Impedance audiometry

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Abstract:

Impedance audiometry is used to assess the status of ear drum and middle ear cavity. This test also helps in the assessment of acoustic reflex pathway which include 7^{th}, 8^{th} cranial nerves and brain stem. This test should not be totally relied to assess the sensitivity of hearing of an individual, but always should be viewed in conjunction with pure tone audiometry.

Introduction:

Impedance audiometry is also known as tympanometry, acoustic immitance test.
The entire science of clinical impedance audiometry owes a lot to Terkildsen and Scott-Nielsen[1] who conducted extensive experiments during 1960's in measuring middle ear pressure. Eventhough technology was not advanced those days their results amazingly hold good even now. Terkildsen conducted pathbreaking experiments describing the role played by ear drum in the impedance matching function of the ear.[2] Their results form the basis of various clinical tympanometric procedures performed these days.

Impedance audiometry is a measurement of energy / airpressure involving the external auditory canal, ear drum, ossicular chain, stapedius muscle, cochlea, $7^{th,}$ 8^{th} cranial nerves and the brain stem.

Tympanometry measures the sound reflected from the ear drum while the pressure of the external canal is varied by the operator. It aids in the assessment of outer ear, middle ear and the eustachean tube. Conventional low frequency probe cannot be used to perform tympanometry in infants below the age of 7 months because of the suppleness of the cartilage of external auditory canal. High frequency probe should be used to perform impedance auditometry in infants.

Impedance audiometry is affected by the following factors:

1. Mass of the external and middle ear cavities

2. Mobility of external and middle ear cavities

3. Resistance systems of external and middle ear cavities.

Acoustic impedance measurement should be performed in the plane of the ear drum. Since the external canal is not a straight tube the probe used should straighten the external canal adequately in order to measure impedance in the plane of the ear drum.

Under conditions where the ear drum is under considerable tension, the impedance measurement is dominated by the volume of external auditory canal space. When the tension of ear drum decreases then the influence of the middle ear space on impedance measurement increases. The difference between the highest and lowest values obtained by varying external canal pressure levels is considered to be the vibrating characteristics of the ear drum.

Early equipment used to measure impedance of the ear used a single low frequency probe tone of 220 Hz. Measuring impedance using a single low frequency proved to be erroneous. These earlier equipment did not have built in automatic gain control circuit incorporated to maintain the sound pressure level of the probe tone at a constant level. This created problems while measuring impedance of various external auditory canal sizes.

In 1970 Grason Stadler introduced a new instrument for measuring impedence of the ear. This model used two probe frequencies (220 and 660Hz). It measured two components of admittance i.e acoustic susceptance and conductance [3].

The currently available instruments have inbuilt automatic gain control circuits which facilitates maintenance of constant probe tone levels in ear canals of all sizes. Measurement values are represented in absolute physical units (acoustic mmho) in contrast to arbitrary units used in earlier models.

The currently available computer based equipment offer the facility of multiple probe tones (226, 678 and 1000 Hz). These instruments are capable of measuring multiple admittance components.

Calibration:

In order to maintain consistently accurate measurement, the instrument should ideally be calibrated. Calibration is usually performed using three calibration cavities (0.5, 2.0 and 5.0 cm^3). Calibration should be periodically checked by recording tympanograms on calibration cavities. Calibration particularly to high frequency tones are sensitive to the presence of debris in the probe device. Hence the probe should be inspected and cleaned before recording tympanogram.

Constraints of Impedance audiometry:

Impedance audiometry measures the acoustic energy flowing into the middle ear and not the sound energy that flows from middle ear to cochlea. Some amount of acoustic energy is lost in the decoupled portion of the ear drum and ossicles and is not passed to the middle ear cavity. Hence this investigation should not be used to assess the sensitivity of hearing. If the ear drum is scarred the tympanometry can be grossly abnormal with clinically normal hearing. (This investigation should be viewed along with clinical examination findings in order to avoid these fallacies). It is hence not possible to expect a 1:1 correlation between specific middle ear pathology and a specific tympanogram pattern. Studies reveal that a same tympanogram pattern can be created by different middle ear pathologies. Tympanogram should be analysed in conjuction with clinical history of the patient and pure tone audiometry.

