MULTICOMPONENT TYMPANOMETRY IN DIAGNOSIS OF MIDDLE EAR DISORDERS

Register No. M2K22

AN INDEPENDENT PROJECT IN PART
FULFILLMENT FOR THE FIRST YEAR
M.Sc. (SPEECH AND HEARING)

UNIVERSITY OF MYSORE,
MYSORE

ALL INDIA INSTITUTE OF SPEECH AND HEARING,
MYSORE

May 2001

DEDICATED TO

Lord Venkatesh
and
Friends

"Who walk beside in the valley of sorrow and along, on the mountains of happiness"

CERTIFICATE

This is to certify that the Independent Project entitled : ***"MULTICOMPONENT TYMPANOMETRY IN DIAGNOSIS OF MIDDLE EAR DISORDERS"*** *is a bonafide work in part fulfillment for the degree of Master of Science (Speech and Hearing) of the student with* ***Register No. M2K22.***

Dr. M. Jayaram
Director,
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Mysore
May, 2001

CERTIFICATE

This is to certify that the Independent Project entitled : ***"MULTICOMPONENT TYMPANOMETRY IN DIAGNOSIS OF MIDDLE EAR DISORDERS"*** *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 Diploma or Degree.*

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May, 2001

DECLARATION

*I hereby declare that this Independent Project entitled : **"MULTICOMPONENT TYMPANOMETRY IN DIAGNOSIS OF MIDDLE EAR DISORDERS"** is the result of my own study at under the guidance of **Mrs.** C.S. Vanaja, Lecturer, Department of Audiology, All India Institute of Speech and Hearing, Mysore and has not been submitted earlier at any other University for the Award of any Diploma or Degree.*

Reg. No. M 2K22

Mysore
May, 2001

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INTRODUCTION

Tympanometry is the measurement of aural acoustic immittance as a function of ear canal air pressure. Since the first tympanometric recording reported in 1959, tympanometry has developed from an experimental procedure for estimating middle ear pressure into routine clinical test that is useful for detecting a wide variety of middle ear pathologies. Tympanometry can be carried out by measuring changes in acoustic impedance or admittance. Admittance measurements are most effective to test middle ear function as the change in admittance is always linear to the change in the pressure applied to the external canal, where as the change in impedance is always non-linear with pressure change (Margolis and Shanks, 1991).

Generally middle ear functioning is assessed using low frequency probe tone that is 226 Hz. As this probe tone is far from the normal resonant frequency of the middle ear, a bell shaped curve is obtained for admittance and the same is observed with the susceptance and conductance. (Van Camp, Raman and Creten, 1976). A low frequency single component tympanometry is sensitive in detection of middle ear disorders with high impedance, (E.g. otosclerosis, otitis media, and cholesteatoma) but may fail to detect the low impedance pathologies such as abnormality of tympanic membrane and ossicular chain. (Margolis and Shanks 1991; Lilly, 1984). Margolis and Shanks (1984) reported that at low frequencies, a majority of the ears, whether normal or abnormal, are stiffness dominated and hence a change in middle car resonance does not necessarily produce a marked change in the tympanometric shape. However, it may alter the shape of the tympanogram for high frequency probe tones. Shanks (1984), found that with a small amount of fluid in the middle ear, the 226 Hz tympanograms were single peaked, but 678Hz tympanogram showed a dramatic change in the shape Colletti (1977) and Lilly (1984) reported that the low frequency probe tones are useful in detecting the high impedance middle ear pathologies where as the high frequency probe tones (678 Hz & 800 Hz) are useful for detecting low impedance pathologies. The high frequency probe tones lead to a notched tympanogams, as they reach closer to the resonating frequency of the middle ear. In this case a separate susceptance and conductance tympanograms should be obtained to get a better picture of middle ear system (Shanks, 1984).

Van Camp et al. (1976) states that information about ossicular chain discontinuity and eardrum pathology, which is sometimes missed in 660 Hz admittance tympanometry can be regained when susceptance and conductance tympanometry is used. Thus the two component tympanometry with a high frequency probe tone enables a better distinction to be made between mobile but normal middle ear system suffering from necrosis and disruption (Vande Heyning, Van Camp, Creten and Vanpeperstraete, 1982). Shanks (1984) reported that the ears with a abnormal middle ear function show a differential effect with regard to probe tone frequency and immitance component for different pathologies. He concluded that the susceptance and conductance seem to give important information regarding the status of the aditus and mastoid air cells system. It was also found that for a majority of the middle ear pathologies, the disease process had more effect on the tympanometric shape at 678 Hz that at 226Hz.

Aim of the study

The present study was designed to study the usefulness of multicomponent tympanometry at 226 Hz, and 1000 Hz in identifying middle ear pathologies which cannot be detected using low frequency single component tympanometry.

Need for the study

A review of literature shows that low frequency single component tympanometry may be normal in some patients with middle ear pathology (Van Camp, Raman and Creten, 1976). Also, there is overlaping of 'A' type and 'Ad' type tympanogram in normal subjects as well as the clinical population. Hence, it becomes difficult to detect a middle ear pathology using a low frequency single component tympanometry. It may be possible to detect some of these pathologies using multicomponent tympanometry. Very few investigators have studied the usefulness of multicomponent tympanometry in clinical population (Margolis and Shanks, 1991; Hall and Chandler, 1994) and the criteria for differential diagnosis of middle ear disorders is not well established. Therefore, in the present results of multicomponent tympanometry was evaluated in patients with known middle ear pathology.

REVIEW OF LITERATURE

Since the introduction of clinical acoustic immittance measurements, most often evaluations have been made using single component, usually complaint reactance, with single probe frequency (approximately 226 Hz) (Hall and Chandler, 1994). Van Camp, Creten, Shanks and Margolis (1986) recommended use of two component tympanogram at either 660 Hz or preferably 678 Hz, an integral multiple of 226 Hz. They presented following three arguments for using the higher frequency probe tones:

(a) low-impedance abnormalities produce unique tympanogram shapes only for high probe frequencies.

(b) contralateral acoustic reflex measurement in both adult and neonatal populations is possible with a high frequency probe tone.

(c) ipsilateral acoustic reflexes, which are useful clinically, are contaminated by artifacts at 226Hz, but not at 660Hz.

In this chapter, a review of multicomponent tympanometry is discussed under following headings :

1. Classification of multicomponent tympanometry.
2. Factors affecting multicomponent tympanometry.
3. Multicomponent tympanometry in ears with middle ear pathology.

