EFFECT OF PROCEDURAL VARIABILITY ON ESTIMATION OF MIDDLE EAR RESONANCE

Register No. 02SH0024

An Independent project submitted as part of fulfillment for the

First year M.Sc. (Speech and Hearing) to University of Mysore, Mysore

ALL INDIA INSTITUTE OF SPEECH AND HEARING, MYSORE-570006

JUNE 2003

To

My Parents

&

My Guide

CERTIFICATE

This is to certify that the independent project entitled: *"Effect of Procedural Variability on Estimation of Middle Ear Resonance"* is a bonafied work done in part fulfillment for the degree of Master of Science (Speech and Hearing) of the student (Register No. 02SH0024)

Dr.M. Jayaram

Director

All India Institute of

Speech and Hearing

Mysore- 6

Mysore

June 2003

CERTIFICATE

This is to certify that the independent project entitled: ***"Effect of Procedural Variability on Estimation of Middle Ear Resonance"*** has been prepared under my supervision and guidance. It is also certified that this has not been submitted earlier in any other University for the award of any other Diploma or Degree.

Guide

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June 2003

DECLARATION

I hereby declare that this independent project entitled: *"Effect of Procedural* ***Variability on Estimation of Middle Ear Resonance"*** is the result of my own study under the guidance of **Dr. C.S. Vanaja,** Lecture in Audiology, Department of Audiology, All India Institute of Speech and Hearing, Mysore, and has not been submitted earlier in any other University for the award of ariy other Diploma or Degree.

Mysore

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June 2003

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Introduction

Tympanometry is a safe and quick method for assessing middle ear function. Low frequency tympanometry can provide useful diagnostic information about disorder of tympanum (effusion and abnormal pressure within the middle ear), about affected tympanic membrane (perforation, atrophicscaring and retraction) and about middle ear dysfunction (Lilly, 1984). However, low frequency tympanometry is proved to be insensitive to many lesions that affect ossicular chain. There is an overlap in peak compensated compliance value between normal individuals and otosclerosis (Jerger, 1970; Alberti & Kristensen, 1970; Jerger, Anthony, Jerger & Mauldin, 1974). It could be because, at low frequency almost all normal and pathological ears are stiffness dominated and a change in the middle ear resonance does not produce a marked change in the tympanometric shape for low frequency tympanometry. Multifrequency and multicomponent tympanometry is developed to overcome the limitations of conventional low frequency tympanometry.

The development of multifrequency and multicomponent tympanometry has made it possible to record admittance across a wide range of frequencies and to derive its polar components (admittance magnitude and its phase angle), rectangular components (susceptance and conductance) and resonance frequency. Resonance frequency corresponds to the frequency at which mass and stiffness equally contribute to the middle ear admittance.

Colletti (1975,1976,1977) measured acoustic impedance tympanograms for probe tones of frequencies ranging from 200 to 2000 Hz. In normal individuals and population with different pathological conditions. He showed that in normal ears the form of tympanogram gradually varies from bell shape (up to 1000 Hz) to W-shape (1000- 1400 Hz) and then to v- shape (above 1400 Hz frequencies). Pathology seems either to shift the range in which a certain form is found to higher or lower frequencies, or to affect the properties of complex patterns. This change in patterns is due to shift in the resonance frequency.

It has been reported that the middle ear function can be assessed using resonance frequency, estimated using multifrequency tympanometry. In ears with otosclerosis, resonance frequency is shifted to higher frequency where as in ears with ossicular chain discontinuity, resonance frequency is shifted to lower frequency (Colletti, 1975,1976, 1977; Lilly, 1973; Vancamp & Vogeleer, 1986). However, in early stage of otosclerosis, there is an overlap of resonance frequency obtained for normal ears and otosclerotic ears (Shanks & Shelton, 1991; Shahnaz & Polka, 1997; Zhao, Wada, Koike, Ohyoma, Kwaski & Stephens, 2002).

Different methods are available to estimate resonance frequency using multifrequency tympanometry. Hunter and Margolis (1992) classify them into the following two categories:

- Sweep Frequency method
- Sweep Pressure method

In sweep frequency method, the external ear canal pressure is changed in discrete steps. At each step, the probe frequency is swept across a pre-selectecl range. An array of several tympanograms, one for each frequency, is constructed as the air pressure changes. In sweep pressure method, the probe tone frequency is held constant while pressure is changed at the rate of 200dapa/sec. This can be carried out for a range of probe tone frequency from 200 to 2000 Hz. Multiple tympanograms at the frequency of interest is obtained individually.

Resonance frequency can be estimated in the above two methods by using three procedures. First is the lowest frequency at which notch in the susceptance tympanogram is equal to the negative tail (negative tail compensation), second is the lowest frequency at which notch in the susceptance tympanogram is equal to the positive tail (positive tail compensation) and third is the lowest frequency at which admittance tympanogram notches.

Aims of the study: The present study was designed to investigate the effect of procedural variability on estimation of resonance frequency. It was further aimed at identifying the best procedure, which detects otosclerosis and healed tympanic membrane.

