TYMPANOMETRY

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Why Do We Have a Middle Ear?

Diagram showing the anatomy of the middle ear, including the eardrum, ossicles (malleus, incus, stapes), and the round window. The diagram also indicates the facial (VII) nerve, stapes in the oval window, anterior ligament of the malleus, lateral ligament of the malleus, tympanic antrum, and the auditory (Eustachian) tube.
To Increase Sound Pressure
So airborne sound can penetrate fluid-filled Cochlea

How?

1. Size of TM Compared To Size of Stapes
1. Eardrum 17 times larger than stapes footplate
Pressure is force/area

From Martin, F., Introduction to Audiology, Allyn & Bacon, 8th edition, 2003, fig 10.6
2. Then there’s this leverage thing…

An axis runs right through here

ie. ossicular chain pivots on this axis

Malleus is lightly longer than incus 1.3:1
The Fulcrum:
Head of Malleus & Short Process of Incus

An axis runs right through here

Note:
Malleus is 1.3 times longer than Incus long process
From Martin, F., Introduction to Audiology, Allyn & Bacon, 8th edition, 2003, fig 10.6
Leverage action of ossicles is like a teeter totter

It increases pressure by 1.3:1

From Martin, F., Introduction to Audiology, Allyn & Bacon, 8th edition, 2003, fig 10.7
Due to its conical shape, the TM “buckles” as it vibrates…This doubles the movement of the Malleus.
SO, IN SUMMARY

The middle ear provides a sound pressure increase of 44:1

1. Eardrum – stapes size: 17:1

2. Ossicles leverage action: 1.3:1

3. Eardrum buckling action: 2:1

\[ \frac{17 \times 1.3 \times 2}{1} = 44 \]
Middle Ear Adds 33dB to Incoming Sound

*It has to, Because the Cochlea is Filled with Fluid!*
Our hearing sensitivity

Note how important speech Hz’s emphasized
By the Way... Have we got this “down?”

Lass & Woodford
Hearing Science Fundamentals Fig 2-7
Otitis Media & Kids

Their Eustachian Tubes Are More Horizontal
Normal Right Tympanic Membrane
Serous Otitis Media
Acute Bulging Otitis Media
Retracted TM

Note stapes in background
Figure 3.3.  A. View of tympanotomy, or surgical puncture of the tympanic membrane, often used to aspirate fluid by suction for culture. B. Myringotomy, or surgical incision of tympanic membrane, is performed in lower half of tympanic membrane to avoid damage to middle ear ossicles. Myringotomy is conducted to provide instant relief from pain, to drain fluid from middle ear space, and thus to help initiate rapid recovery from middle ear disease.
PE (pressure equalizing) Tube
FIGURE 6.1  An electroacoustic immittance meter. (Courtesy of General Electric Co.)
Key Concept of Tympanometry:

For the Middle Ear to be most Efficient...

Air pressure must be even on both sides of TM
Middle ear is a *closed* space:
Quite inaccessible to scrutiny from outside

**Tympanometry:**

*enables examination*

of *closed middle ear space from the outer ear canal!*
Here’s How:

Tympanometry Involves Impedance

• *Middle ear “Impedance” is comprised of 3 things:*

  • Mass
    - Resonates with Low Hz’s

  • Stiffness
    - Resonates with High Hz’s

  • Resistance
    - Like simple friction; equal for all Hz’s in any object
FIGURE 4.3  A complex mechanical system composed of a mass and spring. Friction is encountered when the mass and spring move. The impedance of the system is the vector sum of the effects of the mass, spring, and friction.
Impedance & the Middle Ear:

• Mass
  Middle ear ossicles

• Stiffness
  Load of fluid pressure from inner ear on stapes footplate

• Resistance
  Ligaments of middle ear ossicles

• In short:
  Middle ear is stiffness dominated system!
When Air Pressure is equal on both sides of TM, this creates *least* Stiffness; *most* Compliance.

*Tympanometry* is really a test of *middle ear* efficiency.
**Tympanometry Terms**

- **Impedance:**
  Reactance (opposition due to mass & stiffness)
  &
  Resistance (like simple friction; independent of Hz)

- **Admittance:**
  Inverse of impedance; in middle ear this is mostly stiffness

- **Compliance:**
  Inverse of stiffness; tympanometry thus tests compliance

- **Immittance:**
  Generic term to encompass all of the above
Low Hz (226Hz) tone at about 70 dB SPL bounces off the normally Stiff Middle Ear system

It is supposed to…
That’s what you want
Otherwise, you have nothing to measure!

Fig. 26. Impedance unit ear probe.
While probe pump changes air pressure from + to –

Probe Receiver “spits” out 226 Hz at 70 dB SPL…
&
Probe Microphone picks up what bounces back off TM
Hah!

FIGURE 6.2 Diagram of an electroacoustic immittance meter. (Courtesy of Grason-Stadler Co.)
Why the 226 Hz tone? Why not 250 Hz?

True compliance at this Hz is equal to an enclosed volume of air.

Admittance is 1 mmho when measured in 1 cc cavity, also, one can then obtain PV of ear canal in cc's.