1. CLASSIFICATION OF MULTICOMPONENT TYMPANOMETRY

Various methods of classification of tympanograms are described in the literature (Liden, 1969; Jerger, 1970; Feldman 1976 a, 1976 b, 1977). A majority of the classification procedure can be applied to only single component, single frequency (226Hz) tympanograms. A descriptive analysis has been used most often for multi frequency multi component tympanometry. Van Huyse, Creten and Van Camp (1975) made an attempt to classify tympanograms into different categories based the shape of the susceptance and conductance tympanogram. Van Huyse et al. (1975) suggested the following types of regular and 'W' shaped susceptance and conductance tympanograms using a 220 Hz or 660 Hz probe tone.

(A) Type 1B1G : In type 1B1G tympanograms (Fig. la) both the suceptance and conductance (G) tympanograms are single peaked.

(B) Type 3BIG : The conductance tympanogram is single peaked, but the susceptance tympanogram has a central notch due to a positive shift in the reactance tympanogram. In 3B1G tympanogram (Fig lb), although reactance remains negative for all ear canal pressure, the absolute value for reactance is less than resistance near the peak and greater than resistance at extreme ear canal pressure.

(C) Type 3B3G : As the middle ear becomes more mobile (but normal), both susceptance and conductance tympanograms show two maxima on either side of a central minimum resulting in a total of three extremes. This is called as 3B3G tympanogram (Fig. lc). The pressure interval between the conductance maxima is smaller than the pressure interval between susceptance maxima and both central minima are found to be nearly at the same pressure value.

(D) Type 5B3G: In type 5B3G tympanogram (Fig. 1d) which occurs rarerly the susceptance tympanogram contains five maximas and conductance tympanogram exhibits three maximas. This type must be considered normal, if the following sequence of pressure extrema are encountered:

(a) Susceptance maxima (b) a conductance maximum (c) susceptance minimum (d) close together, the central maximum in susceptance and central minimum in the conductance,

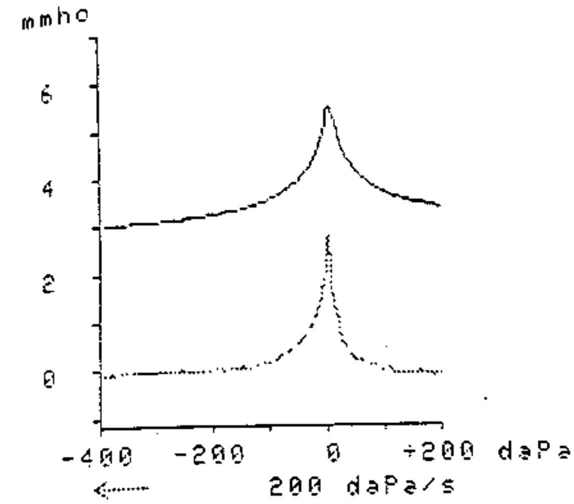

Figure 1: (a) Tympanograms with one extrema in the susceptance (B) and conductance (G) (1B1G tympanogram) .

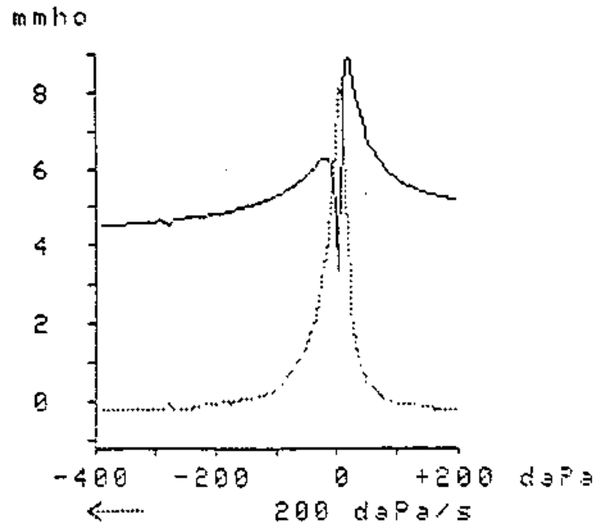

Figure 1: (b) Tympanograms with three extremas in the susceptance (B) and one extrema in the conductance (G) (3B1G tympanogram)

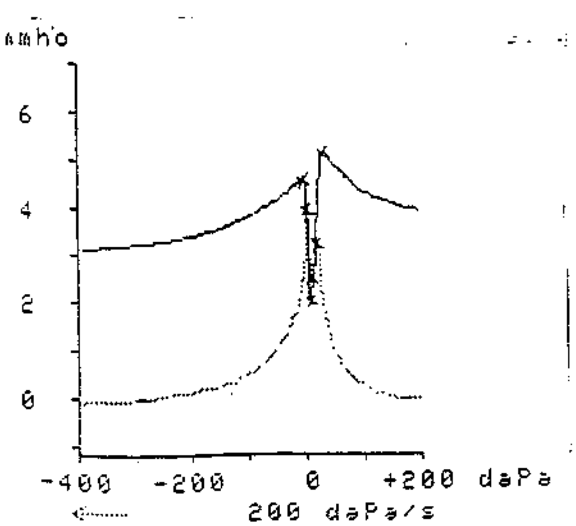

Figure 1: (c) Tympanograms with three extremas in the susceptance (B)and three extremas in the conductance (G) (3B3G tympanograms)

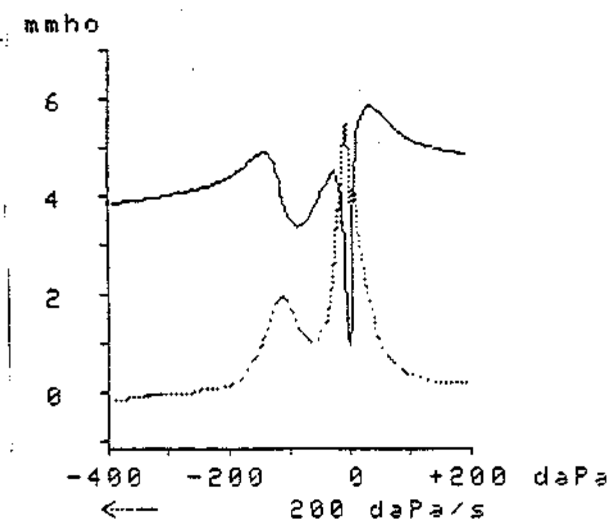

Figure 1: (d) Tympanograms with five extremas in the susceptance (B) and three extremas in the conductance (G) (5B3G tympanogrs=s

(e) a susceptance minimum (f) a conductance maximum, (g) last a susceptance maximum.

