Measurements of Acoustic Impedance *in* Indians

v. BASAVARAJ

A DISSERTATION SUBMITTED IN PART FULFILMENT FOR THE DEGREE OF MASTER OF SCIENCE (SPEECH AND HEARING) OF MYSORE UNIVERSITY—1973

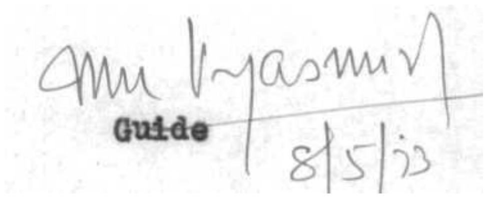
CERTIFICATE

Thia ia to certify that the dissertation entitled "MEASUREMENTS OP ACOUSTIC IMPEDANCE IN INDIANS" is the bonafide work in part fulfilment for M.Sc. Speech and Hearing, carrying 100) marks, of the student with Register No.11

(N.RATHNA)
Director in-charge
All India Institute of Speech and Hearing, Mysore

CERTIFICATE

This is to certify that this dissertation has been prepared under my supervision & Guidance



D E C L A R A T I O N

This dissertation is the result of my own study undertaken under the guidance of Mr. M.N. Vyasamurthy, and has not been submitted earlier at any University for any other diploma or degree.

Mysore,

Dated:11.5.73 Reg.No.11

A C K N O W L E D G E M E N T

The investigator wishes to thank Mr.M.N.Vyasa Murthy, Lecturer and Head, Audiology, for his valuable guidance of the present study. He acknowledges Dr.N.Rathna for his help. His thanks are also due to Mr.J.Bharath Raj, Dr. Subbiah and Dr. Syed Mehaboob, who helped him in his study. He is thankful to Mr.L.Ramesh Chandra. Chaya Subramanya, Anantha Narayana, Devaraj, Jagadish,P.J.Kumar and Jayaram, are acknowledged. He wishes to thank all his subjects. Finally thanks are due to Radhakrishna.

C O N T E N T S

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

". . . .We frankly wonder how we ever got along without it (Impedance audiometry)"

James Jerger, 1970

The above statement reflects the value of Impedance audiometry as a diagnostic tool in clinical amdiology.

The concept of Impedance was introduced in 1914 (Webster, 1919). Its application to clinical audiology became evident from the day Metz (1946) published his classic monograph - "The Acoustic Impedance Measured on Normal and Pathological Ears". The development of Impedance audiometry during the past decade has added new scope and dimension to clinical audiology. Acoustic impedance at the tympanic membrane is ".....not just another audiological test"......it constitutes ".....a whole new field of investigation with an inherent new methodology". (Zwislocki, 1965). The new clinical technique involves well developed concepts, standardized terminology (ANSI, 1960) and easy mathematical procedures (Ketz, Lilly, 1972).

Impedance audiometry is an objective method of assessing the function of the middle ear and it does not require co-operation on the part of the patient.

With respect to middle ear pathologies, the diagnostic information from acoustic impedance measurements goes considerably beyond that which can be derived from otoscopic examination and audiometric tests. (J.J. Zwislocki and A.S. Feldman, 1970).

The otoscopic examination is limited to directly visible anatomical changes and to a quantitative evaluation of the tympanic membrane mobility at amplitudes that far exceed the normal physiological range. It gives inconclusive results in all cases of conductive hearing loss, except those that are associated with gross changes in the eardrum anatomy position or mobility. Otosclerosis, ossicular interruptions, and even massive adhesions to the large ossicles usually remain undetected. (J.J. Zwislocki and A.S. Feldman, 1970).

From the audiometric examination, malfunction in the conductive mechanism is inferred, typically from discrepancy between,the thresholds for air and bone conducted sounds, air-bone gap. Diagnosis is limited to only conductive hearing loss on one hand and sensory neural loss on the other. At best, this inferential approach provides only gross information as to the cause of a hearing loss, and it provides little information as to the specific nature of the problem.

The limitations of visual inspection and of pure tone tests often leave the middle ear shrouded in a veil of diagnostic mystery. Zwislocki (1968.

Recent acoustic research employing improved instrumentation and rigorous analysis has led to a rather detailed understanding of the normal and pathological middle ear function, and to a new diagnostic methodology. (Zwislocki, 1968).

Currently, acoustic impedance measurements constitute the only means of direct examination of the middle ear function. They are performed at physiological vibration amplitudes and, therefore, give a direct estimate of the efficiency of sound transmission. Except in acoustic reflex tests, the sensori-neural part of the auditory system is not involved.

The acoustic method is based on a partial reflection of source depends not only on the state of the tympanic membrane but also on that of the middle ear components and cochlea. Through acoustic measurements on normal and pathological ears and with the help of anatomy and acoustic theory, it is possible to analyze the middle ear function in detail and to correlate the acoustic changes measured at the tympanic membrane to middle ear pathologies. In a way impedance audiometry helps to look acoustically beyond the tympanic membrane and it tells about the sound transmitting characteristics of the middle ear.

As early as 1946 Metz demonstrated that impedance measurements could be used to diagnose accurately the presence of middle ear disease. Still impedance audiometry did not develop as a clinical tool for several reasons.

(1) Accurate measurements of impedance at the plane of the tympanic membrane and meaningful presentation of the data involved procedures, concepts, terminology and quantitative methods that were not familiar to audiologists and to otolaryngologists;

(2) Measurements of impedance at the plane of the tympanic membrane with any acoustic impedance bridge are time consuming. With the Metz bridge, additional time was required to convert the raw data to standard notation;

(3) Measurements of static impedance at the plane of the tympanic membrane are especially valuable in differential diagnosis of clinical otosclerosis from interruption of the ossicular chain. In 1946, however, this type of diagnosis was of minor importance since the otologist did not have access to many of the operative techniques that currently are used in stapes surgery and in reconstructive surgery of the middle ear;

(4) An acoustic impedance instrument designed and calibrated to read impedance at the plane of the tympanic membrane (in absolute physical units) is more difficult to construct..........

Finally as a corallary,

(5) An instrument for the measurements of impedance at the plane of the tympanic

> membrane was not available commercially. This final problem was not solved until Zwislocki (1963) developed a stable acoustic impedance bridge for clinical use. (Ketz, Lilly, 1972)

Added to these problems - the fundamental problem is the discrepancies in the available normative data.

Metz's pioneering work on clinical measurements of acoustic impedance at the ear, and subsequent related investigations have led to considerable discussion. Several controversial questions have arisen and the intensity of arguments has increased with the number of investigations and competing claims.

There appear to be numerous studies to establish norms for impedance measurements by using both Zwislocki's bridge and electro-acoustic impedance bridge. Still there is scarcity of normative data and the available results show discrepancy for both the methods.

The magnitude and direction of deviations from normal impedance indicate the type of middle ear pathology involved. As recently as 1965, criteria for normal impedance were not well established. Both Zwislocki (1963) and Feldman (1965) has published loosely defined "typical normal" values and

Hecker and Kryter (1965) had published range of normal values which was too vide to help the clinician in diagnosis of middle ear pathology. (Burke, 1970).

K.S. Burke et al (1970) have compared 3 normative data published by Feldman (1967), Bicknell and Morgan (1963), Burke et al (1970) and found variations among the 3 reported norms.

Jerger et al (1972) have compared 6 normative data, 3 studies using Zwislocki bridge and 3 studies using electro-aeoustic impedance bridge and have found variations.

Normative data is very important for the classification of ears into normal or abnormal. As has already been mentioned there are a few reports of normative data and there are discrepancies. The classification of the ears into normal and abnormal depends on which normative data was used for the comparison.

In view of all these it was decided to study the impedance values in Indians.

Statement of the problem

"Measurements of Acoustic Impedance in Indians."

The problem of the present study is to find out whether the reported acoustic impedance data agree with the Indians normal as well as pathological.

From the studies on impedance audiometry by Jepsen (1955), Zwislocki (1965), Feldman (1967), Liden (1970), Jerger (1970, 1972), the following predictions can be made:

1. The static compliance of the normal middle war varies uniquely with both age and sex of the subject.

2. In the normal middle ear, the threshold of the acoustic reflex is normaly distributed around a mean of approximately 85 dB (ISO 64) hearing threshold level.

3. In the ear with sensori-neural hearing loss, the sensation level of the acoustic reflex declines in proportion to Increasing hearing loss.

4. The thresholds both of hearing and the atapedius reflexes vary with the age of the subject. The threshold of hearing increases while that of stapedial reflex decreases with age.

6. Tympanograms differ characteristically for normals, for ears with middle ear fluid, and for ears with negative middle ear pressure.

The above predictions are the hypotheses for the present study.

In addition the following prediction is also mad*.

The data on the Indians will not agree with any of the available reported normative impedance data.

The instrument used in the present study is the electro-acoustic impedance bridge Model Z070 associated with Madsen audiometer. In this study the 3 basic components of the impedance audiometry - tympanometry, acoustic impedance and acoustic reflex threshold were carried out.

In this study a total number of 136 subjects (191 ears) have been tested. This includes normal as well as pathological groups.

Implications of the study

l) The data collected on impedance measurements would enable us to use the Electro-acoustic Impedance Bridge for differential diagnosis of middle ear pathology and other clinical entities in Indians.

2) As the present study is not done elsewhere in India, the data collected can begin a chain of further research studies in impedance measurements.

Limitations

1) The sample of the population on which the present study has been conducted may not be an adequate representative of the Indian population.

2) The size of the sample may not be sufficient to general conclusions regarding normative data for impedance measurements.

3) Subjects below 5 years and above 50 years could not be included in this study.

4) As "X-Y plotter" was not available the tympanograms have been obtained by manual operation. The results might have been contaminated by some human errors, such as, parallax error and adjustment error.

5) Due to the non-availability of varieties of cases this study is restricted to a few clinical varieties.

6) In some of the subjects both the ears could not be tested. In these subjects tympanometry and acoustic impedance results belong to the test ear and the acoustic reflex threshold belong to the contralateral ear.

Definitions

Tympanometry: The measurement concerned with artificial pressure changes in the external auditory-meatus is termed tympanometry. It is a method for simultaneous assessment of the integrity and the functional status of the tympanic membrane, the ossiculus chain with its ligaments and muscles, the air cushion of the middle ear cavity, and the status of the Eustechian tube. The graph showing the pressure-compliance relationship of the middle ear is called the tympanogram.

Acoustic Compliance: Acoustic Compliance is that compliance which results from the volume displacement per unit pressure. It is measured in equivalent volumes (CC). (Beranek, 1967).

Acoustic Impedance: Acoustic Impedance is the resistance offered by an object to sound and it is measured in units termed acoustic ohms (Manual, Madsen).

Acoustic Reflex Threshold: Acoustic Reflex Threshold is the intensity (in dBs above the threshold of hearing in the stimulated ear) which is just capable of inducing reflex contraction of the stapedius muscle, as induced by compliance change in the impedance of the tympanic membrane (Jepsen, 1966).

Normal Ear: The ear with no apparent middle ear abnormalities revealed either by history or by E.N.T. examination and with the hearing sensitivity for frequency 250 to 8000 Hz below 20 dB (ISO 1964).

Test Ear: The ear to which probe tip is fixed.

Contralateral Ear: The ear to which audiometric stimulus (pure tone) is presented for measuring acoustic reflex threshold.

CHAPTER II

REVIEW OF LITERATURE

The review of literature concerned with this study is dealt with mainly in two stages. First, it deals with the concepts related to impedance measurements. The latter stage deals with a brief review on the three major aspects of impedance measurements: Tympanometry, Absolute Acoustic Impedance and Acoustic-Reflex Threshold, and their applications in clinical audiology. As the literature regarding the subject is abundant an exhaustive review could not be accomplished.

Evolution of Hearing

Hearing is a late development in the evolution. Its ancestory can be traced to ostracoderms (oldest known animals with back bones) that lived in sea 300 million years ago. Another clue to the origin of hearing is furnished by the hag fish. The hag fish has one semi circular-canal, formed of cartilage - a balancing organ. Later fishes developed air bladders - gas-filled sacs inside their bodies that helped them to keep afloat. Subjected to the pressure variations of a sound wave, an air bladder contracts and expands continually disturbing the surrounding fluids contained in the fish's body. The motions of the fluid then stimulate the sensitive cells present in the fish's inner ear, and the hearing in the conventional sense takes place. (Stevens, 1966).

Curiously, really, acute hearing developed as animals began to live in air, a medium which transmits sound energy less rapidly than water. (Stevens, 1966).

The modification that made hearing in the air possible, however, was the development of the middle ear. When the sound waves through the air media directly impinge on the rigid membrane of the inner ear (inside which there is fluid media) it reflects most of the sound energy. This abrupt change of characteristics is called impedance mismatch. The components of the middle ear serves mainly to overcome this barrier, to match impedances (Stevens. 1966).

Mechanism of the Middle Ear

When sound waves strike the tympanic membrane, its vibration depends on the acoustic impedance resulting from the mechanical properties of the middle ear and partly of the inner ear. The most important factors are (Zwislocki,

In the figures -

The vertical line at the extreme left of the figure indicates the surface of the tympanic membrane on which acts the sound pressure P.

M_1, C_1 and R_1 represent the effective mass, compliance and Resistance of the tympanic membrane respectively.

C_2 and R_2 represent the compliance and the resistance of the elastic coupling between the tympanic membrane and the ossicular chain respectively.

M_3, C_3 and R_3 denote the mass, compliance and Resistance of the malleus and incus and this attachments respectively.

C_4 and R_4 represent the compliance and resistance of incudostapedial joint respectively.

M_5 - mass of the shapes and of a short column of perilymph near to the oval window.

C_5 - compliance of the stapedius muscle and the cochlear windows.

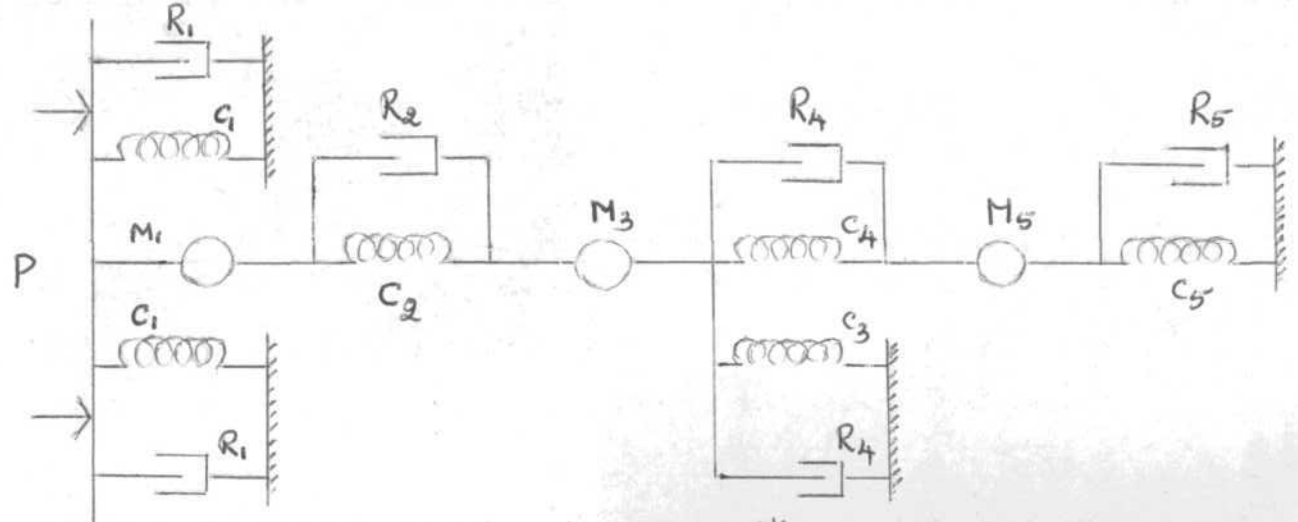


Fig 1. Simplified mechanical analog of the middle ear

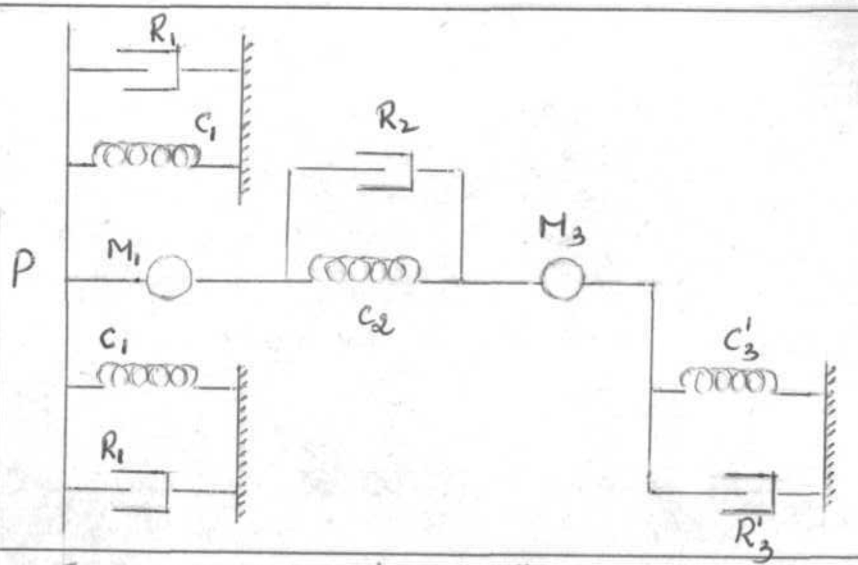


Fig. 2 Mechanical analog of middle ear with severed incudo-stapedial joint

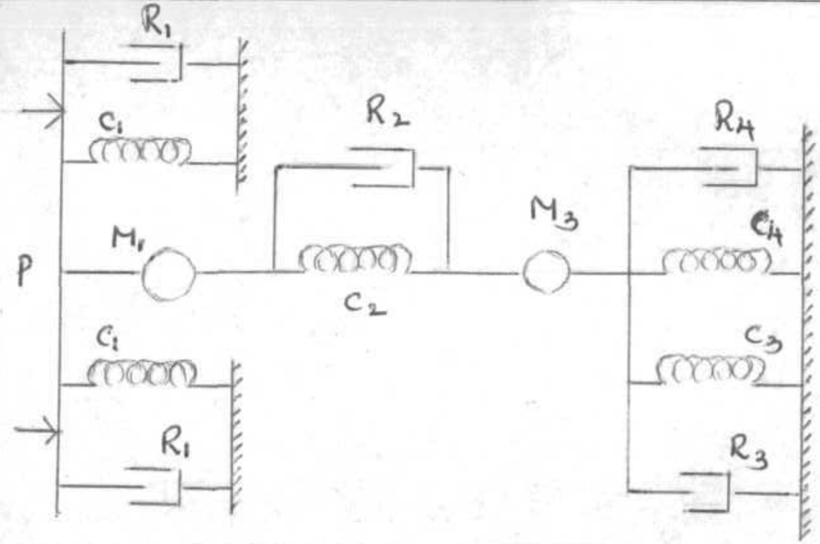


Fig. 3. Mechanical analog of otosclerotic middle ear.