Need for the study. Low frequency tympanometry is sensitive in detecting middle ear pathologies that effect the tympanum or the tympanic membrane (Lilly, 1984) but insensitive in detecting pathologies that affect the ossicular chain. Although research shows that peak compensated admittance decreases in the otosclerotic ears, there exists an overlap in normal and pathological group (Jerger, 1970; Alberti & Kristensen, 1970; Jerger, Anthony, Jerger & Mauldin, 1974), which can be better detected by the resonance frequency measures. Normative studies indicate, different methods for estimation of resonant frequency, results in different mean values and different range of resonance resonant frequency, results in different mean values and different range of resonance frequency (Margolis & Goycoolea, 1993). The resonance frequency is reported to be consistently lower for sweep pressure method than for sweep frequency method, regardless of the component measured. In sweep pressure method, when susceptance tympanogram is used, the negative tail resonance frequency is higher than the positive tail, which reflects asymmetry of susceptance tympanogram (Margolis & Goycoolea, 1993, Margolis & Smith, 1977). Margolis and Goycoolia (1993), based on their studies on normal subjects recommended that sweep pressure recording with +200dapa compensation for detecting pathologies associated with high resonance frequency and sweep frequency method with +200dapa compensation for low resonance frequency pathologies. This recommendation is based on their findings that sweep frequency recording produced higher estimate of resonance frequency in normal individuals. Thus possible ceiling effects occurring with the sweep frequency method. This may limit to measure abnormal high resonance frequency. Sweep pressure method tend to produce relatively low resonance frequency. This suggests that it may be relatively less sensitive than sweep frequency method in detecting pathologies that produce low resonance frequency. However, there is a need to verify this with pathological group. Hence the present study was undertaken.

Review of Literature

Middle ear is a mechano-acoustic system whose function can be analyzed in terms of acoustic admittance or acoustic impedance. Acoustic admittance (Ya) is the ease with which the energy flows in to the system and it has two components i.e. susceptance (Ba) and conductance (Ga). Acoustic impedance (Za) is the opposition to the flow of energy in to a system and it has two components i.e. reactance (Xa) and resistance (Ra). Reactance due to the mass of the system is called mass reactance (Xm) and reactance of the system due to stiffness is called stiffness reactance (Xc). Similarly susceptance can be divided in to mass susceptance and compliant susceptance. Middle ear transformer system is made up of membranes, ligaments, muscles, bones, and air trapped in the middle ear. Among these tympanic membrane can be considered as mechanical spring, the air volume enclosed in the middle ear is considered as an acoustic spring, ossicular chain can be considered as mechanical mass, the air molecules in the mastoid hair cells is considered as acoustic mass, middle ear tendons and ligaments is considered as mechanical friction, the air viscosity is considered as the acoustic friction. Each of these components contributes to reactance and resistance or susceptance and conductance (Lilly, 1972).

Of the three components of impedance, acoustic resistance is independent of frequency. Reactance is due to spring or mass, however, it is strongly dependent on frequency. This is evident in the fallowing two equations.

$Xm = 2 \pi fm$......(1)

$Xc = ½ \pi fc$ —- (2)

Where 'm' is mass, f is frequency; 'c' is coefficient of stiffness.

Equation (1) expresses the relation between mass reactance (Xa), mass (m) and frequency (F). The reactance of mass increases in direct proportion to the frequency. Mass elements, have a low reactance at low frequency and a high reactance at high frequency. In contrast, equation (2) shows that the reactance due to stiffness is inversely proportional to the frequency. So stiffness elements have a high reactance at low frequency and a low reactance at high frequency. If the reactance of the spring elements decreases with frequency and reactance of mass elements increases with frequency. A system, which is composed of a combination of mass and spring elements will be maximally efficient at a frequency at which mass reactance and compliant reactance are equal and this is called as resonance frequency.

At resonance frequency mass reactance and compliant reactance are equal, i.e.

$2\pi \; fM = 1/2\pi \; fc$—(3)

$f = 1/2\pi \; mc$———(4)

Above equation (4) indicates that mass and stiff characteristics of the middle ear determines its resonance frequency. It can be inferred from this formula that any condition of the middle ear, which alters its mass or stiffness, changes the resonance frequency. Thus,measurement of resonance frequency of the middle ear can give information about the conditions of the middle ear.

It is possible to estimate middle ear resonance using multifrequency and multicomponent tympanometry. This is developed to overcome the limitations of conventional low frequency tympanometry. In multifrequency and multicomponent tympanometry, admittance and its polar components (admittance magnitude and its phase angle) and/or rectangular components (susceptance and conductance) can be recorded across a wide range of frequencies. The shape of the tympanogram, which is smooth and bell shaped at low frequencies, becomes complicated at high frequencies. Colletti (1975,1976,1977) observed that the morphology of the typical tympanogram progresses through three characteristics patterns as the probe frequency is increased. First frequency region described is below the resonance frequency and it is identified with the notation "SUB fo". In this region tympanogram is inverted "V" shaped. The second frequency region contains the resonance frequency (fo) tympanograms designated by the notation "fo" and are characterized by two or more peaks. Third region lies above the resonance frequency. In this region tympanogram is "V" shaped and is identified by the notation "SUPRA fo". In subjects with normal middle ear, "SUB fo" is below lOOOHz, "fo" range fromlOOO to 1400Hz and "SUPRA fo"is above 1400 Hz. Colletti, (1975,1976,1977) described only single component i.e admittance tympanogram, whereas Shanks (1984) studied the shape and pattern of admittance, susceptance, and conductance tympanograms for probe tone of various frequencies. It was observed that as the probe tone frequency increases, first the susceptance tympanogram notches then the conductance tympanogram notches and admittance tympanogram is last to notch. It was hypothesized that notching of susceptance tympanogram indicates increase in mass susceptance (-Bra) and decrease in compliance susceptance (+Bc) as a function of frequency. The algebraic sum of the two-susceptance values decreases gradually and reaches 0 at resonance frequency and then becomes negative as mass susceptance increase. Hence, as the probe tone frequency is increased, the notch in the susceptance tympanogram deepens. At resonance frequency, the notch value is equivalent to positive or negative tail value and notch value will be less than the positive or negative value, above the resonance frequency. Admittance tympanogram, however, will always be positive because it represents only magnitude. Notching of admittance tympanogram generally does not occur unless the probe tone is above the middle ear resonance. Thus it is possible to estimate resonance frequency, by observing the patterns of susceptance and/or admittance tympanograms at different frequencies. Multifrequency tympanogram uses this rational to estimate resonance frequency.

