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Auditory brainstem responses (ABR) to brief-tone bone-conducted (BC) stimuli

Susan Small, PhD
Associate Professor
Hamber Professor of Clinical Audiology
University of British Columbia
AudiologyOnline, June 15, 2016

TOPIC AREAS TO BE ADDRESSED

- BC ABR to brief-tones -- preamble
- Overview of methodology
- Estimation of infant hearing thresholds
- Isolation of test cochlea
- Case Study
LEARNING OUTCOMES

As a result of this Continuing Education Activity, participants will be able to:

1) Explain how to set-up clinical equipment to conduct brief-tone bone-conduction auditory brainstem testing in infants

2) Estimate bone-conduction hearing thresholds in infants with normal hearing and hearing loss using bone-conduction auditory brainstem testing

3) Explain how to isolate the test cochlea using brief-tone bone-conduction auditory brainstem testing

BC ABR to brief tones-- preamble

Clinical goal for BC testing?
Accurate estimation of BC thresholds to determine type of hearing loss responsible for elevated air-conduction (AC) thresholds

- Conductive?  Sensorineural?  Mixed?
  - How much is conductive?

- Standard practice for pure-tone audiometry
- Should be standard practice for infant ABR testing
**Very Brief History of BC ABR testing:**

- In the late 1970s and 1980s, BC ABR research emerged (brief tones and clicks) – some technical issues arose but research continued

Examples of early studies:
- Mauldin & Jerger (1979) found that adult wave V latencies to BC clicks were longer than AC clicks
- Boezeman et al. (1983) found the same for 2000-Hz brief tones
- Cornacchia et al. (1983) compared AC & BC ABR wave V latencies in infants & adults; found that infant wave V latencies to BC stimuli were prolonged relative to adults

--- Differences in AC vs BC ABR results and maturational effects emerging in ABR research

---

Examples of early studies that focussed on clinical use of brief-tone BC ABR testing in infants:

**Clicks:**

**Brief-tones:**

Examples of more recent infant brief-tone BC ABR research:

(i) feasible to record brief-tone BC ABRs clinically
(ii) frequency- and mode- (AC vs BC) dependent infant-adult differences to be accounted for in their interpretation

---
Joint Committee on Infant Hearing (2007)

“The audiological assessment should include:

... A frequency-specific assessment of the ABR using air-conducted tone bursts and bone-conducted tone bursts when indicated. When permanent hearing loss is detected, frequency-specific ABR testing is needed to determine the degree and configuration of hearing loss in each ear for fitting of amplification devices.”

Overview of methodology
Typical stimuli used to elicit the ABR (e.g., Davis et al., 1984)

Air- and bone-conduction brief tones

*Stimulus parameters*

"2-1-2" (cycles) linearly-gated tones; 5-cycle Blackman tones (no plateau)

500 Hz: AC/BC 4 ms rise/fall, 2 ms plateau; 10 ms

1000 Hz: AC/BC 2 ms rise/fall, 1 ms plateau; 5 ms

2000 Hz: AC/BC 1 ms rise/fall, 0.5 ms plateau; 2.5 ms

4000 Hz: AC 0.5 ms rise/fall, 0.25 ms plateau; 1.25 ms

* BC 1 ms rise/fall, 0.25 ms plateau, 2.25 ms

* to reduce ringing

(Small & Stapells, 2003)
Calibration

Supra-aural TDH49/ER3-A insert earphones/B71 transducer

UNITs: $\text{dB peak (peak hold) minus 3 dB} = \text{dB ppe}$

**AC: dB ppe SPL**

**BC: dB ppe re: 1 $\mu$N**

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>500 Hz</th>
<th>1000 Hz</th>
<th>2000 Hz</th>
<th>4000 Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC TDH 49 &amp; AC ER3-A BC</td>
<td>25</td>
<td>67</td>
<td>23</td>
<td>54</td>
</tr>
<tr>
<td>AC TDH 49 &amp; AC ER3-A BC</td>
<td>22</td>
<td>32</td>
<td>25</td>
<td>26</td>
</tr>
<tr>
<td>AC TDH 49 &amp; AC ER3-A BC</td>
<td>67</td>
<td>23</td>
<td>25</td>
<td>54</td>
</tr>
<tr>
<td>BC TDH 49 &amp; BC ER3-A BC</td>
<td>26</td>
<td>20</td>
<td>49</td>
<td>29</td>
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<tr>
<td>BC TDH 49 &amp; BC ER3-A BC</td>
<td>46</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

(Small & Stapells, 2003)