ZWISLOCKI 1963

1962): the compliance and mass of the tympanic membrane, acoustic impedance of the middle ear cavities, the coupling between the tympanic membrane and the ossicular chain, the mass of the malleus and incus, the compliance of the ligaments and muscles attached to the ossicles, compliance of the incudostapedial joint, the compliance of the cochlear windows, and the acoustic impedance at the entrance to the cochlea. In all elements motion is accomplished by friction. (Zwislocki, 1963).

Simplified mechanical analog of the middle ear, mechanical analog of the middle ear with severed incudostapedial joint and mechanical analog of otosclerotic middle ear are shown in the figures 1, 2, and 3 respectively.

> If the elements represent actual Mechanical masses, compliances and resistances, they have to be divided by the square of the effective surface area of the eardrum in order to obtain the acoustic impedance. According to Bekesy the effective area is of the order of 0.55 cm^2, so that its square amounts to approximately 0.3 cm^4. (Zwislocki, 1963).

The Concept of Acoustic Impedance

Hearside (1886) first used the term "Impedance" in an analysis of an acoustic network. The concept of impedance came to acoustics from electronics. In electronics it is defined as "a complex ratio of voltage and current at a given point of a network".

$$Z = \frac{E}{I}$$

The above definition applies only to sinusoidal currents which correspond to pure tones. The ratio is called complex because it includes the phase relationship between voltage and current. They are said to be in phase when both reach this maxima and minima at the same time. When a voltage is impressed upon a resistance, it generates a current that is in the same phase as the voltage. Here, the voltage-current ratio is called resistive impedance (resistance). A voltage impressed upon an inductance (coil) generates current that develops gradually and lags behind the voltage. This lag amounts to one-fourth of a cycle, and the impedance is called inductive or a positive reactance. A voltage impressed upon a capacitance generates a current that precedes the voltage by one-fourth of a cycle and the impedance is called eapacitive or a negative reaction. Since the current in an inductance lags behind the voltage by one-fourth of a cycle, and the current in a capacitance leads the voltage by one-fourth of a cycle, the two currents differ by a half cycle and are, therefore, is phase opposition. Resistance is independent of frequency. The positive reactance of an inductance increase in direct proportion to frequency. In ease of capacitance the impedance decreases as the frequency increases.

When a circuit consists of a series connection of resistance, inductance and capacitance, its total impedance is equal to the sum of impedance components: Resistance + positive reactance + negative reactance. The magnitude of impedance amounts to

$$Z = R^2 + \frac{2\ fL - 1}{2\ fc}$$

where

R = resistance

L = inductance

c = capacitance

f = frequency

=3.14

A.G. Webster (1918), was probably the first to introduce the concept of impedance in to acoustics. He suggested that the concept of impedance could be used to simplify the analysis of mechanical and acoustical circuits. This followed with a successful application in the analysis of electrical circuit behaviour. Webster wrote, "Whenever we have permanent vibrations of a single given frequency. . . .

the notion of impedance is valuable in replacing all the quantities involved in the reactions of the system by a single complex number" (Lilly, 1972). Impedance is a very useful quantity, for, once it is known, the reactions of the air on a vibrating system can be determined.

At this stage, inpedance be defined operationally as the complex ratio of a force like quantity (force, voltage, or sound pressure) to a velocity like quantity (velocity, current or volume velocity). This definition suggests that the concept of impedance involves vector quantities. In a two dimensional plane, two numbers are required to specify completely a vector-quantity such as force. One number suggests the magnitude of the force and the second number denotes the direction in which the force is acting. This definition states that impedance is a complex ratio of 2 vector quantities. This means that impedance is also a vector quantity, and, therefore two numbers are required to specify completely the impedance. (Lilly, 1972).

This operational definition does not explicate the relation between impedance and the transmission of electric current, mechanical vibrations or sound. Therefore, input impedance of a given . system or network is defined as the "total opposition" offered by that system to the flow of energy. This intuitive definition suggests that less energy flow into a system with a high input impedance than into one with a low input impedance. Stated differently, knowledge of the input impedance of a system tells us how much energy will flow into the system, it cannot tell us, how much energy will be transmitted through the system unless we know the amount of energy that will be dissipated or stored within the system." (Lilly, 1972).

Types of Impedance

Impedance of acoustic systems is specified in four different ways. The definition for acoustic impedance given below is that of the ASA (American Standards Association). The specific acoustic impedance and the impedance ratio are those that are most often made use of in theoretical acoustics. Mechanical impedance is used when one wishes to mix acoustical Impedances and mechanical impedances (Beranek, 1967).

Acoustic Imnedance (Z_A)

Acoustic impedance of a sound medium on a given surface lying in a wave front is the complex quotient of the sound pressure (force/unit area) on that surface divided by the flux (volume velocity, or linear velocity multiplied by the area) through the surface. When concentrated rather than distributed, impedances are considered, the impedance of a portion of the medium is defined by the complex quotient of the pressure difference effective in driving that portion divided by the flux (volume velocity) (Beranek, 1967). As stated, in the acoustic Impedance sound pressure la related to the rate of volume displacement - also called volume velocity. The acoustic impedance does not require knowledge of the surface area and as a consequence is particularly well suited for measurements at the ear. Symbolically, acoustic impedance,

$$ZA = \frac{P/V = R_A + 1\ 2\ fL_A - 1}{2fC_A}$$

As the resistance and reactance camponents of impedance cannot be added algebrically, the magnitude of impedance amounts to -

$$Z = R^2 + \frac{2\ fL}{2\ fC} - 1$$

The 3nlt ef aeoastic impedance ia the acoustic oha.

Machanical impedance

Mechanical impedance as explained by Zwislocki (1963):

> The mechanical impedance is defined as the ratio of a force acting on an object and of the resulting velocity of motion. It is found that, when the

motion of the object is opposed by friction,a sinusoidal force is in phase with the velocity. In analogy to electronic circuits, we call the resultant impedance "mechanical resistance". When the object is heavy (has a certain mass), an acting force can accelerate it only gradually. The resultant velocity lags behind the force, and the situation is analogous to that at an inductance. We say that a mass produces a positive reactance. When the moving object is attached to a spring, we deal with an elastic opposing force which is proportional to the stiffness of the spring and inversely proportional to its compliance. The velocity of motion precedes the force in phase, and the situation is analogous to that at an electric capacitance. The resultant impedance is called negative reactance. When all three impedance components oppose the motion of the object, the total impedance amounts to

$$Z_m = R_m + 1\ 2\ fM - \frac{1}{2fc_m}$$

where R_M = mechanical resistance, M = mass and

C_m =mechanical compliance

When the force is due to pressure in a gas medium it is often more convenient to relate pressure rather than force to the velocity of motion. We then obtain the specific impedance. Such conditions prevail at the eardrum. When the sound pressure in the ear canal is known, it is sufficient to measure the rate of volume displacement and the surface area of the ear-drum to calculate the specific impedance. First, the rate of volume displacement is divided by the surface area in order to obtain the average the velocity; the complex quotient of sound pressure and average velocity produces the desired impedance value.

Static Impedance Measuring Methods

Beranek (1967) has reviewed twelve basic methods for measuring acoustic impedance under three headings: (l) surface methods, (2) transmission-line methods and (3) comparison methods. At least eight of these methods have been adopted for the measurement of complex acoustic impedance, (a) in a plane through the cavum conchae, (b) within the external auditory meatus or (c) at the lateral surface of the tympanic membrane.

Acoustic and electroacoustic bridges come under the category of comparison methods. Comparison methods require a known standard of acoustic impedance for comparison with the impedance to be determined.

Valid and reliable data on static impedance can be obtained with merely any "acoustic" or "electroacoustic" impedance method. Zwislocki (1957a) summarized this point concisely when he wrote, "considering the difficulties arising from the anatomy of the ear, the theoretical precision of the acoustical method itself becomes of secondary importance." Zwislocki discusses 3 problems that still plague accurate measurements of impedance at the tympanic membrane. These problems emanate from difficulties with:

(l) precise determination of Z_c (the acoustic impedance of the air trapped between the tip of the probe device and the tympanic membrane)

(2) a hermetic scal between the probe device and the external auditory meatus and

(3) methods for holding the distance and the azimuth of the probe device constant relative to the tympanic membrane. (Lilly 1972).

Acoustic Impedance Bridge Methods

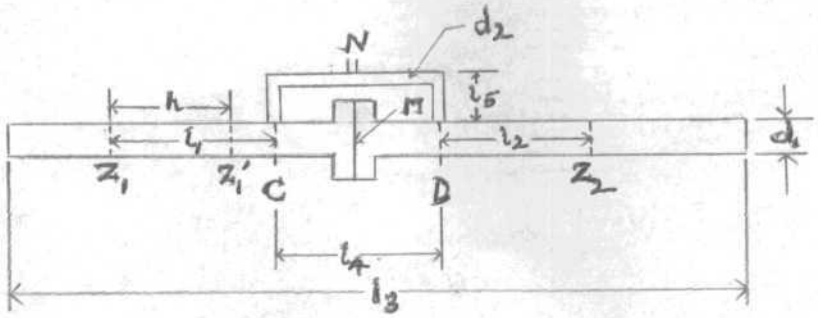
The acoustic impedance bridge has been the primary acoustic system for static measurement of impedance at the tympanic membrane.

Stewart (1926) introduced for the first time the acoustic impedance bridge method. Later, refinements of acoustic bridges have followed from the work of Schuster (1934), Robinson (1937) and Waetzman (1938). (Beranek, 1967; Lilly, 1972).

Schuster (1934) and Robinson (1937) describe the two acoustic bridge arrangements shown in figures 4, 5 and 6.

Bridges

Fig. 4.



(a) Bridge by Schuster

l_1 and l_2 are variable

l_3 = 100 cm

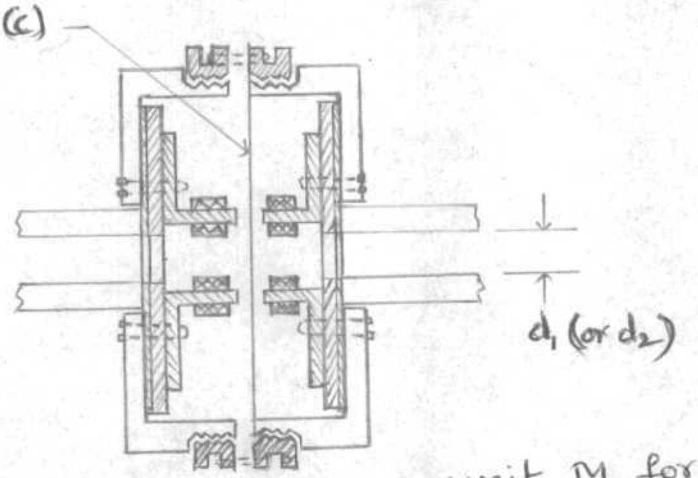
l_4 = 20.5 cm

l_5 = 4 cm

d_1 = 3.4 cm

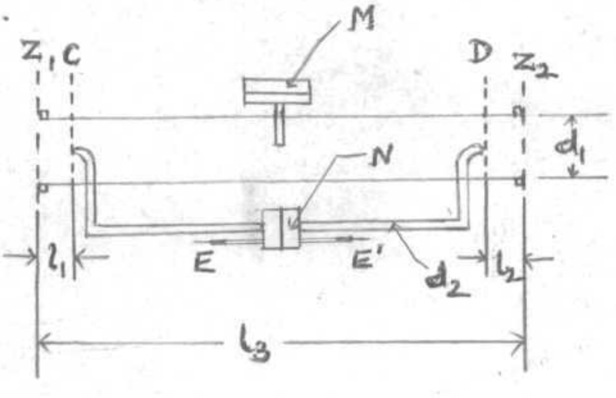
d_2 = 1.6 cm.

Fig. 5.



(b) Detail of Driving unit M for Schuster Bridge or Detector N for Robinson Bridge

Fig. 6.



l_1 = 2.54 cm

l_2 = 2.54 cm

l_3 = 25.4 cm

d_1 = 5.08 cm

d_2 = 0.32 cm

(c) Bridge by Robinson

Beranek

Waetzman (1938) used a Schuster-type bridge (Schusterschen Brucke) to measure impedance at the tympanic membrane in normals, and Menzel (1940) used a similar bridge for measuring impedance at the tympanic membrane with three points. Metz, in 1939, constructed a Schuster-type bridge and began a systematic study of acoustic impedance at the tympanic membrane in man. A complete report of this investigation was published as a monograph in 1946. One section of this monograph focussed upon the relation between changes in acoustic impedance at the tympanic membrane and contraction of the middle ear muscles. In another section, Metz showed that measurement of changes in impedance at tympanic membrane might provide a quantitative test for Eustachian tube function. Both of these applications stimulated additional research and subsequently were developed as eilnical techniques (Lilly, 1972).

In the Metz's (1946) study the primary emphasis, however, was on the measurement of static impedance at the tympanic membrane. Metz demonstrated that impedance measurements could be used to diagnose accurately the presence of middle ear pathology.

Metz bridge has undergone many modifications. The modified version of the bridge currently in use is

I - INSERT TIP

S - SPECULUM

A - TUBE LEADING TO EARDRUM.

T - SYMMETRICAL ELECTRO ACOUSTIC TRANSDUCER

Y - A TUBE CONNECTING 'A' AND 'B'

B - A VARIABLE ACOUSTIC IMPEDENCE TERMINATING TUBE

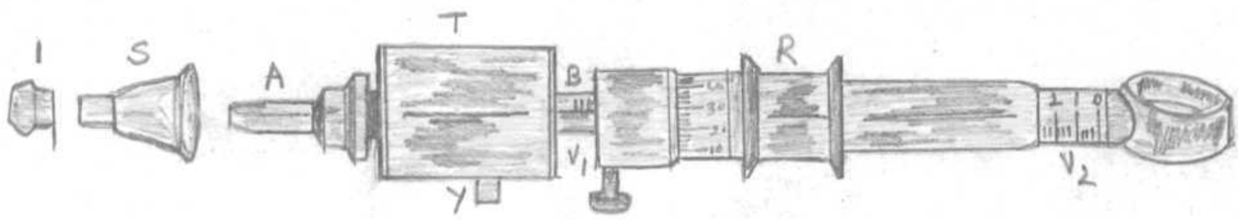


Fig: 8: ZWISLOCKI ACOUSTIC BRIDGE

V1 - AUXILIARY VOLUME SETTING FOR CONCELLETION OF THE EAR CANAL VOLUME

R - ROTETORY RESISTENCE CONTROL

V2 - PLUNGERS - TYPE COMPLIENCE CONTROL.

Zwislocki Acoustic Bridge.

E^ectroaequpt^c I^pe^pnee Bpid%§

Acoustic bridge techniques in acoustics have not found widespread use because of the lack of suitable acoustic standard (Beranek, 1967). Peterson and Ihde have adopted electric bridge techniques to acoustics through the simple arrangement shown schematically in the figure 9.

Electroacoustic impedance systems have been used for a majority of the basic studies of static acoustic impedance at the input of the normal, human auditory system. The earliest auricular acoustic impedance measurements were made by telephone engineers (Kennehy and Kurokave, 1921). These investigators were concerned primarily with the acoustical load provided by human ears to telephone transducers. Data from their experiment and from subsequent investigations have been valuable in the development of acoustic couplers that are used to calibration of audiometric ear phones and hearing aid transducers. The work of Troger (1930) usually is considered as the first systematic investigation of complex acoustic impedance at the tympanic membrane. Subsequent studies)Van Bekesy, 1932, Geffeken, 1934; more recently Zwislocki, 1957a, 1963; Moller, 1960, 1961a, Lilly, 1964; Pinto and Dallos, 1968) have reflected technological advancements in electroacoustics and electronics. The procedure and results reported in these investigations have produced improvements in measurement and calibration techniques and a body of normative data for acoustic impedance at the tympanic membrane.