Different methods are available to estimate resonance frequency using multi-frequency tympanometry. Hunter and Margolis (1992) classify them into the following two categories

- Sweep frequency method
- Sweep Pressure method

In the sweep frequency method, the external ear canal pressure is changed in discrete steps. At each step, the probe tone frequency is swept across a pre-selected range. An array of several tympanograms, one for each frequency, is constructed as the air pressure changes. Berg (cited in Lilly, 1984) was probably the first to use this method in estimating the resonance frequency. A 3-dimensional array of nested tympanograms was constructed using this method. Some of the commercially available instruments have the facility for obtaining this 3-dimencional array. Funasaka, Funai & Kumakawa (1984) also used sweep frequency method for estimating resonance frequency. The probe tone frequency was swept with air pressure in the ear canal at 200 dapa and this sweep was repeated with air pressure in the ear canal at Odapa. Magnitude and the relative phase angle of SPL in the ear canal were measured. The difference in magnitude and the phase angle of the SPL measured during the two sweeps were plotted as a function of frequency. The point at which SPL crosses the zero line corresponded to resonance frequency. Phase angle curve reaches the maximum value near the resonance frequency. A similar method is used in some of the commercially available instruments. But the magnitude and phase angle of the susceptance is measured instead of SPL.

Sweep pressure method, is performed in a conventional way but with an addition of frequencies other than the usual 226 Hz probe tone. The frequency of the probe tone is held constant while external ear canal pressure is changed and multifrequency tympanograms are obtained for frequency of interest. The resonance frequency can be estimated by admittance tympanogram or susceptance tympanogram. In susceptance tympanogram, frequency at which peak compensated susceptance value equals zero is the resonance frequency. Peak compensation is achieved with positive tail/negative tail or average of positive and negative tail. These three procedures were given by Porter and Winston, (cited in Margolis & Smith, 1977). The above procedures are used as three different procedures to estimate middle ear resonance (Margolis & Goycoolea, 1993). In admittance tympanogram the lowest frequency at which admittance tympanogram notches is considered as the resonance frequency.

Factors Affecting Estimation of Middle Ear Resonance

A number of factors can affect middle ear resonance estimated by these different methods and these factors include those related to procedure such as direction of pressure change, rate of pressure change, number of trails, ear canal compensation, procedure and subject related factors such as age, gender.

Procedure related factors: -

Direction of pressure change: The direction and rate of ear canal pressure change has an effect on amplitude, shape, and peak pressure of the admittance, susceptance and conductance tympanograms. A higher incidence of tympanometric notching and/or deepening of notch has been reported for ascending than for descending pressure change (Creten &Vancamp, 1974; Wilson, Shanks & Kaplan, 1984; Margolis, Osguthrope & Polka, 1978). It has also been reported that the complexity of the tympanograms obtained with ascending (-/+) ear canal pressure direction is greater than that with descending (+/-) pressure direction. In an investigation by Shanks and Wilson (1986), the susceptance and conductance tympanograms were single peaked for 226Hz probe tone but were notched (3B1G, 1B3G, 3B3G) for 678 Hz and this notching was more frequent for ascending than descending pressure changes. On the contrary results of some of the studies show that the direction of pressure change does not affect the peak susceptance and conductance in normal middle ear (Porter & Winstion, 1973 cited in Margolis & Smith 1977). The discrepancy on the effect of direction of the pressure change on peak static immittance may be attributed to the analysis of isolated admittance components such as peak susceptance, conductance, and/ or admittance which do not change monotonically when the normal middle ear becomes less stiffness controlled as resonance is approached (Margolis & Smith, 1977).

Rate of pressure change; -A review of literature shows that there is higher incidence of tympanometric notching and/or deepening of the notch for the faster rates (grater than 30 dapa/sec) of pressure change for high probe tones. (Alberti & Jerger, 1974; Certen & VanCamp, 1974; Margolis, 1977; Wilson, et al., 1984). Shanks and Wilson (1986) investigated the effect of direction and rate of pressure change. Different rates used are 12.5dapa, 25.0dapa, 50dapa per second and results revealed that notching was slightly less frequent for slowest rate (12.5 dapa) of pressure changes, but rate effect could not be stated strongly as the significant difference between different rates, was not statistically significant.

Ear canal compensation: -The estimation of middle ear resonance is also affected by the use of different compensation method. These compensation methods are applied due to asymmetries seen in the susceptance tympanogram. These asymmetries are seen because the positive and negative ear canal pressures drive the middle ear to finite and unequal impedances. This asymmetry also increases as the probe tone frequency increases (Margolis & Smith, 1977). The compensation methods that are used include, the difference between susceptance at Odapa and susceptance at positive tail (Bmax-B+), the difference between susceptance at Odapa and negative tail (Bmax - B-), the difference between susceptance at Odapa and the average of susceptance at positive tail and susceptance at negative tail/2[Bmax - (B+ + B-)/2] (Porter & Winston, 1973, cited in Margolis & Smith, 1977). Ear canal pressure chosen to compensate for ear canal volume significantly effects the measurement of middle ear resonance. Estimate of middle ear resonance were 100 to 400 Hz higher when ear canal volume was compensated at negative rather than positive ear canal pressure (Holte, 1996; Morgolies & Goycoolea, 1993; Shahnaz & Polka, 1997; Shanks, Wilson & Camborn, 1993). Although negative ear canal pressure produces more accurate estimates of ear canal volume than positive pressure (Shanks & Lilly, 1981; Margolis & Smith, 1977), positive ear canal pressure is recommended because test- retest reliability is higher and inter subject variability is lower than negative pressure compensation (Holte, 1996; Margolis & Goycoolea, 1993; Shahnaz & Polka, 1997). In other words the normal range for estimated middle ear resonance is smaller for compensation at positive tail and therefore should have less potential for overlap with pathological populations.