Vande Heyning, Van Camp, Creten and Vanpeperstraete (1982) reported that the pressure difference between the first and last susceptance maximum in normal subjects was less than 75 dapa for 3B1G or 3B3G and less than 100 dapa for 5B3G. They later reported that the very broad type of 3B1G tympanogram can occur occasionally for perfectly normal subjects. However, the term broad was not defined.

The normal 226 Hz susceptance and conductance tympanograms are always 1B1G, normal tympanograms at 678 Hz fall into all four categories (Margolis and Shanks, 1984). Investigations have been carried out to find out the percentage of occurrence of different types of tympanograms in young adults by for a 660 Hz probe tone with a pump speed of 30 dapa/sec and negative to positive direction. (By Van Camp, Creten, Vande Heyning, Decraemar and Van Peperstraete (1983) ; Wiley, Oviatt & Block (1987). The results obtained were as follows:

	1B1G	3B1G	3B3G	5B3G
Van Camp et al (1983)	57	28	6	9
Wiley et al (1987)	76	17	6	1

2. FACTOR AFFECTING MULTICOMPONENT TYMPANOMETRY

Some of the factors affecting the multi component tympanometry are discussed below :

1. **Probe tone frequency** : The tympanometric shape changes in an orderly fashion as the probe tone frequency increases. At the lowest frequency (220Hz), the amplitude of susceptance is slightly less than that of admittance but approximately twice the

conductance amplitude. As the probe tone frequency increases the peak magnitude of conductance increases rapidly and becomes greater than susceptance value by 510 Hz. This result is expected as mass susceptance (Bm) increases and compliance susceptance (Bc) decreases as a function of frequency. The algebric sum of two susceptance value (Bt) then gradually decreases, reaches 0 at resonance (between 710 Hz and 810 Hz for descending pressure between 510 Hz and 610 Hz for ascending pressure) and then becomes negative or mass controlled (810 Hz for +/- and 610 for -/+) as probe frequency increases further. The ear becomes mass controlled if the minimum susceptance value in the area of the notch is below the tail value at-400 dapa (Shanks, 1984).

It has been observed that at 220 Hz the tympanogram is symmetrical with single peak near the ambient pressure. As the probe frequency increases, the tympanogram becomes more asymmetrical with susceptance value on the positive pressure side of the tympanogram at 880 Hz; susceptance becomes a monotonically increasing function of the ear canal pressure. The mean conductance tympanograms for normal subject increased in magnitude as probe frequency increases, but remains nearly symmetrical around the maximum that occurs near the ambient ear canal pressure. The increase in asymmetry that occurs in susceptance tympanogram as probe frequency increased can be explained by arithmetic interaction of resistance and reactance. It is assumed that reactance decreases monotonically or probe frequency increases from 440 Hz to 880 Hz, while resistance remains constant. Again similar increase in peak conductance was obtained across tails (Wilson, Shanks and Kaplan, 1984).

The tympanograms begin to notch as the probe tone frequency is increased. Shanks (1984) reported that as probe tone frequency increases notching of the susceptance tympanogram occur first and then the conductance and admittance tympanograms are notched. Similar results were also obtained by Sabitha (1994) and Monica (1994).

2. **Number of Trails** : The static susceptance and conductance at the tympanic membrane change and with the increase in trials and also the tympanometric patterns. Osguthrope and Lam, (1981) reported a 12% mean increase in the 678 Hz susceptance across 10 tympanometric sweeps. They also reported that the peak susceptance and the peak conductance values increased as the number of tympanometric line increased. The mean susceptance peak in cats increased by 13% between first and second trials, with a 17% increase in the tenth trial. Similar increases were also observed for conductance (Osguthrope and Charleston 1986). Wilson et al (1984) reported that the shape of tympanograms becomes more complex for many normal subjects as the number of trials increased. They further observed that the changes among trials generally manifested as increase in admittance, susceptance and conductance for 226 Hz probe tone. Inter subject variability for the 678 Hz probe tone was attributed to notched tympanograms. The mean 678 Hz susceptance function particularly for ascending pressure sweep decreased with successive tympanometric trials. The susceptance magnitude increased across trials for the single peaked group. In contrast for the notched group, the depth of susceptance notch increased with trials, there by producing decrease in the susceptance magnitude.

3. **Direction of pressure change** : The direction of ear canal pressure change and the rate of ear canal pressure change has an effect on the complexity of admittance, susceptance and conductance tympanograms. The 678Hz susceptance tympanogram often are single peaked for descending pressure changes but notched for ascending pressure changes. (Porter and Winston, 1973; Margolis and Smith, 1977). Margolis, Osguthrope and Popelka (1978), also reported that the complexity of the tympanograms obtained with ascending (-/+) ear canal pressure direction is greater than that with descending (+/-) pressure directions (Wilson, Shanks and Kaplan, 1984). They quantified the unnotched susceptance, conductance and admittance tympanograms at 226 Hz and 678 Hz in terms of tympanometric width. They found that the tympanometric width varied significantly with pressure change. The mean negative tympanometric width for both susceptance and admittance were significantly wider for descending than for ascending pressure change at 226 Hz.

Shanks and Wilson (1986) reported that at 678 Hz the mean total tympanometric width for unnotched tympanograms was affected by the direction of pressure change. The tympanometric width was significantly greater for descending than ascending pressure changes for susceptance, conductance and admittance.

On the contrary results of some of the studies shows that the direction of pressure change does not affect the peak susceptance and conductance in normal middle ear (Porter and Winston, 1973). A few studies have shown an interactions between the effect of rates of ear canal pressure and direction of pressure change. It has been reported that the effect of the rate of ear canal pressure change on peak static immittance, peak static admittance is lower for slower rates of pressure change than for faster rates (Feldman, Fria, Palfrey and Dellecker, 1984; Williams, 1976).

4. **Rate of pressure change** : A review of literature shows that there is higher incidence of tympanometric notching and/or deepening of the notch for ascending than for descending pressure changes and for fast rates (greater than 30 dapa/sec) of pressure change for high frequency probe tones. (Alberti and Jerger, 1974; Creten and Van Camp, 1974; Margolis, 1977; Osguthrope and Popelka, 1978; Porter and Winston, 1973; Wilson et al, 1984).

