Conductive Hearing Loss and Carhart’s Notch

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Conductive Hearing Loss and Carhart’s Notch

- Physics of Sound
- Physics of Conductive Hearing
- Tympanogram and the Acoustic Reflex
- Physiopathology of Carhart’s Notch
- Diagnostic Implications of Carhart’s Notch
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- Physics of Sound
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- Frequency
- Wavelength
- Period
- Amplitude
- Intensity
- Speed
- Direction
- **Frequency**: Cycles per second (Hz)
- Wavelength
- Period
- Amplitude
- Intensity
- Speed
- Direction

\[
\text{frequency} = \frac{\text{cycles}}{\text{time}}
\]
- Frequency
- **Wavelength** distance between repeating units of a propagating wave
- Period
- Amplitude
- Intensity
- Speed
- Direction
• Frequency
• Wavelength
• **Period**  \[\text{Implication of a repeating event}\]
• Amplitude
• Intensity
• Speed
• Direction

\[\text{Period} = \frac{1}{\text{frequency}}\]
• Frequency
• Wavelength
• Period
• **Amplitude**
• Intensity
• Speed
• Direction

The amplitude is a nonnegative scalar measure of a wave's magnitude of oscillation.
- Frequency
- Wavelength
- Period
- Amplitude
- Intensity
- Speed
- Direction

• intensity is a measure of the energy flux.

• "intensity" is not synonymous with "strength", "amplitude", or "level"
Sound Intensity is Analogous to Electrical Flux

\[
\text{Intensity} = \frac{\text{Net Power Radiated}}{4\pi r^2}
\]

- If a point source is radiating energy in three dimensions and there is no energy lost to the medium, then the intensity decreases in proportion to distance from the object squared.

http://web.ncf.ca/ch865/graphics/ElectricFlux
• Frequency
• Wavelength
• Period
• Amplitude
• Intensity
• Speed
• Direction

• distance such a wave travels per unit time

• speed 770 mph, or 1130 ft/s) in dry air at 70 degrees F

• speed of sound
  – increases with the stiffness of the material
  – decreases with the density

\[ c = \sqrt{\frac{C}{\rho}} \]
- Frequency
- Wavelength
- Period
- Amplitude
- Intensity
- Speed
- Direction
Resonance:
The tendency of a system to oscillate at maximum amplitude at certain frequencies

- Small periodic driving forces can produce large amplitude vibrations
- If the monkey pushes the ball at the natural frequency (fundamental frequency) of the swing, the ball will go higher and higher
Haunted Swing

http://www.youtube.com/watch?v=l54W2gM-gYM
Pitch

• not an objective physical property

• a subjective psychophysical attribute

• perceived fundamental frequency of a sound

• perceived pitch may differ because of overtones, or partials, in the sound.
Timbre

- Why two guitars sound different even when they play the same note
- “the psychoacoustician's multidimensional wastebasket category “

Sound Pressure Level

\[ L_p = 10 \log_{10} \left( \frac{p^2}{p_{ref}^2} \right) = 20 \log_{10} \left( \frac{p}{p_{ref}} \right) \text{ dB} \]

• As the human ear can detect sounds with a very wide range of amplitudes, sound pressure is often measured as a level on a logarithmic decibel scale.
Frequency Weighting

- human hearing system is more sensitive to some frequencies than others
Frequency Weighting

humans hear random noise differently from pure tones

D curve designed for measuring aircraft noise

A weighting is most common

C, B, frequency weighing curves have fallen out of use
Sound level, loudness and sound intensity are not the same things.
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Purpose of ME

• To transmit sound energy from the air space in the EAC to the fluid in the cochlea

• This is accomplished by vibration of the ossicles

Adapted from “The Acoustic Reflex,” Richard W. Harris, Ph.D., Brigham Young University
So what if we didn’t have a TM or any ossicles?

- most sound energy would bounce off the oval window
- ~30 dB hearing loss
- Purpose of the TM and the ossicles is to eliminate IMPEDANCE MISMATCH
  - Area advantage
  - Lever advantage
- IMPEDANCE – the resistance to flow of energy
Impedance Mismatch
Area Advantage

\[ 55 \text{ mm}^2 : 3.2 \text{ mm}^2 = 17:1 \]

Adapted from “The Acoustic Reflex,” Richard W. Harris, Ph.D., Brigham Young University
Lever Advantage

The Malleus is 1.3 times longer than the Incus

Adapted from “The Acoustic Reflex,” Richard W. Harris, Ph.D., Brigham Young University
therefore the overall increase in pressure equals:

\[
\text{Log } 22 = 26.84 \text{ dB or } 27 \text{ dB}
\]
Hearing by Bone Conduction

1. Distortional
2. Inertial – Ossicular
3. Osseotympanic
Distortional Conductive Hearing
Distortional Conductive Hearing

- Left: Cochlea at rest
- Middle: Cochlear duct is shortened vertically, causing an upward movement of the basilar membrane
- Right: Cochlear duct is heightened vertically, causing a downward movement of the basilar membrane
Distortional Conductive Hearing

Compression of the cochlea causes a downward movement of the basilar membranes. This occurs because the *round window yields more than the oval window*.

