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Basic to Basics: Immittance Questions and Mythbusters

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Topics for Today

- Introduction and Background
- Basics of tympanometry and mythbusters
- Advances in tympanometry and questions
- Basics of acoustic reflexes and mythbusters
- Advances in acoustic reflexes and questions
- Case Studies
- Summary
- Q & A
Immittance Facts – Truth or Myth?

- A type B tympanogram (low “compliance”) is a good indicator that there may be fluid.
- Low frequency tympanometry cannot detect OME in newborns.
- Low frequency tympanometry is insensitive to otosclerosis.
- Immittance at high frequencies offers no diagnostic advantages and is unreliable.
- Equivalent volume may be used not only to detect a non-patent tube, but to predict recurrence of OME.
- Acoustic reflex decay is a sensitive and safe test for acoustic neuroma.
- Absent or elevated acoustic reflex threshold is nearly universal in auditory neuropathy spectrum disorder.

Concept of Impedance

- Simple definition of mechanical impedance: how much force is needed to set a physical system in motion.
- Simple definition of acoustic impedance: how much force is needed to transmit sound energy through the ear.
Three Components of Impedance

- Stiffness (Springiness)
- Mass
- Friction (Resistance)

Middle ear Sources of Impedance
What if we didn’t have a middle ear?

- The much higher impedance of the cochlear fluids, bone and tissue means higher reflection from the surface and much less energy would be transmitted to the cochlea.
- This results in the theoretical maximum conductive hearing loss of about 60 dB, depending on frequency and status of the eardrum and middle ear tissues.
- At this level, hearing occurs via bone conduction rather than air conduction.

Immittance Terminology

- Admittance: total energy flow through the vibrating system
  – NOT COMPLIANCE – MISUSED TERM!
- Impedance: opposition to energy flow through vibrating system
- Admittance and impedance are reciprocal terms
- Immittance includes both of these terms and all of their sub-components
Qualitative Analysis

- Early instruments were uncalibrated, “arbitrary compliance units” from 0 to 10
- Liden (1969) first described tympanogram shapes that became known (in the U.S.) as Jerger classification (Jerger, 1970)
- Jerger/Liden classification includes types ___ ___ ___?
- Feldman (1976) added types ___ ___ ?

Mythbuster: Are Types A, B, C sensitive and specific?

Qualitative Analysis is Subjective!

Height:
- Short
- Medium
- Tall

Width:
- Narrow
- Medium
- Broad
“Compliance Unit” Tympanograms

Truth: Quantitative Analysis Adds Objectivity

- Height: Static Admittance ($Y_{tm}$)
- Width: Gradient or Tympanometric Width (TW)
- Middle Ear Pressure: Tympanometric Peak Pressure (TPP)
- Ear Canal Volume: Equivalent Volume ($V_{eq}$)
Studies of 226-Hz Tympanometry

- Static compensated acoustic admittance is the most often used measurement
- However, static admittance is insensitive to many middle ear conditions
- Many instruments provide automatic measurement, but beware of artifacts and collapsing canals
- Tympanogram must be compensated to obtain admittance of middle ear

You can easily cross-check automatic tympanogram measurements!

$Y_{tm} = \text{Static Admittance}$
$TW = \text{Tymp Width}$
$V_{eq} = \text{Equivalent Volume}$

Note: Compensation at positive or negative tail
Normal Tympanogram Ranges
226-Hz probe tone

• Static Admittance:
  – 0.3 to 1.5 mmho for adults
  – 0.3 to 1.2 mmho for children (5 - 10 years)
  – 0.3 to 0.8 mmho for toddlers (1.5 – 4 years)
  – 0.2 to 0.6 mmho for infants (6 -18 months)

• Tympanometric Width:
  – 35 to 125 daPa for adults
  – 60 to 200 for children (5 - 10 years)
  – 100 to 250 daPa for infants/ toddlers (0.5 – 4 years)

Value of tympanometric equivalent volume

• Interpreting the reason for a flattened tympanogram
• Determining patency of a PE tube
• Detecting cerumen impaction
• Assessing potential for recurrence of OME after tube insertion
• Pre- versus post-tube difference in Veq is 0.4 cc (MRC OME Study, 2008)
Normal Ear Canal Volume