**ASSR: Bone oscillator coupling method in infants**

- Small et al. (2007) compared infant ASSR & adult behavioural thresholds obtained with elastic headband and hand-held coupling method (for trained individuals)

  - **hand-held**
  - **Elastic head band**

  - No significant differences 500-4000 Hz

  **Caveat:** used trained individuals for both methods

  -- We do not recommend that a parent couple the bone oscillator to their child’s skull

  - BC EHP: clinicians use hand-held method
    - least likely to wake up infant
ASSRs: Bone oscillator placement

- Small et al. (2007) compared infant ASSR thresholds at different positions on the skull

No difference for T versus M position

Significantly poorer for F versus T or M position

- BC EHP: clinicians use the T position method
  - greatest range of intensities available
  - easier to maintain firm consistent placement than M position

EEG recording parameters

- Consider two-channel AC recordings if large asymmetry between ears

Adapted from Stapells & Oates (1997)
**EEG recording parameters**

- **Stimulus left**
  - BC: 2-channel recording

- **Stimulus right**
  - BC: 2-channel recording

➢ **Always use two-channel BC recordings**
**EEG recording parameters**

- **EEG filter:**
  - High Pass: 20-30 Hz
  - Low Pass: 1500-3000 Hz
    - (Slope: 6 or 12 dB/octave, analog)

- **Artifact reject:**
  - Trials exceeding ± 25 µV (equals Nicolet "50 µV")
  - *can reduce this to optimize recording (balance with rejection rate)*

- **# of trials:** Typically 2000 per average
- **# of sweeps:** Two or more as needed to obtain good signal-to-noise ratio
- **Display Scale:** Avoid too large a scale close to threshold

*Adapted from Stapells & Oates (1997)*

---

**Air- and bone-conduction brief tones**

**Setting latency window for signal-to-noise ratio (SNR) & residual noise (RN)**

<table>
<thead>
<tr>
<th></th>
<th>500 Hz</th>
<th>1000 Hz</th>
<th>2000 Hz</th>
<th>4000 Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC &amp; BC</td>
<td>AC &amp; BC</td>
<td>AC &amp; BC</td>
<td>AC &amp; BC</td>
<td></td>
</tr>
<tr>
<td><strong>Start</strong></td>
<td><strong>10.5</strong></td>
<td>7</td>
<td>6.5</td>
<td>5</td>
</tr>
<tr>
<td><strong>End</strong></td>
<td><strong>20.5</strong></td>
<td>17</td>
<td>16.5</td>
<td>15</td>
</tr>
</tbody>
</table>

*Note: should shift 10 ms window later for higher presentation levels to avoid stimulus artifact*

500 Hz BC stimuli > 30 dB re: 1 µN → 14 – 24 ms

*BC: 2-channel recording*
Interpretation of waveforms

**Response present:**
- SNR > 1
- Wave V visually replicates

**Response absent:**
- SNR << 1
- Visually flat
- RN < 0.05-0.08 µV

**Cannot evaluate:**
- SNR << 1
- RN > 0.08 µV
- No repeatable peaks
- Not visually flat

(BCEHP, 2012)

SNR latency windows

Infant: 12 months
BC left mastoid

<table>
<thead>
<tr>
<th>dB nHL</th>
<th>2000 Hz</th>
<th>500 Hz</th>
<th>dB nHL</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td><img src="waveforms_2000Hz_500Hz.png" alt="Waveforms" /></td>
<td><img src="waveforms_2000Hz_500Hz.png" alt="Waveforms" /></td>
<td>50</td>
</tr>
<tr>
<td>30</td>
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</tr>
<tr>
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<td><img src="waveforms_2000Hz_500Hz.png" alt="Waveforms" /></td>
<td>20</td>
</tr>
</tbody>
</table>

6/15/2016
What does the absence or presence of a response mean re: the infant’s hearing?

• need to relate these results to what is “normal” or “near normal” for AC & BC stimuli for infants

• need to know how these elevated responses predict the degree & type of hearing loss
Definition of terms (BCEHP, 2012)

*Normal behavioural threshold:*
- 25 dB HL

*Normal ABR maximum level:*
- ABR presentation level at which the majority of normal-hearing infants have a response present

  ![Diagram](image)

*eHL correction:*
- Correction factor used to estimate behavioural hearing threshold (dB HL) from the ABR threshold (dB nHL)

\[
\text{ABR threshold (dB nHL)} - \text{eHL correction (dB)} = \text{estimated behavioural threshold (dB HL)}
\]