- Further downward movement of the basilar membrane causes deflection of the stericilia and stimulation of the auditory nerve.
Inertial – Ossicular
Osseotympanic plug
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A Guide to Tympanometry for Hearing Screening

Tricia K. Mikolai
Jennifer Duffey, MS, CCC-A
David Adlin
Jerger-Liden Classifications

Admittance

Air Pressure daPa

A
Some Fluid or Ossicular Fixation
Ossicular Disarticulation, Atrophic Tympanic Membrane Scarring

Diagram showing the relationship between admittance and air pressure. The diagram indicates that as air pressure decreases, admittance increases. The specific admittance values and pressure values are marked on the axes.
Middle Ear Effusion, TM Perforation, Cerumen Occlusion

![Diagram showing admittance vs. air pressure daPa relationship with labels for 0.5 mmhos, 1.0 mmhos, and 1.5 mmhos. Point B is indicated on the graph.]
Negative Middle Ear Pressure
The Acoustic Reflex
Anatomy
Normal Acoustic Reflex

1. Normal

Impedance
Stimulus
Up to 40% Normal Persons
Diphasic acoustic reflexes are not completely understood
Fixed Anterior & Posterior Footplates

4. Fixed

Impedance

Stimulus
Acoustic Reflex Morphology

1. Normal

2. Mixed

3. Diphasic

4. Fixed
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Otosclerosis

- Valsalva first described ankylosis of the stapes
- Kessel in 1878 described the first “successful stapes surgery”
  - The patient had fallen off a wagon and struck his head. After a brief spell of unconsciousness, the patient found that his sense of hearing was greatly improved. He later died of injuries.
  - Kessel studied his temporal bones and concluded the stapes had been mobilized.
Uncertain Beginnings

• Miot in 1890 reported that he had used Kessel’s techniques to mobilize 200 stapes’ without a single death or labyrinthine complication!

• 1900: International Congress of Otolaryngologists condemned stapes surgery because of the potential to cause meningitis
Knowledge Expands

• 1916: Holmgren demonstrated that the labyrinth could be safely opened with sterile techniques

• Raymond Thomas Carhart in 1950 first used the term air-bone gap

• 1953: Rosen accidentally mobilized the stapes of a patient under local anesthesia
  – The patient’s hearing improved
Breakthrough Occurs

• 1956 Shea, first stapedectomy with a **microscope**
• 1960, Shea inserted a **Teflon piston** into a small fenestra
• 1960, Schuknecht used a stainless steel wire prosthesis placed against **Gelfoam** to seal the oval window
Decline in Case Volume

- late 1970s: 1st publication recognizing a decline in stapedectomy cases
  - ? backlog of surgical cases before 1960 that had been completed
  - ? fluoride water
  - ? immunization for measles virus

  - Retrospective review of public records of population and case demographics
Stapedectomy Patients are Getting Older

• Evidence of Increased Average Age of Patients with Otosclerosis

    • Retrospective chart review
Stapedectomies per Resident Declined, then Stabilized


-retrospective review
Incidence of Stapedectomies has Declined

<table>
<thead>
<tr>
<th>Year</th>
<th>All ear</th>
<th>Stapes</th>
<th>Type 1</th>
<th>Mx</th>
<th>US Pop (000s)</th>
<th>ENTs</th>
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<td>27</td>
<td>72</td>
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<td>23,379</td>
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<td>256</td>
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<td>42</td>
<td>161</td>
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<td>1986</td>
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<td>19</td>
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<td>127</td>
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<td>1987</td>
<td>176</td>
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<td>1988</td>
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<td>12</td>
<td>33</td>
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<td>26,033</td>
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<td>1995</td>
<td>285</td>
<td>16</td>
<td>66</td>
<td>713</td>
<td>26,280</td>
<td>9086</td>
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<td>1996</td>
<td>899</td>
<td>17</td>
<td>76</td>
<td>686</td>
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<td>2000</td>
<td>28,140</td>
<td></td>
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<td></td>
<td>9417</td>
<td></td>
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<td>2001</td>
<td>28,532</td>
<td></td>
<td></td>
<td></td>
<td>9661</td>
<td></td>
</tr>
</tbody>
</table>

