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Auditory Brainstem Responses (ABR) to Brief-tone Bone-conducted Stimuli

Presenter: Susan Small, PhD

Moderator: Carolyn Smaka, AuD, Editor in Chief, AudiologyOnline

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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 Columba
AudiologyOnline, June 15, 2016

NSERC CRSNG

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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

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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**

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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

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

Clicks:

- ❖ **Yang et al. (1987), Stuart et al. (1993, 1994), Gorga et al. (1993)**

Brief-tones:

- ❖ **Gravel et al. (1989), Stapells (1989), Stapells & Ruben (1989), Cone-Wesson (1995), Cone-Wesson & Ramirez (1997), Foxe & Stapells (1993) & Nousak & Stapells (1992); Sininger et al. (1997)**

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

- ❖ **Ferm et al. (2014), Hatton et al. (2012), Vander Werff et al. (2009), & Valeriote & Small (2015)**

(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

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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."

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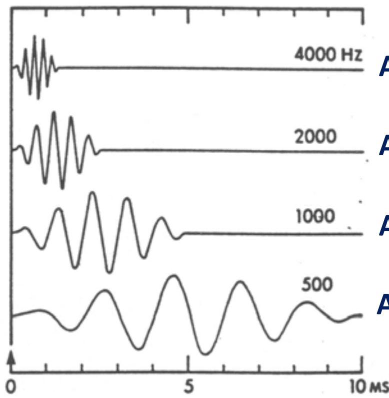
Overview of methodology

Under investigation

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

BC

BC



AC
AC
AC
AC

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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)

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Calibration

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

UNITS: dB peak (peak hold) minus 3 dB = dB ppe x

AC: dB ppe SPL

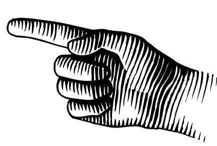
BC: dB ppe re: 1 µN

Acoustic calibration for 0 dB nHL											
500 Hz			1000 Hz			2000 Hz			4000 Hz		
AC TDH 49	AC ER3-A	BC	AC TDH 49	AC ER3-A	BC	AC TDH 49	AC ER3-A	BC	AC TDH 49	AC ER3-A	BC
25	**22**	**67**	**23**	**25**	**54**	**26**	**20**	**49**	**29**	**26**	**46**

(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**

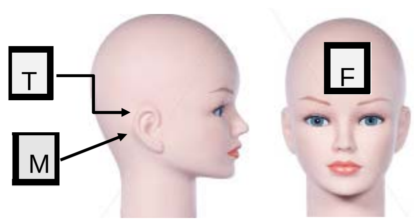
Caveat: used trained individuals for both methods
-- We do not recommend that a parent couple the bone oscillator to their child's skull

- **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 <u>poorer</u> 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

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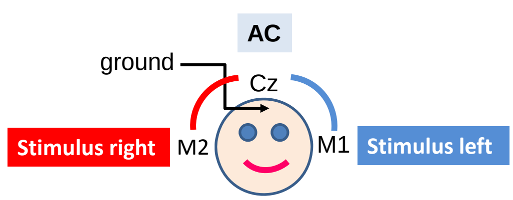
EEG recording parameters



AC: 1-channel recording

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

Adapted from Stapells & Oates (1997)

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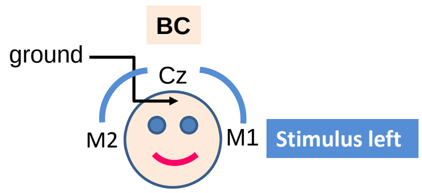
EEG recording parameters



BC*:* 2-channel recording

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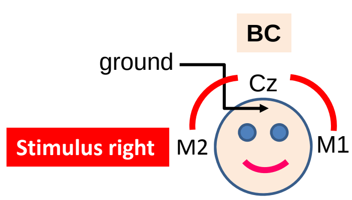
EEG recording parameters



BC*:* 2-channel recording

➢ ***Always use two-channel BC recordings***

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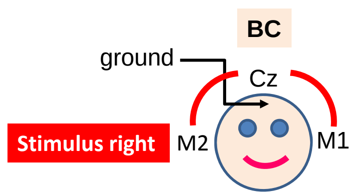
EEG recording parameters



BC: 2-channel recording

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)

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Air- and bone-conduction brief tones

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

	500 Hz	1000 Hz	2000 Hz	4000 Hz
	AC & BC	AC & BC	AC & BC	AC & BC
Start*	**10.5**	**7**	**6.5**	**5**
End	**20.5**	**17**	**16.5**	**15**

*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

(BCEHP, 2012)

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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

