Tympanometry and Reflectance in the Hearing Clinic

Presenters:
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Abstract

Accurate assessment of middle ear function is important for appropriate management of hearing loss. Two tools available for assessing middle ear function are tympanometry and wideband reflectance. Tympanometry and reflectance both assess how the middle ear receives sound. Critical to their interpretation is an understanding of how the resonance(s) of the middle ear change with middle ear pathology or static pressure changes in the ear canal. Seminar attendees will discover how to interpret tympanograms obtained at multiple frequencies and what the different tympanogram shapes mean in terms of middle ear resonance. Participants will be given the tools to make a reflectance measurement and be able to interpret the results, as well as be able to describe what tympanometry and reflectance have in common and how they differ.
Learning Outcomes

Participants will learn:

1. how to interpret tympanograms obtained at multiple frequencies and what the different tympanogram shapes mean in terms of middle ear resonance.

2. how to make a reflectance measurement and how to interpret the results.

3. what tympanometry and reflectance have in common and how they differ.
Finding the Input Impedance of the Ear

Outer and middle ear act to impedance match sound in air to sound in fluid

\[ P_m = P_i + P_r \]

- If \( P_r = 0 \) → perfect impedance match
- If \( P_r = P_i \) → 100% impedance mismatch

Tympanometry:

\[ P_m = P_i + P_r \]

Reflectance:

\[ R = \frac{P_r}{P_i} \]

Tympanometry
Tympanometry

1960s  Clinical measurements from 125 to 1500 Hz was recommended (Zwislocki, 1963; Feldman, 1963, 1964)

226 Hz probe tone

1970s  Tympanometry at 226 Hz

Tympanometry using high frequency probe tones was not diagnostic (Alberti and Jerger, 1974) ????

The most important parameter from a diagnostic standpoint, the first resonant frequency of the middle ear, is ignored.
Tympanometry

A Normal Tympanogram: Liden et al. (1970)

Probe tone frequency = 800 Hz

What probe tone frequency is optimal for measuring a tympanogram?
Data Obtained from a Tympanogram

- **ECV**
  - $Y_a @ -400$ daPa
  - estimated volume of air in front of the probe

- **SC**
  - $Y_{tm}$
  - Maximum compliance of the middle ear system (static compliance)

- **TPP**
  - Pressure at which the middle ear system has the greatest absorption of sound energy (tympanometric peak pressure)

- **TW**
  - Width of the tympanogram curve
Static compliance

- The value of static compliance provides information about the stiffness of the middle ear system.

- Normal range
  - Adults: 0.4 to 1.6 cc
    - 90% range
    - (Shahnaz & Polka, 1997, E&H 18(4))
Ear canal volume

- Tympanometry estimates of ECV over-estimate the actual volume
- As static pressure increases from -400 daPa to 200 daPa the magnitude of the error increases
- Ear canal volume measured with a 660 Hz probe tone is more accurate than the standard 220 Hz tone

*Figure 2. Mean ear canal volumes (in ml) for static ear canal pressures between ±400 daPa. The triangle at 0 daPa represents the mean alcohol volume measurement, and the remaining triangles represent the mean alcohol volume adjusted for changes in ear canal volume with changes in ear canal pressure measured using the gas-law procedure. Tympanometric estimates are shown for the 220-Hz (circles) and the 660-Hz (squares) probe frequencies.*

Shanks & Lilly 1981
• Normal range
  – Adults 48 to 134 daPa
    • 90% range (Shahnaz & Polka, 1997, E&H 18(4))
• TW is the width of the tympanogram measured in daPa at half of the height from tympanogram peak to tail (Wiley & Stoppenbach, in Katz, 2002, p. 170)
Tympanogram shapes

http://pedsinreview.aappublications.org/content/19/5/155
Tympanometry @ 226, 678, and 1000 Hz
Demonstration

Tympanometry @ 226, 678, and 1000 Hz
What do these results mean?
To understand these different tympanogram shapes, obtained with different probe tone frequencies, we need

1. to understand how changing static pressure influences the middle ear
2. a model of the ear
3. a model for generation of tympanograms
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Static pressure change in ear canal

Static pressure changes in the ear canal increases the stiffness of the middle ear
see Rabinowitz (1981)
Huang et al (2000)

\[
Resonance = \frac{1}{2\pi} \sqrt{\frac{\text{stiffness}}{\text{mass}}}
\]

Increase stiffness \(\rightarrow\) increase resonance

\[\uparrow \text{static pressure} = \uparrow \text{middle ear resonance}\]
Tympanogram with a different x-axis