Figure 1-7 Volumes of air with different inherent impedances.

*Keep in mind that this “equivalent volume of air in cc” is subject to changes in atmospheric pressure and temperature. Therefore, the “normal impedance” of an ear would appear to be lower at high altitudes, like the city of Denver as compared with Brooklyn, New York.*
The tympanogram shows SPL change in ear canal as air pressure in ear canal is changed.
Less SPL at the probe tip in ear canal means... more SPL is going through the middle ear!
FIGURE 4.1 Otto Metz testing a patient with the Metz bridge (c. 1955).
FIGURE 5.1 Knut Terkildsen (1918–1984) with the Metz mechano-acoustic bridge (ca. 1980).
Tympanometry (Impedance) Normally consists of Four Tests

1. Tympanogram

2. Static Compliance

3. Physical Volume of EAM

4. Acoustic Reflexes
Figure 3. Changes in middle ear pressure and compliance over a 3-day period (1,2,3) in a patient with acute otitis media.
FIGURE 6.5 Five typical tympanograms illustrating various conditions of the middle ear. Type A

Compliance

Air pressure in mm (water)

-400

-200

0

+200

AD

AS

A

B

C
FIGURE 4.15 226 Hz admittance tympanogram from two patients with chronic otitis media with effusion (A and B), a patient with tympanic membrane retraction (C), a patient with tympanic membrane atrophy (D), and a patient with an ossicular discontinuity (E).
Note

Progression

from Negative (type C)
to Rounded
to Flat

Figure 6–2

Series of tympanograms illustrating various stages through which tympanogram progresses during development of acute serous otitis media.

From Clinical Impedance Audiometry 2nd ed
Jerger, Northern
Static Compliance

According to the description below… Isn’t it just the height of the Tympanogram?

Figure 2-4 Static compliance is based on two volume measurements. The first measurement (A) represents the near-absolute volume between the probe-tip and the eardrum “clamped” with positive air pressure; the second volume measurement (B) is made with the tympanic membrane at the position of maximum compliance. (From Katz, J.: Handbook of Clinical Audiology, 2nd Ed. Williams & Wilkins Co. 1975.)
Figure 2–7  Discontinuity of the middle ear ossicular chain at the incudostapedial joint.
Note the unusually high static compliance.

Figure 2-8 Audiogram and impedance results from unilateral ossicular discontinuity of the incudostapedial joint.

From Clinical Impedance Audiometry 2nd ed Jerger, Northern
Physical Volume of ear canal

Normally is between 1.0 to 1.5 cc

• True Type B tympanogram has normal PV
• If Type B with tiny PV, then probe tip is against EAM wall

Figure 2-6

Diagrammatic representation of the measurement of near-absolute volume known as the Physical Volume Test (PVT). The PVT indicates intactness of the tympanic membrane, and cc volume values in eardrums with perforations or patent ventilation tubes are four or five times greater than when tympanic membrane is intact.
Acoustic Reflexes

• Ipsilateral
• Contralateral

FIGURE 6.3 Configuration of the probe of an immittance earphone on the other ear.
Location of Stapedius muscle
Location of Tensor Tympani muscle

Lass & Woodford
Hearing Science Fundamentals Fig 2-10
Acoustic Reflex Arc

Note:

if one ear gets the loud sound, the AR occurs in both ears

Another view of the Acoustic Reflex Arc

This ear is getting the stimulus and has an AR

This ear did not get the stimulus but still has an AR

Figure 10. Diagram illustrating the basic components of the crossed and uncrossed neural pathways that make up the acoustic or intra-aural muscle reflex arc. The reflex arc for both the stapedius and tensor tympani are shown; however, at present the stapedius reflex is assumed to make the major contribution to changes measured by impedance instruments.
Question:

Why do we really have acoustic reflexes??
ARs are a Low Hz Phenomenon

**FIGURE 5.6** The frequency dependent attenuation characteristics (transmission loss in dB) of the acoustic reflex from four subjects in response to 85 to 110 dB SPL reflex-activator signals. (From Rabinowitz, 1977, with permission)
Answer:

Not to protect against NIHL
- one of the fallacies we are commonly lead to believe

ARs occur especially while we speak
- they actually kick in about 50 msec before we talk

Note ARs strongest for low Hz’s (500, 1000Hz)
- because our voices are louder for vowels

ARs reduce upward spread of masking
- allow us to hear high Hz’s better while talking
- all mammals have them
ARs & Speech Discrimination

AR deals with IHCs
AR arc: IHCs send afferent information to VIII nerve
IHCs are critical part of AR arc

OAEs deal with OHCs
Cochlea: OHCs receive efferent information
OHCs not involved w/ AR arc

Two people with same moderate SNHL
may have very different SD

One with good SD probably has ARs at reduced SLs
one with poor SD probably has absent ARs
Hair Cells: A Closer Look

Picture from Australian Hearing
Hear & Now, issue 4, 1998
Normal Inner & Outer Hair Cells

Fig 1-7, Venema, T. Compression for Clinicians 2nd edition, Thomson Delmar Learning 2006
Damaged Hair Cells

(mostly outer)

Fig 1-8, Venema, T. Compression for Clinicians 2nd edition, Thomson Delmar Learning 2006
The Acoustic Reflex & Tympanometry

With ARs, you are still using Tympanometry
measure how much 226 Hz tone is bouncing off TM

Tympanograms change middle ear compliance by air pressures
ARs change middle ear compliance by loud sounds!

