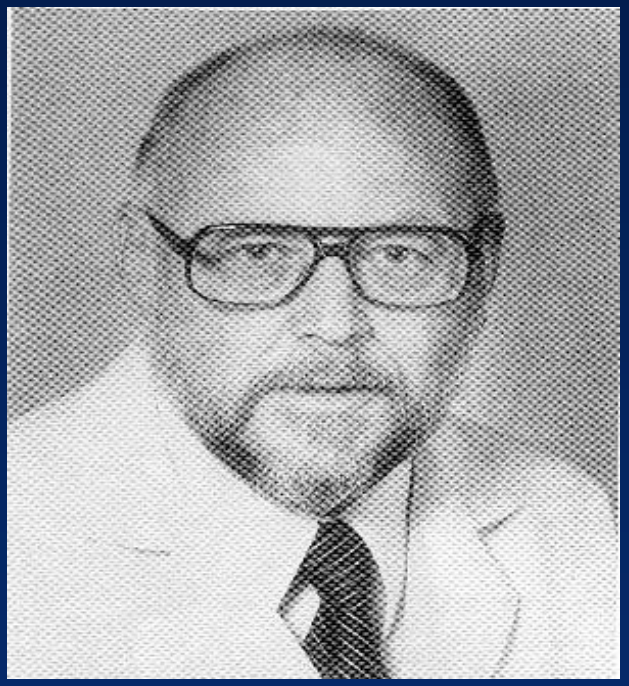
Electro-Acoustic Procedures: Acoustic Immittance Measures

- A Long Tradition with Admittance Measurement
- Historical Overview
- Evidence-Based Practice Includes Admittance Measurement
- Important Terminology
- Tympanometry
- Acoustic Reflexes
- Clinical Applications of Acoustic Immittance Measures

James Jerger
Classic Impedance Studies in Early 1970s at Methodist Hospital And Baylor College of Medicine in Houston Texas, USA



Clinical Experience With Impedance Audiometry

James Jerger, PhD, Houston

Impedance audiometry was performed as part of the routine clinical examination in a consecutive series of more than 400 patients with various types and degrees of hearing impairment. An electroacoustic bridge (Madsen, ZO 70) was used to carry out the measurement of tympanometry, acoustic impedance, and threshold for the acoustic reflex. Results indicate that, while individual components of the total impedance battery lack diagnostic precision, the overall pattern of results yielded by the complete battery can be of great diagnostic value, especially in the evaluation of young children.

THE development of impedance audiometry during the past decade has added new scope and dimension to clinical audiology. Based on the pioneering efforts of Metz,[1] subsequent workers have refined instrumentation, technique, and interpretation to produce an invaluable tool for differential diagnosis.

The development of contemporary instrumentation for impedance audiometry has, in the main, followed two essentially parallel paths. In the United States, Zwislocki and his colleagues[2-6] developed an electromechanical bridge. In Europe, Thomsen, Terkildsen, Møller, and others,[7-10] pioneered the application of the electroacoustic approach, culminating in the present commercially available electroacoustic bridge.

The present paper reports our clinical experience with the latter instrument based on its routine administration to well over 400 successive patients over a one-year period. Our aim was to assess the efficacy of the electroacoustic approach as a routine clinical procedure and to evaluate its diagnostic value in a typical audiologic case load.

In general we found that the testing procedure was easily mastered, even by audiologically unsophisticated personnel, that valid and meaningful results could be obtained for almost every patient, and that, with certain reservations, the data of impedance audiometry constitute extremely valuable diagnostic information.

Subsequent sections present statistical information when patients are grouped according to age and type of hearing loss, and individual case reports illustrating the diagnostic value of impedance audiometry.

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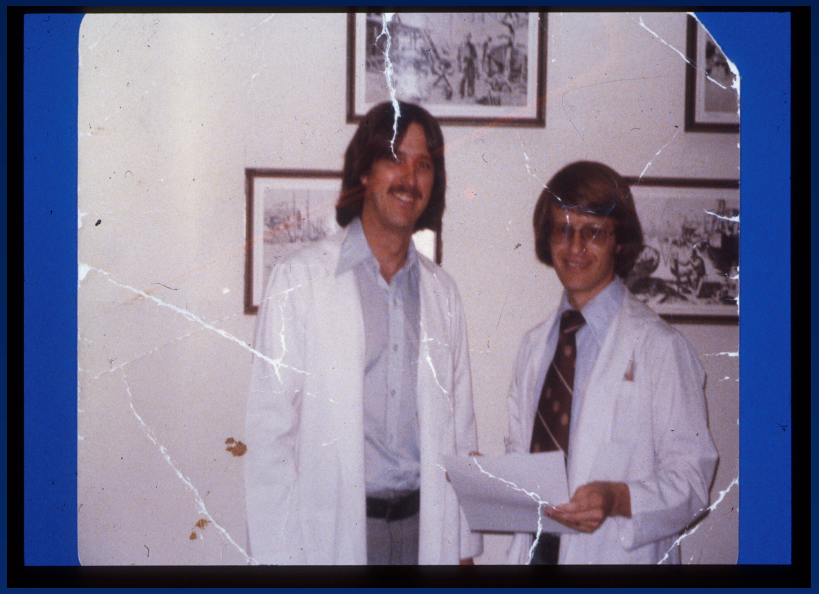
Method

Apparatus.—Impedance audiometry was carried out by means of an electroacoustic impedance bridge (Madsen, type ZO-70) and an associated pure-tone audiometer (Beltone, type 10D). Figure 1 shows a schematic diagram of the principal components of the impedance bridge.

A probe tip containing three tubes is sealed in the external meatus, forming a closed cavity bounded by the inner surface of the probe tip, the walls of the external meatus, and the tympanic membrane. One tube is used to deliver, into this closed cavity, a probe tone generated by a 220-hertz oscillator driving a miniature receiver. The second tube is connected to a miniature probe microphone which monitors the sound pressure level of the 220-Hz probe tone in the closed cavity and delivers the transduced voltage through an amplifier to a bridge circuit and balance meter. The balance meter is nulled by an SPL of exactly 95 dB in the closed cavity. A potentiometer on the output of the 220-Hz oscillator permits variation of the SPL over a range corresponding to a compliance variation (equivalent volume) of 0.2 to 5.0 cc. The third tube is connected to an airpump which permits variation in air pressure in the closed cavity over a range of ±400 mm (water). Air pressure is read on an electromanometer.

Acoustic Immittance Measurement: My First Clinical Activity at Baylor College of Medicine (Houston Texas)

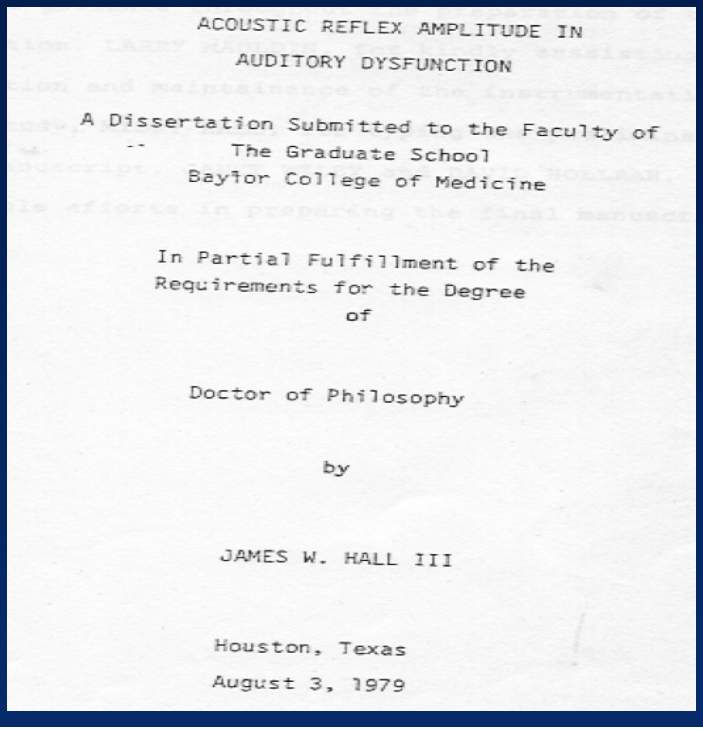


With Larry Mauldin (circa 1975)

Early Publications on Impedance/Immittance Measures

- Hall, JW III and Jerger JF. Acoustic reflexes in spastic dysphonia. *Archives of Otolaryngol 102*: 411-415,1976 [Pub #1]
- Hall JW III. Predicting hearing level from the acoustic reflex: A comparison of three methods. Archives of Otolaryngol 104: 601-605, 1978
- Jerger JF, Jerger S and Hall JW III. A new acoustic reflex pattern. Archives of Otolaryngol 105: 24-28, 1979
- Hall JW III. The effect of age and sex on static compliance. Archives of Otolaryngol 105: 153-156, 1979
- Hall JW III and Weaver T. Impedance audiometry in a young population: The effects of age, sex and minor tympanogram abnormality. J Otolaryngology (Toronto) 8: 210-222, 1979

Acoustic Reflex Amplitude in Auditory Dysfunction
Dissertation: James W. Hall III, 1979