Eleptrq Acoustic Impedance Bridge Madsen Z070

With the Model Z070 tympanic membrane characteristics may be observed by the application of positive and negative pressures to the ear canal. The function of the intraaural muscle reflexes may also be studied and the various observations are seen as changes in acoustic impedance. The basic principle involved in the Model Z070 is given below:

The volume of a hard walled cavity may be determined acoustically by the application of a pure tone of a fixed frequency through the sound level (SPL) within the cavity. If the volume of such a cavity is large, the intensity of the tone must be relatively large to attain a given SPL within the cavity. Conversely, if the cavity is small, the intensity of the tone necessary to attain the same SPL will be relatively smaller.

The detailed description of the Model Z070 is given in the manual -

Madsen Model Z070 Electro Acoustic Impedance Bridge

Applications and Instructions for use.

Madsen Electronics.

TYMPANOMETRY

Since Mats first suggested in 1946 that acoustic impedance of the ear can also be used as an indirect index of pressure equalization on both sides of the tympanic membrane; only a few reports have appeared in the literature on this subject, until recently.

Thomsen (1955), Andersen at al (1956), Terkildsen and Thomson (1959) have published articles on the use of impedance measures as an objective method of testing middle ear function. In the years following these early reports, a technique emerged in the Scandinavian countries which represents a combination and modification of the efforts of Terkildsen and Thomsen and Andersen and his associates. This technique is now referred to as

Tympanometry and applies an objective measurement to the basic principle of Van Dishoeck's subjective pmeunophone test. Van Dishoeck's technique is based on the principle that a tone fed into the ear canal will be heard most distinctly when the air pressure on both surfaces of the tympanic membrane is equal; Tympanometry as it has developed over the past decade, uses an Electro Acoustic Impedance Bridge to indicate changes in the compliance of the tympanic membrane while simultaneously varying pressure in the hermetically sealed ear canal of the same ear. This technique permits simultaneous assessment of (1) the mobility of the tympanic membrane, (2) the status of the ossicular chain, including the supporting mechanism, (3) the air cushion of the middle ear, and (4) the status of the Eustachian tube.

When the acoustic energy reaches the tympanic membrane most of it is absolved in normal ears. The amount of absorption at the tympanic membrane equals a certain increase of the actual Volume of the ear canal and is called the acoustic equivalent volume of the tympanic membrane. It is determined by the 3 separate factors: (1) the tympanic membrane, (2) the ossicular chain, and (3) the middle ear space.

Tympanic Membrane

The compliance of the tympanic membrane is very suceptible to alteration when the air pressure in the middle ear differs from that in the ear canal. Such a condition makes the tympanic membrane to become stretched giving rise to a decrease in compliance. Pressure differences of 100 mm H_2O cause large variations. The effect is almost maximal with pressure differences of 200 mm H_2O and very little change takes place with greater differences in pressure. Such pressure differences occur in tubal occlusion when the middle ear pressure falls below the atmospheric pressure in the external auditory means (Madsen Manual 1970).

If the compliance variation is not found during the pressure variations in the external auditory meatus, This is due either to a perforated tympanic membrane or to a lack of air in the middle ear or fluid in the middle ear or cicatrical obliterations of the middle ear.

Ossicular Chain

The ossicular chain has a considerable influence on the compliance. In otosclerotic ears, on average the compliance is reduced. The statistical variations, however, are quite large and the diagnostic value of the fact alone is questionable. The main importance of the ossicular chain in acoustic impedance measurements is associated with the intra aural muscle reflexes.

The Volume of the Middle Ear Space

It varies from person to person. This individual variation is probably the reason for the large statistical variations in compliance.

If the Eustachian tube is patulous the compliance is large and respiratory variations of pressure in the rhinopharynx are transmitted to the middle ear so that compliance changes which are synchronous with respiration are evident (Madsen Manual). Arterial pulsations in the middle ear may also cause variations of the compliance. In some patients this is quite profound following acute attacks of otitis media (Madsen Manual).

The normal Eustachian tube is closed at rest. The anterior and posterior surfaces of the membranous portion of the tube are held in opposition by the elasticity of the cartillaginous and fibrous elements in the pharyngeal walls and the closure is reduced air tight by a mucous film which coats the walls of the tube. During the act of smelling the surfaces are separated, by the actions of the tensor veli palatini and levetor veli palatini muscles and the lowered pressure that has developed in the tympanic cavity from the absorption of oxygen is equalized with the atmospheric pressure. (Miller, 1965).

Measurement of middle ear preasure has been studied by direct and indirect methods. Direct methods, for the determination of the middle ear pressure, need free air contact between a manometer system and the air filled middle ear space. This contact is produced by the needle puncture technique in man, but have received only limited clinical acceptance, because of the potential risks involved (Ingelsted et al, 1967; Liden, 1970).

By using indirect methods, the middle ear pressure behind the intact tympanic membrane can be estimated provided that the tympanic membrane is movable. Ingelste (1967) further developed the indirect methods for determinations of the middle ear mechanics. These methods are based on recordings of the movements of the tympanic membrane in response to a change of air pressure applied to the tympanic cavity. But this is complex to use clinically and carries a certain risk for the patient (Liden, 1970).

Tympanometry comes under the indirect methods. Today, Tympanometry is an important segment of impedance andiometry. It is rapidly gaining in popularity as a clinical differential diagnostic tool. It consists of a graphic representation of pressure compliance relation of the middle ear as measured at the tympanic membrane.

For unknown reasons no systematic study has been reported on tympanometry in the literature until 1970.

In 1970, Liden, Liden and Petersen, and Jerger have published three articles on tympanometry (Jerger's article has included the other two impedance measurements also), Liden has labelled and Jerger has further classified tympanometry curves into three basic types: type A, type B and type C, as shown in figure 10.

Type A tympanometry curve shows maximum compliance at or around 0 mm H_20 pressure. Usually type A curve is found in normal, sensori neural and otosclerotic ears.

Type B curve characterizes of very little or no compliance change as pressure is varied in the external auditory meatus. Usually type B is found in serious and adhesive otitis media, and perforation of the tympanic membrane.

In Type C curve maximum compliance occurs at negative pressures (around -100 mm H_2O). This is usually found in Eustachian tube malfunction.

Jerger (1970) reports a higher incidence of type C tympanograms in youngsters, 2 to 5 years old with normal hearing and sensori neural hearing loss than in older groups. He believes that this finding suggests the presence of undetected middle ear pathology in children without obvious audiometric evidence of a conductive component. In fact, the type C curve occurred in 31% of the ears in the younger age group reported in his study. (Harford, 1973).

Liden (1970) has observed maximum compliance at two different pressures at or near 0 mm H_2O in ossicular discontinuity cases.

Jerger (1970) has observed a deep type A curve in ossicular chain discontinuity. He attributes the difference in the findings with regard to ossicular chain

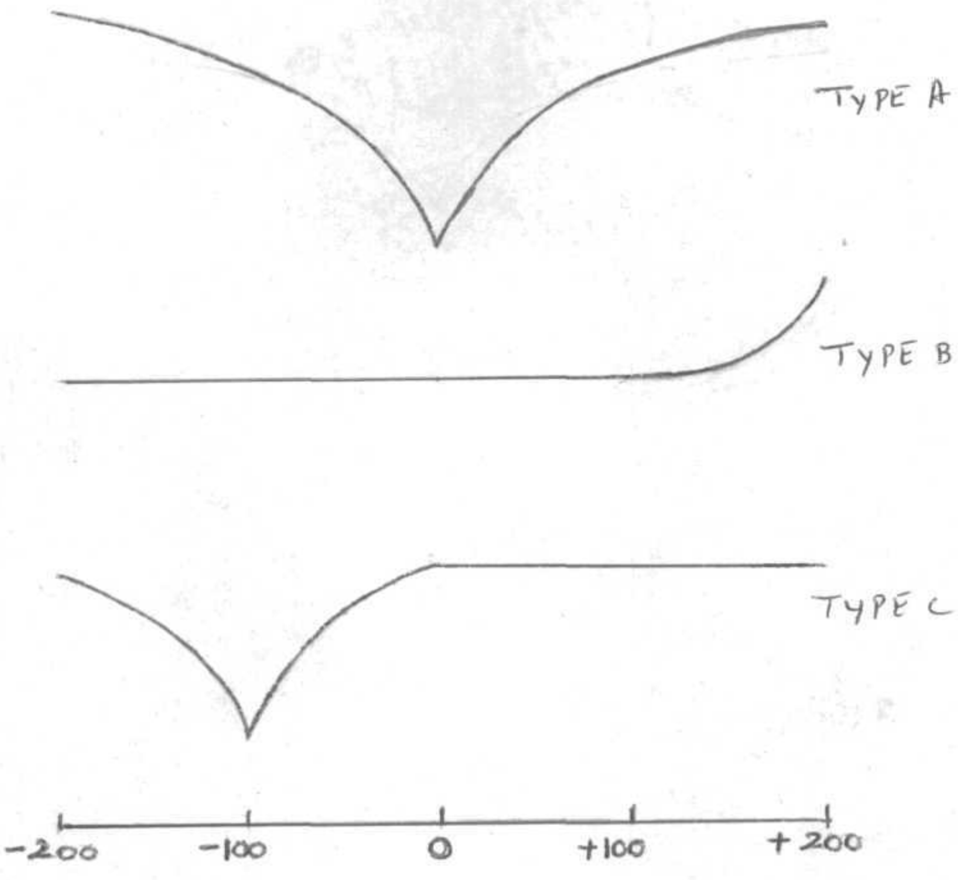


Fig: 8. TYMPANOMETRY CURVES

discontinuity cases to the difference in the used probe tones. Jerger made use of a 220 Hz pure tone. Whereas Liden made use of 800 Hz tone.

Pulton and Lamb (1972) reports that stiffness characteristics of the tympanic membrane are best revealed by the use of 220 Hz probe tone.

Harford (1973) reports that ossicular chain discontinuity results in type D configuration showing rather large undulations indicating a highly compliant ear drum. Liden (1970) also had observed this type of tympanometry curve in disruption of ossicular chain and stapedectomized ears.

Liden (1970) recommends measuring various parameters of tympanogram for quantitative purposes, example: the depth, width, displacement of the notch relative to atmospheric pressure and difference in probe tone reflection between maximum positive and maximum negative pressures. And he further recommends that more research is needed to examine the value of his suggestion.

Liden tested 100 normals, 29 otosclerotics and 27 sensori neural cases. And he studied, for all the cages, the tympanometric characteristics.

Peterson and Liden (1970) made use of the tympanometry technique to a series of 21 fresh human temporal bones, 11 of which vere judged to be normal. The purpose of the study was to create discrete middle ear lesions in fresh human temporal bones and compare the resulting tympanograms with those observed for living ears with similar lesions. The authors conclude that:

> The normal tympanometric patterns were found to be similar to those obtained in a series of 100 normal living ears in terms of notch depth, width, position of the notch relative to atmospheric pressure and difference in probe tone reflection between maximum positive and negative pressures applied. . . . Experimental manipulations on normal and abnormal ears revealed tympanograms similar to those observed for patients with clinically diagnosed pathological abnormalities. This finding permits the interpretation of particular tympanometric shapes in living ears with greater assurance.

Recently the findings of Peterson and Liden on fresh human temporal bones have been confirmed by Harford (1973).

Brooks (1969) made use of the tympanometry technique in the assessment of middle ear function. His study consisted of 1053 school children. His objective was to learn if screening tympanometry could detect the presence of otitis media in the middle ear. He measured middle ear pressure and compliance. He found reduced middle ear pressure commonly in first year school children, diminishing with increasing age. He also found fluid in the middle ear commonly in infant school children, frequently associated with infected and swollen adenoid tissue. He reported that 20% of the children in 5 years old group had clear sign of secretory otitis media.

Brooks (1969) has tried to define the shape of the curve in numerical temrs by measuring the steepness near the peak. He measured the cahnge in compliance for a pressure difference of 50 mm H_2O from the peak vlaue and called it the "gradient". He writes that the gradient value in the normal ear is about 40% of the compliance. but in an ear where the middle ear is filled with fluid it is usually less than 10% of the compliance value, and in an ear where the tympanic membrane is havily scarred it may reach over 80% of the compliance value.

Fulton and Lamb (1970) report a study on acoustic impedance and tympanometry with the retarded individual.

Many investigators have used the tympanometry technique to assess the status of Eustachian tube. Additional information concerning the funcation of the Eustachian tube of the normal and the pathological ears is needed. Eustachian tube dysfunction is the major

2) fluroscopy or clearance tests (Compere, 1958),

3) radiographic (Pariaier and Mansko, 1970)

4) equilibration of negative or positive air pressure introduced to the middle ear (Zollner, 1942) and

5) impedance measurements (Metz, 1946).

Harford considers tympanometry method a quick, quantitative assessment of air pressure in the middle ear and that it has the potential for detecting Eustachian tube malfunction where even microscopic observation may fail to reveal an abnormal conductive system. Further he believes that tympanometry finds a place along with pure tone audiometry as a more effective identifier of middle ear pathologies in school screening programmes.

STATIC IMPEDANCE MEASUREMENTS

Acoustic impedance is the resistance offered by an object to sound and it is measured in units termed acoustic ohms.

In the normal ear, acoustic waves are collected by the pinna and conducted along the external auditory meatus to the tympanic membrane. When sound reaches the tympanic membrane some of the acoustic energy is absorbed by the membrane, setting it and the ossicular chain into mechanical motion. Then acoustic energy reaches the cochlea. However, not all of the acoustic energy is absorbed by the tympanic membrane, some of it remains in the external auditory meatus. It is possible to measure the amount of acoustic energy remained in the external auditory meatus, and thus quantitate the acoustic impedance of the ear, calibrated by analogy in acoustic ohms.

The normal ear absorbs mostly the acoustic energy, and it is said to have a low acoustic impedance or a high compliance. If an ear absorbs a little sound and if it reflects most of the acoustic energy has a high acoustic impedance and low compliance.

Acoustic impedance techniques are used to measure the "opposition" that exists at the lateral surface of the tympanic membrane or at some place within the external auditory meatus. Acoustic impedance measurements are of two types: (1) Static Acoustic Impedance Measurements and (2) Dynamic Acoustic Impedance Measurements.

Static Acoustic Impedance *Measurements* are made with atmospheric air pressure in the external auditory meatus and with the middle ear muscles in a state of "normal" tonus. The words "static" (Lilly, 1964, 1972; Dallos, 1964; Pinto and Dallos, 1968) and "quiscent" (Becker and Kryter, 1965) have been used to distinguish these measurements from measurements of dynamic changes in acoustic impedance at the tympanic membrane. Some investigators have used the word "absolute" as a synonym for the word "static", and have used the word "relative" as a synonym for the word "dynamic".

Dynamic Acoustic Impedance Measurements!- Acoustic impedance at the lateral surface of the tympanic membrane will change when the middle ear muscles contract, when the Eustachian tube opens or when air pressure in the external auditory meatus is made higher or lover than atmospheric pressure. These dynamic changes are measured in absolute physical units.

Static Acoustic Impedance Measurements:- A number of workers have measured the mechanical impedance at the human ear (Wegel and Lane, 1924; Troger, 1930; Geffeken, 1934; Keibbs, 1936; Kurtz, 1938; Metz, 1946; Morton and Jones, 1956 and others) as viewed from a generator of acoustical pressure at the entrance of the meatal canal.

As the acoustic energy reaches the tympanic membrane, it will be set to vibration. As early as 1972, Mach and Kessel succeeded in observing vibrations of the tympanic membrane by making it reflective by implanting a film of gold on it. Since that time, many investigators have studied the vibration of the tympanic membrane either directly by ear microscopes or indirectly by making impedance measurements (Littles, 1965).

Wilska (1935) measured the vibration of the tympanic membrane for certain sounds and estimated the magnitude for just audible sounds. His results are in agreement with later observers. Bekesy (1941a) used a condensor microscope technique invented by Backhaus (1923) to observe the details of vibration of the tympanic membrane (Littles, 1966).

A systematic investigation of the Acoustic Impedance and its application to clinical audiology started after Metz's (1946) work on it.

Some how probably because of historical accidents and misinterpretations, a disagreement arose concerning the suitability of absolute impedance measurements as compared to measurements of impedance changes. (Zwislocki and Feldman, 1970). High individual differences that some investigators (Terkildsen and Nielsen, 1960) have found to obscure the pathological effects seem to constitute the main objection. Secondary objections arose from the need for more sophisticated instruments and necessary techniques. (Zwislocki and Feldman, 1970). For a while, these objections completely eliminated the absolute impedance measurements from the clinical diagnostic armamentorium. However, a series of experiments that started in 1956 have led to a Bomber of publications (Zwislocki, 1957a, 1957b, 1961, 1962, 1963 and 1968; Feldman, 1963, 1964, 1967, 1969), and have revealed that the individual differences could be reduced to a manageable level by eliminating the effect of the individually variable volume of the external auditory meatus, and by performing the measurements with sufficient precision. (Zwislocki and Feldman, 1970).

