Brainstem Auditory Evoked Potentials (BAEPs)

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Outline of This Talk

• What are BAEPs?

• What are the recording techniques for BAEPs?

• What are the generators of the BAEP components?

• How are BAEP waveforms interpreted?

• Presentation of sample BAEP cases (unknowns) for participants to interpret
Latency Classes of AEPs

- **Long-latency AEPs**
  - Affected by the degree of attention being paid to the stimulus and the information content of the stimulus
  - Markedly attenuated by surgical anesthesia

- **Middle latency AEPs**
  - Independent of attention and stimulus information content
  - Prominently affected by surgical anesthesia
  - Small and subject to myogenic contamination

- **Short latency or “brainstem” AEPs**
  - Easy to record, highly consistent across subjects
  - Independent of attention and stimulus information content
  - May be affected by hypothermia, but relatively unaffected by sedation and surgical levels of anesthesia
• BAEPs are most often examined in a Cz-Ai recording linkage
• Ai is the earlobe or the mastoid on the stimulated side
• BAEPs are typically displayed with vertex positivity as an upward deflection and with the major peaks labeled with Roman numerals, according to the convention of Jewett and Williston (1971)
• Waves IV and V often overlap, forming a "IV-V complex"
• The most consistent peaks are wave I, wave III, and wave V (or the IV-V complex)
• Wave VII is seen in the minority of BAEP recordings
• Waves II and VI are not obligate
• In this waveform, the peak of wave IV is higher than that of wave V
• Often the peak of wave V is higher than that of wave IV, or they are equal in size
• IV or V may be visible only as an inflection on the slope of the other, or they may be fused into a wide IV-V complex
Most BAEPs are Far-field Potentials

- Far-field evoked potentials have small spatial gradients, and small movements of the recording electrodes do not substantially alter the waveforms.
Most BAEPs are Far-field Potentials

- The exception is wave I, which is a near-field potential (a scalp negativity) around the stimulated ear. The negativity at Ai produces a positivity in the Cz-Ai waveform; thus, wave I is an upward deflection in the Cz-Ai BAEP when it is displayed in the usual manner (positive up).

- For the far-field components, since small movements of the recording electrodes do not substantially alter the waveforms, additional closely-spaced recording electrodes do not provide useful information.

- BAEPs are typically recorded using three electrodes:
  - Cz = the vertex
  - Ai = the earlobe or the mastoid on the stimulated side
  - Ac = the earlobe or the mastoid contralateral to the stimulated ear
If a second channel is added, the most useful one is a Cz-Ac recording linkage.
BAEPs in Various Recording Linkages

- Note that in Cz-Ac, wave I is absent and wave III is smaller.
- Wave II is relatively unaffected, as are waves VI and V.
- The latencies of waves IV and V may shift (see dashed lines).
BAEPs in Various Recording Linkages

- Wave IV shifts a little earlier and wave V a little later, helping to separate out the overlapping peaks in a IV-V complex.
- This may facilitate measurement of the wave V latency.
It's okay to measure the latency of wave V in a Cz-Ac channel, but if you do so then the normative data to which it is compared must also have been measured in a Cz-Ac channel.
Effects of Changing the Stimulus Intensity

- As the stimulus intensity is lowered, latencies increase and amplitudes decrease
- Wave V (arrow) is the last component to disappear, at threshold
- A conductive hearing loss can produce the same pattern as a decreased stimulus intensity
- In such a case, an increased stimulus intensity can normalize the BAEP latencies
- An increased stimulus intensity will not normalize delayed BAEP latencies that are due to abnormal neural conductions
BAEP Recording Techniques – Extraoperative

- The commonest stimuli are acoustic clicks, generated by delivering 100 µsec duration monophasic electrical square pulses to an acoustic transducer; tone pips can be used, too
- A single click polarity (rarefaction clicks are typically the best)
- Typical stimulus intensity of 60 - 65 dB nHL; higher intensities may be used in patients with a hearing loss, and lower intensities may be used for hearing threshold measurements
- Stimulus repetition rate of approximately 10/sec, but not an exact submultiple of the line frequency (= 60 Hz in the U.S.)
- Stimulate monaurally, with contralateral white noise masking
- Filter bandpass 100 or 150 Hz to 3,000 Hz
- Typical analysis time (epoch duration) = 10 msec, increase to 15 msec for BAEPs in babies, abnormal BAEPs, BAEPs to lowered stimulus intensities, and intraoperative monitoring
- Typical number of sweeps in an average = 2,000
Generators of the Human BAEPs

- Wave I reflects the first auditory nerve volley in the distal (cochlear) end of the eighth nerve.
- If the nerve is transected more proximally (as was done in these two eighth nerve tumor cases), wave I may persist, demonstrating its origin in the most distal part of the nerve.