Number of trials: - The peak compensated susceptance and conductance at the tympanic membrane and the pattern of tympanogram change with increase in number of trails. Osguthrope and Lam, (1981) reported 12% mean increase in 678Hz susceptance across 10 tympanometric sweeps. They also reported that peak conductance values increased as the number of tympanometric trails increased. Wilson, et al. (1984) investigated the effect of number of trials in twenty four normal young adults and the results reveled that successive tympanometric runs in either an ascending or a descending pressure direction produce change in admittance characteristics of the middle ear system. The shape of the tympanogram for many subjects become more complex as the number of trials increased. For 226Hz tympanogram, admittance, susceptance and conductance for 226Hz probe tone increased as the number of trails increased. For 678 Hz probe tone, susceptance function, particularly for ascending pressure changes, decreased with successive tympanometric trails due to the notching of susceptance tympanogram. They speculated that change in the admittance across trials resulted from alteration in the viscoelastic properties of the middle ear transmission system. This changes in the pattern of susceptance has an effect on the estimate of resonance frequency of the middle ear.

Procedure use: Selection of a sweep frequency instead of a sweep pressure method also significantly affects the estimates of middle ear resonance. Sweep frequency procedure results in 105 to 183 Hz higher estimate of middle ear resonance than sweep pressure procedure (Margolis & Goycoolea, 1993; Shahnaz & Polka, 1997). In sweep frequency mode, ear canal pressure is kept constant and probe frequency is swept. In contrast, in the sweep pressure mode, probe frequency is held constant and ear canal pressure is swept. Higher estimate of resonance for sweep frequency method probably is related to the effects of rate of pressure change (Creten & Vancamp, 1974; Shanks & Wilson, 1986) and to the effects of multiple pressure sweeps (Wilson et al., 1984). Faster rates of pressure sweep increase static compliance and lower the resonance. Margolis and Goycoolea (1993) recommended the use of a sweep frequency method when mass related pathology is suspected and sweep frequency method when stiffness related pathology is suspected to maximize the range of abnormal values. Sweep pressure mode is more time consuming than sweep frequency mode (Hunter & Margolis, 1992). Hence sweep frequency mode with positive tail compensation is recommended by a majority of investigators (Margolis & Goycoolea, 1993; Shahnaz & Polka, 1997; Miani, Bergamin & Isola, 2000).

Recording admittance tympanograms can also be used to estimate the middle ear resonance. The disadvantage in this method is that susceptance and conductance are not viewed separately and hence can result in the clinician wrongly identifying a notch that my actually be an artifact (Hunter & Margolis, 1992).

Subject related factors: - Age is the major subject related factor affecting the resonance frequency. As the child grows the middle ear structure also grows which may influence the estimate of the middle ear resonance. There is a general increase in middle ear resonance frequency with increase in age. This resonance frequency appears to remain relatively steady until 199 days of age. At age younger than this the resonant frequency is below 550Hz, there after there is a sharp rise in resonance frequency with the value increasing beyond 800Hz by 120 days of age. This increase in resonance frequency is seen until 200 days of age (Meyer, Jardine & Deverson, 1997; Holte, 1991). The low resonance frequency in newborn may be attributed to the predominance of mass and /or mass component. There is no gender and ear difference observed in resonance frequency (Margolis & Goycoolea, 1993).

Application of measurement of middle ear resonance

Middle ear is stiffness controlled below the resonance frequency and mass controlled above the resonance frequency. At the resonance frequency both contribute equally so measuring the middle ear resonance is more sensitive in detecting pathologies that change either mass or stiffness. Literature regarding pathologies that affect stiffness (otosclerosis and healed tympanic membrane) is discussed here.

Otosclerosis

Otosclerosis is an inherited disorder of bone growth that mainly affects the stapes and the bony labyrinth of the cochlea. The disease is characterized by restoration of the normally hard bone and its replace meant with newer softer bone tissue that is highly vascularised and spongy. This spongy bone growth can eventually turn in to a dense sclerotic mass (Newby and Popelka, 1992). These pathological changes prevent the stapes from vibrating which increases the stiffness and lead to conductive hearing loss.

Theoretically, the resonant frequency of the middle ear system should increase in ears with otosclerosis. Early studies compared the morphology of the tympanograms in the frequency range 200 to 2000Hz, for normal individuals and different pathological conditions. Colletti (1975,1976,1977) contributed several studies. He compared the morphology of the tympanograms in the frequency range 200 to 2000Hz for normal individuals and pathological conditions such as otosclerosis, stepedectomy, ossicular chain discontinuity and otitis media. In subjects with otosclerosis, the frequency range of "fo" region appeared to be significantly higher but there was an overlap in the values obtained for normal individuals and otosclerosis group. In the later studies, Colletti, Fiorino, Sittoni & Policante, (1993) compared normal individuals, otosclerosis and subjects with stepedectomy. Resonance frequency was estimated from the susceptance tympanogram. The frequency at which susceptance tympanogram notched was considered as resonance frequency. Resonance frequency was significantly higher in subjects with otosclerosis but there was an overlap in the range for normal individuals and subjects with otosclerosis.