Total ear, all ear operations: Stapes, stapedectomy; type 1, type 1 tympanoplasty; Mx, myringotomy. (Case data from NCHS Vital and Health Statistics, Series T3) US Pop. Total US population rounded to nearest 10,000 (US Census Bureau) ENTs, total number of otolaryngologists (AMA).
Absolute # of Ear Surgeries


-retrospective review
Different Ethnic Prevalence


- 1011 temporal bones from 507 Japanese individuals
- incidence of histological otosclerosis among Japanese
  - 2.56% of individuals
  - 1.48% of the ears
  - Similar to published histological rates among Caucasians
Different Ethnic Prevalence


- clinical otosclerosis was not as prevalent among Japanese
  - low incidence of involvement of foci anterior to the oval window
  - low activity
  - small lesion without involvement of the footplate and/or membranous labyrinth of the inner ear.
Carhart’s Notch

OTOSCLEROSIS
PORNTHAPE KASEMSIRI
Aj. SUTHEE (Advisor)
ent.md.kku.ac.th/site_data/mykku_ent/38/Topic4/otosclerosis.ppt
Carhart’s Notch

- Elevation of bone conduction thresholds:
  - ~5dB at 4000Hz
  - ~10 dB at 1000 Hz
  - ~15 dB at 2000 Hz
  - ~5 dB at 4000 Hz

Caughey, Robert J.; Pitzer, Geoffrey B.; Kesser, Bradley W. Stapedectomy: Demographics in 2006, Otology & Neurotology Volume 27(6), Sept. 2006, pp 769-775 -retrospective review
Tonndorf

Early 1970s

- Described ossicular inertial component of total bone conduction
- Magnitude of the Carhart notch
  - depended on the extent the middle ear contributed to the total bone conduction response in each of several species tested
Early 1970s

- frequency of the notch varied depending on the resonant frequency of the ossicular chain for bone-conducted signals.
  - The resonant frequency of the human ossicular chain was at a relatively high frequency compared with other species.
  - lowest in cats and highest in rats.
Tonndorf

Early 1970s

- Proposed that the Carhart notch peaks at 2,000 Hz due to the loss of the middle ear component close to the resonance point of the ossicular chain.
Carhart’s Notch is Not Present in Every Patient with Otosclerosis

- Early otosclerosis may not affect the entire stapes footplate
- Cochlear otosclerosis can cause a SNHL component
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Yasan, 2007

- Carhart’s notch can appear in:
  - otosclerosis
  - primary malleus fixation
  - otitis media with effusion

Yasan, 2007

305 patients
retrospective chart review

**Inclusion Criteria**

- depression of bone conduction threshold of > 10 dB at 0.5 – 4 kHz frequencies
- CHL improved after surgery

**Exclusion Criteria**

- Unsuccessfully operated ears
  - (ie, > 20 dB air-bone gap)
- Ears with “Carhart’s notch” at > 4 kHz
Yasan, 2007

Data collected:

- Pre-operative diagnosis
- Mobility of the stapes footplate
- Presence of Carhart’s notch
- *Peri-operative middle ear pathology*
- Improvement of hearing loss
- Disappearance of Carhart’s notch
Yasan, 2007

Distribution of Carhat’s Notch (CN) by Middle-Ear Pathology

<table>
<thead>
<tr>
<th>Pathology</th>
<th>Mean age (years)</th>
<th>Total Ears (n)</th>
<th>CN at 1 kHz</th>
<th>CN at 2 kHz</th>
<th>Total CN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cholesteatoma</td>
<td>-</td>
<td>23</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>TM perforation</td>
<td>-</td>
<td>25</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Ossicular defect</td>
<td>-</td>
<td>47</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Granulation otitis</td>
<td>-</td>
<td>52</td>
<td>8</td>
<td>6</td>
<td>14</td>
</tr>
<tr>
<td>Chronic otitits media</td>
<td>32.7 +/- 14.4</td>
<td>147</td>
<td>10</td>
<td>8</td>
<td>18</td>
</tr>
<tr>
<td><strong>Otosclerosis</strong></td>
<td><strong>43.6 +/- 12.5</strong></td>
<td><strong>26</strong></td>
<td><strong>1</strong></td>
<td><strong>17</strong></td>
<td><strong>18</strong></td>
</tr>
<tr>
<td>Middle-ear effusion</td>
<td>19.5 +/- 19.4</td>
<td>70</td>
<td>1</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Tympanosclerosis</td>
<td>23.3 +/- 7.1</td>
<td>61</td>
<td>1</td>
<td>11</td>
<td>12</td>
</tr>
<tr>
<td>Others</td>
<td>31.5 +/- 13.7</td>
<td>11</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>2936 +/- 16.5</strong></td>
<td><strong>315</strong></td>
<td><strong>14</strong></td>
<td><strong>41</strong></td>
<td><strong>55</strong></td>
</tr>
</tbody>
</table>
Prevalence of patients with a condition who have Carhart’s notch (at 1 or 2 kHz):