Role of external canal volume in tympanometry:

Eventhough the goal in performing tympanometry is to measure acoustic immitance of middle ear, in reality the impedance probe cannot be placed over the ear drum. Hence the acoustic admittance measured at the probe tip is a measure of admittance of external canal volume and admittance at the plane of ear drum.

Y_a (acoustic admittance at probe tip) = y_{ec} (admittance of ear canal volume) + y_{tm} (admittance at the plane of ear drum).

According to Terkildsen and Thomsen [4] ear canal pressure of 200 dapa causes stiffening of ear drum allowing the sound generated by the probe to be reflected completely from the surface of the ear drum. At this pressure the admittance measured at the probe tip is entirely due to volume of external auditory canal. Hence at this ear canal pressure as the volume of the ear canal changes, the tympanogram curve shifts higher or lower in the Y-axis without altering the shape of the tympanogram. Tympanometry overestimates the volume of the external auditory canal by 40%. At ear canal pressure of 200 dapa no sound is literally heard by the patient as most of it are reflected back from the ear drum.

In patients with ear drum perforation, the external canal volume include:

1. Volume of external auditory canal

2. Volume of middle ear cavity

3. Volume of aditus

4. Volume of mastoid air cell system

Wilber and Feldman [5] postulated that external canal volume measurement exceeding 1.5 – 2cm^3 in children, or a difference in ear canal volume between both sides greater than 0.5 cm^3 indicates ear drum perforation. Adults with ear canal volume of more than 2.5 cm^3 indicate perforated ear drum.

Tests that can be performed using Impedance audiometer:

1. Tympanometry

2. Eustachean tube dysfunction

3. Tests to identify perilymph fistula

4. Acoustic reflex threshold

5. Acoustic reflex decay

Ear pathologies that can be identified using impedance audiometry:

1. Middle ear effusion
2. Ear drum perforation
3. Patulous eustachean tube
4. Tympanosclerosis
5. Hypermobile ear drum
6. Eustachean tube dysfunction
7. Glue ear
8. Otosclerosis
9. Ossicular chain discontinuity
10. Acoustic neuroma
11. Facial nerve dysfunction
12. Hearing loss
13. Brain stem disorders

Tympanometry:

This test was first introduced by Terkildsen etal in 1950 to measure middle ear pressure.
This investigation measures the sound reflected from the ear drum, while the pressure of external auditory canal is varied by the observer. This investigation aids in the assessment of outer ear, middle ear and eustachean tube. This test also evaluates acoustic reflex pathways which includes VII, VIII cranial nerves and brain stem. This test should not be used to assess auditory sensitivity and should be viewed in conjunction with other audiological procedures.

This test is non invasive and does not need any response from the patient. The approximate test time for both the ears happens to be about 2 minutes [6].

Tympanometer has a hand held probe which is inserted into the external auditory canal. The inside of the hand held probe contains 3 tubes. These tubes contain:

1. Loud speaker

2. Microphone

3. Pump

The probe tip should fit snuggly into the external auditory canal forming a hermetic seal around it.

Tone is delivered through a loud speaker, while the pressure of the external auditory canal is changed with the help of a pump connected to the third port of the probe. The amount of sound reflected from the ear drum is picked up by the mic connected to the second portal of the probe. This is displayed in a graph form known as the tympanogram. The probe tone is typically presented at 226 Hz while the pressure of external auditory canal is altered between +200 and – 400 decapascals.

Maximum compliance occurs when the pressure of external auditory canal becomes equal to that of the pressure of middle ear cavity.

The compliance peak indicates adequate pressure levels in the middle ear cavity which is only possible with a good functioning eustachean tube [7].

The term static compliance is the height of the tympanogram at its peak. This is actually a measurement of the mobility of the entire system.