Funasaka et al, (1984) studied the resonance frequency and phase measurements in normal individuals, subjects with otosclerosis and ossicular chain discontinuity using sweep frequency method. Probe tone was swept from 220 to 2000 Hz, measurements of sound pressure (P) and phase () were performed at ear canal pressure of 0 and -200 mmlho. The results were expressed as sound pressure curve (P0 -P-200), phase curve (90- 9200) and polar curve (P0 -P200, 90- 9200). Among these parameters the discriminating element turned out to be the resonance frequency. Resonant frequency was higher in subjects with otosclerosis than normal individuals.

Valvik, Johnsen & Loukli (1994) studied fifty normal ears, thirtyeight ears with pre operative otosclerosis, five ears with post-operative otosclerosis and twentyeight ears with various tympanic membrane pathologies. They also used the sweep frequency procedure and the resonant frequency was significantly higher in otosclerosis than in normal individuals. It was significantly lower in other two conditions. Similar results were reported by Wada, Koike & Kobayashi (1989)

Shahnaz and Polka (1997) studied sixtyeight normal and fourteen ears with otosclerosis. They recorded static compliance and tympanometric width from low frequency tympanometry. Two parameters, resonance frequency and frequency corresponding to admittance phase angle of 45° were derived from the multifrequency tympanometry. They concluded that the frequency corresponding to admittance phase angle of 45° was a better index for distinguishing normal and otosclerotic ears than resonance frequency. It was recommended that the resonance frequency and frequency corresponding to 45° phase angle be derived from sweep frequency tympanograms.

Miani et al. (2000) investigated fourtyeight ears of normal individuals, seventy ears of subjects with otosclerosis and sixteen ears of subjects with unilateral cochlear otosclerosis. The resonance frequency, acoustic conductance value (G) at resonance frequency and individual difference in this two parameters in normal individuals and unilateral otosclerosis were studied. The degree to which otosclerosis can influence variation of resonance frequency and the correlation between the value of resonance frequency and degree of conductive hearing loss was also investigated. The study revealed that there was a significant difference between the normal individuals and otosclerosis but there was no correlation between the value of resonance frequency and the degree of conductive hearing loss. There was a significant difference in the conductance (G) at resonance for normal individuals and cochlear otosclerosis.

Frade, Lechuga and Labella (2000) studied 136 normal individuals and 143 subjects with otosclerosis for a mean duration of 10.4years. They estimated admittance of middle ear and resonance frequency through susceptance tympanogram compensated with negative tail compensation. Resonance frequency was significantly higher in otosclerosis than normal individuals and there was a significant correlation between admittance value and resonance frequency.

All these studies support that the resonance frequency is higher in otosclerotic ears than normal individuals, although there is a little overlap in the range of frequencies between normal individuals and otosclerotic ears. However, there are some studies, which indicate that their subjects had extremely low resonance frequency in the initial stages of otosclerosis (Miani, et al., 2000,Collitte et al., 1993). It is generally expected that stiffness is higher or normal in otosclerosis. However in the initial stages of otosclerosis some ears may have low stiffness, which leads to the extremely low resonance frequency. The histopathological studies, have demonstrate that in early stages of otosclerosis bone is replaced by the fibrous tissue, which results in the reduction in stiffness of the middle ear system (Cherukupally, Merehant, Rosowski, 1998).

Tympanic membrane abnormalities

There is a dearth for studies investigating the resonance frequency in ears with tympanic membrane abnormalities. Valvik et al. (1994) studied ears with normal middle ear, tympanic membrane abnormalities (scarring of tympanic membrane and tympanosclerosis), otosclerosis and post-stepedectomy. They estimated resonance frequency by sweep frequency method and the results showed that resonance frequency is estimated to be lower than normal individuals in ear with tympanic membrane abnormalities. There is a need for more number of studies in this direction.

A review of literature indicates that measurement of resonance frequency supplements/complements the information provided by low frequency, single component tympanometry. Generally resonance frequency is higher than normal limits in subjects with otosclerosis where as decreases in subjects with healed tympanic membrane. The review also indicates that a number of factors related to procedure effect the measurement of resonance frequency. Hence the present study was undertaken to study the effect of procedural variation of resonance frequency and also to investigate the best procedure, which detects otosclerosis and healed tympanic membrane.

Method

Subjects

The subjects were divided in to two groups, experimental group and control group. Experimental group included sixty ears of subjects with conductive hearing loss. This included thirty ears with otosclerosis and thirty ears with healed tympanic membrane. The diagnosis of otosclerosis and healed tympanic membrane was made by a qualified otorihnolaryngologist. All the ears had pure tone average of greater than or equal to 20 dB HL with a significant air bone gap (greater than 10 dB HL) and immittance evaluation revealed A, As or Ad type tympanograms with absent acoustic reflexes. The age of subjects ranged from 15 to 50 years.

Control group constituted of thirty ears of subjects, with normal hearing, in the age range of 15 to 50 years. All the ears in the control group had normal otoscopic findings with pure tone thresholds of less than 15dBHL in the octave frequencies ranging from 250 to 8000 Hz (ANSI, 1989). Immittance evaluation ruled out any middle ear pathology.

Instrumentation:

A calibrated two channel diagnostic audiometer was used to estimate pure tone thresholds.

A calibrated, Grason- Stadeler middle ear analyzer GSI- 33 (Version 2) was used to assess the middle ear function. The system was calibrated using three standard cavities (0.5,2.0 and 5.0 cc) as per the instructions given in the manual.