- Otosclerosis: 73 %
- Tympanosclerosis: 20 %
- Chronic otitis media: 12 %
- O.M.E.: 7.1%
- Ossicular anomaly: 5.0%
Yasan, 2007

If you have a Carhart’s notch in otosclerosis at 2kHz, you are likely to find a fixed stapedial footplate.

Stapes footplate fixation present:
• 1 kHz  2 out of 11 patients
• 2 kHz  32 out of 37 patients
Yasan, 2007

• Mean magnitude of Carhart’s notch was 16.44 +/- 4.35 dB

• Observed no specific relationship between magnitude and middle ear pathology observed
Quantifying the Carhart Effect in Otosclerosis

- What is the effect?

Problem
- You don’t know the true bone threshold till afterwards

Quantifying the Carhart Effect in Otosclerosis

Change in Bone conduction is partially dependent upon air bone gap closure. To model the effect of Carhart’s notch, we can express change in bone conduction as a function of change in air conduction.

\[
dBC = \frac{cc}{1 + CC} \cdot dAC + \frac{K}{1 + cc}
\]

\(dBC\) = change in bone conduction
\(dAC\) = change in air conduction
\(CC\) = frequency depended Carhart co-efficient
\(K\) = frequency dependent constant

\(ABGC\) = air-bone gap closure
Pre Op  
BC₁ 15  
AC₁ 40  

Post Op  
BC₂ 5  
AC₂ 10  

\[ d_{BC} = cc(ABGC') + K \]

\[ ABCG = (AC₁ - AC₂) - (BC₁ - BC₂) \]

\[ ABCG = (dAC) - (dBC') \]

\[ d_{BC} = cc((dAC') - (dBC')) + K \]

\[ d_{BC} = cc(dAC') - cc(dBC') + K \]

\[ d_{BC} + cc(dBC') = cc(dAC') + K \]

\[ d_{BC}(1 + cc) = cc(dAC') + K \]

\[ d_{BC'} = \frac{cc(dAC') + K}{1 + cc} \]

\[ d_{BC} = \frac{cc}{1 + cc} dAC + \frac{K}{1 + cc} \]
\[ dBC = cc(ABGC') + K \]
\[ ABCG = (AC_1 - AC_2) - (BC_1 - BC_2) \]
\[ ABCG = (dAC') - (dBC') \]

\[ dBC = cc((dAC') - (dBC')) + K \]
\[ dBC = cc(dAC') - cc(dBC') + K \]
\[ dBC + cc(dBC') = cc(dAC') + K \]
\[ dBC(1 + cc) = cc(dAC') + K \]
\[ dBC = \frac{cc(dAC') + K}{1 + cc} \]
\[ dBC = \frac{cc}{1 + cc}dAC' + \frac{K}{1 + cc} \]

Now we can do our regression

Online Equation Editor
http://www.homeschoolmath.net/worksheets/equation_editor.php
Quantifying the Carhart Effect in Otosclerosis

<table>
<thead>
<tr>
<th>kHz</th>
<th>Air conduction</th>
<th>Bone conduction</th>
<th>Air-Bone gap</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>30</td>
<td>5</td>
<td>25</td>
</tr>
<tr>
<td>1</td>
<td>20</td>
<td>5</td>
<td>15</td>
</tr>
<tr>
<td>2</td>
<td>20</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>4</td>
<td>10</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

• A significant relationship between the change in air-bone gap closure and change in bone conduction was found only at 2 kHz.

• Interesting from a mathematical modeling standpoint.

Conclusion
References

- Yves Pelletier, Physics animations
- [http://web.ncf.ca/ch865/graphics/ElectricFlux.jpeg](http://web.ncf.ca/ch865/graphics/ElectricFlux.jpeg)
- [www.homeschoolmath.net/worksheets/equation_editor.php](http://www.homeschoolmath.net/worksheets/equation_editor.php)
- “The Acoustic Reflex,” Richard W. Harris, Ph.D., Brigham Young University