Wideband Acoustic Immittance: Overview and Clinical Potential

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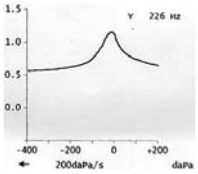
Overview

- Assessment of the conductive pathway
  - Tympanometry
  - Middle ear transfer function
  - Impedance/ admittance
- Wideband acoustic immittance
  - Power absorbance?
  - Normative data
  - Diagnostic potential
- Research Questions
  - Large variability in normal
  - Research on intra-subject variability in newborns
- Further advancements
  - Wideband tympanometry

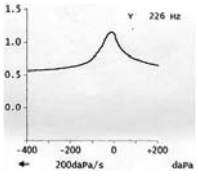
Preview:
Tympanometry assesses which of the following properties about the conducive pathway?

A. Admittance of the middle ear to a probe frequency of 226 Hz.
B. Mobility of the ear drum and the ossicular bones.
C. Indicates how well the middle ear conducts sound to the inner ear.
D. Provides a holistic assessment of the acoustic-mechanics of the conductive pathway.



Tympanometry (Recap.)
Traditional immittance testing

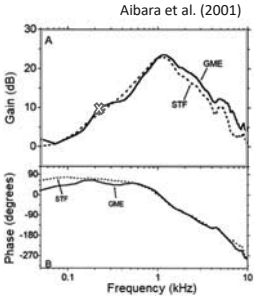
- *Admittance* of the middle ear is measured at a single pure tone frequency.
- Requires pressurization of the ear canal. **Why?**
- A single frequency provides very little information!
  - and cannot test at frequencies > 2000 Hz, **why?**



Middle Ear Gain

- Middle ear transfer function:
  - Show gain and filter of the middle ear system
  - Across a wide range of frequencies
- Conveys valuable information:
  - Physical characteristics that either admit or impede sound energy **(frequency dependent)**.
  - Pathology modifies the transfer function pattern across frequency (how?)
    - Cannot be evaluated at just a single frequency

Aibara et al. (2001)



Revisit:

Tympanometry assesses which of the following properties about the conducive pathway?

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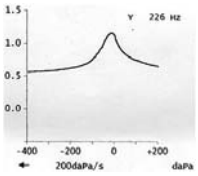


Preview:

What physical characteristics of the conductive pathway determine its impedance/admittance?

A. Dissipation/ preservation of acoustic energy in the conductive pathway
B. Stiffness/ compliance of the conductive pathway
C. How great/ small the mass of the middle ear
D. All of the above

What is immittance?

Clinical measures of the middle ear

- Acoustic **Immittance** (**Im**pedance/ Ad**mittance**)
  - They include measures such as:
    - Impedance (ohms) *Z*
    - Admittance (mhos) *Y*
    - Pressure Reflectance (ratio) *R*
    - Power Reflectance $|R|^2$
    - Pressure Absorbance (ratio) A
    - Power Absorbance $|A|^2$
    - Transmittance (dB) *T*
- Parameterize the *acoustic-mechanics* of a vibrating system **(e.g., conductive pathway)** when measured across a wide range of frequencies.

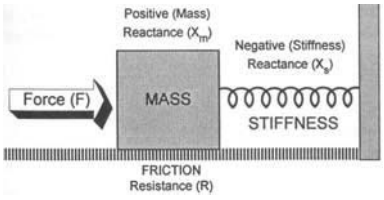
Impedance (Z)
Admittance (Y=1/Z)

- Why objects vibrate at the frequency that they do?
  - Natural frequency of objects
- The middle ear conducts sound best at its natural frequency

Impedance Equation

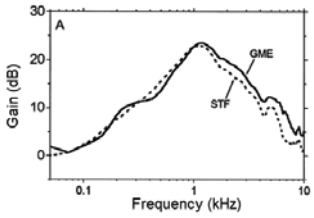
$$Z = iR + j(X_M - X_C)$$

- $Z = \sqrt{R^2 + (2\pi Mf - k/2\pi f)^2}$
  - *R*= Resistance (e.g., friction)
  - *f* = frequency of sound going through the system
  - *M* = mass (frequency dependent)
  - *k* = stiffness constant (frequency dependent)

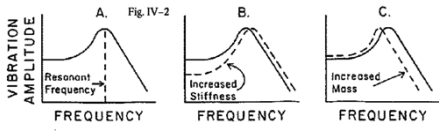


Example:

Natural frequency of the middle ear



Pathology-related changes to the transfer function



- Pathologies that add stiffness shift resonance peak to a higher frequency.
- Pathologies that add mass shift resonance peak to lower frequencies.
- Pathologies that dissipate energy, lower the peak but do not affect frequency.