Investigation by Shanks and Wilson (1986) revealed that notching was slightly less frequent for the slowest rate of pressure changes, but they reported that the rate effect could not be stated strongly due to the absence of data. When the shape was specified in terms of tympanometric width unnotched susceptance, conductance and admittance tympanograms did not change significantly with width.

3. MULTICOMPONENT TYMPANOMETRY IN EARS WITH MIDDLE EAR PATHOLOGY

In case of middle ear disorder the relation between stiffness, mass and friction element change resulting in a shift in resonant frequency of the middle ear transmission system. If the middle ear is stiffened because of pathology such as otosclerosis, then the ear will remain stiffness, controlled over a wider frequency range than a normal middle ear and thus the resonant frequency of the middle ear will be shifted towards a higher than normal frequency. On the other hand, pathology such as ossicular discontinuity, will decrease the resonant frequency of the middle ear.

High Impedance Pathologies

High impedance pathologies of the middle ear include otitis media, ossicular fixation and space occupying lesions such as primary and invading tumors. The effects of these pathologies are complex and the degree of the tympanometric abnormality is not closely associated with the severity of the disease. The most obvious form of high impedance pathology is a flat tympanogram, when fluid or neoplasm occupies the normally air filled cleft, the impedance of middle ear is increased and tympanogram is flat. However there are more moderate high impedance conditions that represents clinically significant pathology that do not produce flat tympanograms. In some of these conditions, the tympanograms go through a stage in which because of mass loading of the middle ear the impedance is actually lower than normal and a variety of multi peaked pattern occurs. As the condition progresses the tympanogram begin to flatten and impedance becomes abnormally high. (Margolis and Shanks, 1991).

Shanks (1984) recorded tympanograms on fresh human temporal bones, with 0.4 cm^3 of water in the middle ear space. It was observed that the magnitude of admittance (Y) remained normal but susceptance (B) was notched, particularly at 678 Hz. This finding was consistent with increase in mass of the tympanic membrane. When tymparnograms were recorded with lcm^3 of fluid in the middle ear, the 226Hz tympanograms were single peaked but the admittance (Y) and susceptance (B) tymparnogram reduced in amplitude and broadened. The 678 Hz probe tones had broad notching demonstrating the superiority of high frequency probe tone in showing effects of increased mass.

Investigations by Margolis and Shanks (1984) showed that in subjects with secretory otitis media, the 226 Hz Y, B and G tympanograms were characterized by shallow peaks than 678 Hz, Susceptance tympanogram were abnormal at 678 Hz as the notch width in the tympanogram exceeded 75 dapa. When the data from resistance and reactance tympanograms were used for simulation of tympanometric patterns associated with secretory otitis media, three extrema conductive tympanograms were seen, the conductance maxima shifted towards more extreme ear canal pressure as reactance was shifted increasingly more positive. The shapes of susceptance tympanograms were extremely broad and became progressively flatter as reactance increase towards more positive values. The susceptance tympanogram also showed 3B pattern as predicted by Van Huyse et al. (1975) model.

Margolis and Shanks (1991) reported that tympanograms obtained in a subject with otitis media in resolving state showed slightly low static admittance and normal tympanic width at 226 Hz where as at 678 Hz the pattern was a very wide 3B3G, indicating a mass controlled ear, probably due to mass loading of middle ear. The pattern was considered abnormal because of the broad interval between susceptance peaks. Shanks (1984) reported that tympanograms recorded from patients with external otitis and debris against the tympanic membrane are normal at 226Hz but are abnormally broadly notched (greater than 100 data) and mass controlled at 678Hz. It was observed that the tympanograms with external otitis were characterized by normal height and width at 226Hz where as 678Hz the pattern was very wide 5B3G due to mass loading of the eardrum. Binu (1997) also studied multicomponent tympanometry in subjects with complaint of ear pain and ear discharge. It was observed that some of the ears with complaint of ear pain had abnormal multicomponent tympanometric patterns despite of normal otological findings. It was also observed that multifrequency, multicomponent tympanometry was superior to single component tympanometry in detecting early stage of Otitis media.

Shanks (1984) recorded tympanograms from patients associated with three middle ear conditions, namely, patent PE tube and history of chronic earache, nasopharyngeal mass occluding the Eustachian tube, tympanic membrane perforation.

It was seen that when the PE tube was patent the susceptance and conductance tympanograms at 678 Hz were reverse, that is conductance elevated and susceptance below the level of equipment. Nasopharyngeal mass occluding the eustachain tube also reversed the conductance and susceptance tympanograms at 678 Hz and all functions were of scale. For tympanic membrane perforation, the reversal of susceptance and conductance tympanogram occurred even at 220 Hz. There it was concluded that in absence of PE tube, a reversal of conductance and susceptance provides strong evidence for normal middle ear and mastoid system.

Shanks (1984) observed that tympanograms for cases with otosclecosis were characterized by greater amplitude of susceptance tympanograms than conductance tympanograms at 678 Hz, that is the resonant frequency of the middle ear was increased due to stiffness caused by the disease process. The increase in resonant frequency was more obvious at 678 Hz. The 678 Hz tympanograms usually showed narrow peak in patients with otosclecosis. Similarly Colletti (1977) reported that probe tone frequencies at which notched tympanograms occurred in otosclerosis are higher (1300Hz) in comparison with normal ears. A steeper or more sharply peaked tympanogram have also been reported by other investigators in some subjects with confirmed ossicular fixation in comparison with normal subjects (Ivey, 1975;

Dieroff, 1978). Van Camp et al. (1986) reported that when tympanograms characteristic of otosclerosis were simulated from normal, stiffness controlled reactance tympanograms, as predicted by Van huyse et al (1975) model all the tympanograms were bell shaped and belonged to 1B1G type at 600 Hz. They further reported that for admittance tympanograms recorded in the plane of probe tip for a subject with surgically confirmed otosclerosis resembled the simulated tymanograms. In both cases the magnitude of susceptance was approximately twice as large as conductance and the peaks were sharper than normal. Margolis and Shanks (1991) reported that the tympanogram from patients with stapedial fixation in otosclerosis are frequently normal at 226 Hz and 678 Hz, hence they concluded that it may be necessary to use more than two probe tone frequencies to detect otosclerosis. They also opined the multi frequency tympanometry by providing a method of estimating the resonant frequency of the middle ear might prove to be an effective method of detecting stapedial fixation.