ACOUSTIC REFLEX AMPLITUDE IN
AUDITORY DYSFUNCTION

A Dissertation Submitted to the Faculty of
The Graduate School
Baylor College of Medicine

In Partial Fulfillment of the
Requirements for the Degree
of

Doctor of Philosophy

by

JAMES W. HALL III

Houston, Texas
August 3, 1979

Published Articles Based on PhD Dissertation

- Hall JW III. Acoustic reflex amplitude: I. Effect of age and sex. *Audiology (Basel) 21:* 294-309, 1982
- Hall JW III. Acoustic reflex amplitude: II. Effect of age-related auditory dysfunction. *Audiology (Basel) 21:* 386-399, 1982
- Hall JW III. Quantification of the relationship between crossed and uncrossed acoustic reflex amplitude. *Ear and Hearing 3:* 296-300, 1982

Additional Published Articles on Impedance/Immittance Measures

- Hall JW III and Bleakney ME. Hearing loss prediction by the acoustic reflex: Comparison of seven methods. *Ear and Hearing 2:* 156-164, 1981
- Hall JW III. Hearing loss prediction in a young population: Comparison of seven methods. *International Journal of Pediatric Otorhinolaryngology 3*: 225-243, 1981
- Hall JW III and Koval C. Accuracy of hearing prediction by the acoustic reflex. *The Laryngoscope 92*: 140-149, 1982
- Hall JW III, Berry GA and Olson K. Identification of serious hearing loss with acoustic reflex data: Clinical experience with some new guidelines. Scandinavian Audiology 11: 251-255, 1982
- Hall JW III. The effects of high-dose barbiturates on the acoustic reflex and auditory evoked responses: Two case reports. *Acta Otolaryngologica (Stockholm) 100*: 387-398, 1985

Book Chapters and Monographs on Impedance/Immittance Measures

- Hall JW III. Predicting hearing level from the acoustic reflex. In Handbook of Clinical Impedance Audiometry (2nd ed), Jerger J (ed). Acton, MA: American Electromedics Corp, 1980
- Jerger JF and Hall JW III. Impedance and behavioral audiometry in the era of brainstem evoked response audiometry. In Controversy in Otolaryngology, Snow JB Jr (ed). Philadelphia: WB Saunders
- Hall JW III and Jerger JF. Impedance audiometry. In Speech, Language and Hearing. Lass NJ, Northern JL, Yoder DE and McReynolds LV (eds). Philadelphia: WB Saunders, Co, 1982, pp. 476-491 Co, 1980, pp. 138-144
- Hall JW III. The acoustic reflex in central auditory dysfunction. In Assessment of Auditory Dysfunction: Foundations and Clinical Correlates. Pinheiro ML and Musiek FE (eds). Baltimore: Williams and Wilkins, 1985, pp. 103-130

Book Chapters and Monographs on Impedance/Immittance Measures (2)

- Hall JW III and Ruth RA. Acoustic reflexes and auditory evoked responses in hearing aid evaluation. Seminars in Hearing 6: 251-277, 1985
- Hall JW III. Contemporary tympanometry. Seminars in Hearing 8: 319-327, 1987
- Hall JW III (guest ed). Immittance audiometry. Seminars in Hearing 8: 1987
- Hall JW III and Jerger JF. Acoustic immittance measurement in clinical audiology. In Handbook of Speech-Language Pathology and Audiology. Lass NJ, McReynolds LV, Yoder DE, Northern JL (eds). New York: Thieme, Inc, 1988
- Hall JW III and Chandler D. Clinical tympanometry. In Handbook of Clinical Audiology. Katz J (ed). Baltimore: William & Wilkens, 1994
- Hall JW III and Mueller HG III (1997). Immittance Measurements. *Audiologists Desk Reference, Volume I.* San Diego: Singular Publishing Group, (904 pp),

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Electro-Acoustic Procedures: Acoustic Immittance Measures

- Luscher (1929) in Germany observed acoustic reflex
- Otto Metz (1946) in Denmark developed mechano-acoustic impedance bridge and measured impedance and acoustic reflexes clinically
- Jepsen (1951) confirmed stapedius muscle acoustic reflex
- Knut Terkildson (1956) developed electro-acoustic impedance device
- Klockoff (1961) clinical studies of acoustic reflexes in humans
- James Jerger (1970) applied electro-acoustic impedance device clinically in U.S.A.
- Anderson, Barr, Wedenberg (1970). Acoustic reflex findings in diagnosis of 8th nerve tumors

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Best Practice is Evidence-Based Practice (EBP)

- Evidence-based practice is "the integration of best research evidence with clinical expertise and patient values" (Sackett et al, Evidence-Based Medicine: How to practice and teach EBM. London: Churchill, 2000, p. 1)
- EBP is a five step process
  - Focused clinical question
  - Evidence is sought to answer the question
  - Clinician evaluates the quality of evidence
  - Clinician must integrate the evidence with the patient's clinical findings and preferred outcome to develop intervention plan
  - Document outcome and identify ways to improve it

Evidence-Based Practice: Categories of Research Evidence (ASHA, 2004)

- **1a:** Well-designed meta-analysis of randomized controlled trials
- **1b:** Well-designed randomized controlled trials
- **2a:** Well-designed controlled studies without randomization
- **2b:** Well-designed quasi-experimental studies
- **3:** Well-designed non-experimental studies, i.e., correlational and case studies
- **4:** Expert committee reports, consensus conferences and clinical experience

Evidence-Based Practice is Standard of Care: Definition of Standard of Care (SOC)

- Is consistent with local, regional or national clinical practice
- Follows peer-reviewed guidelines or recommendations on clinical practice approved by national
  - Multi-disciplinary professional committees or panels
  - Professional organizations,
- Is consistent with statements of
  - Scope of Practice
  - Code of Ethics
- Is in compliance with national health care guidelines for clinical practice and services

British Society of Audiology Recommended Procedure: Tympanometry (August 2013)

- Introduction
- General considerations
- Equipment
- Calibration
- Subject preparation
- Test procedure
- Results and recording
- References
- Appendices

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Electro-Acoustic Procedures: Acoustic Immittance Measures *Important Terminology*

- Definitions
  - Immittance = impedance + admittance
  - Acoustic impedance: The opposition of the flow of sound through a surface [the middle ear system. Acoustic impedance has three components:
    - ✓Resistance
    - ✓Negative reactance (relating to mass of the system)
    - ✓Positive reactance (relating to stiffness of the system)
  - Acoustic admittance: The reciprocal of acoustic impedance. The three components of admittance are:
    - ✓Conductance (G)
    - ✓Positive susceptance (B)
    - ✓Negative susceptance (B)

British Society of Audiology Recommended Procedure: Tympanometry (August 2013)

- Definitions (4)
  - Equivalent volume:
    - ✓The volume of an air-filled cavity having the same acoustic admittance (or impedance or compliance) as that of the component or system which it represents.
    - ✓Ear canal volume is not measured directly but inferred from the measurement of admittance.
  - Middle ear pressure: Static pressure in the middle ear relative to ambient atmospheric pressure, estimated from the tympanic peak pressure.
  - Tympanogram peak pressure: The ear canal pressure at which the peak of the tympanogram occurs.

British Society of Audiology Recommended Procedure: Tympanometry (August 2013)

- Definitions (5)
  - Tympanometry: The measurement of acoustic impedance/admittance (or compliance) as a function of air pressure within the external ear canal.
  - Tympanogram: A graph of acoustic impedance/admittance (or compliance) as a function of air pressure within the external ear canal.
  - Tympanometric width: Calculated by measuring the width of the tympanogram curve at 50% of its height.
  - Also sometimes referred to as tympanogram gradient.

Electro-Acoustic Procedures: Acoustic Immittance Measures *Examples of Admittance Measures*

- One Component Tympanograms (Admittance or Impedance)
- Multi-Component Tympanograms
- Multiple Probe Tones
- Gradient
- Ear Canal Volume
- Acoustic Reflex Measures
  - Threshold for tonal and noise signals
  - Amplitude
  - Latency
  - Decay