Test procedure:

Pure tone evaluation

A pure tone audiogram was obtained in a sound treated air-conditioned room using modified Hughson and Westlake procedure (Jerger & Carhart, 1959). Masked thresholds were obtained whenever indicated

Immittance evaluation

The ear canal was inspected for the presence of any wax or foreign body or discharge, before testing. The probe with appropriate size tip was inserted to get an airtight seal for immittance evaluation. Peak compensated compliance, peak pressure, and ear canal volume was recorded for a 226Hz probe tone. Ipsilateral and contralateral acoustic reflex threshold was obtained for 250 Hz, 500Hz, 1000 Hz, 2000 Hz and 4000 Hz. Resonance frequency was obtained by two methods, sweep frequency method and sweep pressure method.

1. **Sweep frequency metho**d:

The following steps were carried out in sweep frequency method:

- Stepl: - Probe tone was swept from 200 Hz to 2000 Hz in 50 Hz steps at start pressure (200dapa/sec). The instrument stored in its memory susceptance and phase measurements.
- Step2: - A 226 Hz tympanogram for admittance was recorded to obtain peak pressure. A second sweep was run at peak pressure. Susceptance (B) and phase

measurements were stored as before. The change in susceptance (B) and phase value () was plotted as a function of frequency. This graph displays change in susceptance (AB) as a function of frequency. The frequency at which change in susceptance was zero, susceptance (B=0) was considered as resonant frequency (FS,).

2. Sweep pressure method:

In the sweep pressure method, air pressure in the external ear canal was decreased continuously from +200dapa to -400dapa (positive to negative) at a rate of 200dapa/sec while the probe tone frequency was held constant. Initially a susceptance tympanogram was obtained for frequency, which was obtained at resonance frequency determined by sweep frequency method. Then depending on the tympanogram obtained the frequency of the probe tone was increased or decreased to find out resonance frequency in the following was:

- The lowest frequency at which notch in the susceptance tympanogram is equal to or below the negative tail was considered as resonant frequency, PRi.
- The lowest frequency at which notch in the susceptance tympanogram is equal to or below the positive tail was considered as resonant frequency, PR2.

Similarly admittance tympanogram were obtained for different probe tone frequencies starting from FS1.The lowest frequency at which admittance tympanogram notched was considered as resonant frequency, PR3.

During sweep pressure method, if more than seven to nine trials were required to obtained the resonance frequency, a rest period of approximately ten seconds was given and the test was continued.

Results

Results of this study were evaluated from two perspectives, first effect of procedural variables and middle ear condition on estimation of middle ear resonance and second aimed at identifying the effective procedure, for detecting otosclerosis and healed tympanic membrane. Results were analyzed using a statistical software; SPSS (version7.5)

Effect of Procedure and middle ear condition

Resonance frequency of the middle ear was estimated using four procedures for each subject in the 3 groups (normal, otosclerosis and healed tympanic membrane). Table 1 gives the descriptive statistics of the resonance frequency of the three groups.

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Table 1: Mean and standard deviation (SD) of resonance frequency in Hz for all the groups

Procedure	Group1		Group2		Group3	
	Mean	SD	Mean	SD	Mean	SD
SF1	1080.35	198.76	1401.66	268.8	753.3	134.33
PF1	1076	159.5	1325	257.6	643.3	114.2
PF2	1048.28	198.83	1341	304	591.6	127.3
PF3	1080.35	198.7	1323	296.7	568.3	104.6

It is evident from the Table-1 that the estimated resonance frequency of the middle ear is not same when the different procedures were used for determining the resonance frequency. The resonance frequency also varied depending on the middle ear condition. A two - way ANOVA was performed to check the effect of procedure and middle ear condition on resonance frequency.

The results showed that there was a main effect of procedure in all the groups [$F_{(348,3)} = 4.82$; $P<0.05$] and there was a significant effect of the middle ear condition on the resonance frequency [$F_{(348,2)} = 355.13$; $P<0.0001$]. There was no significant interaction of the procedure and the groups [$F_{(348,6)} = 829$; $P>0.05$].

Duncan's post hoc analysis of variance (post hoc ANOVA) revealed that there was a significant difference between the sweep frequency method (SF1) and the other three procedures (PF1, PF2, PF3) but there was no significant among these procedures in sweep pressure method. Duncan's post hoc ANOVA for the condition reveled that all the three groups (normal, otosclerosis, and healed tympanic membrane) differed significantly from each other,

Test performance analysis: -

The test performance analysis was evaluated using criteria for determining normal function that are found in the current literature i.e. value falling with in the 95% confidence interval around the mean. Using these criteria for normal function, correct and iVicorrect classification of pathological group and normal subjects were determined for the each procedure. The percentage of pathological group correctly identified was termed as HT (Hit- Rate) and percentage of subjects in correctly identified was termed as FA (False- Alarm). These results are shown in Table 2 and 3. A' was calculated from the HT and FA by using the formula 0.5+(HT-FA)x(l+HT-FA)/4HTx(l-FA). A' is a way of measuring the test performance in which HT is adjusted by the FA to achieve a high A' score. A test should have high HT and low FA to achieve high A'. A' varies from 0.5 for a less valid test to 1.0 for perfect test (Robinson & Watson, 1972). Test performance in two pathological conditions is presented in table 2