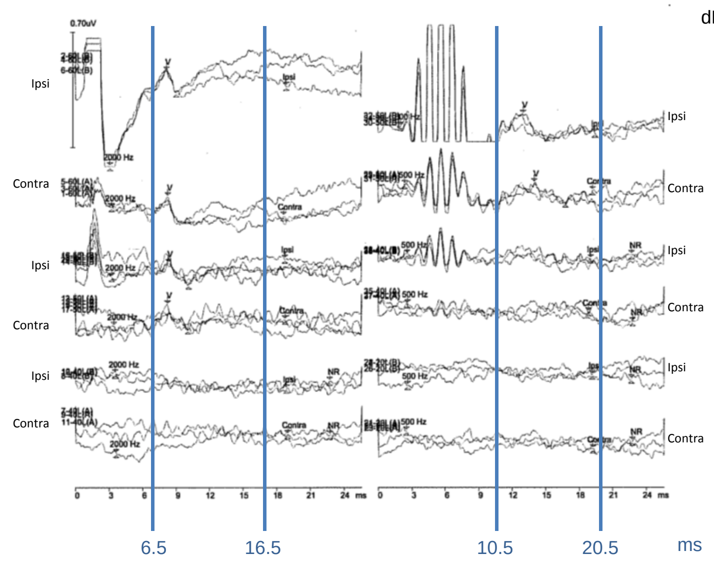
Infant: 12 months

BC left mastoid

2000 Hz | 500 Hz

dB nHL (2000 Hz): ✓ 60, ✓ 50, ✗ 40

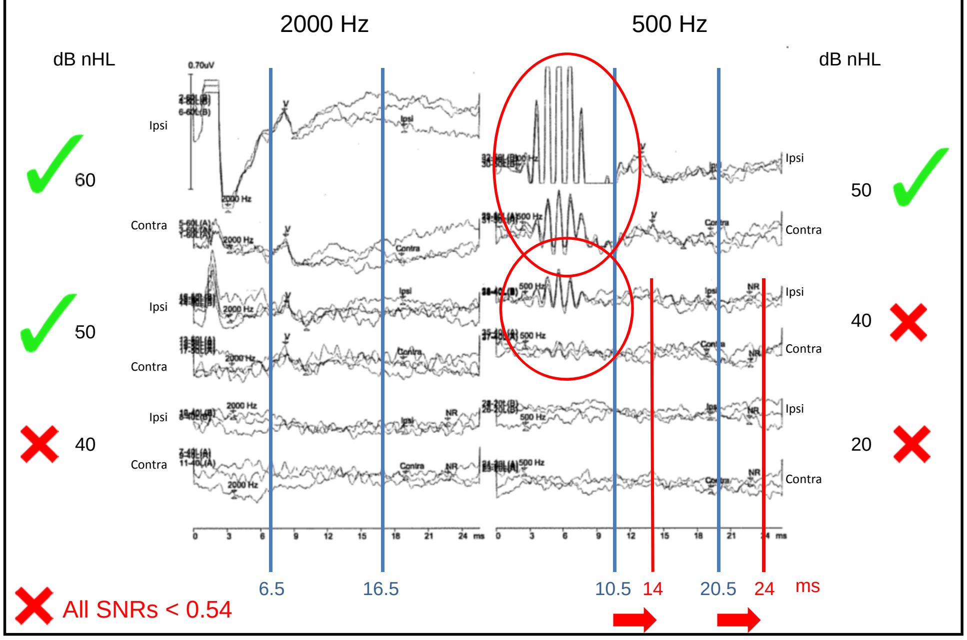
dB nHL (500 Hz): 50, 40, 20



SNR latency windows

Infant: 12 months

BC left mastoid



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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**

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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**

normal ? → **response must be present at normal ABR max**

***eHL correction*:**

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

ABR threshold (dB nHL) — **eHL correction (dB)** = **estimated behavioural threshold (dB HL)**

Normal ABR maximum levels & eHL correction for infants
Air- and bone-conduction ABR

	500 Hz	1000 Hz	2000 Hz	4000 Hz
	AC	AC	AC	AC
BC EHP Normal ABR Max (dB nHL)	**35**	**35**	**30**	**25**
Range in literature	*30-35*	*30-35*	*20-30*	*20-25*
BC EHP eHL correction (dB)	**10**	**10**	**5**	**0**
Range in literature	*10-15*	*5-10*	*0-5*	*-5-0*

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

Normal ABR maximum levels & eHL correction for infants
Air- and bone-conduction ABR

	500 Hz		1000 Hz		2000 Hz		4000 Hz	
	AC	BC	AC	BC	AC	BC	AC	BC
BC EHP Normal ABR Max (dB nHL)	35	**20**	35	**na**	30	**30**	25	**na**
Range in literature	*30-35*	*20*	*30-35*	*na*	*20-30*	*30*	*20-25*	*na*
BC EHP eHL correction (dB)	10	**5**	10	**na**	5	**5**	0	**na**
Range in literature	*10-15*	*-5*	*5-10*	*na*	*0-5*	*5*	*-5-0*	*na*