Van Camp et al. (1986) reported that in lateral ossicular fixation, stiffness instead of mass is added to the entrance of the middle ear system. Because the fixation is located lateral to the incudo-stapedial joint, the entire ossicular chain is severely impaired in its vibratory movements for all pressures across the tympanic membranes. In the three simulated tympanograms generated for lateral ossicular fixation by Van Camp et al. (1986), one condition produced 1B1G type. Admittance (YO and susceptance (Bi) tympanograms showed no central extrema, instead the two tympanograms increased monotonically as the function of ear canal pressure. Van Camp et al. (1986) also observed that the admittance (Y_1)and the susceptance (B_l) tympanograms recorded from a subject, with fibrous adhesion fixing of the entire ossicular chain, were flat and the conductance (GO tympanograms showed a broad peak. The tymanograms recorded using probe tone to 678 Hz were similar to the shape of the simulated tympanogram.

The resultant effect of stapes fixation in cats on an acoustic susceptance and conductance tympanograms was studied by Margolis et al (1978). The result showed marked increase in the height of the tympanormetric peak in cats with stapes fixation except for 200 Hz Ga tympanograms, which in normal animals did not have clearly defined peak. On visual examination, the tympanograms for stapes fixation condition were not clearly different from the normal, where as when data was converted to estimate static acoustic impedance of the middle ear; two distinctly different distributions was seen.

Miani, Bergamin, Barotti and Isola (2000) used multifrequency, multicomponent tympanometry to study resonant frequency and conductance in to ears of patients affected by fenestral otosclerosis. Their study revealed statistically significant differences between the mean resonant frequency for the normal group Vs the otosclerotic group. The mean value of resonant frequency in otosclerotic ear was higher than that of the normal ears. Statistically significant difference was also reported in conductance measurement, as it remained low in case of otosclerotic ears compared to normals. Shanks (1984) obtained admittance (Y), susceptance (B) and conductance (G) tympanograms at 226 Hz and 660 Hz in patients with different middle ear conditions such as tympanic membrane retraction, fibrous adhesion and middle ear effusions secondary to nasopharyngeal mass occluding the Eustachian tube, flat tympanograms were obtained which were indistinguishable for all the three cases. These findings highlight the fact that same tympanograms may be obtained for different middle ear conditions and hence reinforces the idea that tympnogrametry may not always indicate the exact disease process causing a conductive hearing loss.

Low impedance pathologies

Although not as common as high impedance pathologies, low impedance pathologies can be identified more easily because they produced an obvious alteration of tympanometric shape. These shape alterations are more evident near the resonant frequency of the middle ear than the frequencies remote from the middle ear resonance. Consequently, high frequency probe tones such as 678 Hz are more effective than low frequencies in identifying these pathologies (Margolis and Shanks, 1991).

Margolis, Osguthrope and Popelka (1978) studied effects of experimentally induced ossicular lesions on susceptance and conductance tympanograms. The results indicated single peaked Ba and Ga tympanograms at 220Hz, although when compared with normal control conditions the amplitude of the peaks, were increased. At 600 Hz, the susceptance and conductance tympanograms had double peaks. For data obtained after removal of incus, the Ba and Ga tympanogram tended to be more dramatically notched and more displaced towards positive values.

Shanks (1984) reported that susceptance (B) and conductance (G) tympanograms were recorded from a fresh temporal bone following fracture of anterior stapes crus with intact stapedial tendon and fracture of crura, the tympanogram showed unusual notched pattern at frequency when one crus was fractured, but 678 Hz tympanograms did not become grossly abnormal until both crura were fractured. Tympanometric stape was altered more at 678 Hz than at 226 Hz by increase in mass.

Vande Heyning et al. (1982), based on a study of patients with ossicular abnormalities and temporal bones, reported the following three types of susceptance and conductance tympanograms for tympanossicular systems having an incudo-stapedial pathology :

1) The most common tymponagram from patients and temporal bones consisted of regular 'W' shaped but broad tympanograms with one or more supplementary peaks, superimposed on susceptance and/or conductance curves. In cases of W-shaped patterns of type 3B3G or 5B3G, the supplementary peaks were nearly always situated between the outer regular susceptance maxima of the underlying, W shaped patterns. The presence interval between the outer regular maxima was greater than 75 dapa.
2) The second type included a regular broad 3B3G or 5B3G tympanograms with a pressure interval between the outer susceptance maxima of about 150 dapa.
3) The third type of susceptance-conductance tympanograms involved double W-shaped patterns.

Shanks (1984) reported that for increased mass attributable to tympanosclerosis of the tympanic membrane, the tympanogram was abnormally notched at both probe tone frequencies 220 Hz and 660 Hz. They reported that tymapnograms in tympanosclerosis were abnormal: broad notching occurred at 226 Hz and shape was too complex with broad notch at 678 Hz. Pathologies of tympanic membrane such as tympanosclerosis and monomers often produced abnormal mass controlled tympanograms with little, if any, affect on hearing sensitivity. Margolis and Shanks (1991) also found that tympanograms obtained with tympanosclerotic plaques on the tympanic membrane consisted of three extrema, an abnorrnal result at 226 Hz. At 678 Hz, with an increasing air pressure, the pattern matched the normal multipeaked tympanograms although the shapes are somewhat irregular.

Osguthrope and Charleston (1986) in a study of the tympanometric effects of specific ear drum scars and ossicular abnormalities in cats, found that a normal middle ear could be differentiated from stapes fixation or incudo-stapedial discontinuity using static immitance parameters and morphology of tympanogram. 20% of the myringotomy scars produced abnormal 660 Hz tympanogram but this effect could be distinguished from changes caused by a concommitant ossicular abnormality. The very low impedance of a 50%, myingotomy scar resulted in tympanograms, which could not be differentiated from an ossicular discontinuity alone. With this neomembrane, stapes fixation could not even be differentiated from an ossicular discontinuity. These facts supported the view that tympanometry should be interpreted as a part of battery of tests which includes otoscopy, audiometry and acoustic reflex measurements.

Thus a review of literature shows that multi component tympanometry is more sensitive than single component low frequency tympanometry in identifying some of the abnormal conditions of the middle ear. However, these studies were carried out on single case or small group of subjects. Therefore, at present there is no definite classification to differentially diagnose middle ear pathologies based on multi component tympanometry.