As Zwislocki and Feldman (1970) put it -

> Although precision still seems to be lacking in some experimental series (Bicknell and Morgan, 1968), absolute impedance measurements seem to be gaining ground. The best indication of this trend is that some instruments originally developed for the measurement of impedance changes have been modified to permit rough estimates of absolute impedance.
>
> The return to absolute impedance measurements seems to be due not only to improvements in techniques and instrumentation but also to shortcomings of methods relying on impedance changes.

In the normal ear stapedius reflex alters the impedance. Although the absence of impedance changes caused by the stapedius reflex is a good indication of middle ear pathology (Klockhoff, 1961), the reflex cannot always be elicited (Zwislocki, 1970).

As a consequence, the absence of a detectable acoustic reflex is an unsafe indicator of middle ear malfunction. Although a detectable reflex constitutes a strong contra-indication of middle ear pathology, the reflex can be detected in some cases of ossicular separation and serous otitis media (Zwislocki and Feldman, 1970).

In the last decade many investigators studied absolute acoustic impedance both on normals and pathological ears and have given typical normative values. A few investi-gators studied the reliability of acoustic impedance.

Zwislocki (1957a) and Feldman (1963) have reported that certain middle ear abnormalities show characteristic stiffness and frictional properties (acoustic impedance) that are different from that of normal ears. However a few normal hearing individuals also show to one degree or another, the characteristic impedances associated with specific type of middle ear abnormality (Feldman, 1963) so that impedance measures of the middle ear, like other diagnostic tests are not always conclusive with respect to identifying a particular cause of auditory abnormality. (Nixon and Glorig, 1964). This overlap of normal ears with a portion of abnormal middle ear will not exceed 10% (Feldman, 1967).

Nixon and Glorig (1964) have studied the reliability of acoustic impedance measures of the middle ear. In this study 4 repeated tests were made on 13 subjects by the same examiner. They found that the test was a reliable procedure. -

Tillman et al (1964) have also studied the reliability of acoustic impedance measurements performed by different examiners in repeated trials. (Feldman, 1967). This study agrees with the findings by Nixon and Glorig (1964).

Feldman (1967) has performed a normative study (using Zwislocki bridge) on 33 normal hearing individuals and has given the following data for a probe tone of 260 c/s -

Compliance

Mean in CC of equivalent volume of air = 0.67

Ranges of 80% of normals in CC of equivalent volume of air) = 0.45-0.9

(N = 33)

Resistance

Mean in acoustic ohms = 434

Range of 30% of normals in acoustic ohms = 310-610

Zwislocki (1968) has published an excellent article on Acoustic Research and its Application.

Feldman (1969) has conducted impedance measurements on small groups of patients having undergone stapedectomy. The prosthesis studied were polyethylene (9 ears), wire (11 ears), Stainless steel piston (Robinson) (17 ears), and teflon (15 ears). In addition 7 patients undergoing anterior crurotomy were examined.

> The data suggest that on the average compliance at the ear drum with all prosthesis and anterior crurotomy is larger than normal, although ears with stainless steel piston and polyethylene s do present considerable overlap with normal. (Feldman, 1969).

Further he writes:

> An earlier study demonstrated that the elimination of the stapedius muscle would not alter the impedance in a normal ear, (Feldman, 1967) and consequently, a lower impedance in a post stapedectomized ear could not be attributed to a loss of tension or stiffness that may be provided in a normal middle ear system.

He further recommends more studies on this subject.

Priede (1970) performed acoustic impedance measures in 2 cases of ossicular discontinuity. His findings agree with the findings of Bicknell and Morgan (1968), and Feldman (1967).

Burke (1970) has measured acoustic impedance on 25 normal hearing subjects. He used the following criteria for the selection of normal subjects

1) heaving levels were required to be within 15 dB (ASA 1954) from 250 to 8 kHz

2) no history of middle ear pathology

3) presence of bilateral acoustic reflex

and he gives the following data for a probe tone frequency of 250 Hz.

	Reactance	Resistance
Mean	1436	441
S.D	454	168
S.E.	93	34

Zwislocki and Feldman (1970) have discussed about the usefulness of the impedance measurements and have given a range of normative data.

Using electro-acoustic impedance bridge, Fulton and Lamb (1972) have tested the acoustic impedance of 100 mentally retarded subjects.

> It appears that absolute middle ear impedance for normal hearing mentally retarded subjects, as for normal hearing persons in general, is approximately 1500-1600 . Again, this is the reactance component of impedance rather than resistance and the figures are true only for probe frequency at or around 220 Hz.

Jerger (1971), in an article "Clinical Experience with Impedance Audiometry", has given an excellent introduction to Electro-acoustic bridge, Madsen Z070, and he gives the results of impedance measurements performed well over 400 patients. He has found that most normal middle ears will yield impedance scores in the range of 1 K to 3 K acoustic ohms. He also mentions that occasionally scores as low as 800 or as high as 4200 acoustic ohms can be expected. He stresses the usefulness of impedance measures to confirm audiometric impression in the evaluation of young children.

ACOUSTIC REFLEX THRESHOLD MEASUREMENTS

Hensen (1378) was the first to observe acoustic middle ear muscle reflexes. The most important acoustic reflexes are the cochleopalpebral reflex (extrensic acoustic reflex) and middle ear muscle reflexes (intrinsic acoustic reflex), (Jepsen, 1963). Contraction of the middle ear muscles alter the sound transmission, characteristics of the ear.

Interest in the middle ear muscle activity has been shared by investigators concerned with the physiology of the normal ear and clinicians whose primary interest has been on pathologies of the auditory system.

As early as 1946, Metz demonstrated that an intense acoustic stimulus gives rise to a distinct change in the impedance due to connection of the middle ear muscles. Following this approach the middle ear muscle reflexes in man have been extensively studied by impedance measurements. Experimental and clinical investigations have shown that the middle ear muscle reflexes in man are stable phenomenon and gives valuable information both on the middle ear muscles activity and on the auditory system.

Middle Ear Muscles

In the human and mammalian middle ear, two muscles are attached to the ossicles - the tensor tympani, first described by Eustachius (1564), and the stapedius muscle, which was accurately described for the first time by Varolius (1591). Middle ear muscles are mainly striated muscles but may contain some non-striated fibres.

The tensor tympani is a tiny though relatively long bipennate muscle which runs for 35 mm, lying in a bony canal above the Eustachian tube. It arises mainly from the bony tunnel above the osseous part of the tube and passes backwards and laterally through this tunnel. Its band-shaped tendon turns at right angles around a "bony shelf", the cochleariform process and passes laterally, to be inserted into the medial surface of the malleus, just below its neck. It is innervated by the mandibular nerve (a branch of the trigeminal, or fifth cranial nerve) it also receives a twig from the tympanic plexus. On Contraction, the malleus moves inwards and pulls the tympanic membrane with it.

The stapedius is the smallest muscle of the human organism, its average length being 6.3 mm (Wever and Lawrence, 1954). It occupies the pyramid and the canal which curves downwards from it. Its tendon passes through a minute aperture at the apex of the pyramidal eminence, turns a little downwards, and proceeds medially to the posterior margin of the head of the stapes close to the articulation with the lenticular process of the incus. It is supplied by a branch of the seventh cranial (facial) nerve, and its contraction pulls the stapes posteriorly and slightly outwards around a pivot at the posterior end of the foot plate.

The actions of the middle ear muscles are controlled reflexely, and it is thought that they protect the inner ear against the harmful effects of loud sound.

Reflex Arc

A reflex arc, in its simplest form, consists of an afferent neuron, a synapse, and an efferent neuron. A distinction is thus made between the afferent part of the reflex arc, the "reflex center", and the efferent part of the reflex arc, the reflex center being the level in the central nervous system at which the afferent impulse passes over to the efferent neuron.

Based on the work of several investigators (Hammerschlag

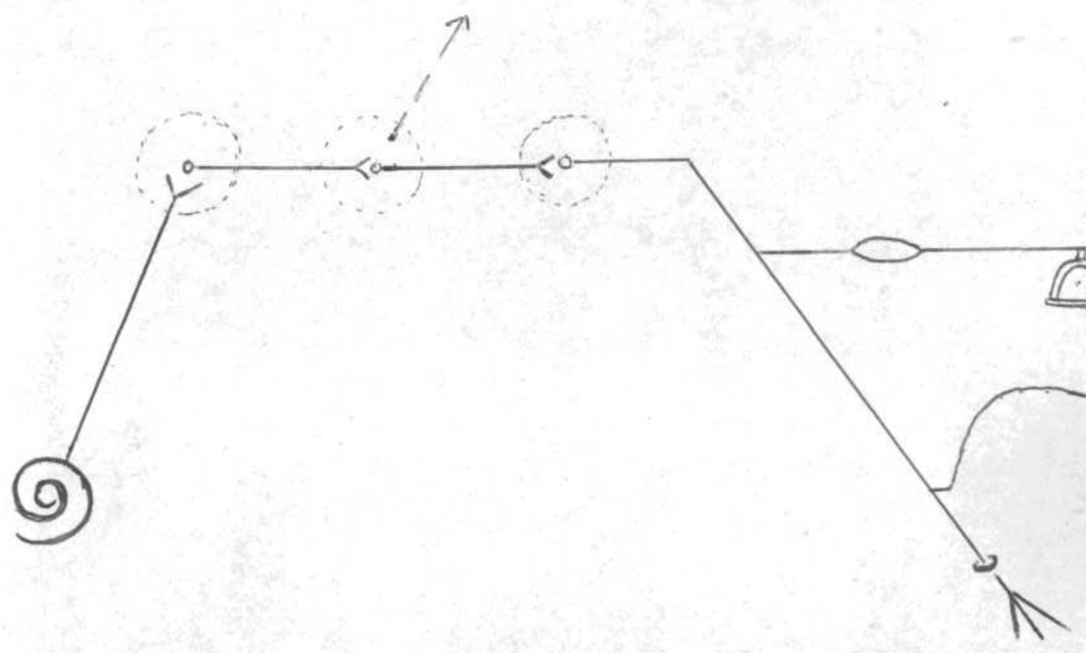


Fig: 9A

1899); Sherringtor and Forbes, 1914; Lorente de No, 1933; Tsukamoto, 1934; and Rasmussen, 1946), the presumed course of acoustic stapedius reflex arc is given in the fig.

Acoustic Reflexes

Hensen (1373), Pollak (1886) and Kato (1980) studied acoustic reflexes using animal subjects like dogs, cats and rabbits.

Luscher (1929 and 1930) was the first to show that acoustic reflex contraction of the stapedius is a constant phenomenon in man. He observed stapedius muscle directly using an ear microscope through a perforation of the tympanic membrane. He demonstrated regular and constant reflex contractions of the muscle, which could be elicited both from the homolateral and contralateral ear. He demonstrated that acoustic reflex could be conditioned. He showed that acoustic reflex could be elicited between 30 to 14000 Hz.

Recording of the Middle Ear Muscle Contraction

1. Director Observation: Luscher (1929 and l930)

Kobrak (1932 and 1948), Lindsay et al (1930) and Potter (1936) observed directly middle ear muscle reflex on acoustic stimulation using ear microscope. Djupesland (1962), Klockhoff (1961), observed middle ear muscle reflex directly on non-acoustic stimulation of the ear.

2. <u>Electromyography</u>: Recording of action potentials from the tympanic muscles has often being used in experiments on animals (Bornshein and Krejci, 1958; Okamoto et al, 1954; Eliasson and Gisselsson, 1955; Wersall, 1958, Kirikae, 1960). Perlman and Case (1939), Fisch and Schulthess (1963) studied stapedius reflex in man using electromyography.

3. Extratympanic Manometry: Various technical arrangements have been proposed for this purpose (Metz, 1951, Anderson, 1959, Moller, 1958 and 1960; Terkildsen and Nielsen, 1960; Zwislocki, 1968). Middle ear muscle reflex changes the impedance of the ear. By measuring this impedance change either by using mechanical bridge Of by using electrical bridge many investigators have studied the middle ear muscles.

The impedance method is probably the only one of clinical value. The test is reliable and it is less time consuming.

Elicitation of the Middle Ear Muscle Reflexes

Acoustic and factial stimuli may be used to elicit the reflex. Spontaneous contractions of the middle ear muscle have been reported in cats and guinea pigs. No spontaneous contractions of the middle ear muscle have so far been discovered by impedance measurements in man.

Acoustic Stimulation

An audiometer serves as a sound source for elicitation of the reflex. The sound stimuli are delivered through a single mount tread phone having the contralateral ear free for application of the impedance apparatus. The threshold of the reflex is recorded for the ear which is connected to the measuring bridge. Thus, the recording for the right ear will at once be an expression of the motor function of the right ear (muscle reflex) and of the sensory function of the left ear (Jepsen, 1963).

Metz (1961) recorded the reflexes from the homolateral ear by a special procedure. He observed that homolateral stimulation resulted in greater impedance than that with contralateral stimulation.

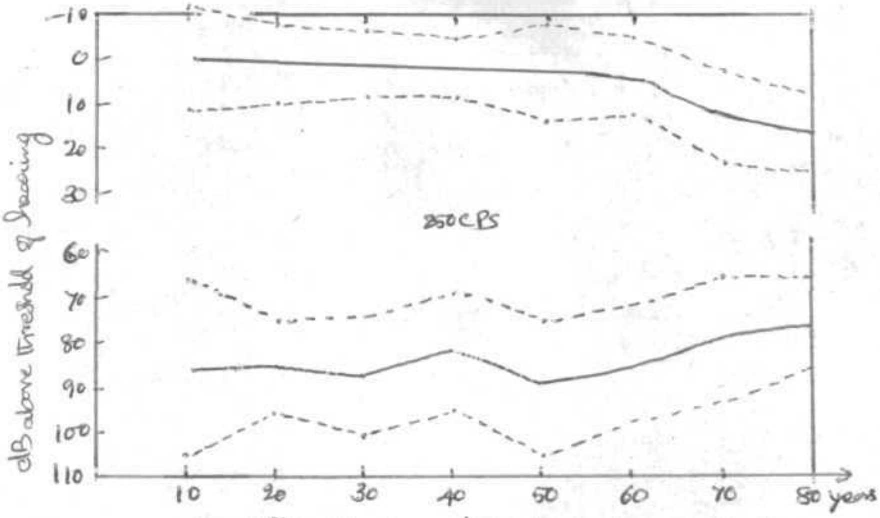
Threshold

Threshold of the stapedius reflex may be obtained either by increasing intensity by S dB steps or reducing the intensity by 5 dB steps after eliciting the reflex. But the lower threshold reading is obtained during the reduction of the intensity. In other words, preceding contractions of the stapedius produced by one stimulus, nay sometimes bring about a fall in the reflex threshold (Jepsen, 1966).

Similar observations were made by Kato (1913) in animal experiments using cats. These observations are in close agreement with well known neurophysiological phenomena that the threshold of each succeeding reflex is lowered by the excitation of just preceding its own. (Sherrington, 1906).