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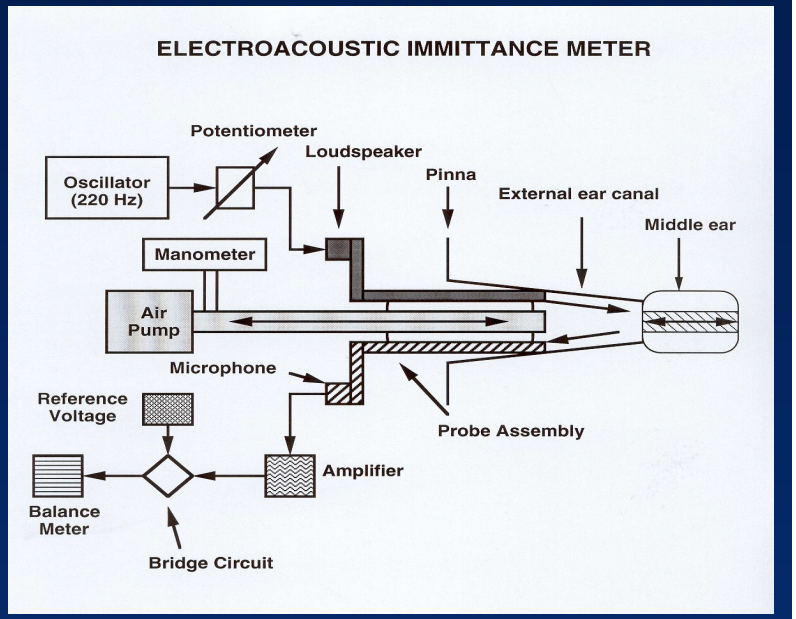
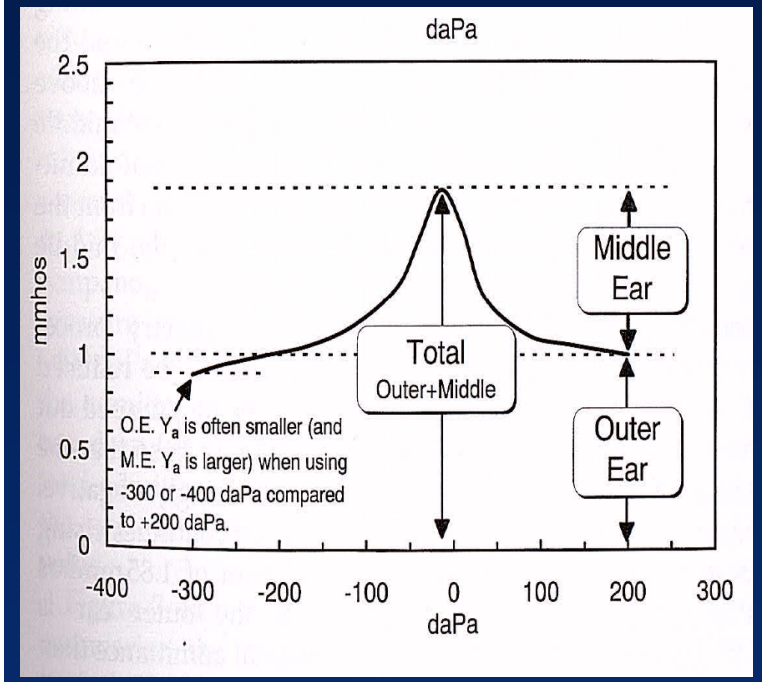
Electro-Acoustic Procedures: Acoustic Immittance Measures

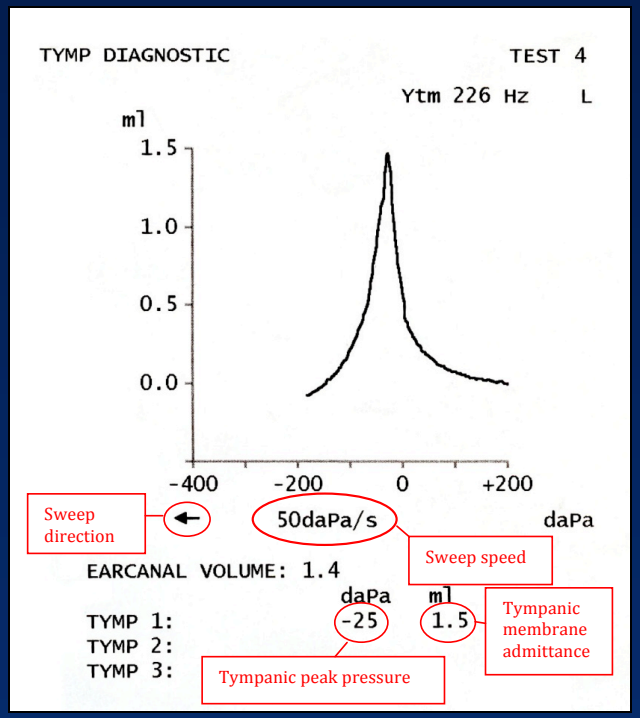
- Ear canal volume
- Static compliance
- Tympanometry
  - 220 vs. 1000 Hz probe tones for adults vs. neonates
  - Multiple admittance components
  - Toynbee and Valsalva procedures
  - Fistula test
- Acoustic reflexes
  - Ipsi - and contralateral
  - Reflex decay

Electro-Acoustic Procedures:
Acoustic Immittance Measures:
Probe Assembly

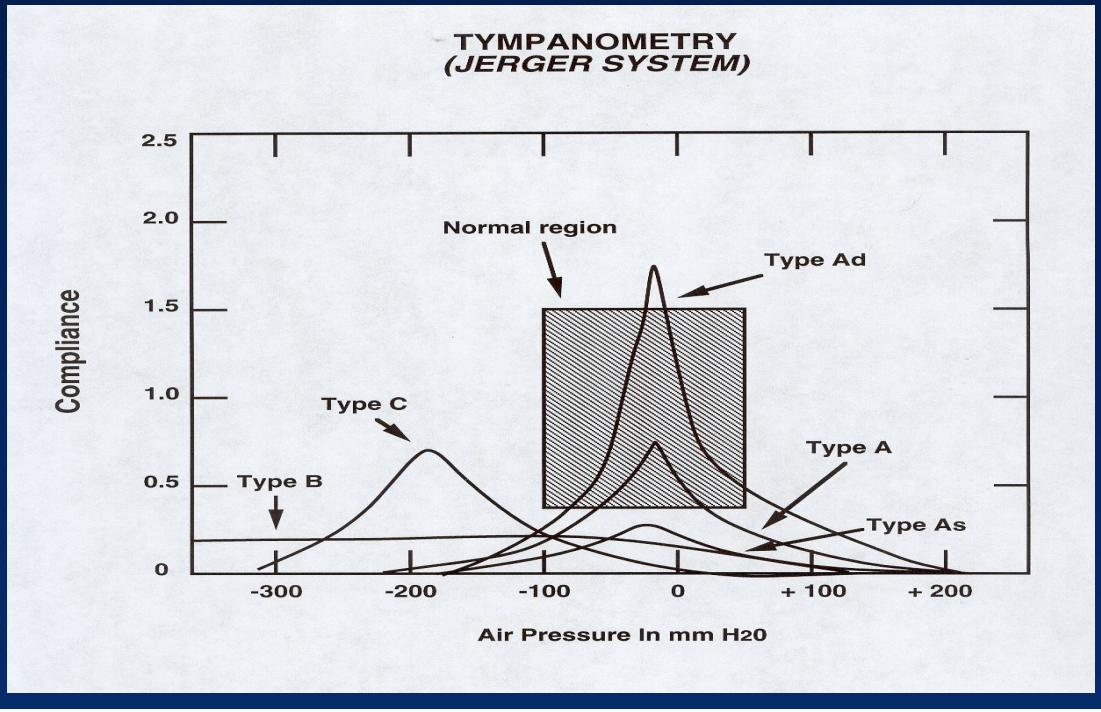


Electro-Acoustic Procedures:
Acoustic Immittance Measures
One Component Tympanogram (Admittance or Impedance)





Electro-Acoustic Procedures:
Acoustic Immittance Measures
Simple and Traditional Tympanogram Analysis



Type A Tympanogram

- Normal middle ear pressure
- Normal eardrum movement
- Normal ear canal volume

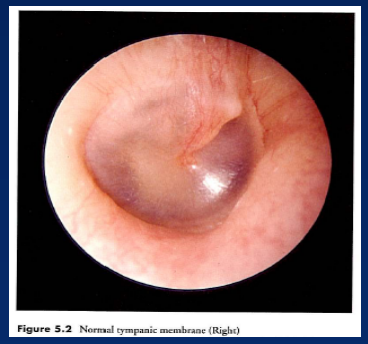
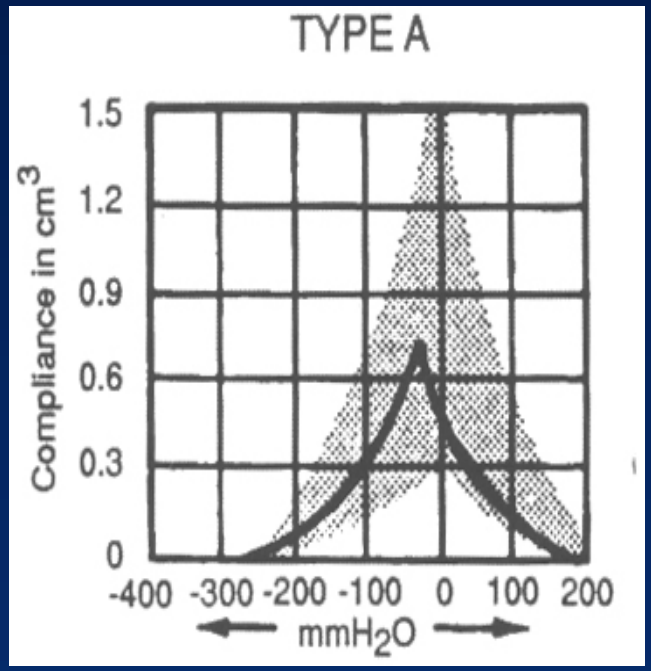


Figure 5.2 Normal tympanic membrane (Right)