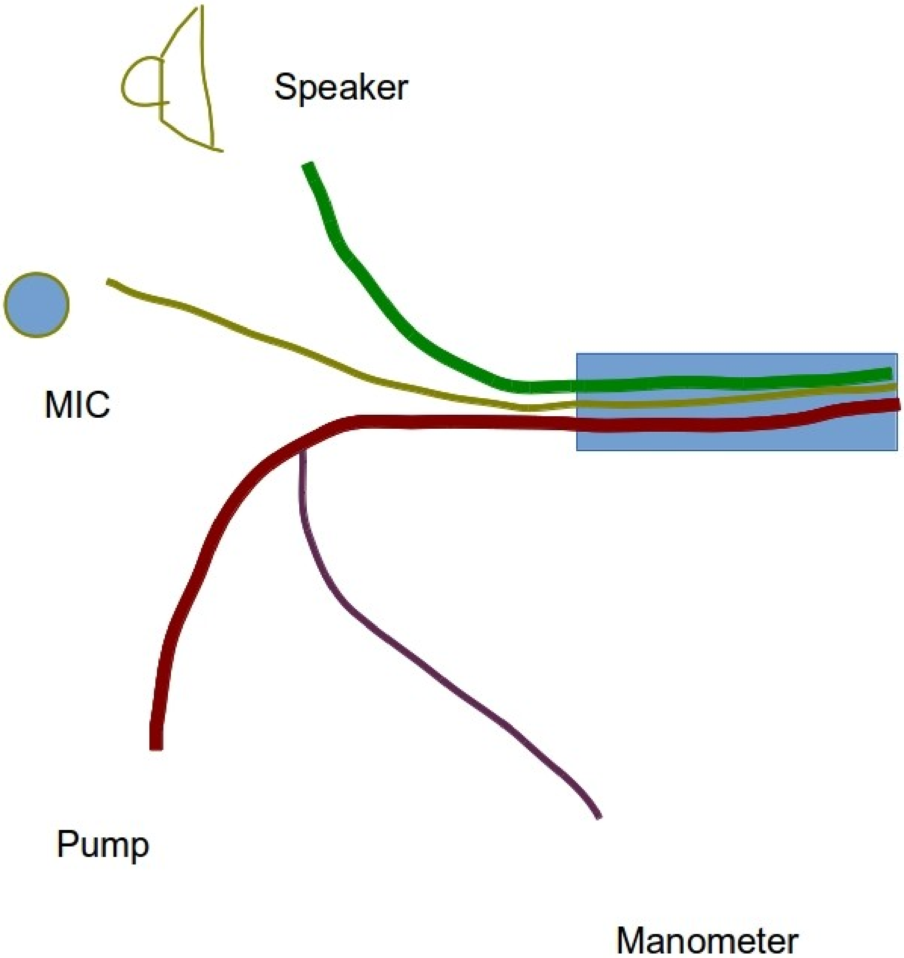

Image showing components of impedance probe

Information provided by tympanogram:

1. Compliance of middle ear system (drum movement)

2. Volume of external auditory canal

3. Pressure of middle ear cavity (almost similar to that of atmospheric pressure in healthy ears)

4. Patterns corresponding to various disorders

Compliance of middle ear system:

Compliance is plotted vertically in the tympanogram.

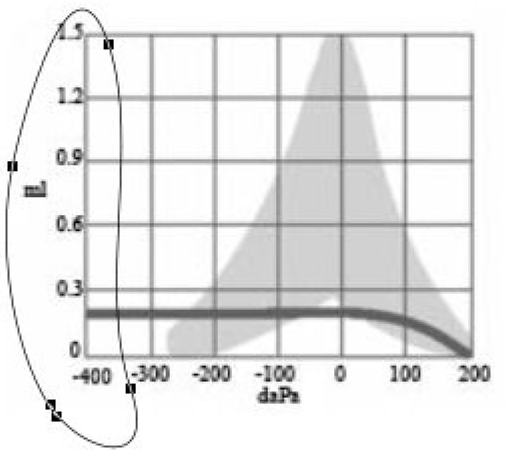

Figure showing compliance plotted in the vertical axis of a tympanogram

Maximum compliance will occur when the middle ear pressure and pressure of external canal are equal (i.e. Atmospheric pressure).