The compound action potential to click stimulation, recorded from the intracranial eighth nerve following resection of a vestibular schwannoma; the arrowheads mark the two afferent volleys within the nerve. The patient’s hearing was preserved during the surgery.

Generators of the Human BAEPs

- Components after wave I are composites of contributions from multiple generators. Why is this? Two reasons:

- (1) Loud sounds, such as are typically used to elicit BAEPs, produce at least two eighth nerve volleys, as is shown here:
Generators of the Human BAEPs

• Components after wave I are composites of contributions from multiple generators. Why is this? Two reasons:

• (2) The anatomy of the brainstem auditory pathways is extremely complex:
  • All first-order afferent auditory axons synapse at the cochlear nucleus
  • Some second-order auditory axons synapse at the superior olivary complex (either ipsilateral or contralateral to the stimulated ear, perhaps with an interposed neuron in the medial nucleus of the trapezoid body), some go directly to the nucleus of the lateral lemniscus, and some go all the way to the inferior colliculus without synapse.
  • Anatomical studies suggest that in higher primates, some second-order auditory axons may project all the way to the medial geniculate nucleus without synapse.
Generators of the Human BAEPs

- Because of the complex anatomy of the brainstem auditory pathways and the two eighth nerve volleys, multiple structures are active simultaneously, and components after wave I are composites of contributions from multiple generators.

- Wave II has two generators:
  - The first afferent volley, which has reached the level of the cochlear nucleus
  - The second afferent volley in the distal cochlear nerve

- While subsequent components have multiple generators, clinical-pathological correlations have identified the major generators for some of them:
  - Wave III predominantly reflects activity in the lower pons, around the region of the superior olivary complex
  - Wave V predominantly reflects activity in the mesencephalon, around the region of the inferior colliculus
BAEP waves I, II, and III are present, but later components are absent, in a 4 year old girl with a brainstem glioma (marked with an asterisk in the MRI). These Cz-Ai BAEP waveforms were recorded at the beginning of the surgery to biopsy the lesion. The pathology report on the biopsy specimen was astrocytoma, WHO grade II.
Generators of the Human BAEPs

- Wave IV and V are usually both affected or both unaffected by pathology, so their major generators are close together, but rarely they are differentially affected. The major generator of wave IV is probably just caudal to the inferior colliculus.

- The superior olivary complex is the first level at which the ascending auditory pathways become bilateral.

- BAEPs are generated in a subset of auditory system with short latencies and a high degree of synaptic security, specialized for sound localization. This subset seems to ascend predominantly ipsilaterally in the brainstem.

- Unilateral abnormalities of wave III and of wave V most often reflect ipsilateral dysfunction (i.e., the abnormal BAEPs are obtained by stimulating the ear ipsilateral to the dysfunction), though this is not the case 100% of the time.
Generators of the Human BAEPs

• In the early literature, which attributed a single anatomical generator to each component, waves VI and VII were ascribed to the medial geniculate nucleus and to the auditory radiations, respectively, based on very sparse evidence.

• Intracranial recordings show that activity in the mesencephalon probably contributes to both wave VI and wave VII; thus, these components may persist even if the medial geniculate nuclei are not functioning.

• Conversely, waves VI and VII are not obligate, and may be absent in patients in whom the medial geniculate nuclei and the auditory radiations are completely normal.

• Therefore, waves VI and VII do not reliably assess the auditory pathways above the mesencephalon, and these components are not used in the interpretation of diagnostic BAEP studies.
Human BAEPs and their Generators - Summary

- The obligate components are waves I, III, and V.
- Waves IV and V may be fused into a IV-V complex with a morphology that varies among subjects.
- Wave I is the eighth nerve compound action potential in the most distal part (the cochlear end) of the eighth nerve.
- All subsequent components are the composites of contributions from multiple generators; for example, wave II receives contributions from the second eighth nerve volley in the distal end of the eighth nerve, and the first eighth nerve volley at the level of the proximal nerve and cochlear nucleus.
- In clinical-pathological correlations, wave III reflects activity within the auditory pathways in the lower pons, and wave V reflects activity at the level of the mesencephalon.
- BAEPs cannot be used to assess the auditory pathways rostral to the mesencephalon.
BAEP Interpretation (Extraoperative)

