the display shows a relatively flat line.
- When **c** is compared to **d**, there is another small deflection upwards also suggesting that **c** is slightly more negative than **d** or that **d** is more positive than **c**.
- When **d** is compared to **e**, there is another small deflection upwards also suggesting that **d** is slightly more negative than **e** or that **e** is more positive than **d**.
- When **e** is compared to **f**, there is a small downward deflection suggesting **e** is either slightly more positive than **f** or **f** is slightly more negative than **e**.
- Finally, in the last channel **f** and **g**, there is a large deflection upwards when **f** is compared to **g**. In this case, **f** is either much more negative than **g** or **g** is much more positive than **f**.

*Note: There is a positive phase reversal at **e** and a negative phase reversal at **f**.*
The conclusion from this analysis suggests that e is more positive and f has maximal negativity. To be able to see both a positive and negative end suggests a horizontal dipole with the positive end at **e** and the negative end at **f**.

Referential Montage

- In the first channel when **a** is compared with the reference electrode, there is no net difference in the electrical potentials so the display shows a relatively flat line.
- When **b** is compared to the reference electrode, there is also little net difference in the electrical potentials so the display also appears as a flat line. These findings suggests that neither a nor b is involved in the discharge of interest.
- When **c** is compared to the reference, there is still little net difference in the electrical potentials so the display also appears as a flat line. These findings suggests that neither **a, b, nor c** is involved in the discharge of interest.
- When **d** is compared to the reference, there is still little net difference in the electrical potentials so the display also appears as a flat line. These findings suggests that neither **a, b, c, nor d** is involved in the discharge of interest.
- There is a small downward deflection when **e** is compared to the reference. This finding suggests that e is much more positive than the reference.
- When **f** is compared to the reference, there is a large upward deflection suggesting that f is slightly more negative that the reference.
- Finally, the last channel **g** has a slight upward deflection suggestive that g is slightly more negative than the reference.

*Note: There is an apparent phase reversal between **e** and **f**.*

The conclusion from this analysis suggests that electrode *f* is the maximally negative electrode with a field that extends to the surrounding electrodes *g*. There is also an additional conclusion that **e** has a positive polarity. Together this analysis suggests that there may be a horizontal or tangential dipole with both the positive and negative ends of the dipole are apparent. This analysis of the same set of electrodes draws us to the same conclusion as when we the bipolar montage was analyzed systematically. A referential display also allows quantification of the events recorded since the voltage of each channel is being compared to a common reference.