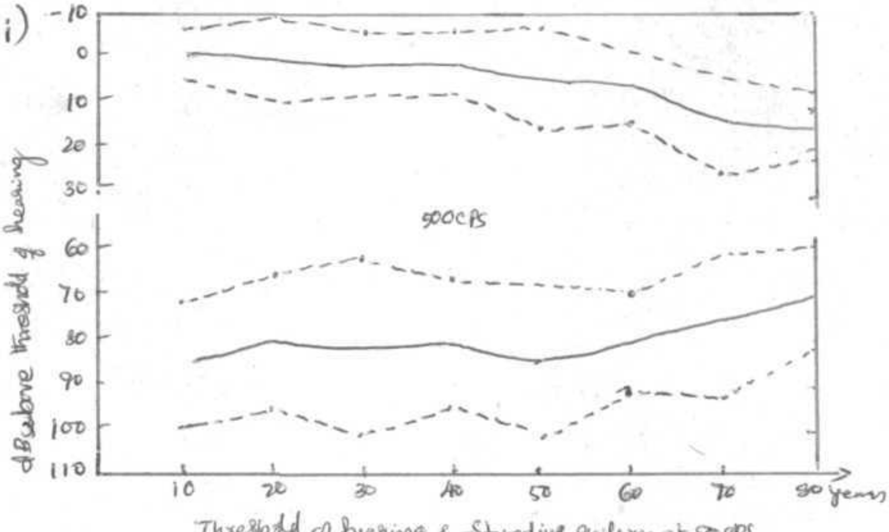
As the strength of the stimulating tone is increased, the strength of the muscle contraction increases, and the muscle contraction is greater for stimuli of low frequeneies than for higher frequencies. Metz (1951) and Moller (1958] showed this correlation between the intensity and muscle contraction by ossilographic registration. But the reflex can be abolished by exposure to very strong stimuli (for example, 140 dB at 1 kHz for 20 seconds) and Perlman state that this is due to fatigue not in the muscle but

Fig: 9B (i)



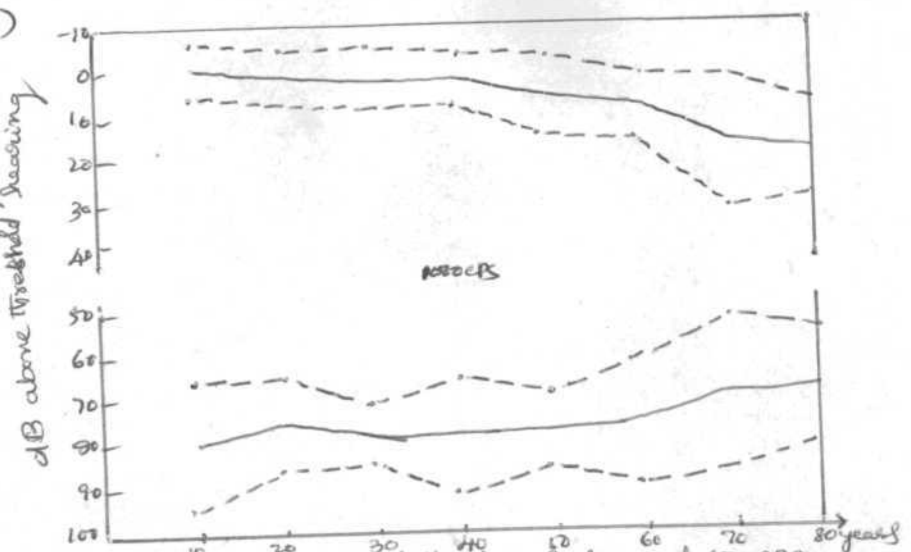
Thresholds of hearing and Stepedius reflexes at 250 CPS

(ii)



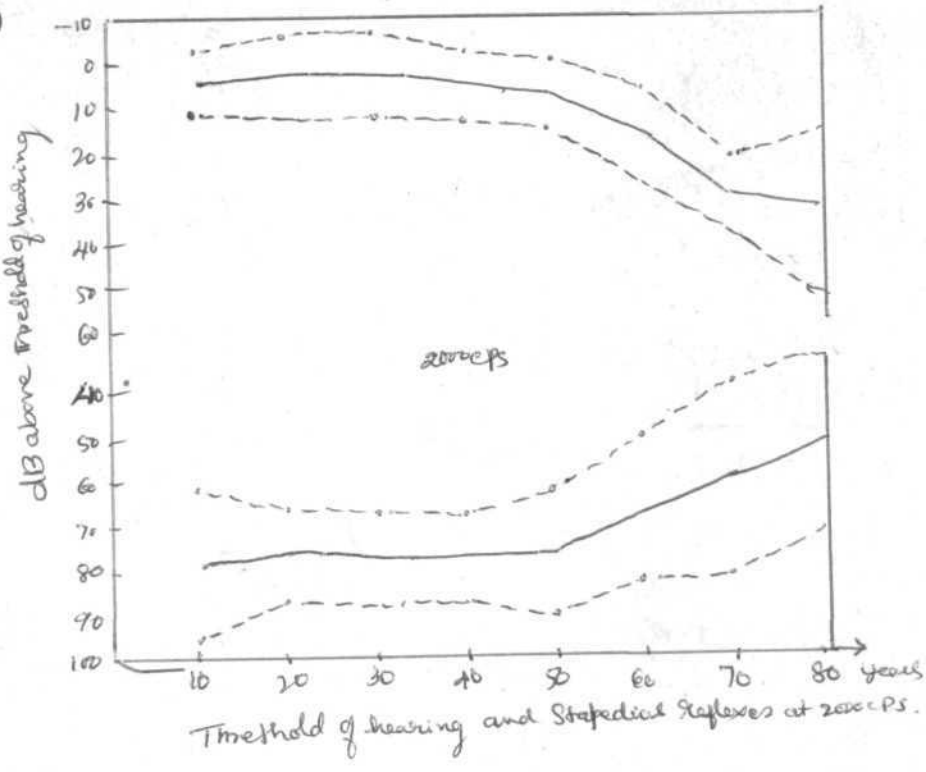
Threshold of hearing & Stapedius reflexes at 500cps

(iii)



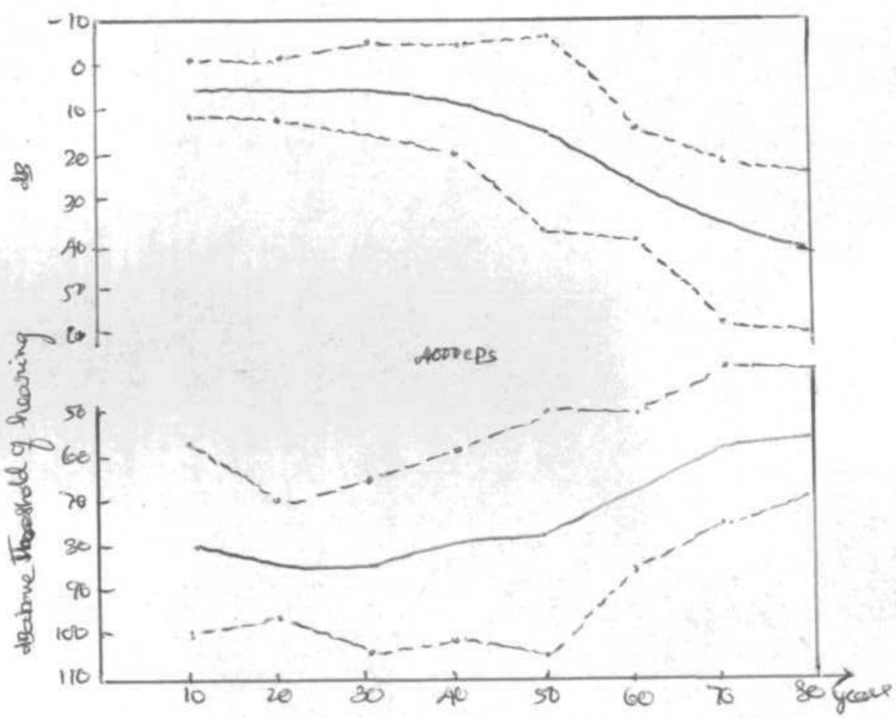
Threshold of hearing and Stapedius reflexes at 1000 CPS

(iv)



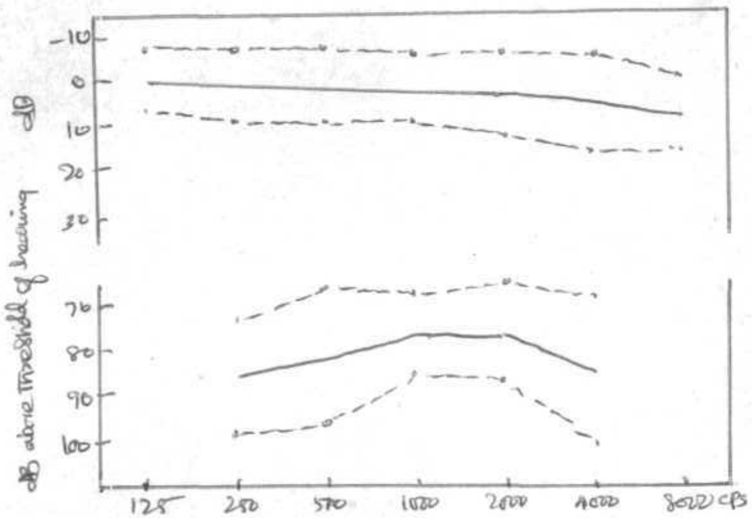
Threshold of hearing and Stapedial reflexes at 2000 CPS.

(v)



Thresholds of hearing and stapedial reflex at 4000 cps

(vi)



Threshold of hearing and stapedial reflexes age group 15-34 years (85 ears) presumably in the neural circuit of the reflex are.

Jepsen (1955) investigated the threshold of the stapedius reflexes in a control series of 91 normal subjects. The results are shown in figures

In figures solid lines represent the mean values of the thresholds, while the broken lines indicate the dispersion. This dispersion includes 95% of the subjects.

> It appears clearly from the figures that the thresholds both of hearing and of the stapedius reflexes vary with the age of the subject. The threshold of hearing increases, while that of stapedius reflexes decreases with age . . . . The changes in the threshold of the stapedius reflexes in aging subjects manifests itself in such a manner that at frequencies above 1000 Hz a lower sound Intensity than in younger persons is capable of eliciting a response of the stapedius muscle. This may be assumed to be a manifestation of recruitment. (Jepsen, 1966).

Metz (1952) was the first to emphasize that studies of the acoustic reflex could be made use of in the demonstration of recruitment.

Another study by Jepsen (1966) shows that the threshold of the stapedius reflex depends not only on the intensity of the stimulus tone, but also on its frequency. High and low tones have higher thresholds than those of the middle frequency band.

Jepsen (1966) reports two cases, where the threshold of the visible acoustic reflex contractions of the stapedius muscle was recorded and afterwards the threshold was determined by the impedance method. The two showed almost identical results.

Direct observations of the stapedius tendon are in support of the assumption that it is the contractions of the stapedius and not of the tensor tympani that are recorded by the impedance measurements.

B) Dependance of Tympanic Reflexes on Middle Ear Pressure

Terkildsen is of the opinion that the contraction characteristics of the individual muscles arc influenced by changes in the position of the ossicular chain by the application of pressures to the tympanic membrane. As a matter of fact, the contractile strength of the individual muscles is highly dependent upon the resting length. (Wersell, 1958).

C) Latency

Many investigators have measured the latency time of the reflex both in animals and in human subjects. Perlman and Case (1939) found a figure of 10 m sec. for the human stapedius. This is almost identical with the latency found in experimental animals (Hallpike, 1935; Boruschein and Krejci, 1952; Eliasson and Gissenson, 1955; Wersell, 1958; Galambos and Rupert, 1959; and others). Perlman and Case's finding was confirmed by Fisch and Schulthess (1963). Metz (1951) studied latency by impedance method and he found that the minimum value was 35 m sec., and confirmed the findings of Lorente de No (1933) that the latency became progressively shorter as the stimulus intensity was raised. Kato made a similar observation For the cat. Moller (1958) confirmed the results of Metz.

Stevens and Devis (1947), and Tirkildsen (1960c) have also studied the latency aspect of the reflex.

D) Summation

Summation of stimuli occurs when two tones of equal contraction-inducing power are applied simultaneously to produce twice the power of muscle contraction (John Groves, 1971). This results only if both the stimuli are above the reflex threshold. Perlman (1960), Jepsen (1963) and Djupesland and Zwislocki (1971) have studied the effect of temporal summation on the human stapedlus reflex. ;

E) Effects upon Sound Transmission

The effect of the muscle reflex upon the performance of the ear is a reduction in transmission of sound energy This is because of an increase in stiffness of the vibrating parts. Experimental investigations, on animal showed that this effect is limited to frequencies below 1200 Hz and at higher frequencies, Wiggers (1937) found' that the reflex actually caused a small increase in sensitivity.

McRobert et al (1969) conducted experiments, using a 250 Hz masked tone delayed in discrete steps with respect to the high frequency masking tone or noise (SO dB SPL) They found that there is an increase in masking between 100-200 m seconds delay that is attributable to reflex contractions of the middle ear muscles.

In the literature only a few studies are there concerned with this problem in man. Jepsen (1966) classifies these studies into the following three groups;

i) investigations on threshold shift after voluntary and acoustically or non-acoustically elicited contractions of the tympanic muscles,

ii) equal loudness experiments, and

iii) measurements of the acoustic impedance.

F) Fatigability of the Middle Ear Reflex

Luscher (1930) and Kobrak et al (1941) have studied fatigability of the stapedius reflex, by direct observatic of the stapedius tendon, in human subjects with tympanic membrane perforations when the contralateral ear was stimulated with an intense continuous sound, a sustained contraction was first observed. Despite continued sound stimulation a decrease in contraction and a final return to the resting state were observed. If another tone of s different frequency was superimposed, a new stapedius contraction was elicited. Metz (1951) reported similar findings.

Brasher et al (1969) have reported an article on middle ear muscle activity and temporary threshold shift. The purpose of this study was to examine the possible correlations between individual variations in temporary threshold shift from steady state and impulse noises on the one hand and in acoustic reflex response and anticipatory middle ear muscle contraction on the other.

Non-acoustic Stimulation and the Reflex

Luscher (1929), Pickles and Bornschein (1957), Klockhoff and Anderson (1969a) and Klockhoff (1961), have studied the stapedius reflex characteristics using tactile stimulation. Responses were obtained in most cases when stimulus was applied to the homolateral tragus and in the canal wall.

Reflex Studies in the Last Decade

Feldman and Zwislocki (1965) have studied the effect of the acoustic reflex on the impedance at the tympanic membrane on 17 normal ears. The reflex is shown to affect the impedance by a decrease in compliance and a slight decrease in resistance. The authors conclude that:

> The major effect of the reflex appears to be two fold. The compliance of the system is decreased. This change is in the same direction but smaller than that produced by otosclerosis. At the same time, the resistance of the system is decreased somewhat. Otosclerosis effects the resistance in the opposite direction. As a consequence it is concluded that contraction of middle ear muscles and otosclerosis do aot produce mechanical changes of the same kind. Possibly, the muscle contraction leads to a loosening of the incudostapedial joint in addition to & partial fixation of the stapes.

There is a need for further study to confirm the above findings.

Liden (1954) has reported that, the discomfort level for speech was only slightly higher for an otosclerotic impedance than for the sengorineural groups with recruitment. Consistent with this is Harford and Jerger's observation.

Based on the above findings, Anderson and Barr (1968) write that conductive loss is not entirely devoid of recruitment like properties. This was substantiated by studying reflex measurements on 30 cases of unilateral pure conductive loss (24 cases of ossicular fixation + 6 cases of ossicular interruption). And they have used the reflex measuring methods to substantiate their recruitment.

Elicitation of the reflex in the above study is contrary to the published reports (Jepsen, 1963; Klockhoff, 1961), that minimal conductive hearing loss will usually prevent impedance changes from occurring.

Further studies are needed on this line.

Jepsen has reported that, a test stimulus of 70 to 90 dB above auditory threshold is needed to elicit the stapedius reflex in case of normal hearing subjects. A number of studies have stated that stapedius reflex appears to be related to loudness growth rather than to signal intensity. Thus, impedance changes that are found to occur by stimulating with signals less than 70 dB sensation level have been interpreted as showig loudness recruitment (Metz, 1952; Kristensen and Jepsen, 1952; Thomson, 1955; Ewertsen et al, 1958; Jepsen, 1963).

Lamb, Peterson and Hansen (1968) have conducted a study using 10 normals (19 ears), 15 bilateral sensori-neural (29 ears) and 10 unilateral sensori-neural loss (10 ears). They have found that with both the unilateral and bilateral loss groups the mean range between pure tone threshold and reflex threshold was 40 to 45 dB. They have also found that individual thresholds in these groups ranged from 55 dB to as little as 10 dB.

Djupesland and Flottorp (1970) have studied the correlation between the ABLB and Metz's Recruitment Test. They have drawn the following conclusions based upon their investigation of 83 patients exhibiting sensori-neural loss of varying degrees -

1) Metz's Recruitment Test differentiates between cochlear and retrocoehlear pathology as reliably as the ABLB, MLB tests.

2) Metz's Recruitment Test possesses a broader range of application than the loudness balance tests.

Andersen, Barr and Wedenberg (1970) used the stapedius reflex test, along with the threshold test, ABLB, tone decay and speech discrimination test for early detection of acoustic tumors. They have tested 21 cases of verified retrocochlear involvement (16 acoustic tumors, 5 posterior fossa tumors) with a hearing loss not exceeding 60 dB.

In the reflex measurement the following data were collected:

1) the threshold of the acoustic reflexes for different frequencies; and

2) the persistence of the reflex response on prolonged stimulation.

They have observed pathologically elevated reflex thresholds in all but one of the patients and in 13 cases they have observed abnormally rapid reflex on prolonged stimulation.

> These reflex tests appear to reveal the earliest audiological signs of an incipient retrocochlear lesion. This is borne out by a few extremely early cases where the hearing threshold was still entirely normal and where none of the traditional differential diagnostic hearing tests disclosed the presence of a retrocochlear disorders.

Liden (1970) has reported a study elucidating the behaviour of the stapedius reflex in clinical presumptive cochlear and retrocochlear lesions after correlating the results with those obtained from experimentally induced lesions in the cat. The number of subjects included in the study were patients with Mineire's disease, 15 with athetosis and 9 with acoustic tumors.

Greisen and Rasmussen (1970) have used stapedius muscle reflex examinations on two patients shown to have brain stem tumors. Reflexes were examined by using an impedance device capable of measuring the stapedius reflexes both by contralateral stimulation and by homolateral stimulation.

> Comparison of the stapedius muscle reflexes elicited by homolateral and contra-lateral stimulation increases significantly the possibility of making a topical diagnosis of a disruption of the reflex and it helps in the diagnosis and localization of brain stem affections.
>
> Johnson (1973) made use of the reflex tests on Meniens syndrome and acoustic neurone patients. He observed reflexes at reduced SL in case of Miniers disease. In the case of acoustic neurone he found that there was a considerable decay of the acoustic reflex on the affected side as compared to the normal ear. Apparently acoustic reflex decay in acoustic neurones occur only when the hearing loss is relatively mild in the affected ear. In other cases of more loss caused by acoustic neurones, there is a complete absence of the acoustic reflex. It is of considerable diagnostic significance if the normal reflex is elevated in the good ear with no acoustic reflex present in the affected side.

So far no study seems to have been done or reported in India on impedance audiometry except a report by Venkateshamurthy. The article deals with the study carried out by the author while he was working as Commonwealth Scholar at Royal Infirmary, Edinburgh, U.K.

The present study seems to be the first attempt in this area of research in India.

Clinical Application of Impedance Measurements

The excellent review on clinical applications of impedance measurements published in "Clinical Audiology" edited by Katz has been extensively made use of.