Table 2: - Hit rate and False alarm rate of different procedures

Procedure	95% confidence interval in normal subjects	Otosclerosis		Healed tympanic membrane	
		Hit Rate (in %)	False Alarm (in%)	Hit Rate (in %)	False Alarm (in%)
SF1	1004.8 to 1148	76.6	30	100	30
PF1	1021.1 to 1132.6	76.6	43.3	100	46.6
PF2	970.3 to 1110.3	80	26.6	100	26.6
PF3	931.6 to 1075.2	73.3	46.6	100	43.3

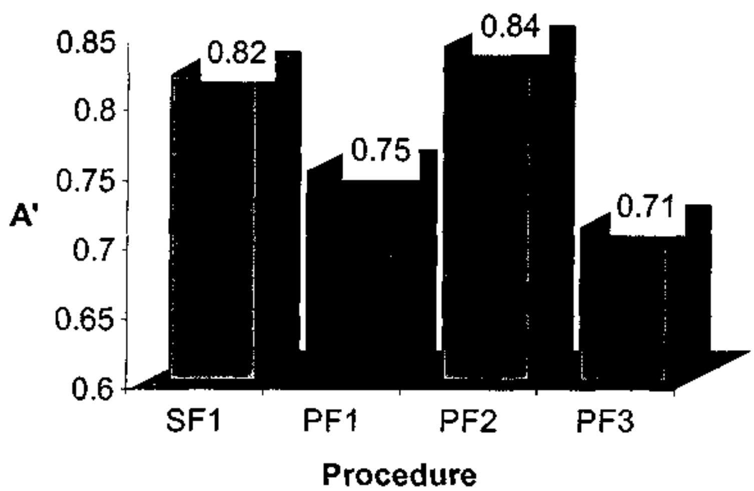

Figure-1: - Effect of procedure on test performance in otosclerosis

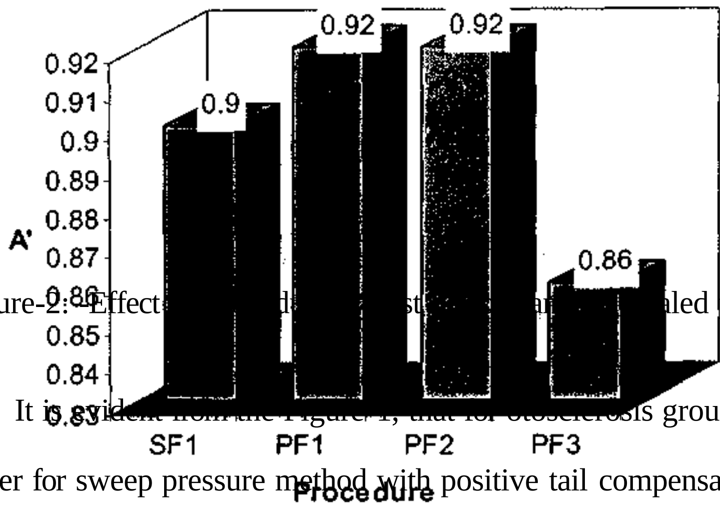

Figure-2: Effect [illegible] healed tympanic membrane

It is evident from the Figure 1, that for otosclerosis group, the A' values were higher for sweep pressure method with positive tail compensation and sweep frequency method than the other two procedures. It can be observed from Table 1 that the hit rate are comparable for all the procedures but the false alarm is lower for positive tail compensation and sweep frequency method leading to higher A' value.

Inspection of Figure 2 revels that for healed tympanic membrane group, that the A' values were similar for all the procedures except admittance tympanogram because of slightly lower hit rate and higher false alarm.

Discussion

Effect of procedure on estimation of resonance frequency

In the present study, resonance frequency estimated by sweep pressure method was higher than the results reported in a majority of the previous studies (Margolis & Goycoolea, 1993; Shahnaz & Polka, 1997; Colletti et al., 1993). The variation in the estimated resonance frequency may be attributed to the different instrumentation and procedure. Performing large number of consecutive tympanograms than in the present study could have lead to the lower estimate of resonance frequency. Although a majority of the studies shows lower estimate of resonance frequency, the study by Margolis and Goycoolea (1993) showed higher estimate of resonance for negative tail compensation. This could be due to the use of higher negative tail compensation (-500dapa) than in the present study (-400dapa). As the susceptance value is lower at -500 dapa than that for -400 dapa, notch value will be equivalent to negative tail value at higher frequency leading to higher estimate of resonance frequency.

Resonance frequency estimated using sweep frequency method in the present study is higher than that reported in the several previous studies (Valvik, et al., 1994; Hanks & Rose, 1993). The reason for the discrepancy is not known, as the procedure and instrumentation used in the two studies are same. The lower cut off of the range is lower in the earlier studies when compared to the present study. This may have lead lower mean value. The number of subjects in the present study is lesser than the earlier studies and this also could have lead to the statistical discrepancy in the results.

In the present study, there was a significant difference between the resonance frequency estimated using sweep pressure and sweep frequency recording method. These results are in accordance with the previous studies (Margolis & Gyocoolea, 1993; Shahnaz & Polka, 1997), where the resonance frequency estimated was higher for sweep frequency method than the sweep pressure method. The lower estimation of resonance frequency in sweep pressure method may be attributed to performing a large number of consecutive tympanograms, which can be expected to produce a lower estimate of resonance frequency (Osguthorpe & Lam, 1981; Wilsion et al., 1984). The faster rate of pressure change used in the sweep pressure method may also contributed to the lower estimate of resonance frequency. Although the present study reduced the number of trails by taking resonance frequency estimated by sweep frequency method as a reference, it was necessary to perform at least five to six tympanograms, which would have contributed to the lower estimate of resonance frequency. Wilson et al. (1984) reported that a majority of the changes in the susceptance tympanogram (notching) occurs by the third to fifth trail of the consecutive tympanogram. Previous studies have shown differences in the estimation of resonance frequency in sweep pressure method by different compensation methods (Margolis & Gyocoolea, 1993; Shahnaz & Polka, 1997) and this is attributed to the asymmetry in the susceptance tympanogram. In the present study, resonance frequency estimated using negative tail compensation was slightly higher than that of positive tail compensation but the difference was not statistically significant. This difference in the results may be attributed to the difference in compensation procedure used and higher rate of pressure change used in the present study.