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

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Estimation of infant hearing thresholds

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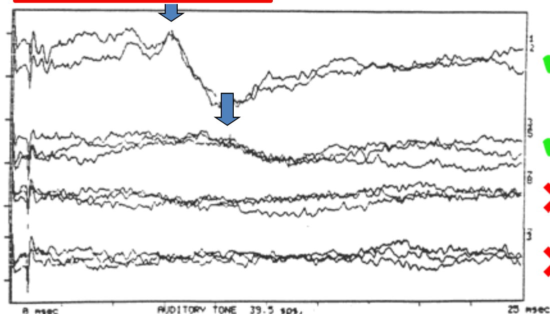
BABY X

AIR-CONDUCTION, 2000 Hz



80 ✓
60 ✓
50 ✗
30 ✗

NORMAL → 30

dBnHL

ELEVATED THRESHOLD @ 60 dB nHL

Flat tympanogram
Absent OAE

Conductive?

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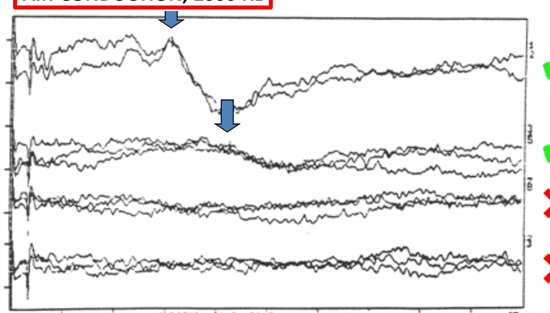
BABY X

AIR-CONDUCTION, 2000 Hz



80 ✓
60 ✓
50 ✗
30 ✗

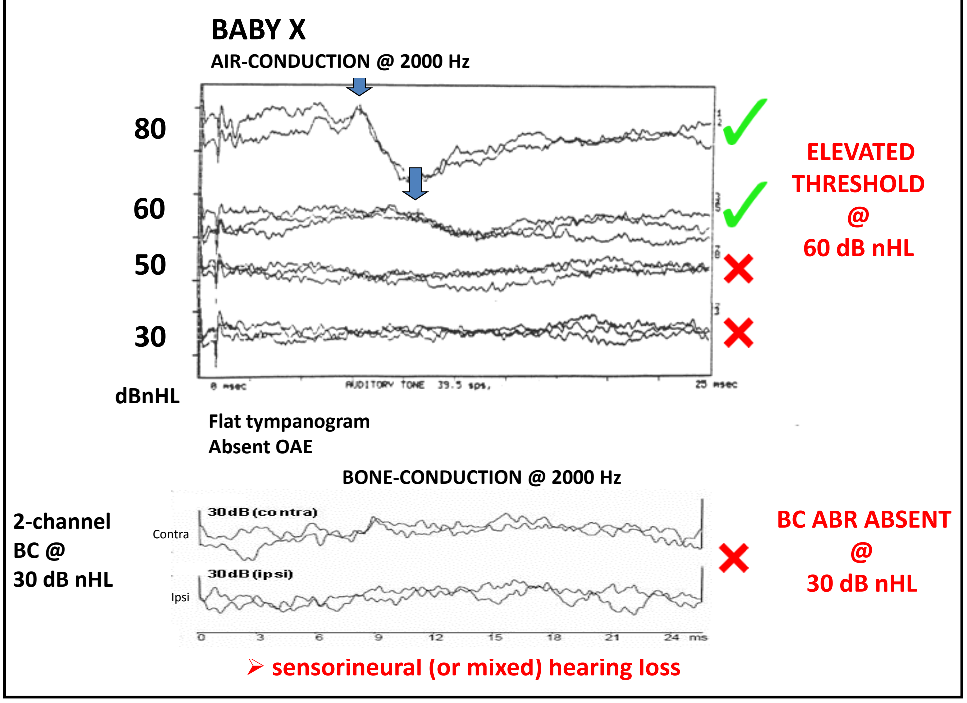
NORMAL → 30

dBnHL

ELEVATED THRESHOLD @ 60 dB nHL

Flat tympanogram
Absent OAE

Conductive?
Could be sensorineural or mixed!
<u>Need BC ABR testing to be sure!</u>



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- If audiologist conducts <u>only</u> AC ABR testing and tympanometry & otoacoustic emmissions (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

<u>AND</u>

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:

	Nature of loss is certain	All data (includes cases where assumptions made)
500 Hz	91.9% (65 cases)	81.2% (126 cases)
2000 Hz	94.2% (37 cases)	93.7% (49 cases)

(Hatton, Janssen & Stapells, 2012)

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Where does BC ABR testing fit in the diagnostic protocol?