---

Normal ABR maximum levels & eHL correction for infants

*Air- and bone-conduction ABR*

<table>
<thead>
<tr>
<th></th>
<th>500 Hz</th>
<th>1000 Hz</th>
<th>2000 Hz</th>
<th>4000 Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td>BC EHP</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal ABR Max (dB nHL)</td>
<td>35</td>
<td>35</td>
<td>30</td>
<td>25</td>
</tr>
<tr>
<td>Range in literature</td>
<td>30-35</td>
<td>30-35</td>
<td>20-30</td>
<td>20-25</td>
</tr>
<tr>
<td>BC EHP eHL correction (dB)</td>
<td>10</td>
<td>10</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Range in literature</td>
<td>10-15</td>
<td>5-10</td>
<td>0-5</td>
<td>-5-0</td>
</tr>
</tbody>
</table>

(BC-EHP 2012, 2015; Small & Stapelis, Ch. 21, 2017)
### Normal ABR maximum levels & eHL correction for infants

**Air- and bone-conduction ABR**

<table>
<thead>
<tr>
<th></th>
<th>500 Hz</th>
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<th>4000 Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC</td>
<td>BC</td>
<td>AC</td>
<td>BC</td>
<td>AC</td>
</tr>
</tbody>
</table>

**BC EHP**

<table>
<thead>
<tr>
<th>Normal ABR Max (dB nHL)</th>
<th>35</th>
<th>20</th>
<th>35</th>
<th>na</th>
<th>30</th>
<th>30</th>
<th>25</th>
<th>na</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range in literature</td>
<td>30-35</td>
<td>20</td>
<td>30-35</td>
<td>na</td>
<td>20-30</td>
<td>30</td>
<td>20-25</td>
<td>na</td>
</tr>
</tbody>
</table>

**BC EHP**

<table>
<thead>
<tr>
<th>eHL correction (dB)</th>
<th>10</th>
<th>5</th>
<th>10</th>
<th>na</th>
<th>5</th>
<th>5</th>
<th>0</th>
<th>na</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range in literature</td>
<td>10-15</td>
<td>-5</td>
<td>5-10</td>
<td>na</td>
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<td>5</td>
<td>-5-0</td>
<td>na</td>
</tr>
</tbody>
</table>

*(BC-EHP 2012, 2015; Small & Stapells, Ch. 21, 2017)*

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**School of Audiology and Speech Sciences**

*Blending real-life learning with sound science.*

---

**Estimation of infant hearing thresholds**
**Baby X**

**Air-Conduction, 2000 Hz**

- **80 dBnHL:** Elevated threshold @ 60 dB nHL
- **60 dBnHL:** Absent OAE
- **50 dBnHL:** Absent OAE
- **30 dBnHL:** Normal

**Flat Tympanogram, Absent OAE**

**Conductive?**

---

**Baby X**

**Air-Conduction, 2000 Hz**

- **80 dBnHL:** Elevated threshold @ 60 dB nHL
- **60 dBnHL:** Absent OAE
- **50 dBnHL:** Absent OAE
- **30 dBnHL:** Normal

**Flat Tympanogram, Absent OAE**

**Conductive?**

*Could be sensorineural or mixed! Need BC ABR testing to be sure!*

---

6/15/2016
If audiologist conducts only AC ABR testing and tympanometry & otoacoustic emissions (OAEs) to identify a conductive component  

- May lead to error

• Tympanometry in very young infants:  
  - may fail to identify middle-ear involvement  
  - flat tympanogram does not assess amount of hearing loss attributed to the conductive component

• OAEs:  
  - sensitive to middle-ear involvement but only helpful if present

Only BC thresholds can distinguish between sensorineural, conductive and mixed losses  

AND

determine magnitude of conductive loss
How well do BC ABR results predict the nature of the hearing loss (conductive versus sensorineural loss?)

Data collected from BC EHP diagnostic follow up:

<table>
<thead>
<tr>
<th>Nature of loss is certain</th>
<th>All data (includes cases where assumptions made)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>500 Hz</td>
<td>91.9% (65 cases)</td>
</tr>
<tr>
<td></td>
<td>81.2% (126 cases)</td>
</tr>
<tr>
<td>2000 Hz</td>
<td>94.2% (37 cases)</td>
</tr>
<tr>
<td></td>
<td>93.7% (49 cases)</td>
</tr>
</tbody>
</table>

(Hatton, Janssen & Stapells, 2012)

Where does BC ABR testing fit in the diagnostic protocol?