Effect of middle ear condition on resonance frequency

Group (normal Vs otosclerosis and healed tympanic membrane) and resonance frequency estimation difference was statistically analyzed in Duncun's post hoc ANOVA. This analysis revealed a significant main effect of group, indicating that mean resonance frequency was significantly higher in otosclerosis and these results are in par with previous studies (Shahnaz & Polka, 1997; Valvik, et al., 1994; Colletti et al., 1993; Funasaka & Kumakava, 1988). Histo-pathological changes reported in the literature support this higher estimate of resonance frequency. It has been reported that in otosclerosis normal bone is replaced by sponge bone, which leads to fixation of stapes to oval window (Dhingra, 1992).

Resonance frequency is significantly lower in healed tympanic membrane subjects and these results are in agreement with the previous studies (valvik, et al., 1994). Histo-pathological studies show thinning or destruction of medial fibrous layer (lamina proprea) of the tympanic membrane secondary to the otitis-media or traumatic perforation and this results in decreased stiffness or hyper mobility which leads to lower estimate of resonance frequency (Hunter & Margolis, 1999).

Test performance analysis

The test performance analysis based on the 95%confidance interval around mean was analyzed for all the procedures in two pathological groups and analysis revealed that better performance was obtained for positive tail compensation in sweep pressure method and sweep frequency method compared to the other methods. These results supported the earlier recommendations, Margolis and Goycoolea, (1993) suggested +200 dapa positive tail compensation in sweep pressure method as a preferred method for determining resonance frequency where abnormally high resonance frequency is suspected, where as Shahnaz and Polka, (1997) suggested positive tail compensation in either of the methods. The better performance with the positive tail compensation in sweep pressure method and sweep frequency method shows that the difference between the normal and otosclerotic is high when positive tail compensation is used than the negative tail compensation. In contrast, the difference between the normal and otosclerotic ears appears to be less affected by the use of sweep pressure or sweep frequency-recording method.

In healed tympanic membrane group, except for resonance frequency estimated by admittance tympanogram, all the other procedure showed similar performance and these results are contradicting the recommendations by Margolis and Goycoolea, (1993) who also suggested +200 dapa positive tail compensation in sweep frequency method of Margolis and Goycoolea, (1993). Recommendation is based up on their investigation on normal subjects. Shahnaz and Polka, (1997) studied only subjects with higher resonance frequency. Further studies are needed on population with low resonance frequency to confirm the results of the present study.

The low performance of the resonance frequency estimated by admittance tympanogram in identifying pathological conditions could be because notching of admittance tympanogram occurs above the resonance frequency, which may not be very sensitive in detecting pathological conditions (Shanks, 1984)

Thus the results of the present study indicated that resonance frequency is significantly different from that of normal individuals. The choice of procedure has an effect on the estimated resonance frequency. The resonance frequency estimated by the admittance tympanograms is least sensitive in detecting otosclerosis and healed tympanic membrane.

Summary and Conclusion

Middle ear is stiffness controlled below the resonance frequency and mass controlled above the resonance frequency. At the resonance frequency both contribute equally. So measuring the middle ear resonance is more sensitive in detecting pathologies that change either mass or stiffness. Middle ear resonance can be estimated using different procedures in multifrequency tympanometry. A review of literature shows that there exists variability in estimation of middle ear resonance by different procedures in normal individuals. Different investigators estimated the middle ear resonance by different procedures in pathological group. Although these studies show that resonance frequency is higher in otosclerosis and lower in tympanic membrane abnormalities, there exists an overlap in normal individuals and pathological group.

The objective of the study was to determine the effect of procedural variability on estimation of middle ear resonance and to identify best procedure, which detects otosclerosis and healed tympanic membrane. To study the objective, 30 ears of normal individuals, 30 ears of subjects with otosclerosis and 30 ears of subjects with healed tympanic membrane were evaluated for middle ear resonance by four different procedures. One was using sweep frequency method and other three were using sweep pressure method (positive tail compensation in susceptance tympanogram, negative tail compensation in susceptance tympanogram, and admittance tympanogram). Results were analyzed using two-way ANOVA.

The results of the present reveals that there is effect of procedure on estimation middle ear resonance in normal individuals and pathological group. The procedural variability is more with method of estimating than the compensation procedure used in normal individuals as well as pathological group.

The resonance frequency is estimated to be higher in otosclerosis group. This pathological group was well identified by the positive compensation in sweep pressure method and sweep frequency method. Estimate of middle ear resonance by negative tail compensation in susceptance tympanogram and admittance tympanogram in sweep pressure method is not recommended due to poor performance in identifying pathological group. These conclusions are consistent with the recommendations by (Shahnaz & Polka, 1997).

The resonance frequency is estimated to be lower in healed tympanic membrane group. This pathological group was well identified by using all the procedures except admittance tympanogram, which showed poor performance.

Future Directions

Further studies should aim at

- Studying on large number of population to support the recommendations of the present study.
- Carrying out studies on different pathological conditions that effect ossicular chain.
- Investigating the usefulness of multifrequency tympanometry in a test battery for otosclerosis.

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