METHODOLOGY

Subjects

The subjects were divided into two groups, control group and experimental group. The control group constituted of thirty subjects with normal hearing in the age range of 15 years to 40 years. All the ears in the control group had normal otoscopic finding with pure tone thresholds of less than or equal to 15dBHL at octave frequencies from 250 Hz to 8000 Hz. The experimental group included 17 ears with conductive or mixed hearing loss. Pure tone average was greater than or equal to 20 dBHL with a significant air bone gap (greater than 10 dB). The age of subjects ranged from 15 years to 50 years. The experimental group was further classified as shown in Table A based on the etiology or history.

Etiology/History	Number of Ears
OTOSCLEROSIS	6
CHRONIC SUPPERATIVE OTITIS MEDIA	3
SECRETARY OTITIS MEDIA	3
ADHESIVE OTITIS MEDIA	2
OTOLGIA	3

Instrumentation

A calibrated Madsen OB 822 audiometer was used to check the behavioral thresholds. The transducers were TDH 39 housed in Mx 41/AR ear cushion for air conduction and Radio ear bone vibrator B-71 for bone conduction.

A calibrated Grason stadler middle ear analyser 33 (version 2) was used for immittance evaluation.

Test procedure

Pure tone audiogram

A pure tone audiogram was initially obtained at the octave frequencies from 250 Hz to 8000 Hz for air conduction and from 250 Hz to 4000 Hz for bone conduction using the modified Hughson Westlake procedure. The non-test ear was masked, whenever required.

Immittance Evaluation

The ear canal was inspected for the presence of any wax, foreign body or discharge. The probe with an appropriate sized tip was selected. Admittance tympanogram was recorded using 226 Hz probe tone and following parameters were recorded:

a) Admittance at the tympanic membrane
b) Tympanometric peak pressure

Ipsilateral and contralateral acoustic reflexes were checked at frequencies 250 Hz, 500 Hz, 1000 Hz and 4000 Hz. Multicomponent tympanometry was then carried out for 226 Hz, 678 Hz and 1000 Hz probe tone to study the following components of immittance.

a) Admittance (Y)
b) Susceptance (B)
c) Conductance (G)

Uncompensated tympanogram was obtained for all subjects using the descending procedure, that is, varying the pressure from +200 to -400 dapa. The pump speed selected was 200 dapa/sec. The tympanograms were classified as 1B1G, 3B1G, 3B3G and 5B3G based on the classification given by Van Huyse et al (1975). A tympanogram in these set of categories was considered abnormal if any of the following pattern was observed.

1. The difference between the outermost pressure maxima for the susceptance tympanograms classified as 3B1G or 3B3G was greater than 75 dapa and/or the difference between the outermost pressure maxima for the susceptance tympanograms classified as 5B3G exceeded 100 dapa.
2. The tympanometric pattern was observed at a frequency lower than what is expected in normals. The admittance, susceptance and conductance at the tympanic membrane was determined by subtracting the acoustic immittance at -400 dapa from the immittance at the peak pressure (Margolis and Popelka, 1975).

The values for the notched tympanograms were calculated by subtracting the susceptance/conductance at -400 dapa from susceptance (B) value at the minimum in the notch and the corresponding conductance (G) value. (Margolis and Smith, 1977).

RESULTS AND DISCUSSION

The aim of the present study was to study the usefulness of multicomponent tympanometry (that is admittance (Y), susceptance (B), and conductance (G) tympanograms) at three different probe tone frequencies (226 Hz, 678 Hz and 1000 Hz) in identifying middle ear pathologies which cannot be detected using low frequency single component tympanometry. The data collected from two groups, control group and experimental group was analysed to investigate this aim.

1. Results of the control group

A. Type **of tympanogram**

Analysis of the data obtained from thirty otoscopically normal ears revealed the presence of single peaked tympanogram for all the ears at 226 Hz. Notched susceptance tympanogram was obtained for 7 ears resulting in a 3BIG pattern at 678 Hz. For 1000 Hz probe tone 19 ears showed 3BIG pattern and 4 ears had 3B3G pattern. 1BIG pattern was obtained in rest of the ears even for high frequency probe tones. The pressure difference between the extreme maxima's was within 75 dapa for 3BIG and 3B3G pattern. Table 1 shows the percentage of occurrence of different types of tympanograms for the three probe tones.

Table 1: Percentage (%) of occurrence of different types of tymponagrams.

Probe tone	1B1G	3BIG	3B3G
226Hz	100%	-	-
678 Hz	76.6%	23%	-
1000 Hz	26.6%	60%	13.3%

The results obtained in the study are comparable with that reported in the literature. Shanks (1984) reported that as the probe tone frequency increased the tympanogram begins to notch, the susceptance tympanogram is the first to notch followed by conductance and admittance. The same trend was observed in the present study also. The shape of the tympanogram changed in an orderly fashion from 1B1G to 3B3G.

Van Camp et al. (1983) reported that 57% of the normal subjects had 1B1G type, 28% had 3BIG type, 6% had 3B3G type and 9% had 5B3G type for 678 Hz probe tone. Wiley et al. (1987) reported the percentage of occurrence (for 678 Hz probe tone) to be 76% for 1B1G, 17% for 3BIG, 6% for 3B3G and only 1% for 5B3G. However, in the present study 3B3G pattern was obtained only at 1000 Hz and 5B3G pattern was not obtained even at 1000 Hz. The variations in the results could be because of methodological problem. It has been reported that the 678 Hz susceptance tympanogram often are single peaked for descending pressure changes but notched for ascending pressure changes. (Porter and Winston, 1973; Margolis and Smith, 1977; Margolis, Osguthrope and Popelka, 1978). In the present study descending pressure change was used where as the earlier investigators had used ascending pressure change. The results of the investigations using descending pressure change (Sabitha, 1995; Monica, 1995) have revealed results similar to that obtained in the present study.

B. Immittance at the Tympanic Membrane

Table 2 : Mean and SD of admittance, susceptance and conductance at the tympanic membrane for normal subjects.