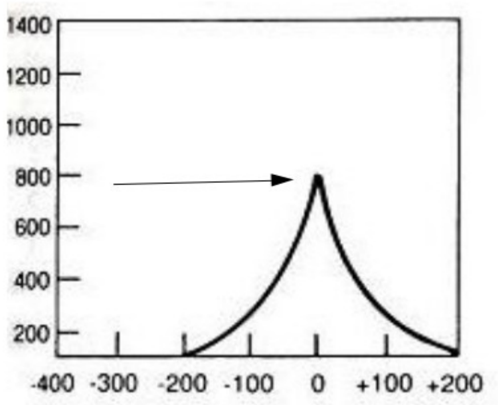

Figure showing peak of the compliance indicated by an arrow in the tympanogram

Ear canal volume:

Ear canal volume ranges between 0.2 and 2 ml (children and adults). A reading of more than 2 ml in a small child indicates perforated ear drum / patent eustachean tube. On the contrary this is normal reading for an adult. The volume of the middle ear cavity can be estimated by locating the peak of maximum compliance on the vertical axis.

Middle ear pressure:

This value corresponds to atmospheric pressure. Normal pressure in the middle ear cavity is maintained by the normally functioning eustachean tube. Middle ear pressure can be estimated from a tympanogram by locating the value on the horizontal axis corresponding to the peak maximum compliance on the vertical axis.

Classification of tympanograms:

Commonly used classification system of tympanograms was devised by Jerger[8]. Eventhough other systems have been suggested, none of them are being followed on a regular basis as the one devised by Jerger.

Type A curve:

In this type of curve the peak compliance occurs at or close to atmospheric pressure indicating normal middle ear pressure[9]. The compliance peak occurs between -150 to + 100 dapa. The compliance values range between 0.2 – 2.5 millimhos. This curve is seen in normal individuals.

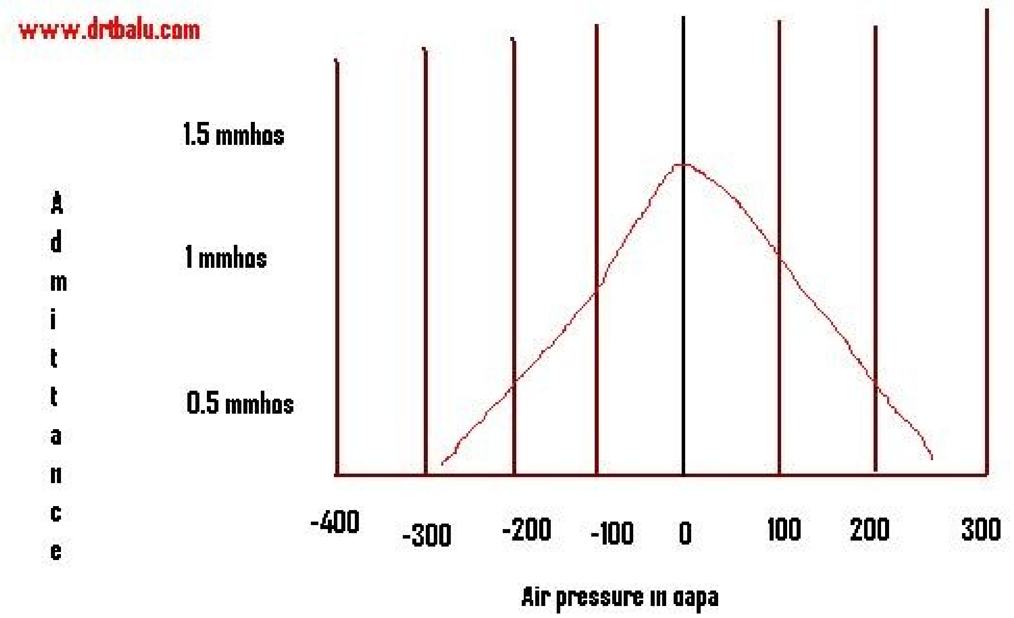

Figure showing Type A Jerger curve

Type As curve:

This curve is rather shallow indicating a stiffened middle ear system. Compliance peak occurs between -150 to + 100 dapa. The compliance value is less than 0.2 mmhos. This curve is commonly seen in patients with:

1. Glue ear [11]

2. Stiffened ear drum

3. Otosclerosis [10]

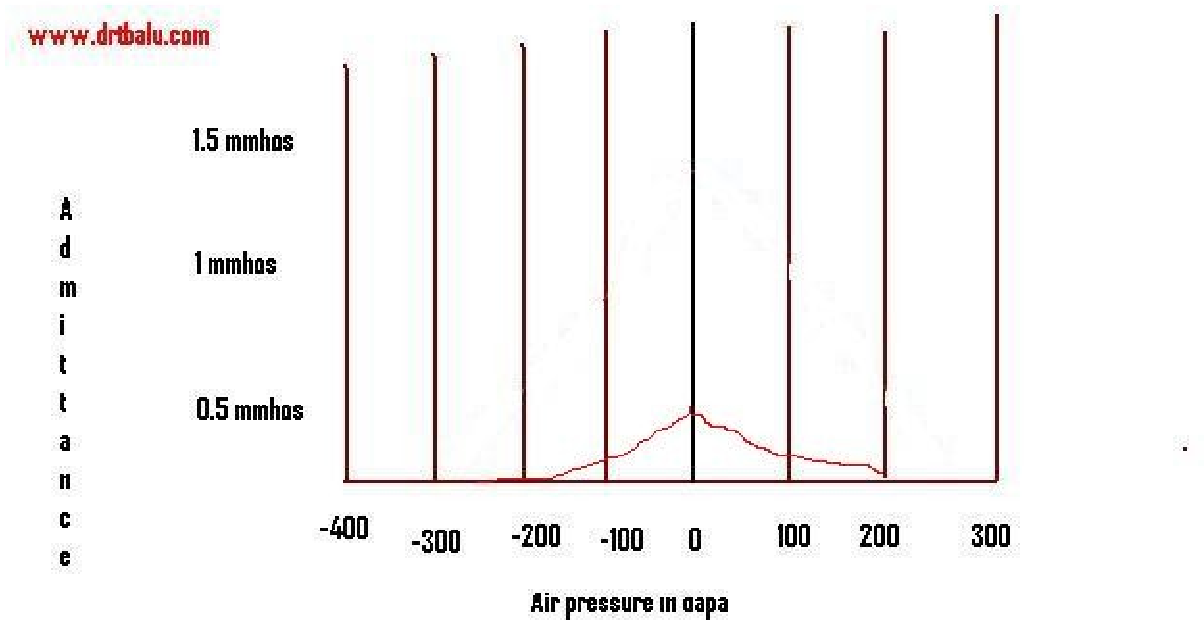

Figure showing Type As Jerger curve

Type Ad curve:

Ad curve is a very deep curve suggesting a flaccid drum, or ossicular chain disruption. Ossicular chain disruption usually gives a compliance which is way beyond the recording ability of tympanometer. In other words it is way off the chart. The compliance occurs between – 150 to + 100 dapa as it is the case in all A type curves. The compliance value is more than 2.5 mmhos.