Can think of static pressure axis on tympanograms as middle ear resonance rather than pressure
To understand these different tympanogram shapes, obtained with different probe tone frequencies, we need:

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2. a model of the ear
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Modeling input impedance of ear

- **Ear canal**
  - Lossy transmission line
- **Middle ear and cochlea**
  - Three stiffness terms
    - Middle ear cavity
    - Eardrum, ossicles, annular ligament?
    - Cochlea
  - Six tuned oscillators... six resistance terms
- **RC term for cochlea**
To understand these different tympanogram shapes, obtained with different probe tone frequencies, we need

1. to understand how changing static pressure influences the middle ear
2. a model of the ear
3. a model for generation of tympanograms
Modeling Tympanometry

- Static pressure change (+ or −) in the ear canal increases the stiffness of middle ear.
- Stiffness change probably not symmetrical... treated as symmetrical for +,− change.
- Static pressure change produces probable change to cavity, middle ear and cochlear stiffness... model change only in middle ear stiffness.
Model fit to data for tympanograms

Model tympanograms normalized to fit tail at +200 daPa at each frequency

To get asymmetry in tympanograms, had to have $R$ vary for negative static pressures (in addition to $k$)
Model-generated family of Tympanograms - relationship to resonance
What is the inverted W?

Peaks associated with static pressure change shifting first resonance of middle ear to probe frequency

Probe frequency is above the first resonance of the middle ear

middle ear resonance

Peaks associated with static pressure change shifting first resonance of middle ear to probe frequency

Probe frequency is above the first resonance of the middle ear
- Multiple tympanogram frequencies better describes filtering of ME
- Shape of tympanogram reflects proximity to ME resonance
Pathologies of the Middle Ear

Tympanogram shapes represent a continuum with respect to resonance of the middle ear.

For a 226 Hz probe tone:

A flat, type B tympanogram, is a long way from resonance.

A shallow type A tympanogram is far from resonance.

The bigger the peak, the closer the probe tone frequency is to resonance.
Reflectance
Tympanometry vs Reflectance

- **Tympanometry**
  - Impedance of sound source ($Z_s$) is not known
  - Impedance of ear ($Z_{\text{ear}}$) is estimated

- **Power Reflectance**
  - Impedance of sound source ($Z_s$) is known
  - Derive impedance of ear $Z_{\text{ear}}$

- **Sound pressure**
  - measured by a microphone in both cases ($P_m$)
• **Tympanometry**
  - $Z_{\text{ear}}$ is a relative measure
  - $Z_{\text{ear}}$ expressed as a volume

• **Power Reflectance**
  - $Z_{\text{ear}}$ is derived
  - $P_s, Z_s$ obtained from calibration

- Sound pressure at the microphone is inversely proportional to $Z_{\text{ear}}$

$$Z_{\text{ear}} = Z_S \cdot P_m$$

- $P_s - P_m$

Withnell et al. (2009)
Comparing methods

**Tympanometry**
Acoustic impedance v. Pressure (Z vs. P)
*frequency is fixed (e.g., 226 Hz)*

**Power Reflectance**
Acoustic impedance v. frequency (Z vs. f)
*static pressure in the ear canal is fixed*
0.5, 2 and 5 cc cavities calibrate 226 Hz
0.5 and 2 cc cavities calibrate 678 Hz
0.5 cc cavity calibrates 1000 Hz (GS Tympstar)
- **Volume calibration**
  - Limited to low frequencies (up to 1500 Hz)
- **Cylinder calibration, known radius and lengths**
  - Upper frequency limit depends on radius
  - Probably at least 10 kHz
  - Standing waves in cylinders complicate calibration
  - Radius of cylinder must be similar to ear canal (bony portion)
Reflectance

Provides a broad spectrum measure of the impedance mismatch between the ear canal and middle ear
Does not require static pressure changes in the ear canal
The reflectance transfer function alters predictably with middle ear pathology

Withnell et al., 2009
Stiffness dominated region of middle ear

Withnell et al., 2009
Increase in stiffness of middle ear

Power reflectance results from a subject with otosclerosis (Allen et al., 2005)

Withnell et al., 2009
Decrease in stiffness of middle ear

Power reflectance results from a subject with middle ear disease as a child (Mimosa data)

Withnell et al., 2009
OME

Middle ear not fluid-filled

Power reflectance results from a subject with otitis media with effusion (Allen et al., 2005)

Withnell et al., 2009
Tympanometry and Reflectance in the Clinic. The how, what and why.

how to do it
what the results mean
why multiple frequencies

Questions?....
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