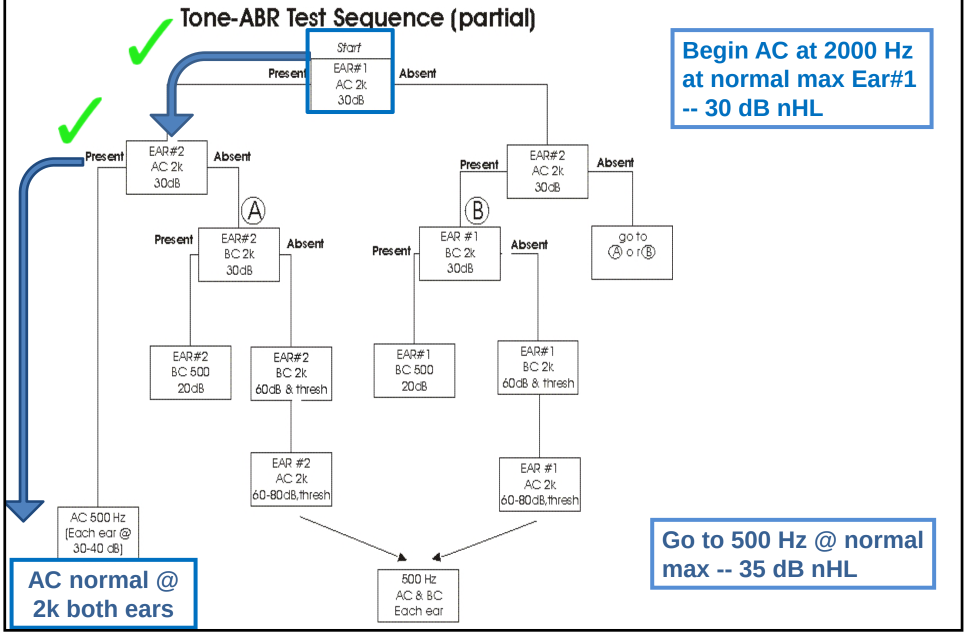
- ❑ After AC thresholds are established for both ears?
- ❑ After AC threshold search, tympanometry & OAEs?
- ❑ Before AC testing?
- ☑ As soon as AC thresholds are determined to be elevated?

➢ **Want BC ABR thresholds <u>early</u> 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)