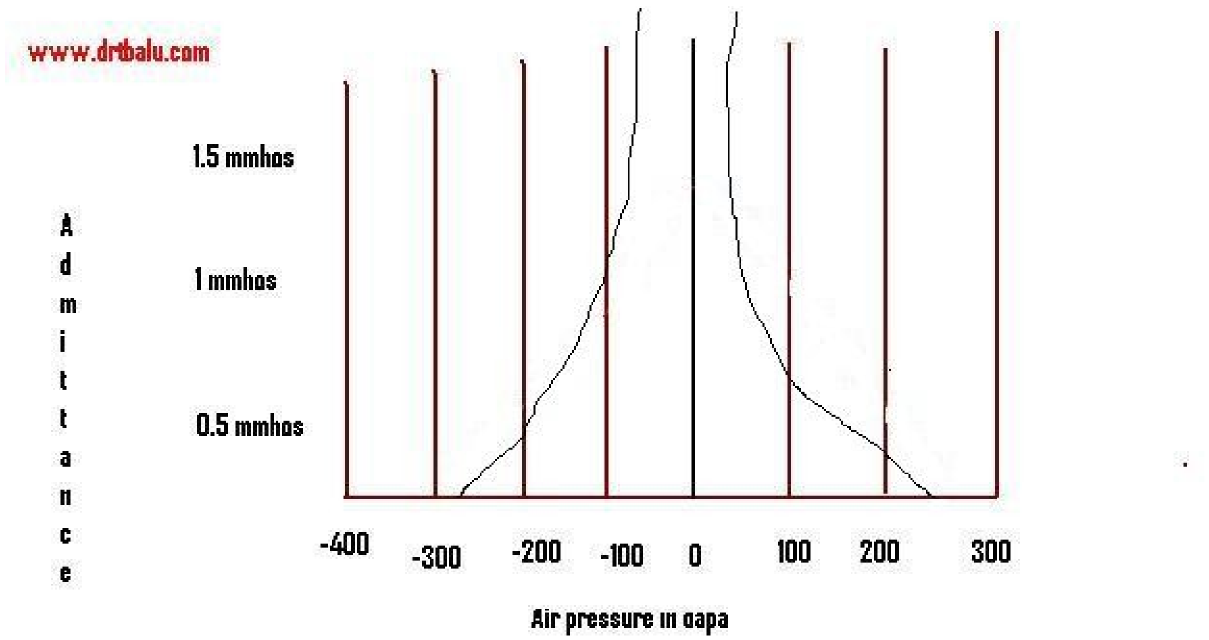

Figure showing Type Ad curve. Note the peak goes way off the chart

Type B curve:

This is a flat curve with no compliance peak. This curve should always be interpreted in conjunction with ear canal volume. Average ear canal volume in children ranges between 0.42 and 0.97 ml, where as in adults it ranges between 0.63 – 1.46 ml.

Type B curve in the presence of normal ear canal volume suggests otitis media.

Type B curve with small canal volume suggests that the ear canal is occluded by wax, or in the event of improper positioning of impedance probe.

Type B curve with large canal volume suggests perforation of ear drum.

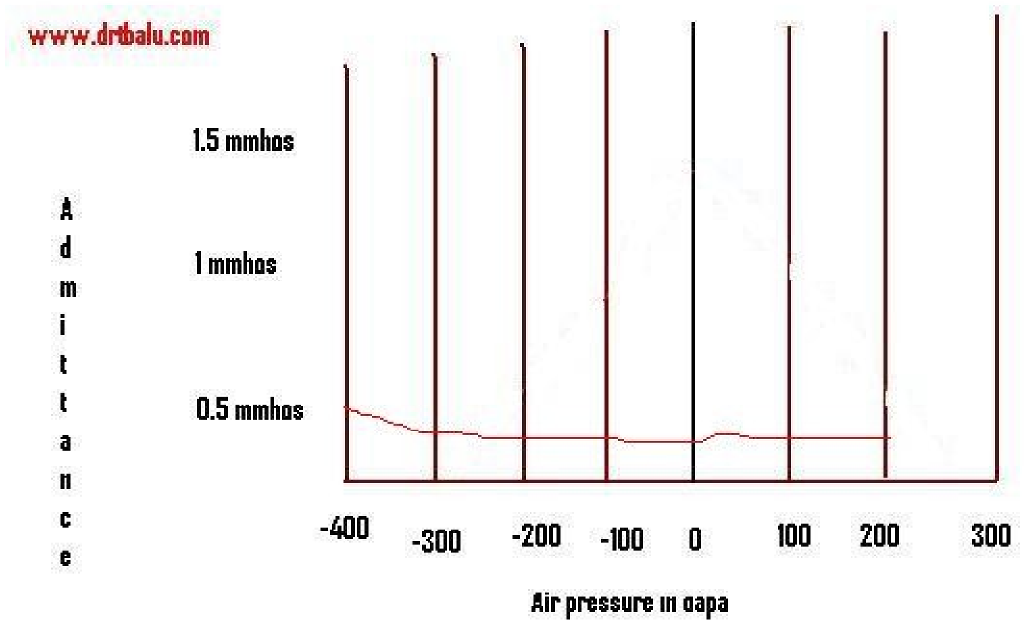

Figure showing Type B curve

Type C curve:

This curve suggests significant negative pressure in middle ear cavity, which could be caused by eustachean tube dysfunction. Compliance peak is recordable but occurs at – 150 dapa pressures.