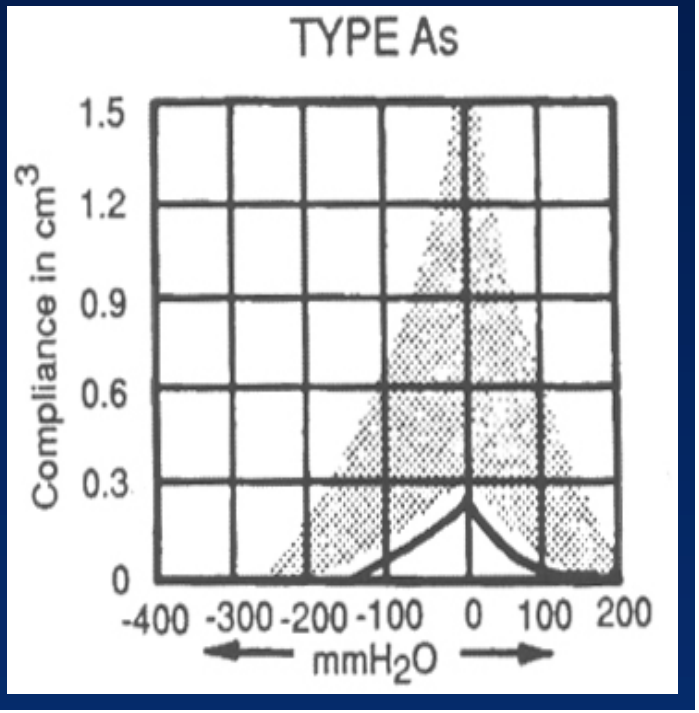


Type As Tympanogram

(e.g., Fixation of Ossicular Chain; Scarred TM)

- Normal middle ear pressure
- Reduced eardrum movement (compliance)
- Normal ear canal volume

Figure 5.24 Tympanosclerosis

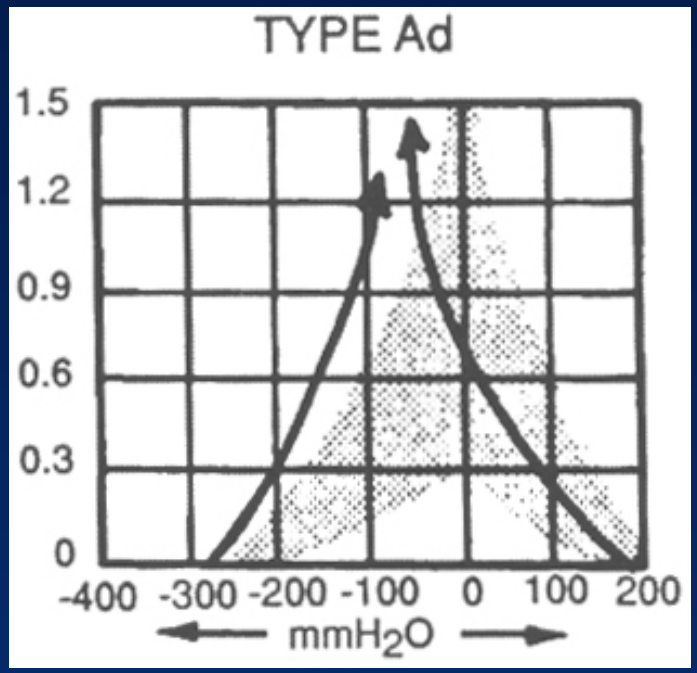


Type Ad Tympanogram

(e.g., Disarticulation of Ossicular Chain; Monomeric TM)

- Normal middle ear pressure
- Increased eardrum movement (hyper-compliance)
- Normal ear canal volume

Figure 5.24 Tympanosclerosis



Type B Tympanogram
(e.g., Middle Ear Effusion)

- Flat pattern
- No compliance or pressure peak
- Normal ear canal volume

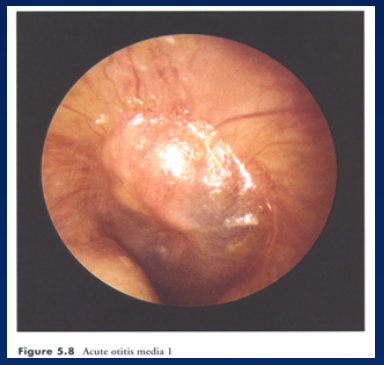
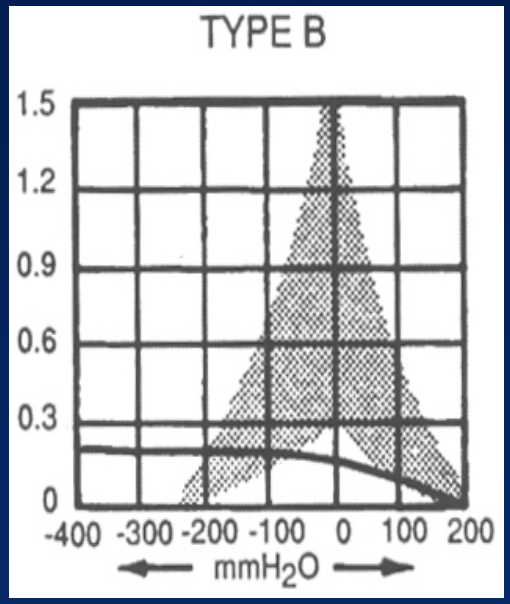


Figure 5.8 Acute otitis media 1

Figure 5.17 Serous otitis media



Increased Estimated Ear Canal Volume

(e.g., Patent Grommet; Perforated TM)

- Cannot perform tympanometry (cannot change pressure in the external ear canal)
- No compliance or pressure peak
- Increased ear canal volume

Figure 5.19 ventilation tube

Figure 5.34 Perforation

Apparent Type B
Tympanogram
(Invalid)

Type C Tympanogram
(e.g., Eustachian tube dysfunction)

- Abnormal negative middle ear pressure
- Normal or reduced compliance
- Normal ear canal volume

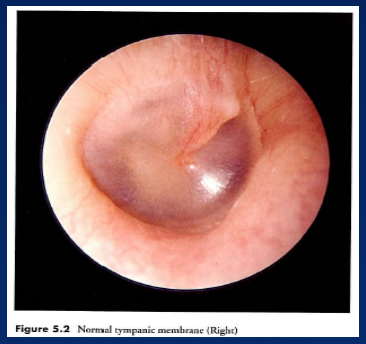
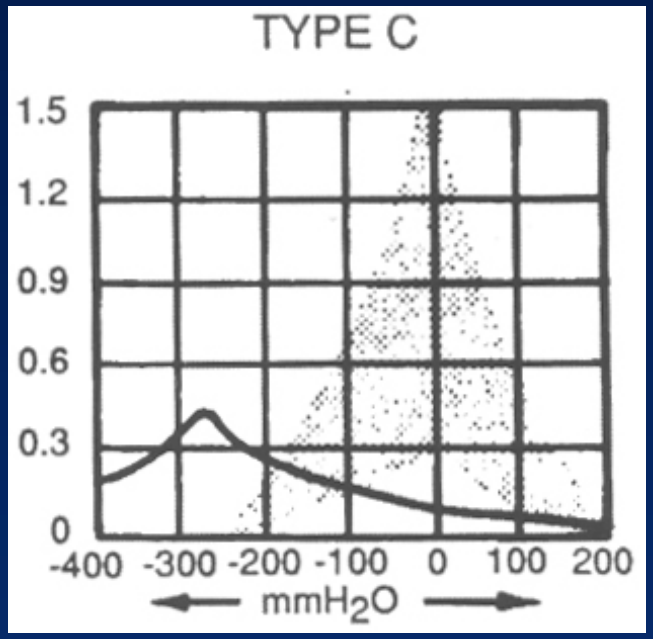
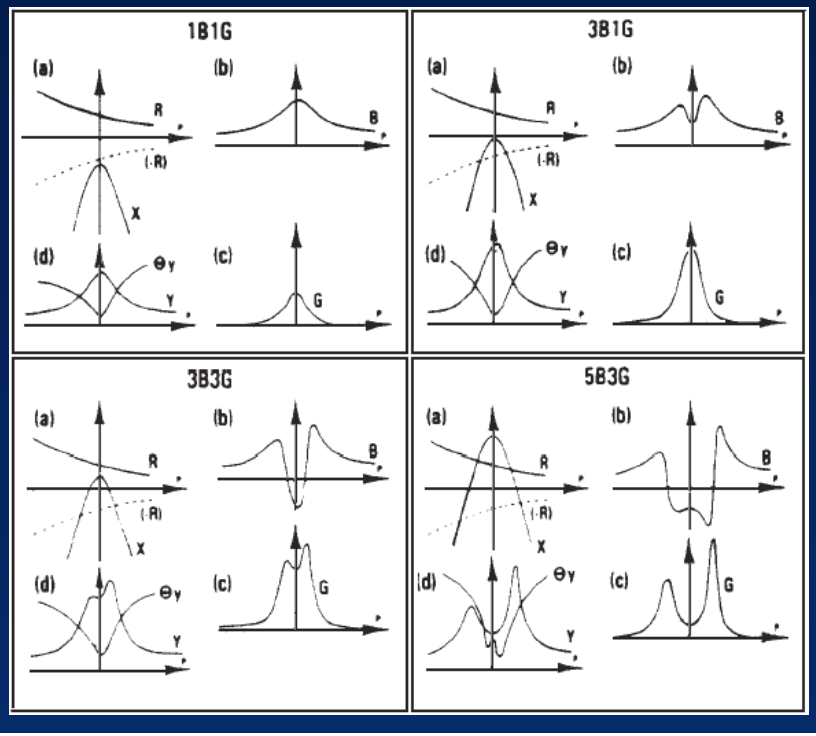