Acoustic Impedance as Measured in the Plane of the Tympanic Membrane

It has considerable variations. However, it is an additional diagnostic observation which when used along with other tests can be helpful in diagnosing otosclerosis, ossicular chain discontinuity, otitis media and other inflammatory and chronic conditions of the middle ear. In general, acoustic impedance at the tympanic membrane is

1) lewer than normal with ossicular discontinuity

2) higher than normal with otosclerosis

3) very much higher than normal with acute inflammatory and chronic conditions of the middle ear (Lilly, 1972)

II Acoustic Reflex Measurements

The reflex threshold provides objective evidence of the supra threshold hearing function.

The presence or absence of the reflex provides information regarding:

1) hearing sensitivity of neonates and young children (Terkildsen, 1960; Wedenberg, 1963; Robertson, Peterson and Lamb, 1968; Jerger, 1970, 1972; and Lilly, 1972).

2) the existence and magnitude of functional hearing loss (Jepsen, 1983, 1963; Thomsen, 1955a; Terkildsen, 1964; Lamb, Peterson and Hansen, 1968; and Lilly, 1972).

3) Conductive hearing loss:

   a) to differentiate between otosclerosis or ossicular discontinuity (Klockhoff and Anderson, 1959, 1960; Anderson and Barr, 1971; Flottorp and Djupesland, 1970; Jerger, 1970, 1972; Liden, Peterson and Harford, 1970; and Lilly, 1972)

   b) to verify the absence of conductive lesion (Metz, 1946; Thomsen, 1955b; Klockhoff and Anderson, 1959; Brooks 1963, 1969; Liden, 1969; Jerger, 1970, 1972; and Lilly, 1972)

   c) to verify the presence of conductive recruitment (Anderson and Barr, 1968).

4) Sensori-neural hearing impairment:

a) to verify the presence of recruitment (Kristensen and Jepsen, 1952; Metz, 1952; Thomson, 1955b, 1955d; Ewertsen et al, 1958; Liden, 1969, 1970; Alberti and Kristensen, 1970; Jerger, 1970, 1972; Lilly, 1972; and Anderson et al, 1970)

b) to verify the presence of abnormal auditory adaptation (Anderson et al, 1969, 1970; Alberti and Kristensen, 1970; and Lilly, 1972)

e) to rule out the existence of conductive lesions for patient with severe sensorl-neural loss (Klockhoff and Anderson, 1959; Klockhoff, 1961; Farrant and Skurr, 1966; and Lilly, 1972)

5) Neurotology:

a) topographic localization of lesions to auditory nerve (Metz, 1946; Thomsen, 1955b; Klockhoff, 1961; Holst, et al, 1963; Liden, et al, 1970; and Lilly, 1972)

b) in differential diagnosis of patients with brain stem lesions (Jepsen, 1963; Greisen and Rasmussen, 1970; Anderson, et al, 1970; and Lilly, 1972)

c) as an indirect measure of changes la intracranial pressure (Klockhoff, et al, 1965; and Lilly, 1972)

d) as a test for motor function of trigeminal nerve (Klockhoff and Andersen, 1960; Klockhoff, 1961; Lindstrom and Liden, 1964: and Lilly, 1972)

e) test for facial paralysis (Madsen Manual).

Further, it may give information regarding:

i) susceptibility to noise exposure (Ward, 1962; Becker & Kryter, 1965; Johansson et al, 1967)

ii) the identification of normal hearing

"......carriers of genes for recessive deafness....." (Anderson & Wedenberg, 1968)

iii) temporary summation of the auditory system for pure tones. (Djuperland & Zwislocki, 1971)

Tympanometry

Tympanometry measures are useful regarding the following

1) detection of the middle ear fluid (Terkildsen and Thomsen, 1959; Thomsen, 1961; Brooks, 1968; Liden, 1969; Alberti and Kristensen, 1970; and Jerger, 1970).

2) finding the air pressure in middle ear space (ibid)

3) scarring of the tympanic membrane (Terkildsen and Thomsen, 1959; Terkildsen, 1964; and Liden, et al, 1970)

4) acoustic impedance (Terkildsen and Thomson, 1959; Terkildsen, 1964; and Liden et al, 1970)

5) status of the Eustachian tube (Mats, 1953; Thomson, 1955; Terkildsen and Thomsen, 1959; Miller, 1965; Alberti and Kriatensen, 1970; Johnson, 1973; and Harford, 1973).

CHAPTER III

METHODOLOGY

Subjects

136 subjects were tested. Table 1 gives the frequency distribution of the subjects.

Table 1

Sl. No	Group	Age Range	Mean Age	No. of subjects	No. of ears
1	3-14 yrs (boys)	6-14	8.65	7	13
2	5-14 yrs (girls)	6-13	8.66	6	11
3	15-29 yrs (males)	17-29	20.96	30	47
4	15-29 yrs (females)	16-29	21.32	25	32
5	30-50 yrs (males)	30-49	38	16	30
6	Sensori-neural loss	12-56	..	20	14
7	Conductive loss other than otosclerosis			18	28
8	Otosclerosis			8	13
9	Mixed loss			11	18
10	Functional loss			1	1

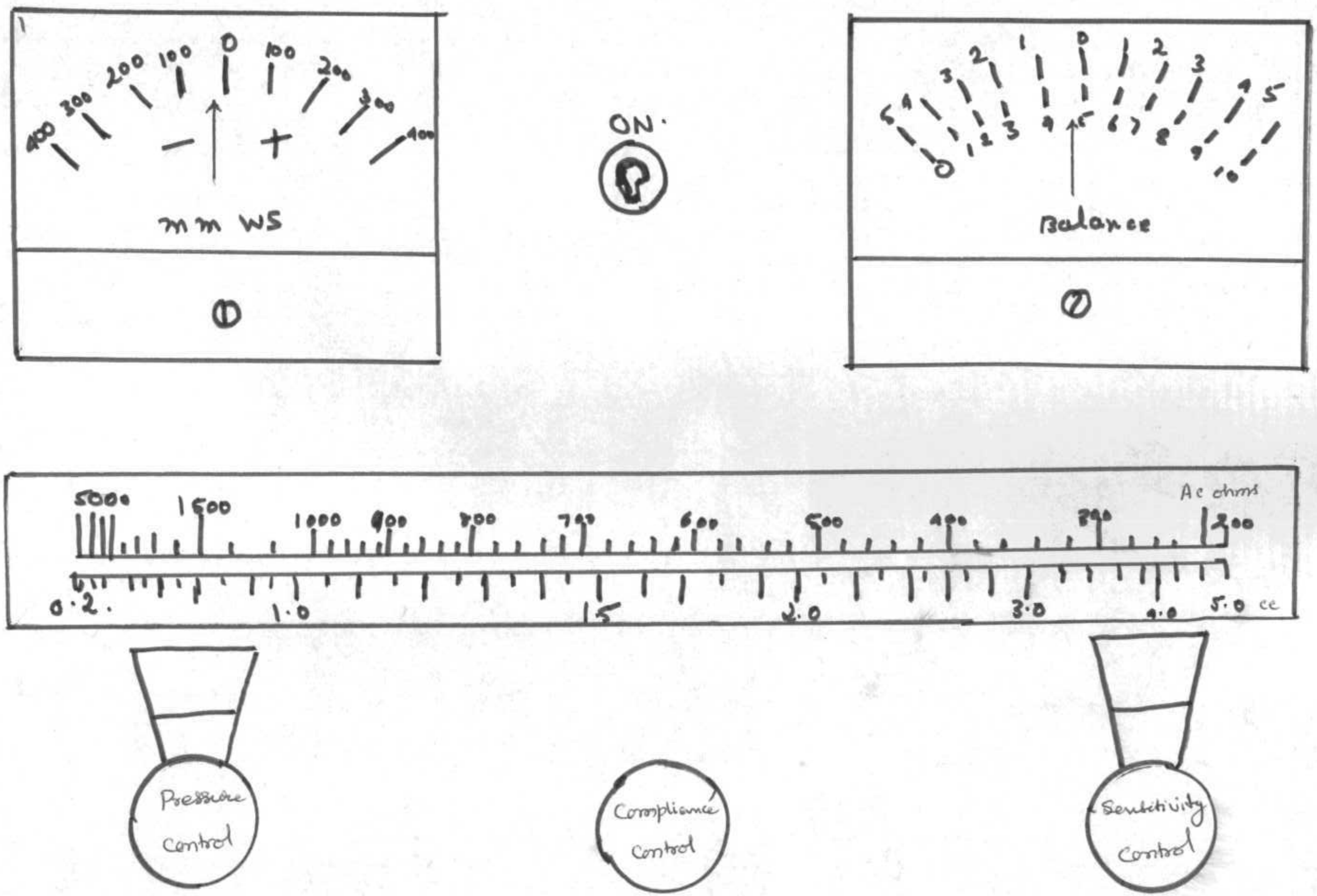
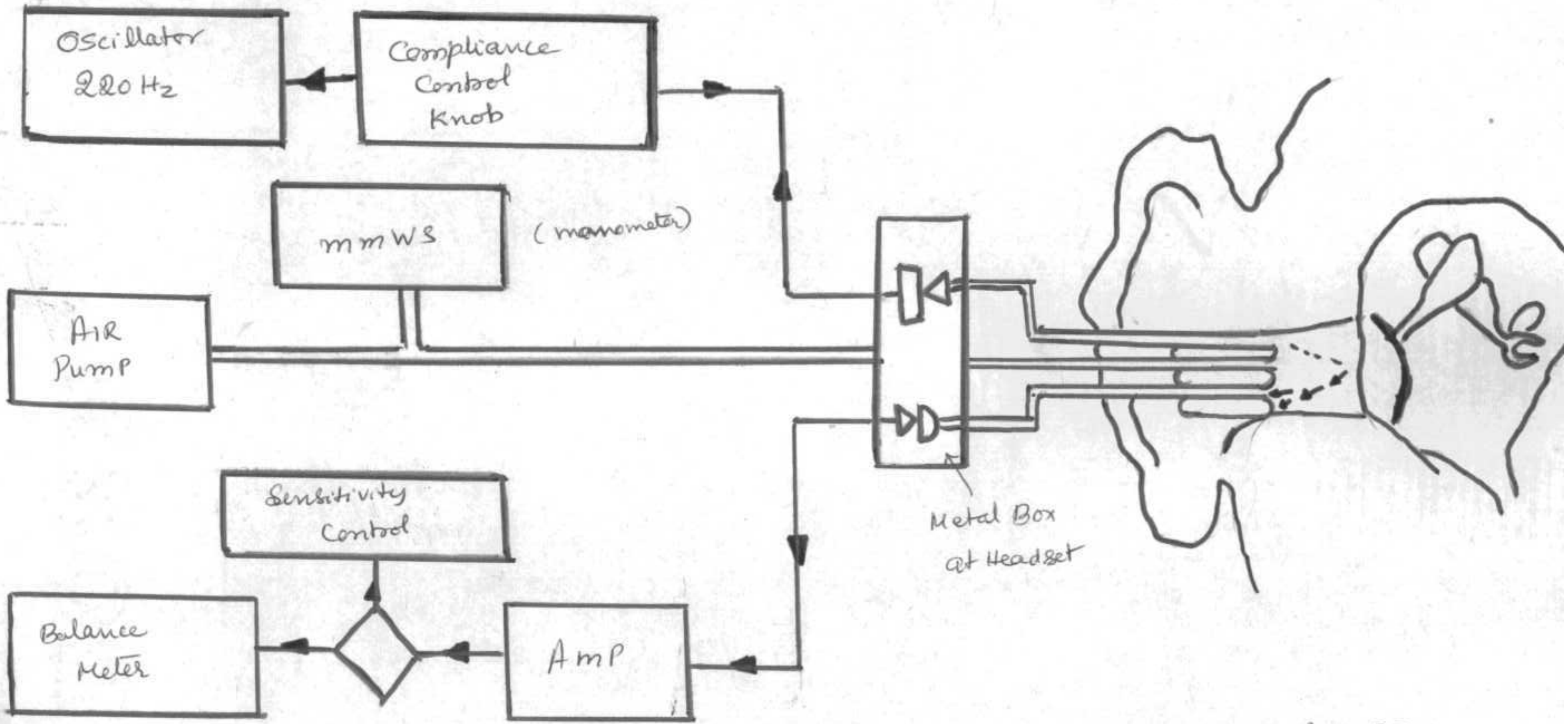


Fig: 10A. BLOCK DIAGRAM OF THE MADSEN ELECTRO ACOUSTIC IMPEDENCE BRIDGE.



SCHEMATIC DIAGRAM OF PRINCIPAL COMPONENTS OF THE MADSEN ELECTROACOUSTIC IMPEDANCE BRIDGE.

Apparatus and Acoustical Environment of the Testing Rooms

A calibrated audiometer (Amplivox 103 Audiometer) was used to obtain the pure tone thresholds. Pure tone thresholds were taken in a sound treated room.

Madsen Z070 Electroacoustic Impedance Bridge was used in this study. To measure the acoustic reflex thresholds an audiometer (Madsen portable) was used along with the impedance bridge. Audiometer was calibrated periodically using artificial ear and Bruel and Kjaer equipment.

Madsen Z070 Electroacoustic Impedance Bridge has been described in detail by Jerger (1970). Only a brief description of the bridge will be given here. The apparatus consists of 3 main controls and a probe tip:

1) An air pump control which permits variation of air pressure in the external auditory meatus from -400 mm H_2O to +400 mm H_2O.

2) A compliance control which controls the probe tone intensity in the external auditory meatus (when the balance meter reads zero the SPL in the external auditotry

in 95 dB).

3) A sensitivity control which is used to alter the sensitivity of the balancing mechanism.

4) Probe tip consists of 3 tubes - (l) tube carrying air to vary the pressure in the external auditory meatus, (2) tube carrying the probe tone, and (3) tube collecting the reflected sound energy from the tympanic membrane and delivering to the probe microphone.

Pure tone thresholds were taken in & sound treated set up.

The noise levels in the test room were measured by Bruel & Kjaer SPL meter type 2203 with an Bruel & Kjaer Octave filter set - 1613 and were as follows: *

Table 2

Sound Pressure Level in the Sound Treated Room using Weighted Scales

Sl.No.	Scale	SPL value Re: .0002 dyne/cm^2
1	C	42
2	B	35
3	A	36

Table 3

Noise Levels in the Audiometric Room Measured in Octaves

Sl. No.	Central frequency of the Octave Band in Hz	SPL Value	ISO Specifi- cations 1963
1	250	22	25
2	800	20	26
3	1K	18	30
4	2 K	15	38
5	4 K	36	51
6	8 K	20	51

Impedance audiometry was done in a room where the noise levels were:

Table 4

Sound Pressure Levels in the Sound Treated Room using Weighted Scales

Sl.No.	Scale	SPL Values in dB re: 0.0002 dyne/cm^2
1	C	56
2	B	48
3	A	44

Table 5

Sound Pressure Levels at various Frequencies

Sl. No.	Central Frequency of the Octave Band ia Hz	SPL values in dB re: 0.0008 dyne/
1	125	38
2	250	40
3	500	44
4	1 K	40
5	2 K	30
6	4 K	36
7	8 K	29

Test Procedure

Prior to impedance audiometry all the subjects were examined by an ENT specialist. And they were given pure tone audiometric test for both ears. Hughson - Westlake was used in obtaining the thresholds. Later all the three measures of impedance audiometry were done on all the subjects. A few subjects were selected randomly and tested for acoustic reflex at varying pressures in the external auditory meatus.

The subjects were asked to sit relaxed and they were instructed not to swallow during the test and not to jerk the body.

Air tight seal between the external auditory canal wall and the probe tip was a problem. This problem was solved by using petrollium jelly. Care should be taken to see that the probe openings will not get smeared with petrollium jelly. Even with petrollium jelly air tight seal was not possible for all ears.

Procedure for tympanometry

Usually tympanometry curves are drawn by using an X-Y plotter. The graphic record of pressure compliance relation is called "Tympanogram". Due to the non-availability of the X-Y plotter, the following procedure was designed to obtain the tympanograms.

1. Sensitivity control was set to position 1.
2. Pump control was rotated until the manometer read -400 mm H_2O.
3. At this pressure the compliance control was adjusted until the balance meter was nulled

and the compliance reading on the compliance scale (in equivalent volumes in cc) was recorded.

4. Pump control was rotated until the manometer read -360 mm H_2O. At this pressure compliance control was adjusted to null the balance meter (if required) and the compliance reading on the compliance scale was recorded.

This procedure of varying the pressure in steps of 40 mm H_2O (except around zero mm H_2O pressure wherein 20 mm H_2O step was used as there was greater variation in compliance around zero mm H_2O pressure - because, middle ear pressure of normals lie around 0 mm HgO) was repeated until the manometer showed +200 mm HgO. Each time the pressure vas varied, the balance meter was nulled by adjusting the compliance control and the corresponding reading on the compliance scale was recorded.

Middle ear pressures of the subjects were determined by tympanometry. Maximum compliance results when the pressure in the middle ear space and external auditory meatus are equal. By varying the pressure in the external auditory meatus maximum compliance was determined.

The pressure at which the maximum compliance resulted vas considered as the middle ear air pressure of the subject (when the pressures are equalized on both sides of the tympanic membrane, it will be in its normal position and hence it will be maximally compliant).