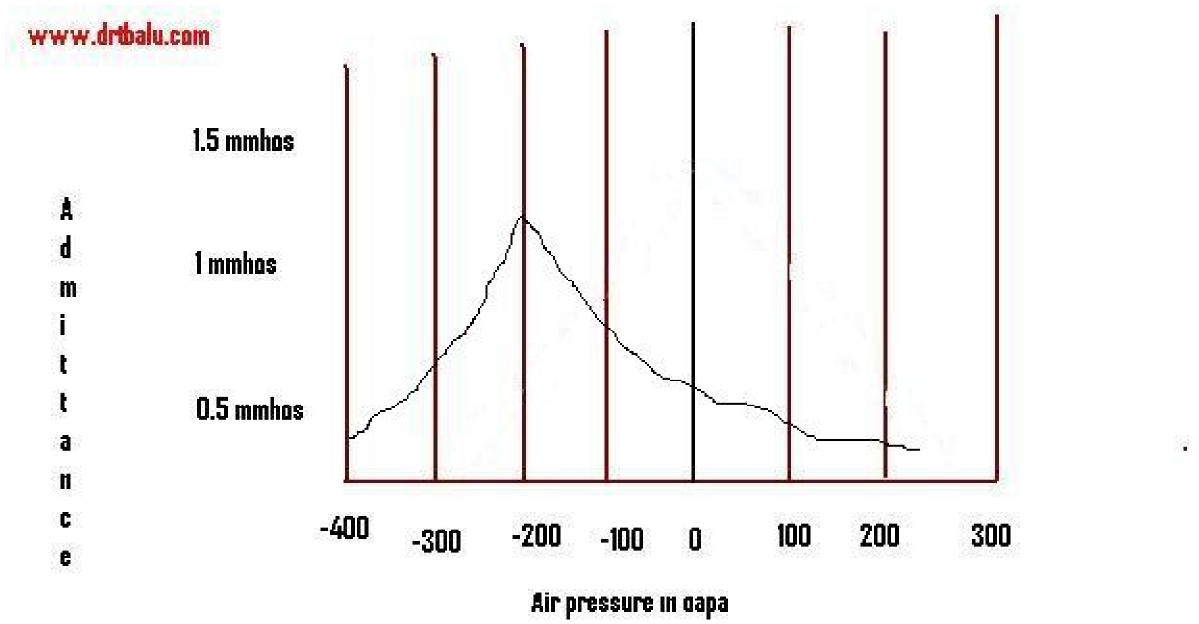

Figure showing Type C tympanogram

Acoustic reflex measurements:

Acoustic reflex (contraction of stapedius muscle) occurs in normal individuals in response to loud noise presented to the auditory pathway. The contraction of this muscles stiffens the ossicular chain which changes the compliance of middle ear system. As in tympanometry the probe tone is used to measure this change in compliance in response to loud sound. When the stimulus presentation and measurement of compliance is made in the same ear then it is known as ipsilateral acoustic reflex measurement. If the stimulus is presented to one ear and the impedance is measured from the other it is known as contralateral acoustic reflex. Usually this test is performed after performing routine tympanometry.

This test is usually conducted at probe tip pressures where the compliance peak occured during routine tympanometry. Stimulus tones of varying intensities (500, 1000, 2000, 4000 Hz) are presented at short bursts. If change in compliance of greater than 0.5 ml is detected then acoustic reflex is supposed to be present. Even very small probe movements during test procedure can cause artifacts producing false positive results.

Precautions to be taken while preforming acoustic reflex measurements using tympanometry:

The external canal should be cleared of all debris.

Air tight seal should be created between the probe and the ear canal being tested.

The patient should be asked to still still without swallowing.