Figure 5.2 Normal tympanic membrane (Right)

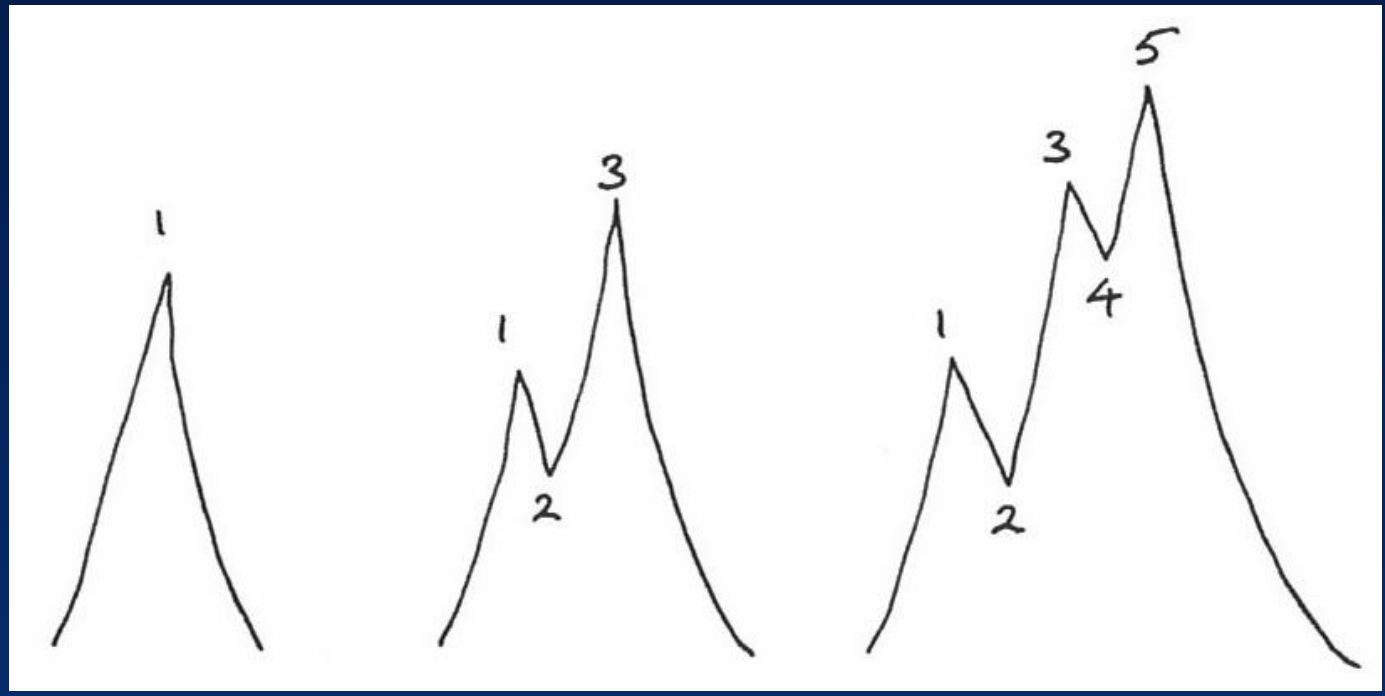


Electro-Acoustic Procedures:
Acoustic Immittance Measures
Multi-Component (B & G) Tympanograms

Normal Conductance (G) and Susceptance (B) Tympanograms for a 678 Hz Probe Tone



Electro-Acoustic Procedures:
Acoustic Immittance Measures*Classifications of Multi-Component Tympanogram Peaks*



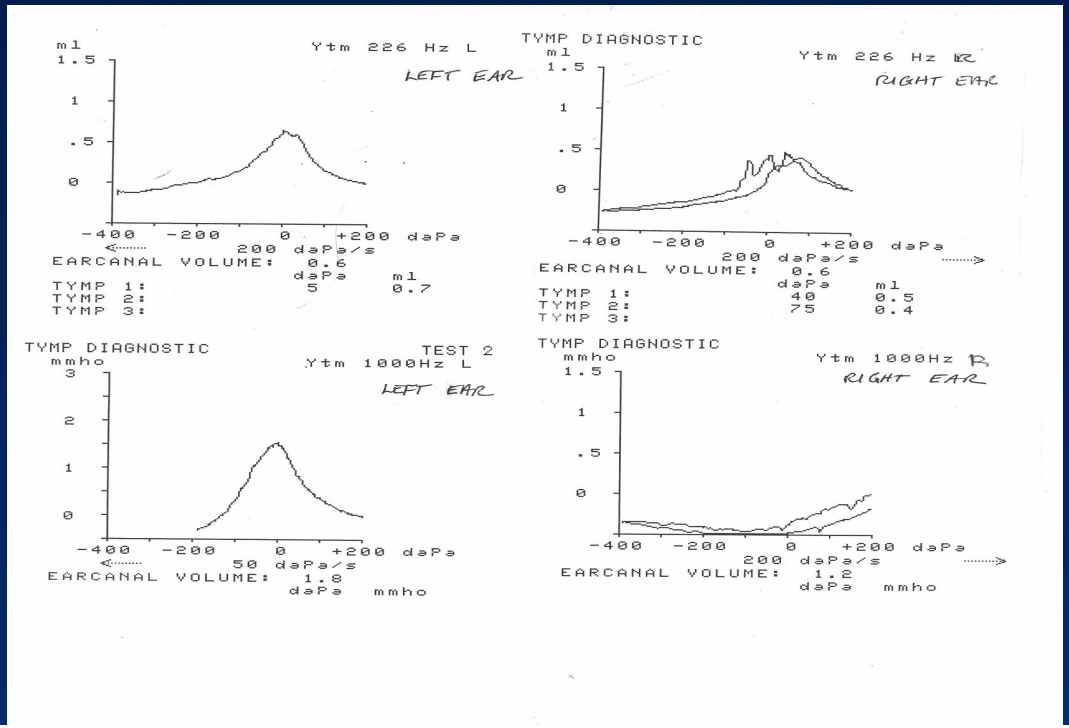
Electro-Acoustic Procedures:
Acoustic Immittance Measures
Normal Distribution of Peaks for 678 Hz Probe Tone

			(Study A)	(Study B)
1G	1B	1|Y|	56.8%	75.8%
1G	3B	1|Y|	28.0%	17.4%
1G	3B	3|Y|		
3G	3B	3|Y|	6.1%	5.5%
3G	5B	3|Y|	9.1%	1.2%

Diagnosis of Hearing Loss: Protocol for Confirmation of Hearing Loss in Infants and Toddlers (0 to 6 months)
Year 2007 JCIH Position Statement

- Child and family history
- Otoacoustic emissions
- ABR during initial evaluation to confirm type, degree & configuration of hearing loss
- Acoustic immittance measures (including acoustic reflexes) *using high frequency (1000 Hz) probe tone*
- Supplemental procedures (insufficient evidence to use of procedures as "sole measure of auditory status in newborn and infant populations")
  - Auditory steady state response (ASSR)
  - Acoustic middle ear reflexes for infants < 4 months
  - Broad band reflectance
- Behavioral response audiometry *(if feasible)*
  - ✓ Visual reinforcement audiometry *or*
  - ✓ Conditioned play audiometry
  - ✓ Speech detection and recognition
- Parental report of auditory & visual behaviors
- Screening of infant's communication milestones

Low (226 Hz) versus High (1000 Hz) Probe Tone for Infant Tympanometry



Tympanometry in Infants and Young Children: Clinical Recommendations and Cautions

- The middle ear system of a newborn infant is mass dominated with a lower resonant frequency (Kei et al, 2007)
- The adult middle ear system is stiffness dominated with a higher resonance frequency
- External ear canals of neonates "are distensible under applied air pressure because of the underdeveloped osseous portion of the ear canal" (Kei et al, 2007)
- "Compensating for the ear canal contribution by making measurements of admittance at extreme ear canal static pressures (I.e., +200 or - 400 daPa) may introduce errors in estimating the static admittance." (Kei et al, 2007)
- Use a 1000 Hz probe tone with infants up to the chronological age of at least 4 months
- Calculate ear canal volume with a 226 Hz probe tone
- Ear canal volume measurements at extreme positive or negative pressures may not be accurate in neonates.