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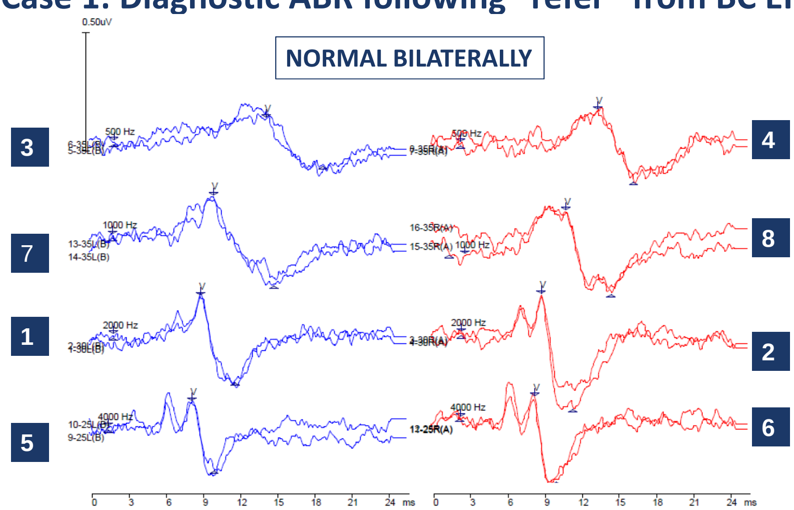
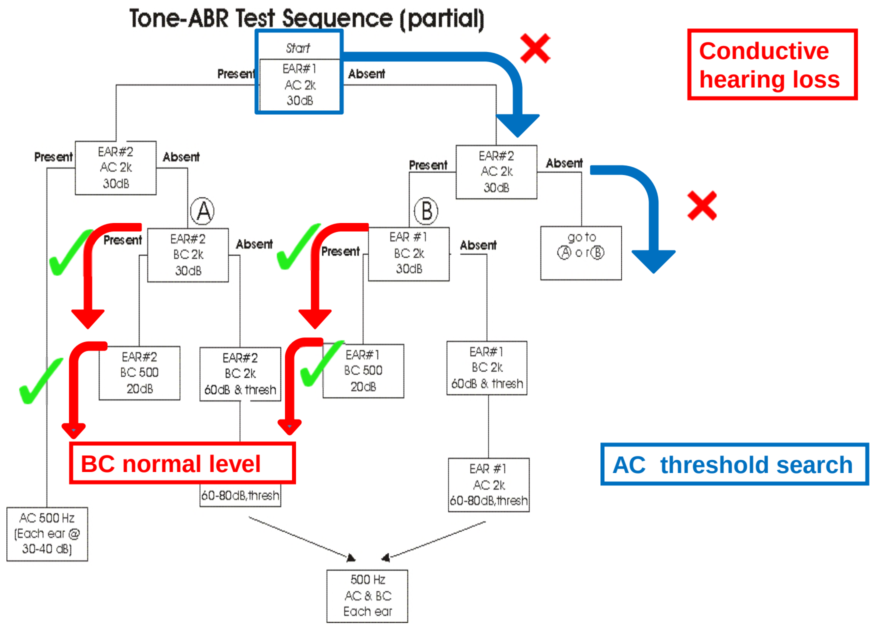
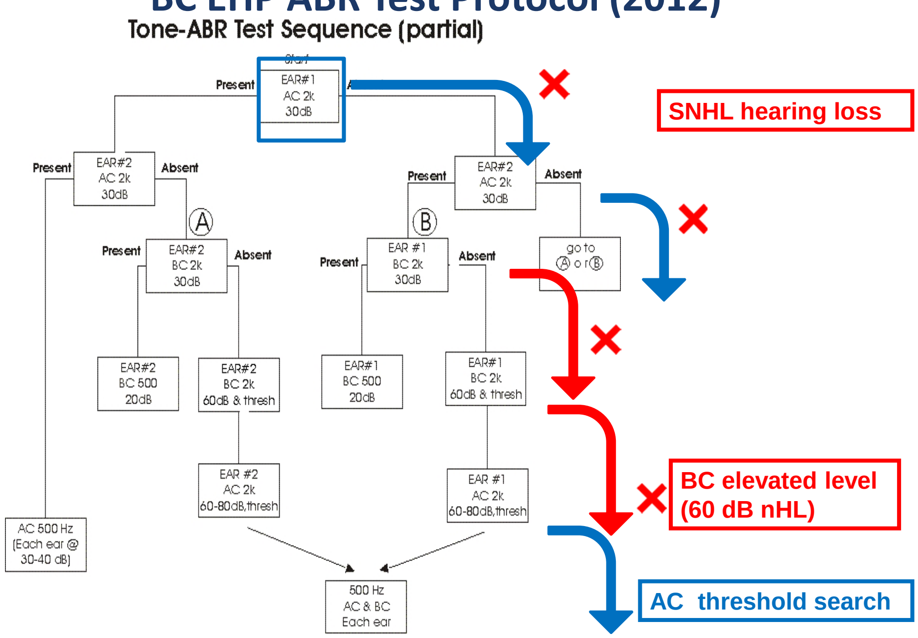
Case 1: Diagnostic ABR following "refer" from BC EHP



BC EHP ABR Test Protocol (2012)



BC EHP ABR Test Protocol (2012)



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Isolation of test cochlea

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BC ABR: Isolation of test cochlea

INFANTS

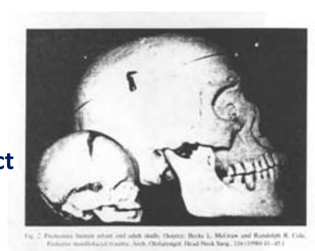
- Clinical masking?

-- 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 know 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 attentuation (IA) & effective masking levels for AC & BC stimuli are well established

- corrections for occlusion effect are known

Interaural attenuation of BC stimuli – indirect measures

Study	Method	Indirect measure	Age	Interaural Attenuation (dB)
Yang & Stuart 1987	ABR clicks	Wave V latency	Adult	0-10
			Neonate	**25-35**
			12 months	**15-25**

Interaural attenuation of BC stimuli – indirect measures

Study	Method	Indirect measure	Age	Interaural Attenuation (dB)
Yang & Stuart 1987	ABR clicks	Wave V latency	Adult	0-10
			Neonate	**25-35**
			12 months	**15-25**
Small & Stapells 2008	ASSR- AM/FM 500-1000 Hz Fc	Ipsi/contra asymmetries	Adult	0-10
			0-6 months	**10-30**

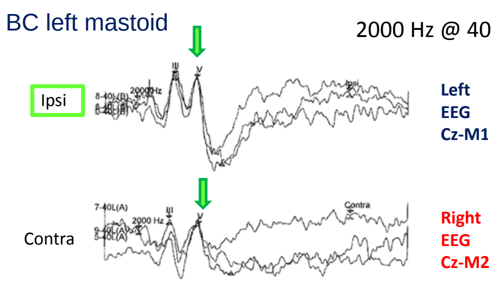
Interaural attenuation of BC stimuli – indirect measures

Study	Method	Indirect measure	Age	Interaural Attenuation (dB)
Yang et al 1987	ABR clicks	Wave V latency	Adult	0-10
			Neonate	**25-35**
			12 months	**15-25**
Small & Stapells 2008	ASSR- AM/FM 500-1000 Hz Fc	Ipsi/contra asymmetries	Adult	0-10
			0-6 months	**10-30**
Hansen 2010 (M.Sc. Thesis)	ASSR- AM/FM 1000 Hz	Effective masking levels (Binaural AC)	Adult	0
			0-7 months	**10-15**

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

Utilize ipsilateral/contralateral asymmetries?