Tympanometry in combination with acoustic reflex measurements gives a clear picture of the middle ear function.

If the patient develops intense giddiness associated with nystagmus as the probe pressure at the external auditory canal is increased then perilymph fistula should be strongly suspected.

Advantages of tympanometry:

1. A good clinical evaluation tool

2. This testing method is objective

3. Patients of any age can be tested

4. Test results are documented as printed report

5. It can be performed real quick (about 2 minutes)

6. It is non invasive and cost effective

Multiple frequency tympanometry:

In this test measurements are made through a series of freqencies ranging from 250 – 2000 Hz. This test helps in the assessment of resonant frequency of the middle ear system. Normal value of resonant freqeuncy of middle ear system is 900 Hz. Below this value the middle ear resistance to sound is stiffness controlled and above this value middle ear resistance is mass controlled [12]. At the resonant frequency middle ear has the least resistance to the conduction of sound.

The external and middle ear systems vary in their acoustic response properties. This is because the bony portion of the external canal is not completely developed. The cartilagenous portion of external canal is extremely pliable thereby making the results of tympanometry unreliable [13].

Changes that occur in external and middle ears after infancy that could have a bearing on impedance audiometry:

1. External ear size increase

2. Change in the orientation of ear drum

3. Fusion of tympanic ring

4. Decrease in the overall mass of middle ear due to changes in bone density and loss of mesenchyme

5. Tightening of ossicular ligaments

6. Closer coupling of stapes to annular ligament

7. Formation of bony external auditory canal

Because of the above factors the infant middle ear is a mass dominated system which has a lower resonance frequency when compared to that of adult which is stiffness dominated system at low frequencies. Best choice of probe frequencies in infants under 4 months of age is 1000 Hz. In infants above 4 months of age 226 Hz probe tone can be used.

Conclusion:

Impedance audiometry is very useful when used in conjunction with other audiological evaluations in the assessment of middle ear pathologies. The major advantage of this investigation is that it is objective, recordable and can be performed in patients of all ages.

References:

1. Terkildsen K, Scott Nielsen S. (1960) An electroacoustic impedance measuring bridge for clinical use. Arch Otolaryngol. 72, 339–346

2. Terkildsen K, Thompsen KA. (1959) The influence of pressure variations on the impedance of the human ear drum. J Laryngol Otol. 73, 409–418.

3. ZWISLOCKI I, FELDMAN AS: Acoustic impedance of pathological ears. Asha Monogr 15, 1970.

4. Terkildsen K. (1976) Pathologies and their effect on middle ear function. In: Feldman AS & Wilbur LA, eds. Acoustic Impedance and Admittance: The Measurement of Middle Ear Function. Baltimore: Williams & Wilkins, 78–102.

5. Feldman A.S. (1975) Acoustic Impedance-admittance measurements in Bradford LJ (Ed.): Physiological measures of the Audio-vestibular system. New York: Academic Press 87-145

6.http://www.maico-diagnostic.com/eprise/main/_downloads/com_en/Documentation/Guide.Tymp.pdf

7. http://drtbalu.co.in/imp_audio.html

8. Jerger, J.F. (1970). Clinical experience with impedence audiometry. *Archives of Otolaryngology, 92*, 311-324.

9. Margolis RH, Hunter LL. Tympanometry: basic principles and clinical applications. In: Musiek FE, Rintelmann WF. Contemporary perspectives in hearing assessment. Boston: Allyn and Bacon, 1999:89–130.

10. Zhao F, Wada H, Koike T, Ohyama K, Kawase T, Stephens D. Middle ear dynamic characteristics in patients with otosclerosis. *Ear Hear*. 2002;23:150–8.

11. Managing otitis media with effusion in young children. *Pediatrics*. 1994;94:766–73.

12. Shanks, J. E., and D.J. Lilly (1981). An evaluation of tympanometric estimates of ear canal volume. J. Speech and Hear. Res. 24, 557566.

13. Keefe, D. H., Bulen, J. C., Arehart, K. H. & Burns, E. M. (1993). Earcanal impedance and reflection coefficient in human infants and adults. JAcoust Soc Am 94: 261738.