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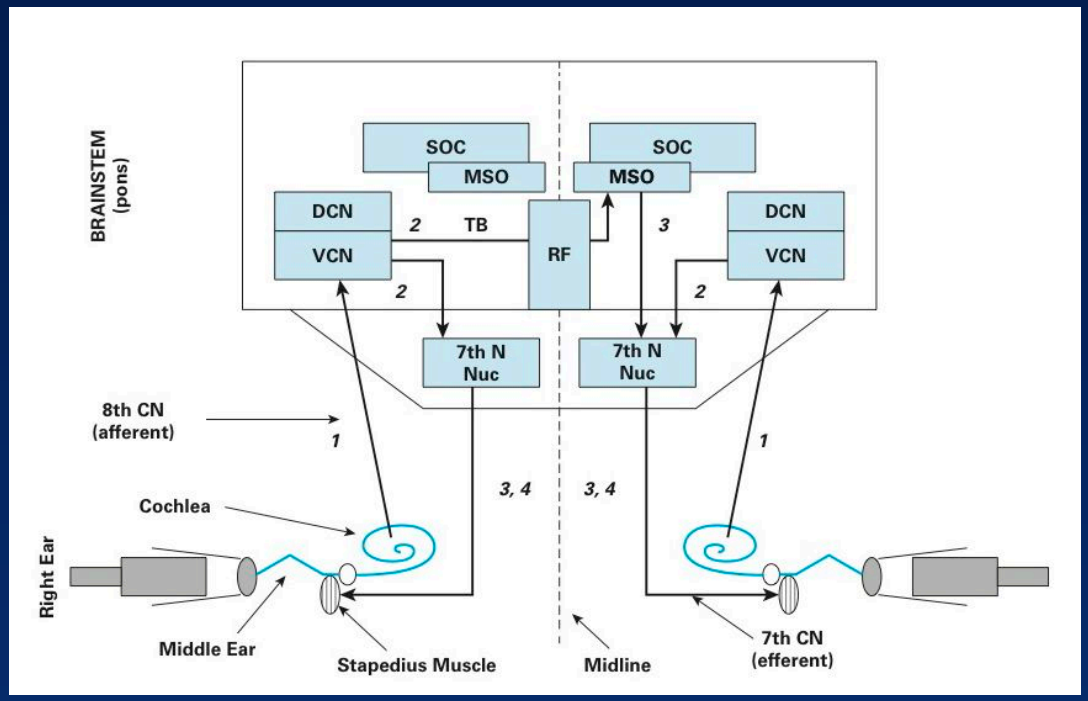
Acoustic Stapedial Reflex Pathways According to Erick Borg

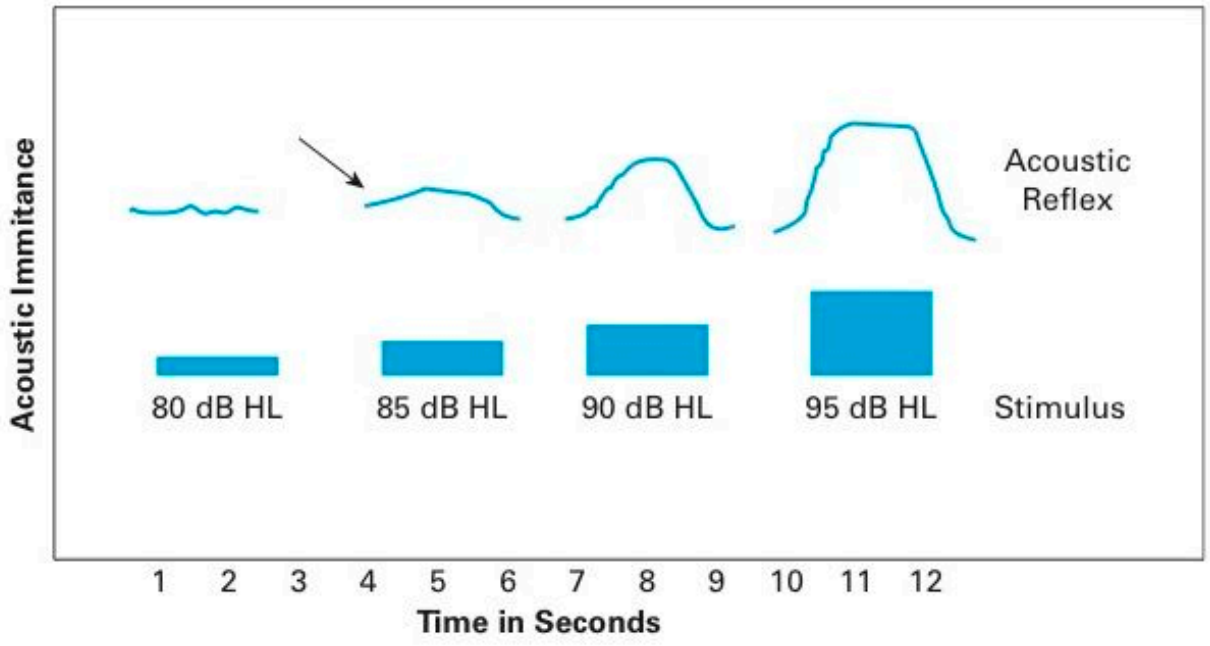
(From Hall JW III (2014). *Introduction to Audiology Today*. Boston: Pearson)



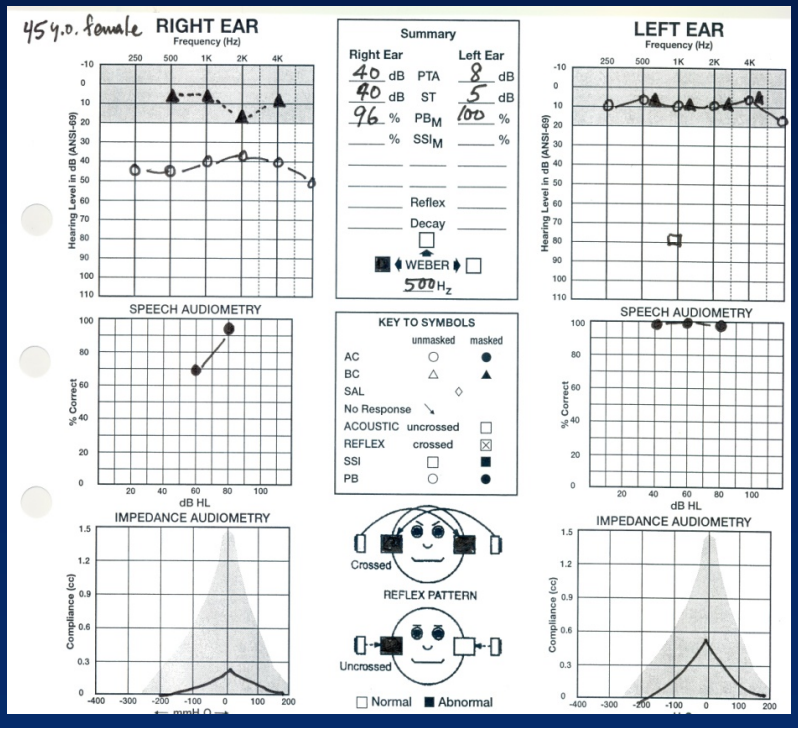
Acoustic Reflex Measurements
Making Acoustic Reflex Measurements

- Acoustic threshold (ART) or minimum response level
- Acoustic reflex amplitude
- Acoustic reflex decay
- Acoustic reflex latency
- Estimation of hearing threshold with acoustic reflex
- Differentiating among auditory disorders with acoustic reflexes

Making Acoustic Reflex Measurements
Acoustic Reflex Threshold



Making Acoustic Reflex Measurements
Plotting Acoustic Reflex Threshold Results

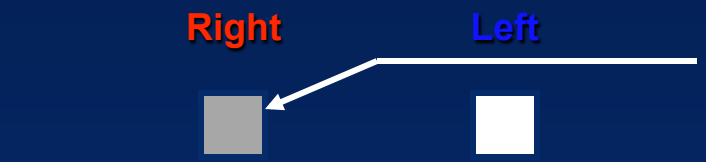


Application of Admittance Measures in Neonates: Acoustic Reflexes

Abnormal Acoustic Reflex

Vertical pattern

- Mild conductive hearing loss pattern or efferent (7th CN) pattern (normal tymp and no air bone gap) on right ear



Contralateral (Crossed) Sound Right Probe Left

Contralateral (Crossed) Sound Left Probe Right

Ipsilateral (Uncrossed) Sound Right Probe Right

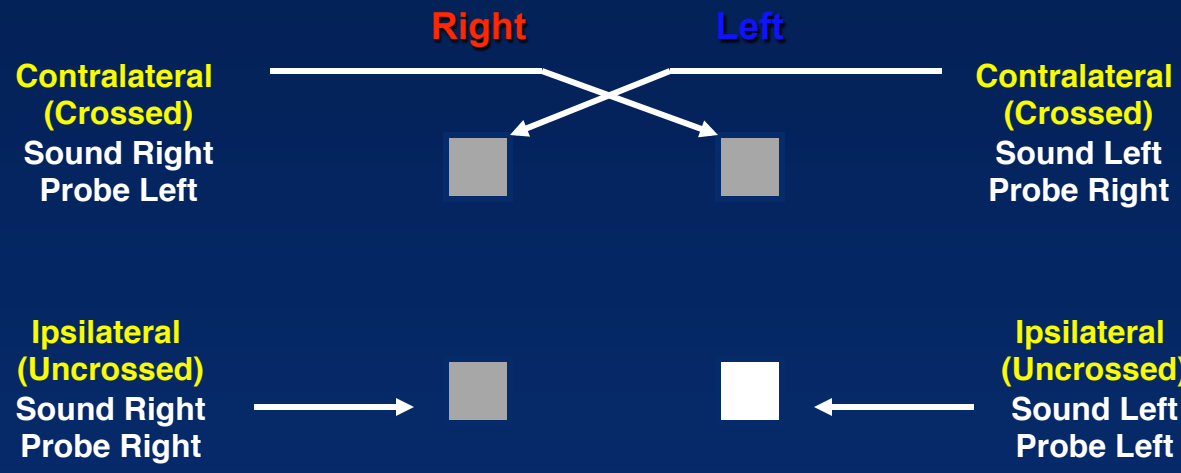
Ipsilateral (Uncrossed) Sound Left Probe Left