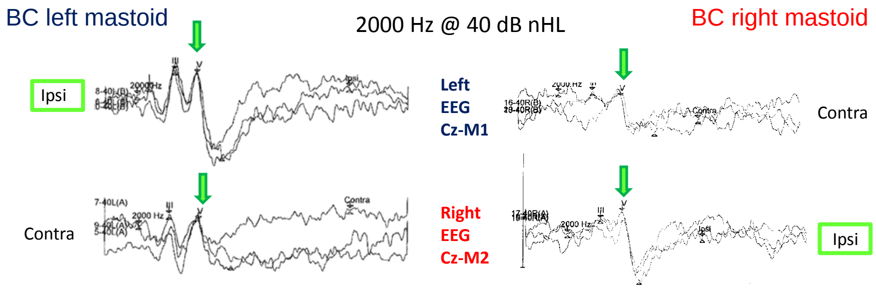
- Expected pattern for normal cochleae up to 1-2 years of age -- normal hearing or conductive loss (e.g., aural atresia)
  [e.g., Foxe & Stapells, 1993; Stapells & Ruben, 1989; Stapells & Mosseri, 1991]



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

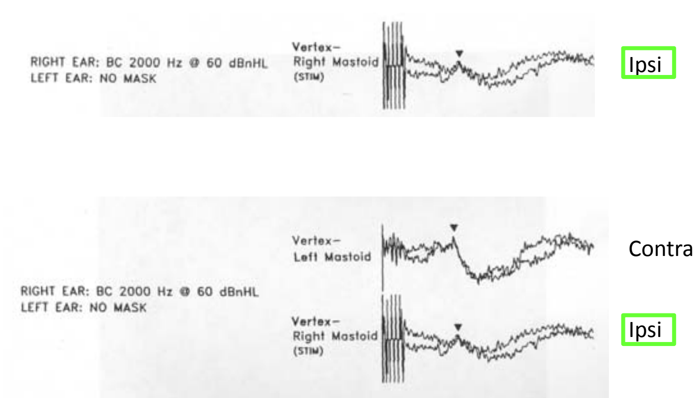
Utilize ipsilateral/contralateral asymmetries?

- 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)

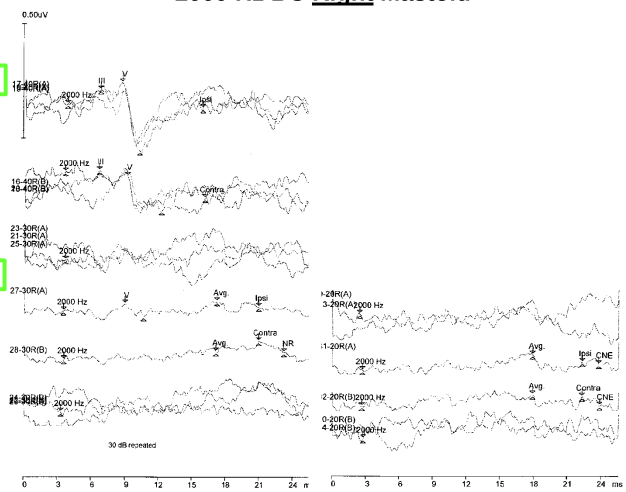
Case 2: 13 months – referred from NHS

Ch A = right
Ch B = left

2000 Hz BC Right Mastoid

dB nHL

dB nHL



40 — Ipsi ✓, Contra ✓

30 — Ipsi ✓, Contra ✗

20 — Ipsi, Contra ?