- 1.0 to 2.2 cc (adult males)
- 0.8 to 1.9 cc (adult females)
- 0.6 to 1.2 cc (1.5-10 years)
- 0.5 to 1.0 cc (6-18 months)
- 0.2 to 0.8 cc (< 6 months)

- Abnormally small volume:
  - May indicate blocked probe
  - Excessive cerumen

- Abnormally large volume:
  - May indicate eardrum perforation

Tympanometry in Children with OME
(Nozza, et al., 1994)

**Best Test Performance:**
Tymp Width $\geq$ 250 daPa
(80% sensitivity and specificity)

*Or*

Pneumatic Otoscopy + admittance $<0.3$ mmho

**Worst Test Performance:**
Type B tympanogram

10% sensitivity
1-kHz Tympanometry
Newborns and Infants < 6 Months Normal Ranges

<table>
<thead>
<tr>
<th>Equivalent ear canal volume ($V_{eq}$)</th>
<th>Static compensated admittance ($Y_{tme}$)</th>
<th>Tympanometric width (TW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2 – 0.8 cc</td>
<td>$\geq 0.6$ mmho (positive tail)</td>
<td>$&lt; 150$ daPa</td>
</tr>
<tr>
<td></td>
<td>$\geq 0.4$ mmho (neg tail)</td>
<td></td>
</tr>
</tbody>
</table>

Multifrequency Tympanometry

- Allows middle ear function to be tested over a wide frequency range
- Calibration assumes that the ear canal is a pure compliant element in parallel with the middle ear impedance
- Calibration assumption generally holds only at 2000 Hz and below
- Allows estimation of the resonant (best) frequency of the middle ear
Multicomponent Tympanometry
Rectangular Admittance Notation

\[ Y_{tm} = \sqrt{B_{tm}^2 + G_{tm}^2} \]

Ear canal air pressure (daPa)

Multicomponent Tympanometry
Cartesian Admittance Plot

Acoustic Conductance (mmhos)

Acoustic Susceptance (mmhos)

imaginary (Bₐ)

real (Gₐ)

\[ \varnothing = 70^\circ \]
Effect of Probe Frequency

- Phase Angle is close to 90 degrees in normal adult ears at 226 Hz
- Phase angle approaches 0 degrees when compliant and mass elements are balanced
- This balance point is known as the resonant frequency, occurring at a phase angle of 0 degrees

Determining Compliance or Mass Effects

- Ears that are dominated by compliance have a positive phase angle
- Ears that are dominated by mass elements have a negative phase angle
- Normal adult ears are compliant at low frequencies (<1000 Hz) and mass dominant at high frequencies (>1000 Hz)
### Effects of Pathologies

<table>
<thead>
<tr>
<th>Fluid</th>
<th>Tympanosclerosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wide Width</td>
<td>Low Admittance</td>
</tr>
<tr>
<td>Low Admittance</td>
<td>Mass Loading</td>
</tr>
<tr>
<td>Mass Loading</td>
<td>Low Resonant Frequency</td>
</tr>
<tr>
<td>Low Resonant Frequency</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TM Atrophy / Ossicular Discontinuity</th>
<th>Lateral Ossicular Fixation</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Admittance</td>
<td>Low Admittance</td>
</tr>
<tr>
<td>Low Resonant Frequency</td>
<td>High Resonant Frequency</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Perforation</th>
<th>Otosclerosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flat Tympanogram</td>
<td>Normal Tympanogram</td>
</tr>
<tr>
<td>High Volume</td>
<td></td>
</tr>
</tbody>
</table>

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**Otosclerosis: Standard vs. Multifrequency Tympanometry Test Performance**

*Shahnaz et al., 2009*

![Graph showing sensitivity vs. 100-specificity for different types of tympanometry tests.](image)
Why is 226-Hz tympanometry insensitive to otosclerosis?