Revisit:

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Wideband Acoustic Immittance (WAI)

Clinical test
Tympanometry provides **limited information** about the function of the conductive pathway

Transfer function
Middle ear function is best assessed across a wide range of frequencies. **However, not viable clinically!**

Wideband acoustic immittance:
A non-invasive clinical assessment of the conductive pathway over a wide range of frequencies

Wideband Acoustic Immittance (WAI)

- Advances in acoustic calibration of test probes:
  - Allow for derivation of power measurements from pressure recordings **(not affected by standing waves)**
  - Does not require pressurization of the ear canal
- Commercially available:

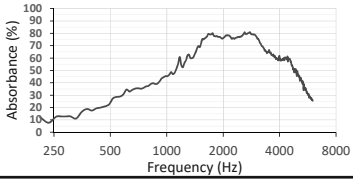
Mimosa Acoustics' HearID

Interacoustics' Titan

WAI: Power Absorbance/ reflectance

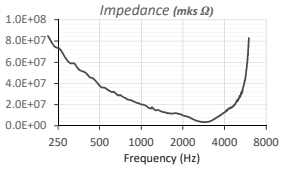
- Power Absorbance: $= \frac{Absorbed\ \mathbf{power}}{Incident\ \mathbf{power}}$
- Power Reflectance: $= \frac{Reflected\ \mathbf{power}}{Incident\ \mathbf{power}}$
- **Values range from 0 to 1 (0-100%)**

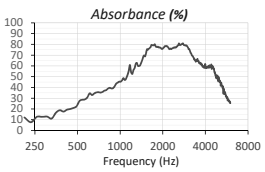
Power reflectance + Power absorbance=1

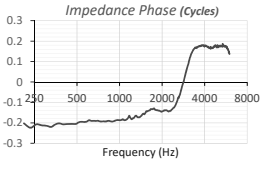


WAI: Impedance & Impedance Phase

- In addition to absorbance, *other WAI measures* can be obtained:
  - Derived from the same acoustic measurements
  - Can aid in interpretation
  - Measurement quality assessment
  - E.g., *Impedance* & *Impedance phase*

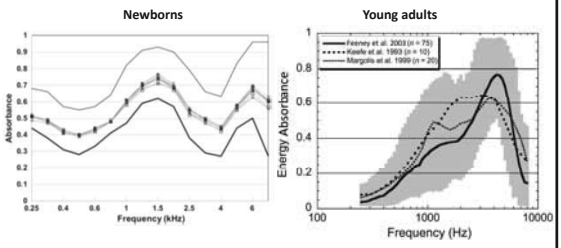






What is the normative range for absorbance measurements?

Absorbance norms: Maturational differences

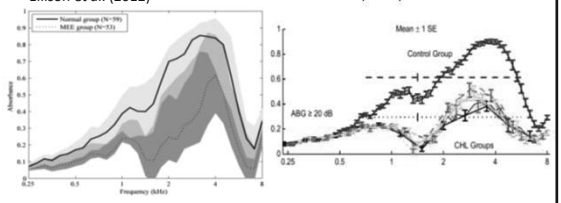


What about absorbance measurements in conductive hearing loss and middle ear pathologies?

Example Clinical Application:
Middle Ear Effusion and CHL in Children

Normal vs. MEE
Ellison et al. (2012)

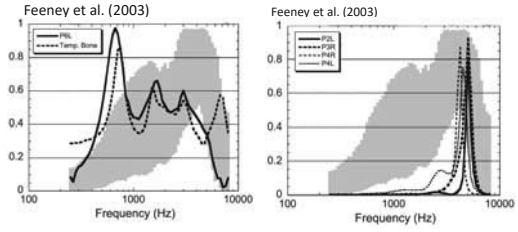
Normal vs. CHL
Keefe et al. (2012)



Example Clinical Application:
Ossicular disarticulation & OME

Ossicular disarticulation
Feeney et al. (2003)

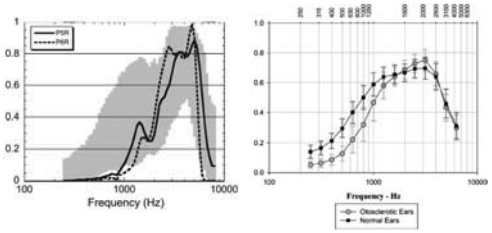
Otitis media with effusion cases
Feeney et al. (2003)



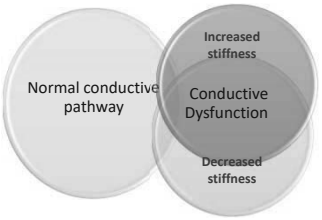
Example Clinical Application:
Otosclerosis

Otosclerosis cases
Feeney et al. (2003)

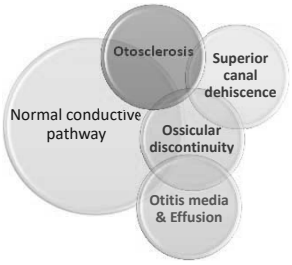
62 normal & 28 otosclerotic
Shahnaz et al. (2009)



Differential Diagnosis:
Tympanometry

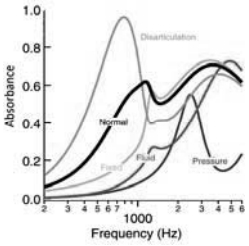


Differential Diagnosis:
WAI Potential

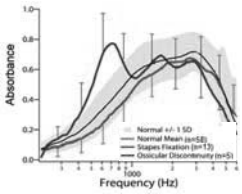


Differential Diagnosis:
Model Predictions & Clinical Data

Model-predicted
Voss et al. (2012)



Clinical data
Nakajima et al. (2012)



Clinical Adoption?