- BAEP latencies are highly consistent across subjects, whereas amplitudes are much more variable (one possible reason: we are not stimulating supramaximally)

- The only amplitude criterion that is used is the IV-V:I amplitude ratio
  - Measure the amplitude of the IV-V complex and the amplitude of wave I, each from the highest point to the lowest point of the following trough, and take the ratio
  - Usually, the IV-V complex is larger than wave I, so the IV-V:I amplitude ratio is usually greater than 1.0
  - A IV-V:I amplitude ratio of less than 0.5 is abnormal
BAEP Interpretation (Extraoperative)

- Identify components

- Measure the latencies of waves I, III, and V
  - Mnemonic: the normal latencies of waves I, III, and V are roughly 1.5, 3.5, and 5.5 msec

- Calculate the I-III, III-V, and I-V interpeak intervals

- Calculate the right-left differences of these measures

- Measure the amplitudes of wave I and of the IV-V complex, each from the highest peak to the low point of the trough that follows

- Calculate the IV-V:I amplitude ratios

- Compare the above values to the laboratory norms
BAEP Interpretation (Extraoperative)

- You’re not looking at the electrical signal from a single neuron, but from many neurons firing in synchrony
- Temporal dispersion can cause absence of the BAEP
- Absence of the BAEP does not mean the “nothing is getting through”
- Absence of the BAEP is compatible with preservation of hearing
Patterns of BAEP abnormalities

- Absence of wave I and subsequent waves
- Delay of wave I and subsequent waves
- Peripheral auditory dysfunction (conductive or cochlear)
Classification of Cochlear Dysfunction

- When doing Weber/Rinné, cochlear dysfunction and eighth nerve dysfunction are both included in the category “sensorineural” (as opposed to “conductive”).

- When doing BAEPs, cochlear dysfunction is classified as “peripheral” while eighth nerve dysfunction is “central” – this is based on whether wave I is affected.

- Actually, most of the auditory nerve has CNS-type myelin, produced by oligodendroglial cells.
Patterns of BAEP abnormalities

- Normal wave I, absence or delay of wave III and subsequent waves

- Dysfunction between the distal eighth nerve and the lower pons

- If the abnormality is unilateral, and BAEPs are abnormal to stimulation of one ear, the abnormal BAEPs are most often obtained following stimulation of the ear ipsilateral to the lesion – though not always
Patterns of BAEP abnormalities

- Normal waves I and III, absence or delay of wave V
- Dysfunction between the lower pons and the mesencephalon
- If the abnormality is unilateral, and BAEPs are abnormal to stimulation of one ear, the abnormal BAEPs are most often obtained following stimulation of the ear ipsilateral to the lesion – though not always
BAEP Case Presentations
BAEP Interpretation – Normal values

- Norms are for 65 dB nHL, 11/sec rarefaction clicks
- Upper limits of normal (ULN) defined as mean + 3 s.d.

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<tr>
<th></th>
<th>ULN</th>
<th>ULN of R-L diff.</th>
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<tr>
<td>Wave I latency</td>
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<td>Wave III latency</td>
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<td>Wave V latency</td>
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<td>I-III interpeak interval</td>
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<td>I-V interpeak interval</td>
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- Lower limit of normal for the IV-V:I amplitude ratio = 0.50
34 year old man with blurred vision, diplopia, vertigo, and numbness of the fingers; he had a similar episode 5 months ago.
17 year old girl with a prior episode of right facial pain and paresthesias, and a new episode of bilateral arm and leg paresthesias

Left ear stimulation

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Right ear stimulation

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35 year old woman with right hand weakness, numbness, and paresthesias as well as dizziness, imbalance, and diplopia.

Left ear stimulation

| I   | 1.66 |
| III | 3.58 |
| V   | 5.60 |
| I – III | 1.92 |
| III – V | 2.02 |
| I – V | 3.94 |

Right ear stimulation

| I   | 1.60 |
| III | 5.66 |
| V   | 8.52 |
| I – III | 4.06 |
| III – V | 2.86 |
| I – V | 6.92 |
28 year old woman

Left ear stimulation

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Right ear stimulation

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30 year old woman

Left ear stimulation (↑ gain)

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Right ear stimulation

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