30 & 40 dB nHL: Ipsi > contra

Which ear is responding? **Right ear!**

---

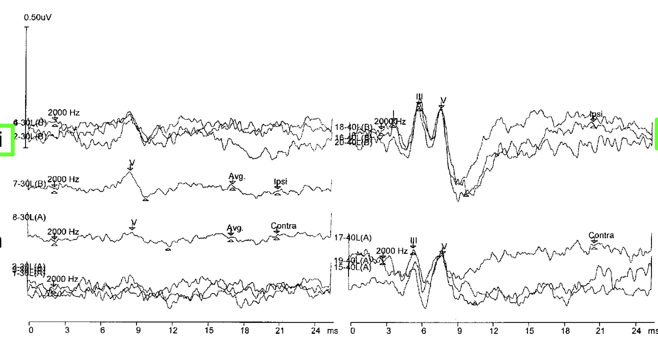
13 months – referred from NHS

Ch A = right
Ch B = left

2000 Hz BC Left Mastoid

dB nHL

dB nHL



30 — Ipsi ✓, Contra ✓

40 — Ipsi ✓, Contra ✓

Which ear is responding? **Left ear!**

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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)

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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)

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Recommended EMLs (dB SPL) for BC ASSR stimuli presented at 35 dB HL

	Frequency (Hz)			
	500	1000	2000	4000
Infant	81	68	59	45
Adult	66	63	59	55
Difference	15 *	5 *		-10 *

** 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)

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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)**

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Earphones in or out during BC testing?

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

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Case Study

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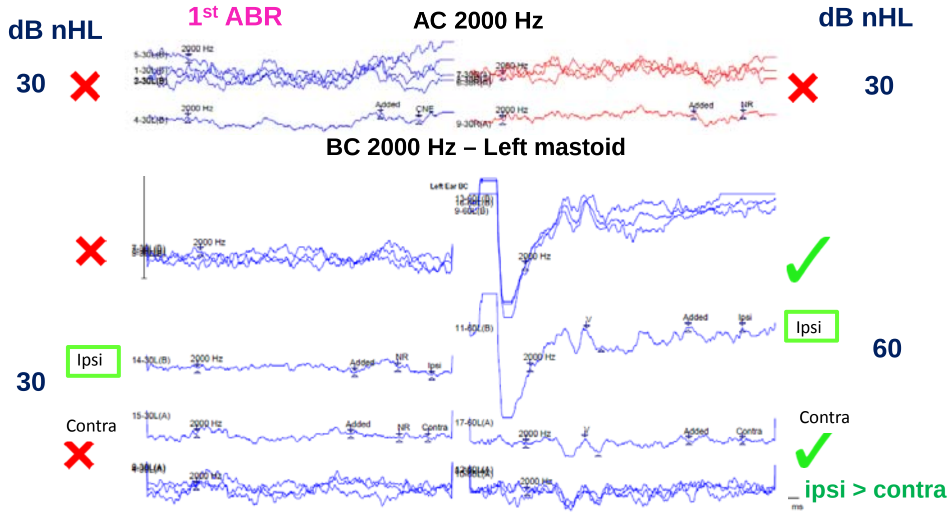
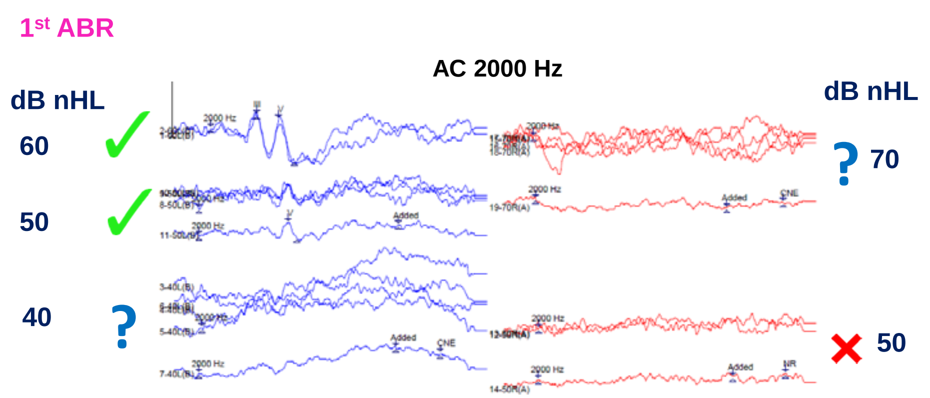
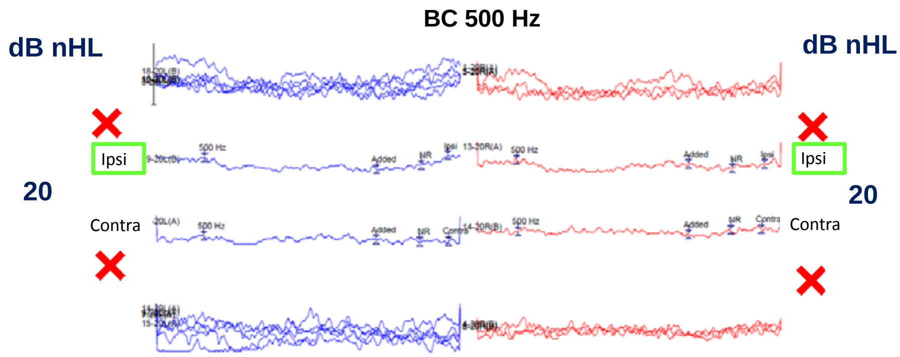
Case 2: Diagnostic ABR following "refer" from BC EHP