- **☑** Want BC ABR thresholds **early** in diagnostic testing to avoid delays in medical follow-up or intervention
- **☑** BC testing occurs after AC thresholds are shown to be elevated in at least one ear at 2000 Hz (> normal max) -- **before AC threshold search**

BCEHP, 2012
BC EHP ABR Test Protocol (2012)

Tone-ABR Test Sequence (partial)

Begin AC at 2000 Hz at normal max Ear#1 ~ 30 dB nHL

Go to 500 Hz @ normal max ~ 35 dB nHL

Case 1: Diagnostic ABR following “refer” from BC EHP

NORMAL BILATERALLY
Isolation of test cochlea

**INFANTS**
- Clinical masking?
  -- IA for AC stimuli are not known
  -- IA for BC have been approximated with indirect measures (ABR & ASSR data)
- effective masking levels for BC not known for ABR (BC ASSR data available)
- are corrections for occlusion effect needed? (BC ASSR data available)

**ADULTS**
- Use masking to isolate test ear as needed
  - interaural attenuation (IA) & effective masking levels for AC & BC stimuli are well established
  - corrections for occlusion effect are known
<table>
<thead>
<tr>
<th>Study</th>
<th>Method</th>
<th>Indirect measure</th>
<th>Age</th>
<th>Interaural Attenuation (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yang &amp; Stuart 1987</td>
<td>ABR clicks</td>
<td>Wave V latency</td>
<td>Adult</td>
<td>0-10</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Neonate 25-35</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>12 months 15-25</td>
<td></td>
</tr>
<tr>
<td>Small &amp; Stapells 2008</td>
<td>ASSR- AM/FM 500-1000 Hz Fc</td>
<td>Ipsi/contra asymmetries</td>
<td>Adult 0-10</td>
<td>0-10</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0-6 months 10-30</td>
<td></td>
</tr>
</tbody>
</table>
### Interaural attenuation of BC stimuli – indirect measures

<table>
<thead>
<tr>
<th>Study</th>
<th>Method</th>
<th>Indirect measure</th>
<th>Age</th>
<th>Interaural Attenuation (dB)</th>
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<tr>
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<tr>
<td></td>
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<td></td>
<td>0-6 months</td>
<td>10-30</td>
</tr>
<tr>
<td>Hansen 2010 (M.Sc. Thesis)</td>
<td>ASSR- AM/FM 1000 Hz</td>
<td>Effective masking levels (Binaural AC)</td>
<td>Adult</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0-7 months</td>
<td>10-15</td>
</tr>
</tbody>
</table>

» Interaural attenuation for BC stimuli in infants is a minimum of 10-35 dB depending on the age

### Utilize ipsilateral/contralateral asymmetries?

» Expected pattern for normal cochleae up to 102 years of age -- normal hearing or conductive loss (e.g., aural atresia)  
  [e.g., Foxe & Stapells, 1993; Stapells & Ruben, 1989; Stapells & Mosseri, 1991]

**BC left mastoid**  
2000 Hz @ 40 dB nHL

**Amplitude:** contra *smaller than* ipsi  
**Latency:** contra *later than* ipsi
Utilize ipsilateral/contralateral asymmetries?

- Expected pattern for normal cochleae up to 102 years of age -- normal hearing or conductive loss (e.g., aural atresia)
  [e.g., Foxe & Stapells, 1993; Stapells & Ruben, 1989; Stapells & Mosseri, 1991]

Amplitude: contra smaller than ipsi  Latency: contra later than ipsi

Bone-conduction ABR

Contra >> IPSI
SEVERE UNILATERAL (RIGHT EAR) SNHL
(Stapells, personal communication)
**Case 2:** 13 months – referred from NHS

2000 Hz BC Right Mastoid

<table>
<thead>
<tr>
<th>dB nHL</th>
<th>Ipsi</th>
<th>Contra</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Which ear is responding? Right ear!

30 & 40 dB nHL: Ipsi > contra

---

13 months – referred from NHS

2000 Hz BC Left Mastoid

<table>
<thead>
<tr>
<th>dB nHL</th>
<th>Ipsi</th>
<th>Contra</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td></td>
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</tr>
</tbody>
</table>

Which ear is responding? Left ear!
Factors contributing to ipsi/contra asymmetries?

1. Greater IA compared to adults due to unfused cranial sutures

2. Infant-adult differences in positioning of neural generators

Evidence: infant AC ABR/ASSRs show consistent ipsi/contra asymmetries; adult AC ABR/ASSRs do not show these patterns

(Reviewed in Small & Stapells, 2017)

- Two-channel recordings are routinely used by our provincial program (BCEHP) for BC brief-tone ABRs

NOTE: Can also use ipsi and contra EEG channel for AC if a large difference in thresholds between ears exists (and contra masking not used)

What if ipsi/contra asymmetries in BC ABRs are ambiguous?