By using two compliance values i.e., (1) the minimum compliance (C_1) recorded and (2) the compliance value (Cg) obtained at +200 mm H_2O pressure, the static compliance (C_S) for the subject vas computed:

$$C_s = C_2 - C_1$$

Analysis of the tympanograms showed three patterns of pressure compliance relation. The three patterns were

1) Maximum compliance around 0 mm HgO (A type)

2) No change in compliance as pressure vas varied (B type) - and

B) Maximum compliance at negative pressure (more than -100 mm HgO - C type)

These patterns resemble A B C tympanometry curves reported by previous investigators. (Liden, 1970; Jerger, 1970).

Procedure for obtaining acoustic impedance at the tympanic membrane

The procedure given in the Manual (Manual of Madsen Electro-Acoustic Impedance Bridge Model Z070) published by Madsen Electronics) was followed.

Acoustic Impedance is given by the formula:

$$Z_X = \frac{Z1\ Z2}{Z1-Z2}$$

where

Z_1 was determined when the air pressure in the external auditory meatus was set at 100 mm H_2O.

Z_2 was determined at that pressure when the tympanic membrane was maximally compliant.

Procedure for obtaining acoustic reflex thresholds .

The procedure given in the Madsen Manual was followed.

Air pressure in the external auditory meatus was adjusted to middle ear pressure. Sensitivity control was set at "3" position and the balance meter was nailed. Tone from the audiometer was given to contralateral ear (the ear opposite to the ear to which probe device is fitted). Tone was varied using ascending descending procedure, and the lowest level in dB. required to elicit the detectable deflection in the balance meter by the acoustic reflex was noted as the acoustic reflex threshold. Acoustic reflex thresholds were obtained for following frequencies using the above procedure!

250 Hz
800 Hz
1000 Hz
2000 Hz
4000 Hz
6000 Hz
8000 Hz

Some procedure was used to get the acoustic reflex threshold at -100 mm H_2O and +100 mm H_2O pressure in the external auditory meatus.

A few normal subjects from the original sample were randomly selected and they were tested to find out the test-retest reliability.

CHAPTER IV

RESULTS AND DISCUSSION

The fact that impedance audiometry is useful only as a complete battery and that its diagnostic value Bust be based on the results of tympanometry, acoustic impedance and the acoustic reflex, it is quite essential to know the normative data on the impedance measures. However, the reported results show that there is a considerable overlap between the impedance distributions of normal and abnormal middle ears. The analysis of the results of the present study is aimed at finding the distribution of impedance measures in normals and a few pathological ears. The results are presented in two parts: The first part deals with the statistical data on the distribution of the impedance measures. The second part deals with a few case reports.

Tympanometry

Table 6 gives the values of mean pressure compliance for the following 6 groups:

1. Boys (5-14 years)
2. Girls (5-14years)

3. Males (16-29 years)
4. Females (15-29 years)
5. Males (30-60 years)
6. Sensorineural hearing loss

Using pressure compliance values middle ear pressure, difference in compliance between -400 mm H_2O and +200 mm H_2O pressures, and static compliance have been computed. The results are given in Table 7 for the mentioned 6 groups.

Table 7 also provides the acoustic impedance data for the mentioned groups.

Pig. 11 represents the mean tympanometry curve for boys (13 ears) of normal hearing in the age group 5-14 years. The maximum compliance occurs at two mean pressure Values: -40 mm H_2O and +20 mm H_2O. The probable explanation for two values of maximum compliance is due to the variation in the middle ear air pressure which ranges from -90 to +20 mm H_2O, with a mean of -26.92 mm H_2O and standard deviation of 40.49.

Fig. 11 shows the mean tympanometry curve for girls (11 ears) of normal hearing in the age range 5-14 years.

TABLE 6

Mean Pressure Compliance Values

N	-400	-360	-320	-280	-240	-200	-160	-120	-80	-40	-20	0	20	40	80	120	160	200
Boys 5-14 yrs																		
13	1.27	1.27	1.27	1.26	1.26	1.27	1.28	1.34	1.41	1.48	1.39	1.40	1.46	1.37	1.27	1.22	1.18	1.15
Girls 5-14 yrs																		
11	1.30	1.30	1.30	1.28	1.30	1.31	1.33	1.37	1.42	1.44	1.39	1.35	1.31	1.28	1.23	1.20	1.16	1.13
Boys 15-29 yrs																		
47	1.47	1.47	1.44	1.46	1.45	1.46	1.47	1.50	1.59	1.61	1.71	1.85	1.89	1.82	1.61	1.46	1.41	1.36
Girls 15-29 yrs																		
32	1.46	1.45	1.44	1.44	1.43	1.43	1.44	1.45	1.49	1.61	1.79	1.93	1.87	1.73	1.55	1.46	1.35	1.34
Males 30-50 yrs																		
30	1.21	1.21	1.21	1.21	1.21	1.22	1.23	1.25	1.31	1.32	1.42	1.42	1.43	1.42	1.30	1.21	1.17	1.13
Sensori-neural loss																		
22	1.30	1.30	1.30	1.32	1.33	1.37	1.43	1.56	1.60	1.55	1.59	1.63	1.68	1.50	1.41	1.38	1.29	1.27

Table 7 showing Range, Mean and Standard Deviation (SD) of Acoustic Impedance (Z_x) Static Complicance (C_s) and Middle Ear Pressure (MP), and Range and Mean of "difference" for the 6 groups

Group	Z_x Range in Acoustic Ohms	Z_x Mean Acoustic Ohms	Z_x SD	C_s Range in cc	C_s Mean in cc	C_s SD	MP Range in mm H_2O	MP Mean in mm H_2O	MP SD	Difference Range in cc	Difference Mean in cc
5-14 yrs. Boys	1056-4500	2457	1018	0.25-0.83	0.49	0.20	-90 to 20	-26.92	40.49	-0.02 to 0.28	0.12
5-14 yrs. Girls	1610-8707 in one case 10782	4813	3170	0.11-0.73	0.36	0.23	-200 to 10	-72.72	52.93	0.07 to 0.34	0.17
15-29 yrs. Males	685-5840	1848	1030	0.17-1.98	0.71	0.36	-60 to 60	7.02	23.13	-0.15 to 1.45	0.13
15-29 yrs. Females	712-4257 in one case 360 in another case 5100	2013	1048	0.21-2.79	0.75	0.50	-20 to 40	2.50	2.63	-0.17 to 0.22	0.12
30-50 yrs. Males	682-4610 in one case 523 in another case 5840	2786	1251	0.2-1.3	0.45	0.25	-20 to 40 in one case -80	12.00	25.60	0.05 to 0.18	0.08
Sensori-N-eural Hearing Loss	713-5718 in one case 353 in another case 6310	2558	1793	0.15-2.94	0.70	0.71	-80 to 40	8.18	27.76	-0.34 to 0.11	0.07

The maximum compliance occurs at -40 mm H_2O. The middle ear air pressure for this group ranges from -200 mm H_2O to +10 mm H_2O with a mean of -72.72 and SD of 52.93. The static compliance ranges from .25 cc to .83 cc with a mean of .49 cc and a SD of .20.

Fig. 12 indicates the mean tympanometry curve for males (47 ears) of normal hearing in the age group 15-29 years. The maximum compliance occurs at 20 mm H_2O. The middle ear pressure ranges from -6O to 60 mm H_2O with a mean pressure of 7.02 mm H_2O and a SD of 23.13.

The mean tympanometry curve for females (32 ears) with normal hearing in the age range 15-29 is shown in Fig.12. The maximum compliance occurs at 0 mm HgO. This group has a middle ear pressure range of -20 to 40 mm H_2O and has a mean and SD of 2.50 and 2.63 respectively.

The mean tympancaetry curve for males (30 ears) with normal hearing is represented in the Fig. 13.

For this group at +20 mm H_2O maximum compliance occurs. The variation in the middle ear pressure is from -20 to +40 mm H_2O . The mean pressure and SD are 12 mm $H1_2O$ and 25.6 respectively.

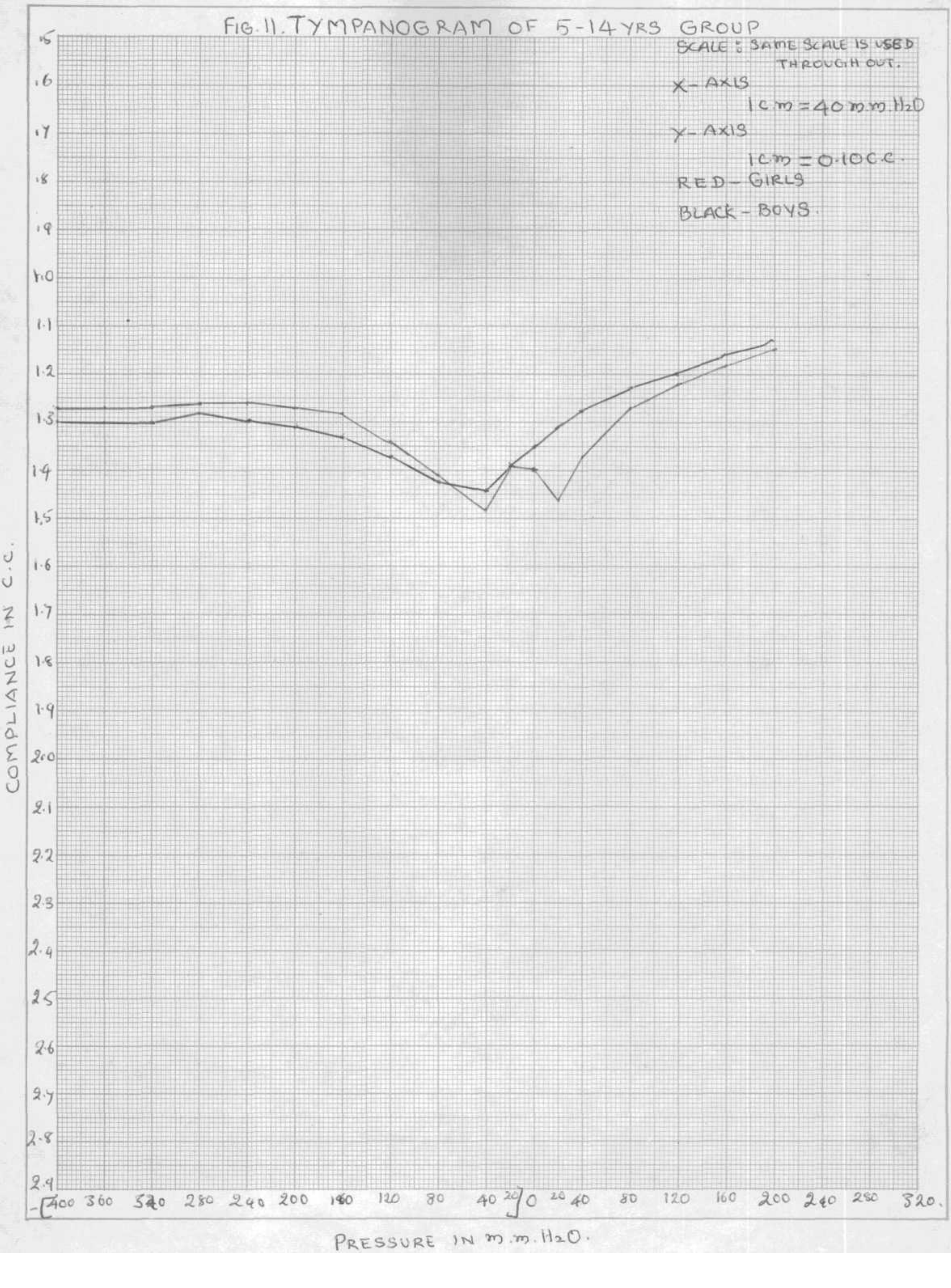


FIG. 11. TYMPANOGRAM OF 5-14 YRS GROUP
SCALE : SAME SCALE IS USED THROUGH OUT.
X-AXIS 1cm = 40 m.m. H2O
Y-AXIS 1cm = 0.10 C.C.
RED - GIRLS
BLACK - BOYS.
COMPLIANCE IN C.C.
PRESSURE IN m.m. H2O.
-400 360 320 280 240 200 160 120 80 40 20 0 20 40 80 120 160 200 240 280 320.
.5 .6 .7 .8 .9 1.0 1.1 1.2 1.3 1.4 1.5 1.6 1.7 1.8 1.9 2.0 2.1 2.2 2.3 2.4 2.5 2.6 2.7 2.8 2.9

FIG. 12. TYMPANOGRAM OF 15-29 YRS GROUP.

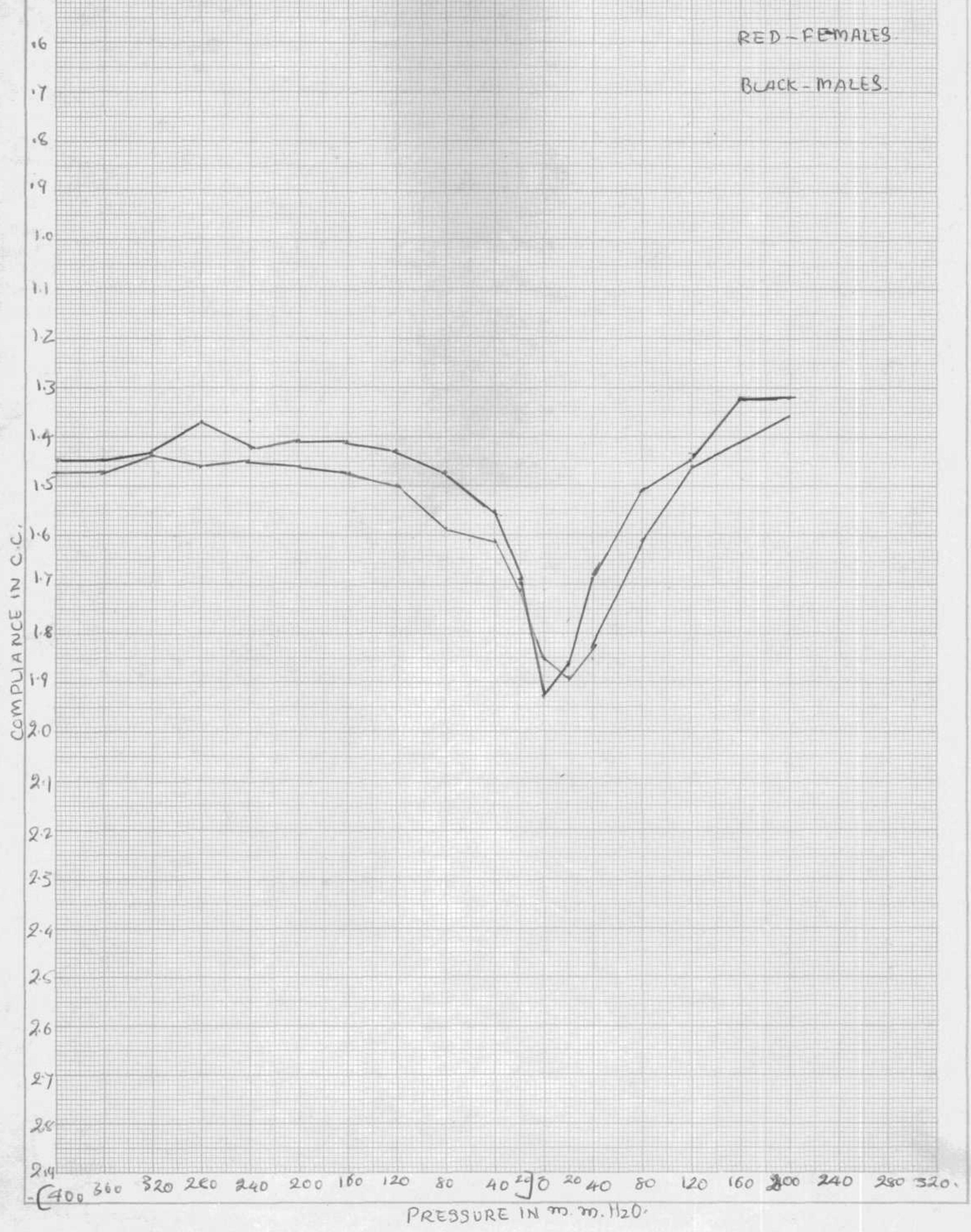


FIG. 13. TYMPANOGRAM OF 30-50YRS MALE GROUP.