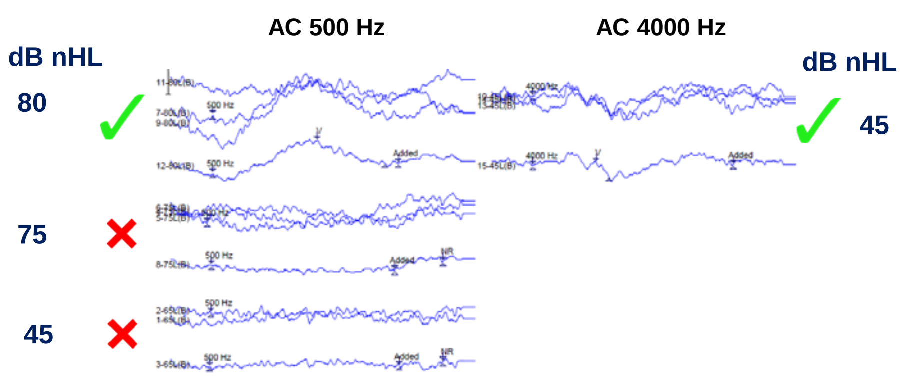




1st ABR

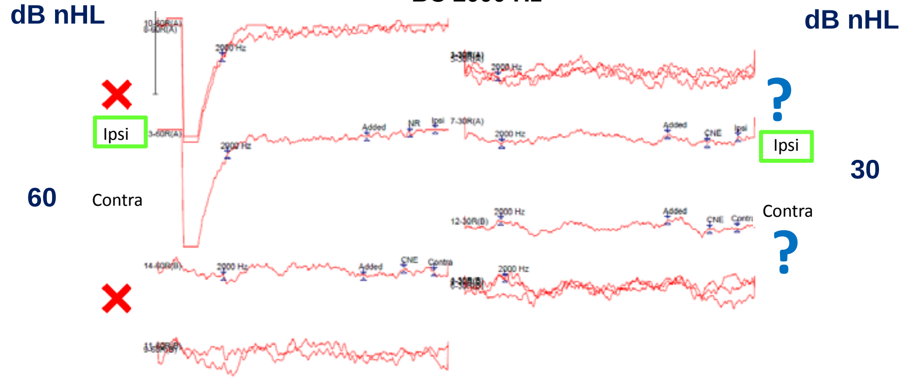


1st ABR



1st ABR

BC 2000 Hz



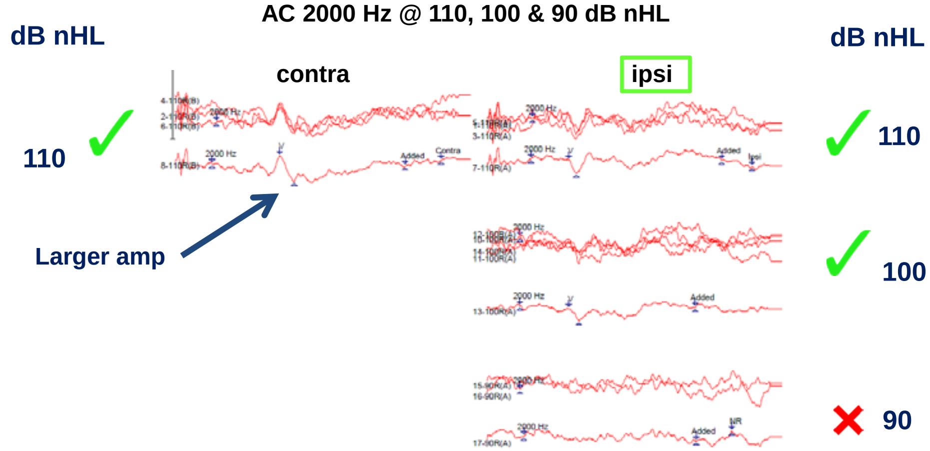
What we know so far: Elevated AC & BC both ears

- 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

3rd ABR

AC 2000 Hz @ 110, 100 & 90 dB nHL



Stimulus	ABR (dB nHL)		Estimated Behavioural Threshold (dB eHL)	
	RIGHT	LEFT	RIGHT	LEFT
AC – 500 Hz	> 100	80	> 110	70
BC – 500 Hz	> 20	> 20	> 25	>25
AC – 1000 Hz	> 100	≤ 55	> 110	≤ 45
AC – 2000 Hz	> 100	40	> 105	35
BC – 2000 Hz	> 60	35-60	> 65	30-55
AC – 4000 Hz	> 90	25	> 90	25

+ ipsi/contra 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)

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Thoughts?

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Thank you!