- Summary
  - Wideband acoustic immittance is a promising tool for clinical testing:
  - It has the potential to improve diagnosis of all instances of conductive hearing loss.
  - Moreover, improvement in differential diagnosis of etiologies can be achieved without need for surgical exploration.
- So what are the barriers to clinical adoption?

  Research efforts underway…

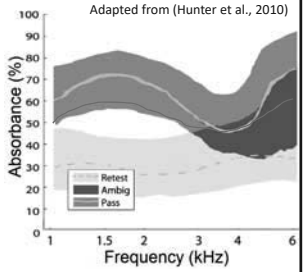
Areas of research:

1. Large variability in normal
   - Factors that introduce variability
   - Intra-subject, e.g., test-retest
   - Inter-subject factors, e.g., anatomy
2. How to quantify diagnostically useful absorbance regions across many frequencies?
   - Changes in absorbance at which frequencies reflect pathological change?
   - Which show the most difference among pathologies?
   - Can we identify pathology-specific patterns across frequency?
     - E.g., a notch with

The problem of large absorbance variability

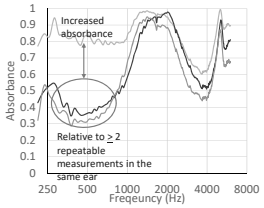
- Variability in normal is large:
  - Range of possible values
  - Expressed in SD, IQR, 10th%-90th%
- Large variability leads to overlap between ranges of normal & abnormal
- Limits clinical interpretation
- What factors contribute to variability?
- Can variability be reduced?

Adapted from (Hunter et al., 2010)



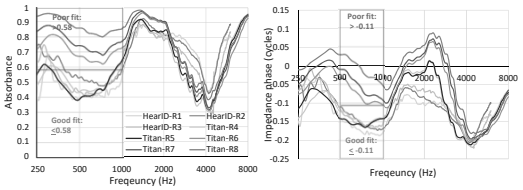
Refining WAI measurements in Newborns:
Probe tip fitting vs. probe-reinsertion

- Intra-subject factors that increase variability.
- The effect of improper probe-tip fits
  Vs.
  Variability with probe reinsertion
- Clinical tool:
  - Probe-tip fit template



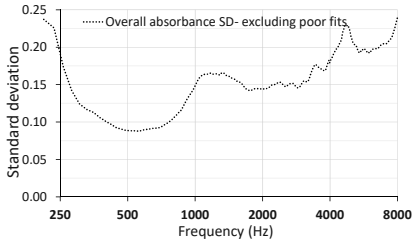
Example of leaky probe-tip fit

Using the clinical probe-fit criteria

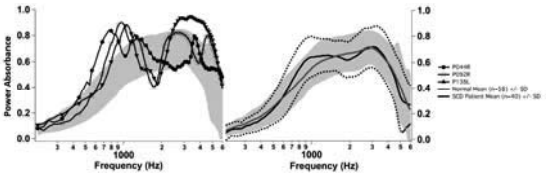


Need to be validated for clinical use:
- Validate in a separate data set
- Validate against other methods, e.g., ear-canal pressurization.

Eliminating poor fits reduces variability in absorbance



Characterizing the "Notch" in Superior Canal Dehiscence (Merchant et al., 2015)

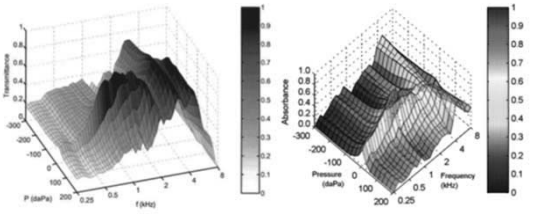


Diagnostic potential for cochlear/ vestibular pathology?
- Can WAI help in Meniere's diagnosis?

Further Developments

- Wideband tympanometry
  - Adding pressure sweeps
- Equivalent Impedance
  - Wideband impedance determined at the TM
  - Interpreted together with phase information
  - Group delay
- Wideband middle ear muscle reflexes

Wideband Tympanometry



Adding another variable besides frequency:
- Could reveal diagnostically beneficial interactions with pathology

Thank you!
Q & A