• It tests only a restricted frequency range
• The pathology is far from the location of measurement
• The effects on admittance are subtle and variable
• Multifrequency tympanometry and wideband absorbance is more sensitive
Wideband tympanometry advantages

- Assesses the entire frequency range with one stimulus
- Examines absorbance, reflectance and impedance with one measurement
- Wide frequency range as a function of air pressure
- Increased sensitivity for some pathologies

Acoustic Stapedial Reflex (ASR)

- The stapedius muscle can be activated by either acoustic or tactile stimulation.
- To activate the stapedius, sounds of sufficient intensity and duration are required.
- Contraction of the stapedius muscle is an obligatory reflex and is consensual, meaning that stimulation of just one ear (ipsilaterally) results in contraction for both ears.
Correct nomenclature to report results is by recording thresholds and presentation mode for the stimulus ear.

Acoustic reflex thresholds: Normal-hearing adults

<table>
<thead>
<tr>
<th>Stim Freq</th>
<th>500 Hz</th>
<th>1 kHz</th>
<th>2 kHz</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Contra</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Ipsilat</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Golding et al., 2007 Mean (dB HL)</td>
<td>95</td>
<td>90</td>
<td>90</td>
</tr>
<tr>
<td>SD</td>
<td>9.1</td>
<td>8.7</td>
<td>8.1</td>
</tr>
<tr>
<td>90% PR</td>
<td>85-105</td>
<td>80-100</td>
<td>80-100</td>
</tr>
<tr>
<td><strong>Contra</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Ipsilat</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Golding et al., 2007 Mean (dB HL)</td>
<td>88</td>
<td>87</td>
<td>NA</td>
</tr>
<tr>
<td>SD</td>
<td>7.9</td>
<td>8.3</td>
<td></td>
</tr>
<tr>
<td>90% PR</td>
<td>80-100</td>
<td>75-100</td>
<td></td>
</tr>
</tbody>
</table>
Safety of ASR Tests

- Emanuel, Henson, and Knapp (2012) found that 89% of audiologists reported patients with discomfort, tinnitus, and hearing loss related to ART and decay testing.
- Pure tone stimuli at high levels are a potential risk for damage; reflex testing should be performed at safe levels (<115 dB SPL).
- Hunter et al (1999) reviewed several cases of iatrogenic hearing loss due to acoustic reflex decay testing at levels above 115 dB SPL.
- Broadband noise can be used as an alternative to pure-tone stimuli. The threshold for BBN is 20–25 dB less than for pure tones (Margolis & Levine, 1991)

<table>
<thead>
<tr>
<th>Site of Lesion and Laterality</th>
<th>Ipsi - affected ear</th>
<th>Contra – affected ear</th>
<th>Ipsi-unaffected ear</th>
<th>Contra – unaffected ear</th>
</tr>
</thead>
<tbody>
<tr>
<td>Middle ear, unilateral</td>
<td>A</td>
<td>A or E</td>
<td>N</td>
<td>A</td>
</tr>
<tr>
<td>Middle ear, bilateral</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>Cochlea, unilateral</td>
<td>N, E, A</td>
<td>N</td>
<td>N</td>
<td>N, E, A</td>
</tr>
<tr>
<td>Cochlea, bilateral</td>
<td>N, E, A</td>
<td>N, E, A</td>
<td>N, E, A</td>
<td>N, E, A</td>
</tr>
<tr>
<td>Eighth n., unilateral</td>
<td>E,A,D</td>
<td>E,A,D</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Eighth n., bilateral</td>
<td>E,A,D</td>
<td>E,A,D</td>
<td>E,A,D</td>
<td>E,A,D</td>
</tr>
<tr>
<td>*Seventh n., unilateral</td>
<td>A</td>
<td>N</td>
<td>N</td>
<td>A</td>
</tr>
<tr>
<td>*Seventh n., bilateral</td>
<td>A</td>
<td>A</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>Brainstem, unilateral Extra-axial</td>
<td>E,A</td>
<td>E,A</td>
<td>N</td>
<td>A</td>
</tr>
<tr>
<td>Brainstem, midline- Intra-axial</td>
<td>N</td>
<td>A</td>
<td>N</td>
<td>A</td>
</tr>
</tbody>
</table>

N=normal, E=elevated, A=absent, D=decay
Effect of Conductive Hearing Loss

- Conductive hearing loss of 20 dB or less in the stimulated ear is enough to cause the reflex to be absent.
- In the ear measured with the probe, admittance may be decreased to an extent that the stapedial reflex cannot be detected, such as in otosclerosis or otitis media.