ARs are done at Static Compliance
at the air pressure yielding highest tympanogram
Contralateral ARs were 1st to be Developed

Contralateral ARs relatively straightforward to comprehend

Low-Hz tones (500 & 1000 Hz at 85-110 dB HL) are presented with headphone to one ear...

ARs (temporary increases in 226 Hz SPL) measured with probe in opposite ear
Ipsilateral ARs are harder to Comprehend

Loud 500 or 1000Hz tone stimuli & 226 Hz tone to measure AR are all in same ear canal at same time!
Temporary increases in 226 Hz SPL) are now measured with probe in opposite ear

226 Hz tone to measure AR
500 or 1000 Hz AR stimulus tone
Acoustic reflex is always reported according to ear that got the stimulus.
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*FIGURE 6.7  Eleven theoretical examples of the results of ipsilateral and contralateral acoustic reflex testing. (Key: R = right ear; L = left ear; HL = hearing loss; SL = sensation level. In conditions H-K there is a lesion in the anatomical region in parentheses.)*
Acoustic Reflexes are measured as temporary decreases in Compliance (Admittance)

Think of a temporary drop in the Tympanogram peak (Static Compliance) while the loud AR stimulus is presented.

The results here are shown for a 1000 Hz tone presented for 1 second.
ARs *Reported* in Sensation Level (SL)

ARs *tested* in dB HL (*tympanometer calibrated in dB HL*)
ARs normally found between 80-100 dB HL

ARs *reported* in dB SL (*always relative to one’s own thresholds*)
ARs can be tested at 500, 1000, 2000, or 4000 Hz

*Normal & mild-moderate SNHL*
may have ARs at similar dB HL
but at very different SLs

*Eg:* normal HL & flat 50 dB SNHL may have ARs at 100 dB HL
*but normal HL has ARs at 100 dB SL*
*the SNHL has ARs at 50 dB SL*
ARs and SNHL

Note: The SL for ARs tends to decrease linearly as the degree of SNHL increases (up to about 60 dB HL)

Fig 6.—Relation between reflex SL and degree of hearing loss in patients with sensorineural (presumably cochlear) loss.
SNHL and Reduced SL

Note: SL decreases in almost exact proportion to degree of SNHL!

From Clinical Impedance Audiometry 2nd ed Jerger, Northern

Fig 4.—Reflex SL and degree of hearing loss (in HTL) in 515 patients with sensorineural loss.
Absent ARs and SNHL

Note:
Absence of ARs increases dramatically with SNHL of 60 dB HL or more
Bilateral SNHL & ARs

Figure 13.15. Acoustic reflex thresholds within the applicable 90th percentiles and negative reflex decay in a typical case of cochlear impairment.

Katz, Handbook of Clinical Audiology
Unilateral SNHL & ARs

Contralateral & Ipsilateral AR are normal for both ears

![Graph showing hearing level in decibels vs frequency in Hertz and acoustic reflex thresholds and decay](image)

**Figure 13.16.** Elevated and/or absent acoustic reflexes and positive reflex decay (where measurable) in a case of retrocochlear pathology (left eighth nerve tumor).

Katz, Handbook of Clinical Audiology fig 13.18
Conductive HL tends to obliterate ARs

Unilateral Conductive HL

Contralateral ARs with stimulus in *good* ear:
mechanical middle ear problems in bad ear prevent AR

Contralateral ARs with stimulus in *bad* ear:
HL in bad ear prevents intensity sufficient to cause AR in opposite ear

Result: Only good ear Ipsilateral AR present
Conductive HL tends to obliterate ARs
Bilateral Conductive HL

Contralateral & Ipsilateral ARs all absent
**Figure 13.21.** Typical configuration of contralateral and ipsilateral acoustic reflex outcomes associated with a unilateral retrocochlear disorder, such as an acoustic tumor or extra-axial brainstem lesion. Notice that reflex abnormalities are seen for both the crossed (contralateral) and uncrossed (ipsilateral) conditions in which the pathologic side is stimulated.

**Figure 13.22.** Typical configuration of contralateral and ipsilateral acoustic reflex outcomes associated with an intra-axial brainstem lesion. Notice that reflex abnormalities are seen for the crossed (contralateral) conditions, whereas the uncrossed (ipsilateral) conditions may be unaffected.
Figure 13.23. Abnormal contralateral and normal ipsilateral acoustic reflex findings in a patient with an intra-axial brainstem lesion.
Relationship between degree of HL and Absent ARs in SNHL vs VIII nerve pathology

From: Musiek & Rintelmann
Acoustic Reflex Decay & VIII nerve pathology

Stimulus Tone

No Decay

No Decay b/c AR reduced by <50% over 10 sec

AR Decay b/c AR Reduced by 50% over 10 sec