Probe frequencies	226 Hz			678 Hz		lOOOHz	
Components of immittance	Y	B	G	**B**	G	B	G
Mean in (mmhos)	0.94	0.84	0.37	1.29	2.41	0.35	4.38
SD (a)	0.51	0.45	0.27	0.92	1.75	2.31	2.08

It can be observed form Table 2, that for 226 Hz probe tone, the mean susceptance at the tympainc membrane was slightly less than the admittance but more than two times the value of conductance. The range of admittance (0.33 mmho to 2.29 mmho) was comparable with that of suseptance (0.33 mmho to 2.19 mmho). But the conductance value ranged only from 0.12 mmho to 1.43 mmho. When the probe tone frequency was increased to 678 Hz the mean susceptance value increased from 0.84 mmho to 1.29 mmho but it was less than the conductance value at that frequency. Conductance at the tympanic membrane ranged from 0.67 mmho to 7.15 mmho at 678 Hz whereas susceptance at the tympanic membrane ranged from a negative value of -2.28 mmho to 2.78 mmho. Further increase in probe tone (1000 Hz) showed reduced susceptance at tympanic membrane ranging from -5.69 mmho to 4.66 mmho. Conductance at the tympanic membrane showed further increase with increase in probe tone with a range of 1.7 mmho to 7.7 mmho. T-test of significance was done for the susceptance between 226 Hz and 678 Hz, 226 Hz and lOOOHz and 678 Hz and 1000 Hz. The results revealed the difference in susceptance to be significant at .001 level.

The change in susceptance with increase in probe tone frequency clearly reflects the relationship between frequency and susceptance. For 226 Hz probe tone, the susceptance was always positive, indicating that the total susceptance was controlled by stiffness of the system. At 1000 Hz, the susceptance value decreased indicating that mass susceptance (Bm) and stiffness suceptance (Bc) were nearly equal at that frequency. Total susceptance (BT) was negative in some ears at 678 Hz and 1000 Hz suggesting that those ears were mass dominant at that frequency. The negativity was greater at 1000 Hz compared to 678 Hz reflecting the increase in mass susceptance with increase in frequency.

The results of the present study support the report found in the literature. Shanks (1984) observed that for the lowest frequency (220 Hz) the amplitude of susceptance is slightly less than the admittance but approximately twice the conductance amplitude. As the probe tone frequency increases the peak magnitude of conductance increases rapidly and becomes greater than susceptance value by 510 Hz.

The admittance (Y) value was not calculated at higher probe tone frequency as the error in calculation with high frequency probe tones is higher. The conductance vector is large in magnitude compared with the magnitude of the suceptance vector resulting in a small phase angle. The magnitude of admittance vector is dissimilar from that of the susceptance vector. Therefore the error in calculating the static acoustic admittance of the outer ear from the static acoustic admittance of the total ear may be as large as 50% (Wiley and Block, 1979).

2. Results of the Experimental Group

Multi component tympnometry was done on 17 ears with middle ear pathology. The tympanograms obtained from subject's are described based on classification by Van Huyse et al (1975). Admittance, susceptance and conductance at the tympanic membrane was calculated. No statistical procedure could be applied on the data as the number of subjects in each subgroup was very less. Admittance, susceptance and conductance values were considered abnormal if the deviation was more than mean ±2SD.

1. Otosclerosis

Out of the 6 ears with Otosclerosis, 3 ears presented 3BIG pattern for 1000 Hz probe tone with 1BIG for 678 Hz and 226 Hz probe tone. 1B1G pattern was obtained at all the frequencies in rest of the ears. Thus, it was difficult to identify middle ear pathology based on type of multicomponent tympanograms. Admittance, susceptance and conductance at the tympanic membrane were all within normal limits for 226 Hz probe tone. When the probe tone frequency was increased to 678 Hz, there was an increase in the susceptance and conductance value at the tympanic membrane. Only one ear had abnormal conductance value where as the susceptance was within normal limits. In the remaining ears both susceptance and conductance value were within normal limits.

Susceptance and conductance at the tympanic membrane increased when the probe tone was changed to 1000 Hz. The conductance at the tympanic membrane was normal, however, the susceptance value was abnormal for three ears. The susceptance value at the tympanic membrane for three ears were greater than the normal range also. In contrast to normal subjects, there was an increase in susceptance value when the probe tone was increased to 1000 Hz. The susceptance values were also higher than that obtained for normal subjects. It can be inferred from this that, there was an increase in compliant susceptance due to increase in stiffness in subjects with otosclerosis. Greater than normal suceptance value at 1000 Hz also indicates that the resonant frequency was higher in those ears.

A study by Shanks (1984) on otosclerotic ears by comparing the amplitude for 678 Hz susceptance and conductance shows that susceptance was greater than conductance and this was attributed to the increase in resonant frequency of the middle ear due to an increase in stiffness caused by disease process. The increase in resonant frequency was more obvious at 678 Hz than at 226 Hz and the tympanograms at 678 Hz showed narrow peaks even in the present study, otosclerotic ears showed narrow peaks and the increase in resonant frequency was clearly seen at 1000 Hz.

2. Chronic Supperative Otitis Media

All the 3 ears with history of CSOM revealed the presence of notched tympanograms with 3BIG pattern at 678 Hz and 3B3G at 1000 Hz. One of the ear with 3BIG and 3B3G pattern had pressure difference more than 75 dapa between the pressure extremas (145 dapa for susceptance (B), 75 dapa for conductance (G)) at 1000 Hz. The wider notch indicated that the ear was more mass dominated.

One of the ear had abnormal value for admittance and susceptance at the tympanic membrane where as two ears showed abnormal values for conductance for 226 Hz probe tone. For 678 Hz, probe tone, both susceptance and conductance was greater than the normative data for all the three ears. This again can be attributed to the mass dominated middle ear in these cases. The susceptance value at the tympanic membrane decreased as the frequency increased to 1000 Hz compared to the normal values. In one ear the value was less than the lower limits of the normals.

Similar findings have been reported in the literature. A study by Shanks (1984) on fresh temporal bones reported of tympanogrms recorded with 0.4 cm3 of water in the middle ear space. The magnitude of admittance (Y) remained normal but susceptance (B) was notched, particularly at 678 Hz. This finding was consistent with an increase in mass of the tympanic membrane. The 678 Hz tone, showed a much more dramatic change than the 226 Hz tone, when there was a small amount of fluid in the middle ear space. The broad notching of 678 Hz tympanograms demonstrates the superiority of a high frequency probe tone in detecting the effects of increased mass.

3. Secretary Otitis Media

All the 3 ears had 1B1G tympanograms at 226 Hz when the probe tone frequency was increased. Among them, one ear showed 1B1G pattern at 678 Hz also but 3B1G at 1000 Hz. Another ear had 3B1G tympanogram at both 678 Hz and 1000 Hz with the normal pressure difference between the maximas. Only one ear showed abnormal multi component tympanogram with more than 75 dapa pressure difference for the susceptance tympanogram at 1000 Hz.