ASR in Acoustic Neuroma

- Elevated or absent acoustic reflex thresholds and abnormal ABR findings have been the most cited diagnostic tools.
- Effectiveness of ART for detection of acoustic neuroma using the gold standard of magnetic resonance imaging was studied by Hunter et al.
- Ipsilateral ART at 1000 Hz has poor sensitivity and specificity for detection of acoustic neuroma, and involves potential risk at levels higher than 115 dB SPL, especially for decay testing.
- Asymmetry in hearing is actually more sensitive.
ASR in Auditory Neuropathy Spectrum Disorder

- ASR is an effective low-cost test to assess the possibility of ANSD, in combination with behavioral audiometry and otoacoustic emissions.
- Berlin et al. (2005) examined ASR in 136 patients with ANSD. Nearly all patients had absent acoustic reflexes for both 1000 and 2000 Hz, whether ipsilaterally or contralaterally elicited.
- If the emissions are present and the reflexes are absent or elevated, an ABR is recommended to determine whether ANSD may be present.

ASR and Pseudohypacusis

- When the ART is close to the patient’s admitted threshold at the same frequency, this may indicate pseudohypacusis.
- This situation is not physiologically possible; thus, ART is useful as a cross check for severe to profound functional hearing loss.
- ART is only useful to detect pseudohypacusis for hearing losses of >60 dB HL.
Acoustic Reflexes in Infants

- Recommended protocol for acoustic reflex measurement in infants less than 6 months of age:
- Ipsilateral presentation of BBN or pure tones at 1000 and 2000 Hz at levels <105 dB SPL, and a 1000-Hz probe tone.
- At ages greater than 6 months, a standard 226- Hz probe tone is adequate for detection of ASR.
- In infants, due to smaller size ear canal, must know if reflexes are in SPL or HL and adjust accordingly for safe presentation levels!

Weatherby and Bennett (1980)
The Neonatal Acoustic Reflex

Optimal probe tone for detecting reflexes in infants is 1000 Hz.
Acoustic Reflexes in Adults versus Infants

**ADULT**

**INFANT**

Wideband tympanometry in a case of otosclerosis

Courtesy of Navid Shahnaz, Ph.D.
Adult Case: Otosclerosis

Courtesy of Navid Shahnaz, Ph.D.
Infant Case

- 6 month old male, full-term, family history (sister has craniofacial anomalies and permanent conductive hearing loss; has BAHA.
- OAEs absent in both ears at birth; passed screening ABR
- Diagnostic ABR normal at 1 month
- OAEs normal on right
- OAEs still absent on left

Infant Case

3D Tympanograms

Right Ear

Left Ear
Infant Case RE Tymps

Infant Case LE Tymps

change the outcome
Take Home Messages

- Let’s get more sensitive & specific than the A, B, C’s
- Width is more sensitive than admittance
- Use a 1000 Hz probe tone in infants <6 months for tympanometry and reflexes
- Multifreq/wideband tymp is more sensitive for OME, and otosclerosis, need more research for other conditions

Take Home Messages

- Acoustic reflex thresholds are not very sensitive to acoustic neuroma
- Absent or elevated acoustic reflex threshold is nearly universal in auditory neuropathy spectrum disorder
- Reflex testing should be limited to < 115 dB SPL and adjusted downward for small ear canals
Back to Basics Webinar Series

Principles of Audiometric Calibration
Ross J. Roeser, PhD

Pure Tone Testing and Audiogram Interpretation
L. Maureen Valente, PhD

Immittance Audiometry
Lisa L. Hunter, PhD

Pediatric Audiology
Christine Yoshinaga-Itano, PhD

Hearing Science Concepts as a Foundation for Clinical Audiology
Diana C. Emanuel, PhD

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