Application of Admittance Measures in Neonates: Acoustic Reflexes

Abnormal Acoustic Reflex

Inverted "L" pattern

- Moderate or severe conductive hearing loss on right ear

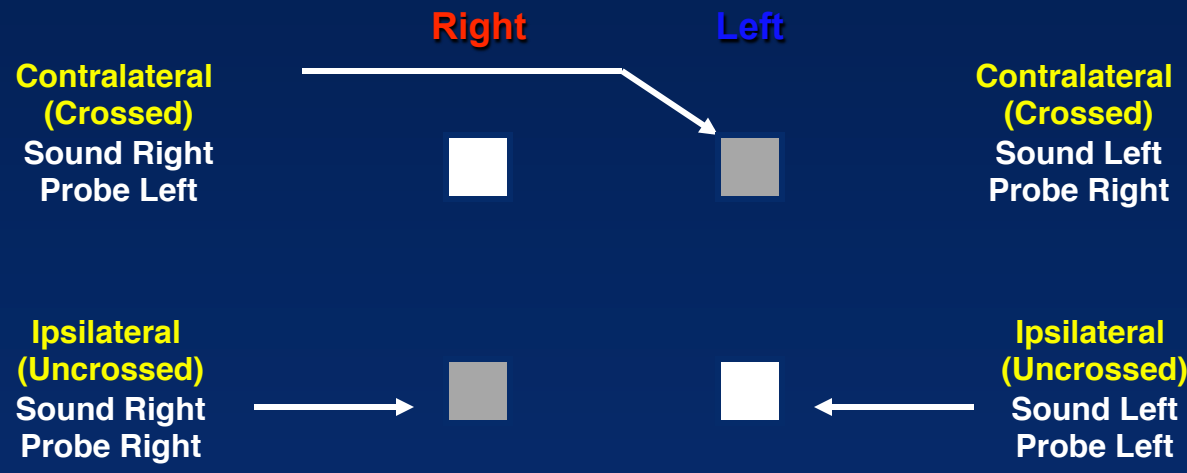


Application of Admittance Measures in Neonates: Acoustic Reflexes

Abnormal Acoustic Reflex

Diagonal pattern

- Severe sensory hearing loss or 8th nerve auditory dysfunction on right ear

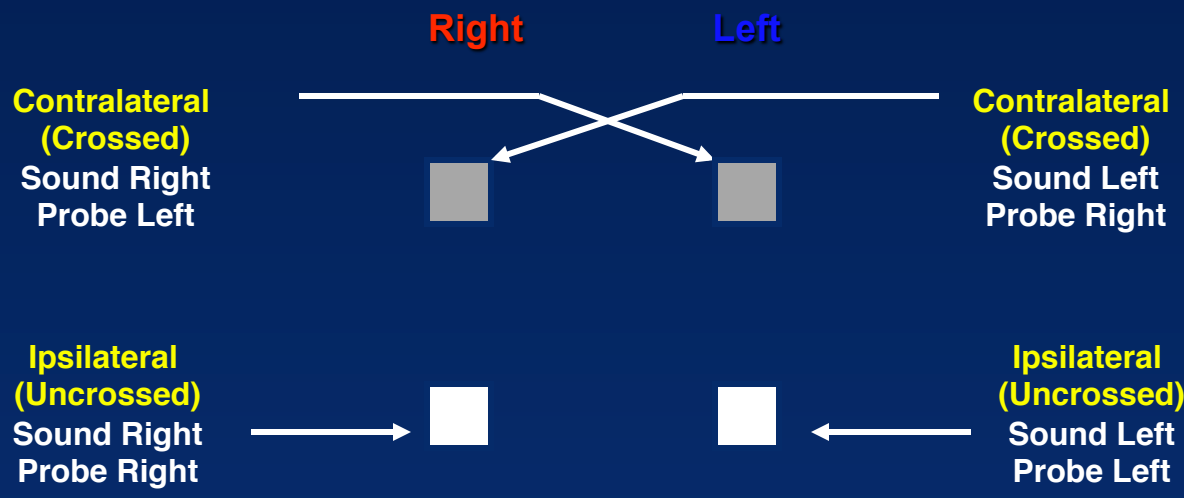


Plotting the Results of Acoustic Reflex Measurements

Abnormal Acoustic Reflex

Horizontal pattern

- Brainstem auditory dysfunction



Assorted Applications of Admittance Measurement: Assessment of Non-Organic Hearing Loss

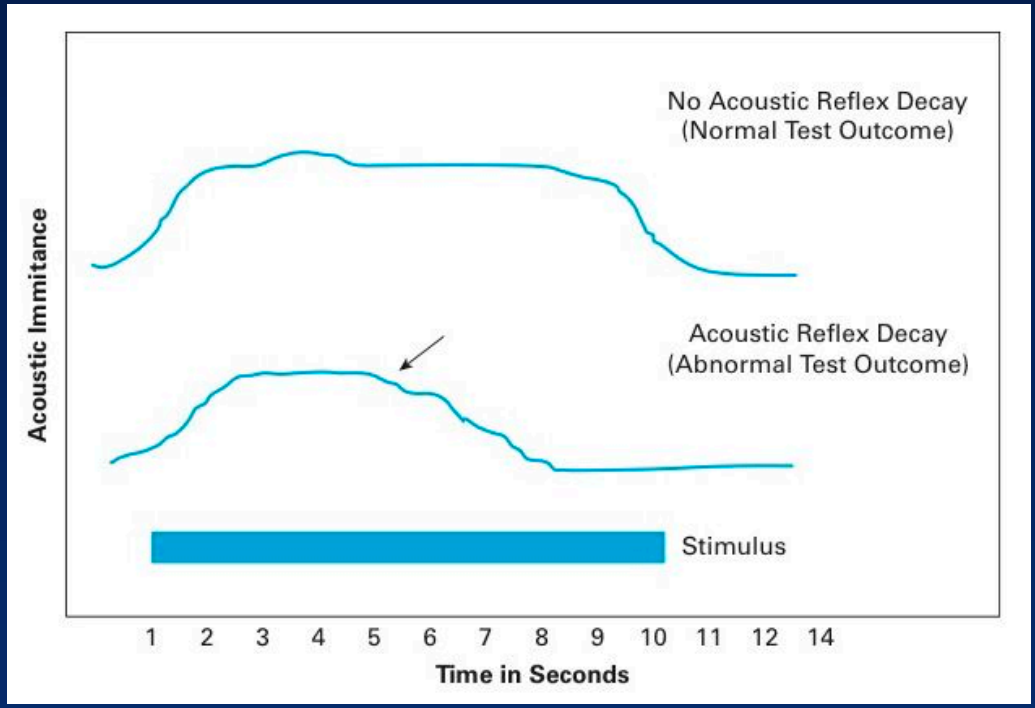
- Other terms for "non-organic hearing loss
  - Pseudohypacusis
  - Functional hearing loss
  - False or exaggerated hearing loss
- Risk factors for false or exaggerated hearing loss
  - Children
    - ✓Adolescent girls
    - ✓Trauma (physical, sexual, psychological)
  - Adults
    - ✓Potential compensation
    - ✓Legal action
    - ✓Trauma (physical, sexual, psychological)

:Assessment of False or Exaggerated Hearing Loss
Why Prompt Diagnosis is Important

- Elimination of unnecessary health care costs. e.g.,
  - Radiological studies
  - Laboratory studies
  - Compensation for non-existent impairment
  - Referral to specialists
- Prevention of inappropriate treatment, e.g.,
  - ✓Medical
  - ✓Surgical
  - ✓Audiological
- Prompt intervention for underlying cause or factors
  - Counseling
  - Psychological or psychiatric management

Patterns of Acoustic Reflex Deflections: Normal and Abnormal

(From Hall JW III. *Introduction to Audiology Today*. Boston: Pearson, 2014)



Assorted Applications of Admittance Measurement: Neonates, Non-Organic Hearing Loss, Eustachian Tube Dysfunction

- Application of admittance measurement in neonates
  - Importance of probe tone frequency
  - Differentiation of sites of dysfunction
- Assessment of hearing level
  - Sensitivity Prediction by the Acoustic Reflex (SPAR)
  - Simplified technique with BBN signal
  - Identification of “non-organic” hearing loss
- Eustachian tube (ET) function
  - Valsalva technique
  - Toynbee technique