- Need clinical masking

Main reason masking not routinely used clinically for infant BC ABRs:
  -- effective masking levels (EMLs) for BC ABR stimuli in young infants have not been measured directly

- What do we know about EMLs for BC auditory evoked potentials?

  -- EMLs for infant BC ASSR stimuli were estimated for 500-4000 Hz using binaural AC masking (Hansen & Small, 2012; Small, Smyth & Leon, 2014)
### Recommended EMLs (dB SPL) for BC ASSR stimuli presented at 35 dB HL

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>500</th>
<th>1000</th>
<th>2000</th>
<th>4000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infant</td>
<td>81</td>
<td>68</td>
<td>59</td>
<td>45</td>
</tr>
<tr>
<td>Adult</td>
<td>66</td>
<td>*63</td>
<td>*59</td>
<td>55</td>
</tr>
</tbody>
</table>

* Significant infant minus adult EML difference (dB)

- Frequency-dependent infant-adult differences in EMLs except at 2000 Hz

(Hansen & Small, 2012; Small, Smyth & Leon, 2014)

### Is there an occlusion effect (OE) in infants?

- Adults with normal hearing or a sensorineural hearing loss: occluding the ear canal results in a significant improvement in pure-tone BC thresholds.
- Do we need to correct for an OE in infants when we obtain BC thresholds with earphones in place?

We investigated this phenomenon in infants (2 studies):

(i) Small, Hatton & Stapells, 2007
   - no occlusion effect for BC ASSR thresholds 500-4000 Hz

(ii) Small & Hu, 2011
   - Sound pressure in ear canal when occluded: infants >> adults
   - % occurrence of OE:
     - Older infants: OE emerging at 500 & 1000 Hz
     - Young infants: OE absent at 1000 Hz (very small at 500 Hz)
Earphones in or out during BC testing?

- Recommendations (conservative):
  (i) Young infants: leave earphones in place
  (ii) Older infants: remove earphones

Case Study
Case 2: Diagnostic ABR following “refer” from BC EHP

1st ABR

AC 2000 Hz

dB nHL

30

BC 2000 Hz – Left mastoid

dB nHL

60

ipsi > contra

IPS

30

Contra

30

ipsi > contra

IPS

Contra

IPS

ipsi > contra

ipsi > contra

ipsi > contra

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1st ABR

BC 500 Hz

dB nHL

20

Ipsi

Contra

dB nHL

20

Ipsi

Contra

AC 500 Hz

AC 4000 Hz

dB nHL

80

✓

75

×

45

×

45

✓
What we know so far: Elevated AC & BC both ears
- LEFT: severe SNHL at 500 Hz (threshold @ 80 dB nHL) rising to no worse than mild/moderate SNHL at 2000 & 4000 Hz
- RIGHT: at least a moderate SNHL at 2000 Hz

➢ need further ABR testing to fill in gaps – summarized in table on next slide
<table>
<thead>
<tr>
<th>Stimulus</th>
<th>ABR (dB nHL)</th>
<th>Estimated Behavioural Threshold (dB eHL)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RIGHT</td>
<td>LEFT</td>
</tr>
<tr>
<td>AC – 500 Hz</td>
<td>&gt; 100</td>
<td>80</td>
</tr>
<tr>
<td>BC – 500 Hz</td>
<td>&gt; 20</td>
<td>&gt; 20</td>
</tr>
<tr>
<td>AC – 1000 Hz</td>
<td>&gt; 100</td>
<td>≤ 55</td>
</tr>
<tr>
<td>AC – 2000 Hz</td>
<td>&gt; 100</td>
<td>40</td>
</tr>
<tr>
<td>BC – 2000 Hz</td>
<td>&gt; 60</td>
<td>35-60</td>
</tr>
<tr>
<td>AC – 4000 Hz</td>
<td>&gt; 90</td>
<td>25</td>
</tr>
</tbody>
</table>

+ Ipsilateral/contralateral asymmetries (BC & AC) support left ear responding

- 1st appointment: BC ABR established nature & severity of loss L & R
- 2nd and 3rd appointment completed AC ABR testing:
  - L: thresholds at 500, 1000, 2000 & 4000 Hz
  - R: established profound loss
- MRI/CT: confirmed absence of cochlear nerve on the R
  (click ABR– no clear signs of ANSD)

Thoughts?
References


References cont’d


References cont’d


Thank you!