One ear showed abnormal value for admittance, susceptance and conductance at the tympanic membrane for 226 Hz probe tone. For 678 Hz, two ears showed abnormal values for susceptance and conductance. This can be attributed to the mass loading pathology of the middle ear. The increase in mass lead to increase in the compliance at the tympanic membrane.

The susceptance values at 1000 Hz were lower compared to the values obtained at 678 Hz. One ear showed lower than normal susceptance value and two ears showed greater than normal conductance value at the tympanic membrane. The susceptance values for two ears were negative indicating a mass loading pathology. However, one of the ear had positive values for susceptance. This is possibly because of the type of tympanogram obtained varies depending on the stage of the disease. Early investigations have also demonstrated the superiority of multicomponent tympanometry over single component tympanometry. A study by Margolis and Shanks (1991) on otitis media showed slightly low static admittance and normal tympanic width at 226 Hz where as at 678 Hz the pattern was very wide 3B3G indicating mass controlled ear. Binu (1997) reported that multifrequency, multicomponent tympanometry was superior to single component tympanometry in detecting early stages of otitis media.

4. Adhesive Otitis Media

The two ears revealed the presence of 1B1G type of tympanogram across the frequency range of 226 Hz, 678 Hz and 1000 Hz. The values for the admittance, susceptance and conductance at the tympanic membrane were normal for 226 Hz and 678 Hz probe tones.

For 1000 Hz probe tone, both the ears showed increased values for susceptance and one ear showed increased conductance value at the tympanic membrane. The increased susceptance value indicated the increase in stiffness of the middle ear. These results also indicate that it is difficult to differentiate between otosclerosis and adhesive otitis media based on multicomponent tympanometry.

5, Otolgia

Three ears with complaint of otolgia presented notched tympanograms with 3BIG pattern at 678 Hz and 3B3G pattern at 1000 Hz probe tone. One of the ear showed more than 75 dapa pressure difference between the extreme of susceptance tympanogram at 1000 Hz. The admittance, susceptance and conductance at the tympanic membrane were normal for 226 Hz probe tone. At 678 Hz, one ear showed greater susceptance and conductance values. At 1000 Hz, one ear showed abnormal value for susceptance at the tympanic membrane. This can attributed to the stiffness dominance of the system. This indicates that multicomponent tympanometry can detect subtle changes in the middle ear. Similar to the results of the present study, Binu (1997) observed that in subjects with complaint of ear pain multicomponent tympanometry was abnormal, despite normal otological findings.

Thus to conclude, the results of the multicomponent tympanometry vary depending on the pathophysiology. Increase in mass lead to abnormal notching of tympanogram. Susceptance at the tympanogram also indicates whether the system is mass dominated or stiffness dominated. Acoustic susceptance is a vector quantity, it is the algebric sum of positive (stiffness) and negative (mass) components. (Wiley and Fowler, 1997). The sign of the peaks of the acoustic susceptance tympanogram, then, provides information on the condition of the middle ear system. If the value is positive, the ear is stiffness controlled and if the value is negative, then the ear is mass controlled.

SUMMARY AND CONCLUSIONS

The multicomponent tympanometry at different probe tone frequencies is more sensitive to abnormalities of the middle ear at the tympanic membrane and enables a better distinction between mobile but normal middle ear and middle ear system suffering from luxation, necrosis and disruption (Margolis and Shanks, 1984). During low frequency tympanometry, sometimes there is overlapping of 'A' and 'Ad' type tympanogram in both normal subjects and the clinical population. Hence, it becomes difficult to detect a middle ear pathology using a low frequency single component tympanometry. In such patients multifrequency, multicomponent tympaonmetry may help in differential diagnosis. Therefore the present study was carried out to study multicomponent (admittance, susceptance and conductance) tympanometry at 226 Hz, 678 Hz and 1000 Hz in subjects with conductive or mixed hearing loss.

In the present study two groups were taken, that is the control group and experimental group. The control group had thirty otoscopically normal ears with hearing thresholds less than or equal to 15 dB. The age range of the subjects was 15 to 40 years. The experimental group had 17 ears of adults with conductive or mixed hearing loss. The age range of the subjects in experimental group was from 15 to 50 years. Pure tone audiometry was carried out for all the ear using a 2 channel clinical audiometer. Immittance measurements were obtained using Grason Stadler 33 middle ear analyser (version 2). Initially an admittance tympanogram was recorded using 226 Hz probe tone and static admittance and tympanometric peak pressure were obtained. In the second step multicomponent tympanometry was carried out for 226 Hz, 678 Hz and 1000 Hz probe tone. The susceptance (B) and conductance (G) tympanogram were classified based on Van Huyse et al (1975) classification. Admittance, susceptance and conductance at the tympanic membrane was also calculated for all the three probe tones.

The following observations were made from the analysis of results :

1. In the control group as the probe tone frequency was increased, the tympanograms began to notch. The susceptance tympnogram notched first followed by the conductance and admittance. At 226 Hz, all the ears showed 1BIG tympanogram. At 678 Hz, 23% of the ear showed 3BIG whereas for 1000 Hz. 60% of the ear showed 3 BIG and 13.3% showed 3B3G pattern. 1BIG pattern was observed in rest of the ears.

2. Multicomponent tympanometry was more sensitive than conventional tympanometry in identifying middle ear pathology. The result of the multicomponent tympanometry varied depending on the pathophysiology. In the present study the pathologies differed from one another in terms of the mass and stiffness in the middle ear. For the system which was mass dominant, the susceptance values were in the negative side and the tympanograms showed broad notching. For the system which was stiffness dominant, the susceptance values were always positive and as the probe tone frequency increased the values becomes greater than that observed for normal ears.

It can be concluded that multicomponent tympanometry is more advantageous over single component tympanometry in detecting high impedance pathologies especially when high frequency probe tones are used. However, the sensitivity is not 100% . That is all the subjects with middle ear pathology may not show abnormal patterns on multifrequency, multicomponent tympanometry. Hence, multifrequency, multicomponent tympanometry should be used along with a battery of tests for a better understanding of the middle ear conditions.

Suggestions for future research :

1. The tympanometric patterns need to be obtained for a large group of subjects with different middle ear disorders.
2. The results of multicomponent tympanometry need to be correlated with resonant frequency of the middle ear in subjects with different middle ear disorders.
3. Results of multifrequency, multicomponent tympanometry in pre and post medical or surgical subjects needs to be studied.

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