Acoustic Reflexes in Neonates

- Kei J. Acoustic stapedial reflexes in healthy neonates: normative data and test-retest reliability. *JAAA, 23,* 2012
  - 66 full term infants
  - Acoustic reflexes recorded with 1000 Hz probe tone
  - Tone and BBN stimuli
  - All neonates had acoustic reflexes

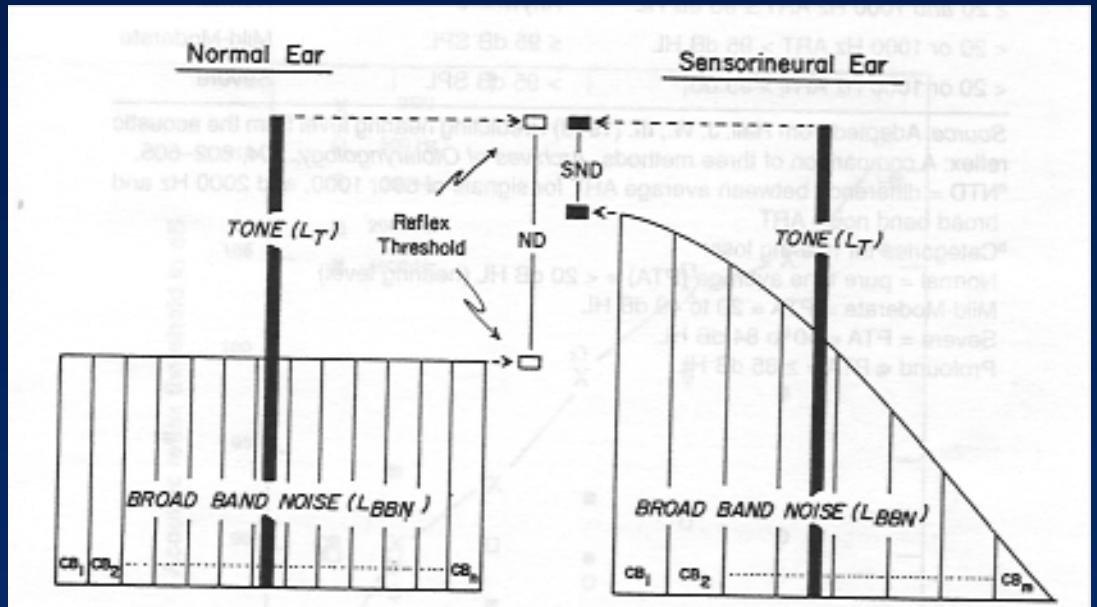
Acoustic Reflexes in Neonates

(Kei J. Acoustic stapedial reflexes in healthy neonates: normative data* and test-retest reliability. *JAAA, 23,* 2012)

Stimulus	Median ART (dB HL)	90% Range
500 Hz	80	70 - 95
2000 Hz	70	60 - 85
4000 Hz	65	50 - 80
BBN	55	50 – 75

** N = 68 ears*

Jerger J, Burney P, Mauldin L & Crump B (1974). Predicting hearing loss from the acoustic reflex. *JSHD, 39,* 11-22

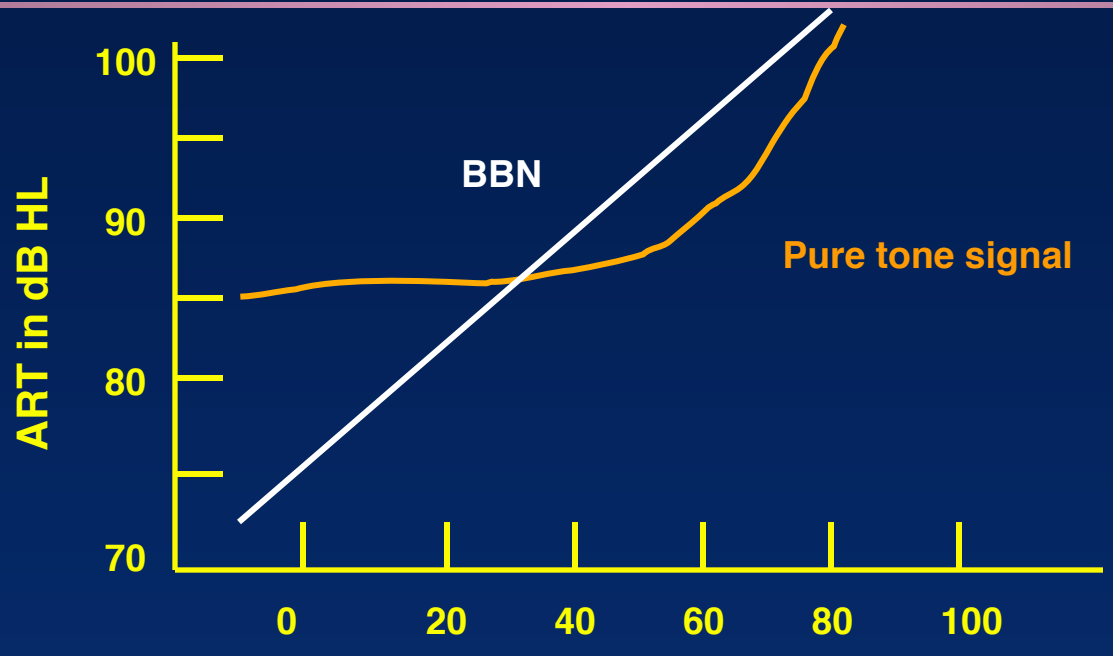


From the original paper on Sensitivity Prediction by Acoustic Reflex (SPAR) by Jerger et al., 1974.

Estimation of Hearing Thresholds with Acoustic Reflexes: A Sampling of Publications

- Hall JW III and Bleakney ME. Hearing loss prediction by the acoustic reflex: Comparison of seven methods. Ear and Hearing 2: 156-164, 1981
- Hall JW III. Hearing loss prediction in a young population: Comparison of seven methods. International Journal of Pediatric Otorhinolaryngology 3: 225-243, 1981
- Hall JW III and Koval C. Accuracy of hearing prediction by the acoustic reflex. The Laryngoscope 92: 140-149, 1982
- Hall JW III, Berry GA and Olson K. Identification of serious hearing loss with acoustic reflex data: Clinical experience with some new guidelines. Scandinavian Audiology 11: 251-255, 1982

Estimation of Hearing Sensitivity with Acoustic Reflex Thresholds for Pure Tones versus Broad Band Noise (BBN): Simplified SPAR (Sensitivity Prediction by the Acoustic Reflex)



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Assorted Applications of Admittance Measurement:
Assessment of Eustachian Tube Dysfunction with Intact TM (1)

- Inflation-Deflation Test
  - Record baseline tympanogram
  - Create high positive or negative pressure in the external ear canal (e.g. 400 daPa or -400 daPa)
  - Patient swallows several times
  - Tympanogram is repeated
  - Small shift in tympanogram peak(away from applied pressure) suggests normal ET function

Assorted Applications of Admittance Measurement:
Assessment of Eustachian Tube Dysfunction with Intact TM (2)

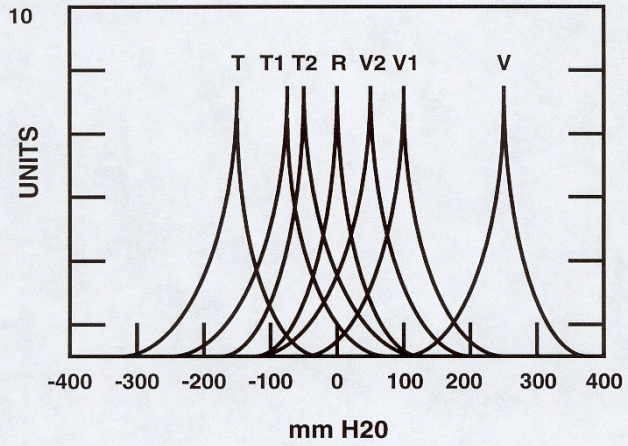
- Valsalva Procedure
  - Named after Antonio Maria Valsalva, a 17th century Italian physician and anatomist
  - Record baseline tympanogram
  - Patient pinches nose while attempting to exhale through the nose to inflate the nasopharynx
  - Tympanogram is repeated during Valsalva maneuver
  - Clear positive shift in tympanogram peak is observed if procedure is successful

Assorted Applications of Admittance Measurement:
Assessment of Eustachian Tube Dysfunction with Intact TM (2)

- Toynbee Procedure
  - Named after Joseph Toynbee, a 19th century British otologist
  - Record baseline tympanogram
  - Patient pinches nose while swallowing water
  - Tympanogram is repeated after Toynbee maneuver
  - Clear negative shift in tympanogram peak is observed if procedure is successful, indicating ET functioning

Toynbee and Valsalva Tests

R = RESTING PRESSURE
T = PRESSURE AFTER TOYNBEE
T1 = PRESSURE AFTER ONE OPEN-NOSE SWALLOW
T2 = RESIDUAL PRESSURE AFTER MULTIPLE OPEN-NOSE SWALLOWS
V = PRESSURE AFTER VALSALVA
V1 = PRESSURE AFTER ONE SWALLOW
V2 = RESIDUAL PRESSURE AFTER MULTIPLE SWALLOWS



Thank You!
Any Questions?