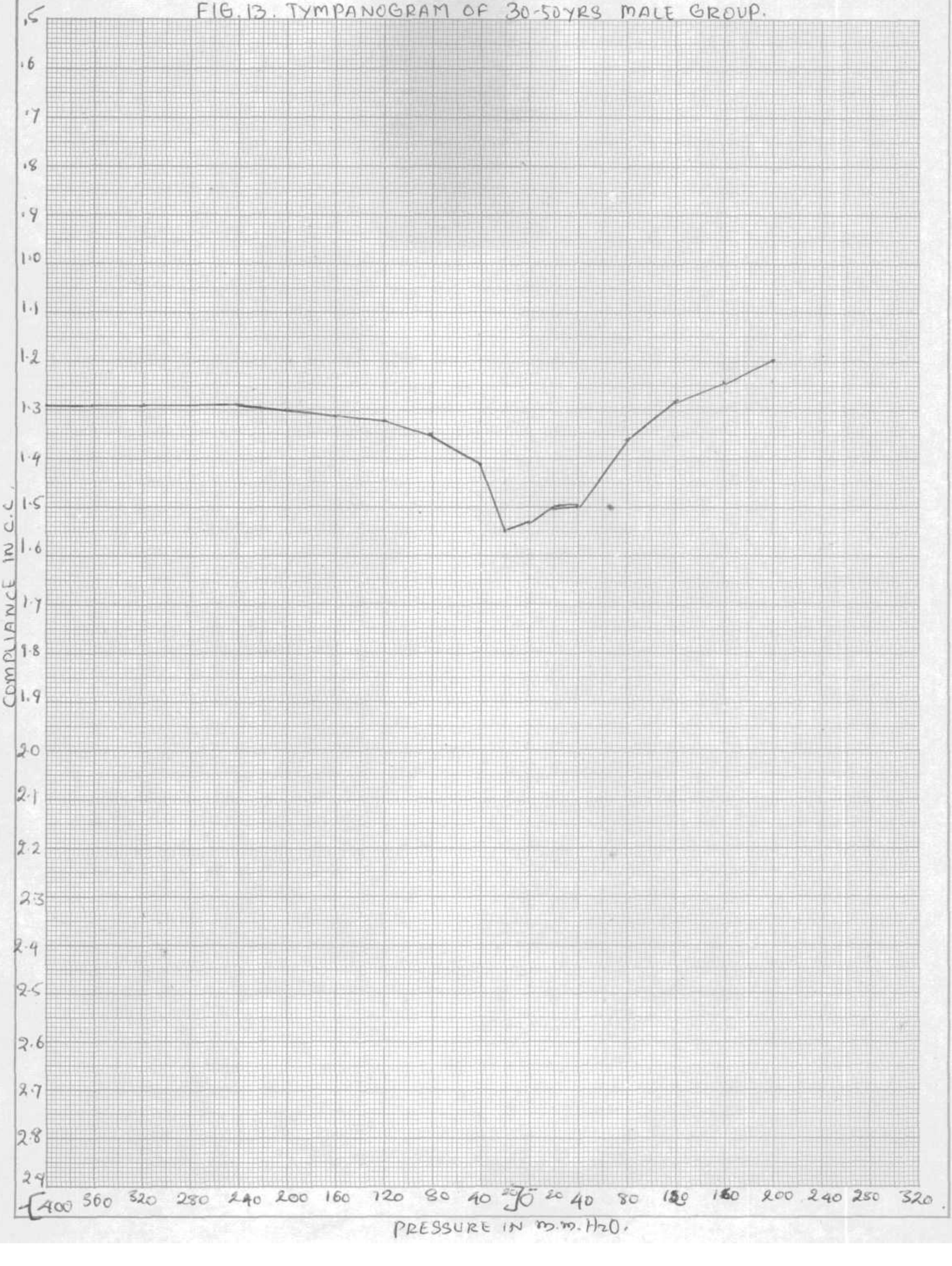
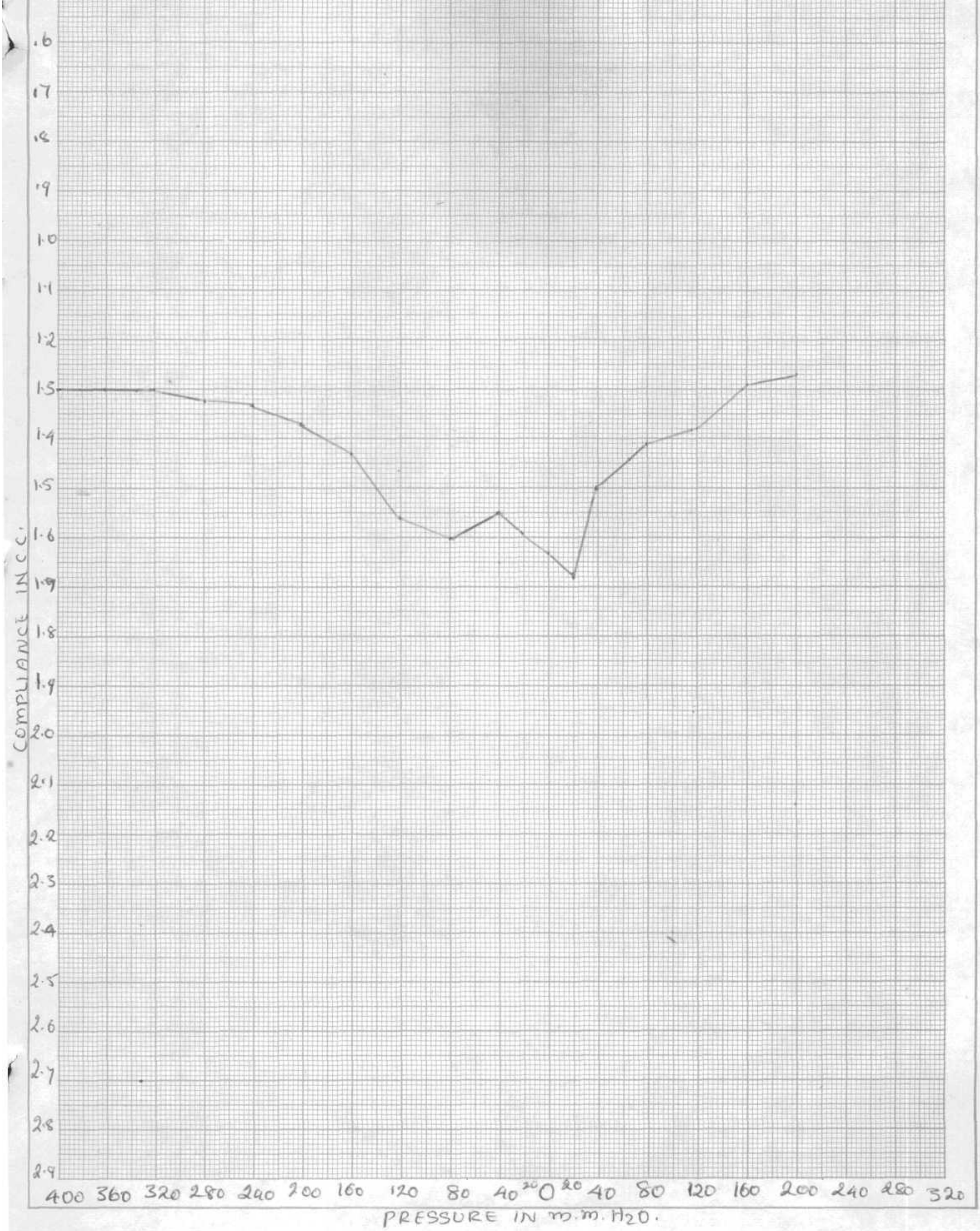


FIG. 14. TYMPANOGRAM OF S.N. LOSS GROUP.



Sensori-neural hearing loss group shows maximum compliance at +20 mm H_2O (Fig.14). The middle ear pressure variation is from -80 to 40 mm HgO. The mean and SD of middle ear pressure for this group are 8.18 mm HgO and 27.76 respectively.

All the above groups show A type tympanometry curve. This agrees with the published reports that the normal ears exhibit A type tympanometry curve.

Table 6 gives the mean complicance values at various pressures for all the mentioned 6 groups.

Table 8 reveals the frequency distribution of the ears exhibiting different static compliance values. Statistical significance of the difference between the means with regard to static compliance of the groups:

1) 5-14 years Boys and Girls
2) 15-29 years Males and Females
3) 15-29 years males with 30-50 years males

has been computed. Table 9 gives the results.

The results show the following:

1) There is no significant difference in compliance

Table 8

Number of ears and Percentage of ears exhibiting different Static Compliance Values

Compliance in cc	5-14 yrs Boys		5-14 yrs Girls		15-29 yrs Males		15-29 yrs Females		30-50 yrs. Males		Sensori Neural Loss	
	No. of ears	% of ears	No. of ears	% of ears	No. of ears	% of ears	No.of ears	% of ears	No. of ears	% of ears	No.of ears	% of ears
0.2	6	46.15	4	36.36	1	2.12	-	-	2	6.66	2	10
0.4	6	46.15	2	18.18	9	19.14	7	21.87	16	53.33	5	25
0.6	2	15.38	3	27.27	9	19.14	9	28.12	6	20.00	10	50
0.8	4	30.76	2	18.18	18	38.29	5	15.62	3	10.00	-	-
1.0	1	7.69	-	-	4	8.51	2	6.25	1	3.33	2	10
1.2	-	-	-	-	2	4.25	6	18.75	1	3.33	1	5
1.4	-	-	-	-	1	2.12	1	3.12	1	3.33	-	-
1.6	-	-	-	-	3	6.38	1	3.12	-	-	-	-
.												
.												
.												
.												
2.6	-	-	-	-	-	-	1	3.12	-	-	-	-

Table 9 showing statistical significance of the difference between the means with regard to compliance acoustic impedance and middle ear pressure

5-14 yrs. Boys and 5-14 yrs. Girls

Impedance

SD = 22.66.3

SED = SD N1+ N2
N1N2

= 2266.3 24 0.16
143

= 2266.3 x 0.4 = 906.52
t = D = 2356 = 2.59
SED 906.52

There is significance difference at 0.05 & 0.01 levels.

Compliance

SD = 0.26

SED = SD N1+N2

N1N2

= 0.26 0.16 = 0.10

$$t = \frac{0.13}{0.10} = 1.30$$

No significant different at both 0.05 and 0.01 levels.

Middle Ear Pressure

SD = 46.96

S_{ED} = 18.62

$$t = \frac{45.80}{18.62} = 2.45$$

There is significant difference at 0.05 level and not 0.01 level.

15-29 yrs. Males and 15-29 yrs. Females

Impedance

$D = 1^2 + 2^2$

N_1 N_2

= 22572.34 + 34322

= 56894.34

= 238.55

CR = D

D

238.55 = 0.69

No significant difference at 0.05 level.

Complication

D = 0.011

$$CR = \frac{0.04}{0.010} = 3.64$$

There is significant different at 0.05 and 0.01 levels.

Middle Ear Pressure

D = 34

$$CR = \frac{4.52}{34} = 0.12$$

No significant difference at 0.05 level.

15-30 yrs. Males and 30-50 yrs. Males

D = 2733

$$CR = \frac{938}{2733} = 0.34$$

There is no significant difference at 0.05 level.

Compliance

D = 0.069

$$CR = \frac{0.26}{0.069} = 3.77$$

There is significant difference at 0.05 and 0.01 levels.

Middle Ear Pressure

D = 5.76

$$CR = \frac{4.98}{5.76} = 0.86$$

No significant difference at 0.05 level.

at .05 and .01 levels for the 1st group indicating no sex difference in this age group. This agrees with Brooks (1971) study that "variability in compliance is at its absolute minimum in both sexes in the age range 4-11 years."

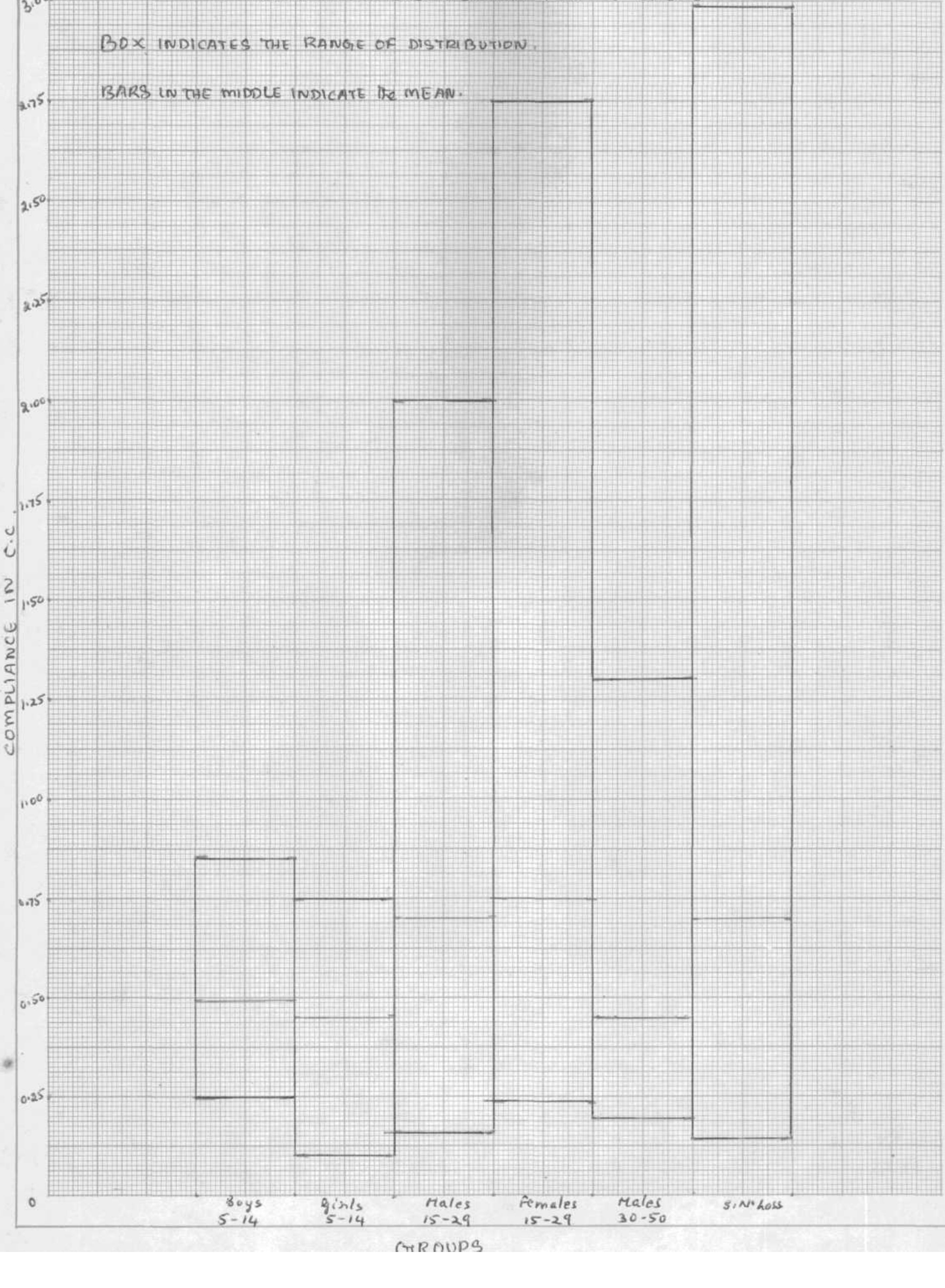
2) There is significant difference in compliance at .05 and .01 levels for 2nd group, indicating sex difference for compliance. This agrees with the studies of Zwislocki and Feldman (1969), Bicknell and Morgan (1968), and Jerger (1972).

From Table 8 it is evident that males show higher compliance than females. 38.29% of the ears of male group show a compliance of .8 cc, whereas 28.12% of the ears of female group show a compliance of .6 cc. This is in agreement with Bicknell and Morgan (1968) study.

3) There is significant difference in compliance at .01 and .05 levels for the 3rd group, indicating age difference with regard to compliance.

From Table 8 it is clear that older age group (30-50 years) shows less compliance than the younger age group (15-29 years). 53.33% of the ears of the older

FIG. 15. COMPLIANCE DISTRIBUTION FOR 6 CASES.



age group show a compliance of .4 cc and 38.27% of the ears of the younger age group show a compliance of .8 cc. This is an agreement with the study of Jerger et al (1972).

Further the mean values, for older age group .45 cc, for younger age group .71 cc, also indicate the decline in compliance as a function of age.

Fig. 15 illustrates the distributions of compliance for the 6 groups.

An interesting significant factor emerges from the Fig. 15, the average compliance and the variance in compliance are more with females than with males. This finding is in contrary to Jerger's (1972) report that ". . . .Women consistently show a lower average compliance and has variance than men at all ages".

Table 10 illustrates the frequency distribution of middle ear pressure values for the normal middle ears of the mentioned 6 groups.

Acoustic Impedance

Table 7 illustrates the impedance values of mentioned six groups.

TABLE 10

Frequency distribution of middle ear pressure values for normal middle ears of the 6 groups

Middle ear pressure in mm H_2O	5-14 yrs Boys		5-14 yrs Girls		15-29 yrs Males		15-29 yrs Females		30-50 yrs Males		Sensori Neural Loss	
	No.of ears	% of ears	No.of ears	% of ears	No.of ears	% of ears	No.of ears	% of ears	No. of ears	% of ears	No. of ears	% of ears
-100 and above	-	-	1	9.09	-	-	-	-	-	-	-	-
-100	1	7.69	2	18.18	-	-	-	-	-	-	-	-
- 80	2	15.38	2	18.18	-	-	-	-	1	3.33	2	9.09
- 60	2	15.38	3	27.27	2	4.25	-	-	-	-	-	-
- 40	1	7.69	2	18.18	1	2.12	-	-	-	-	-	-
- 20	3	23.07	-	-	6	12.76	6	18.75	3	10.00	2	9.09
0	3	23.07	-	-	15	31.91	16	50.00	7	23.33	6	27.27
20	-	-	1	9.09	16	34.04	9	28.12	10	33.33	5	22.72
40	-	-	-	-	6	12.76	1	3.12	9	30.00	7	31.81
60	-	-	-	-	1	2.12	-	-	-	-	-	-

FIG. 16. IMPEDANCE DISTRIBUTION FOR 6 GROUPS

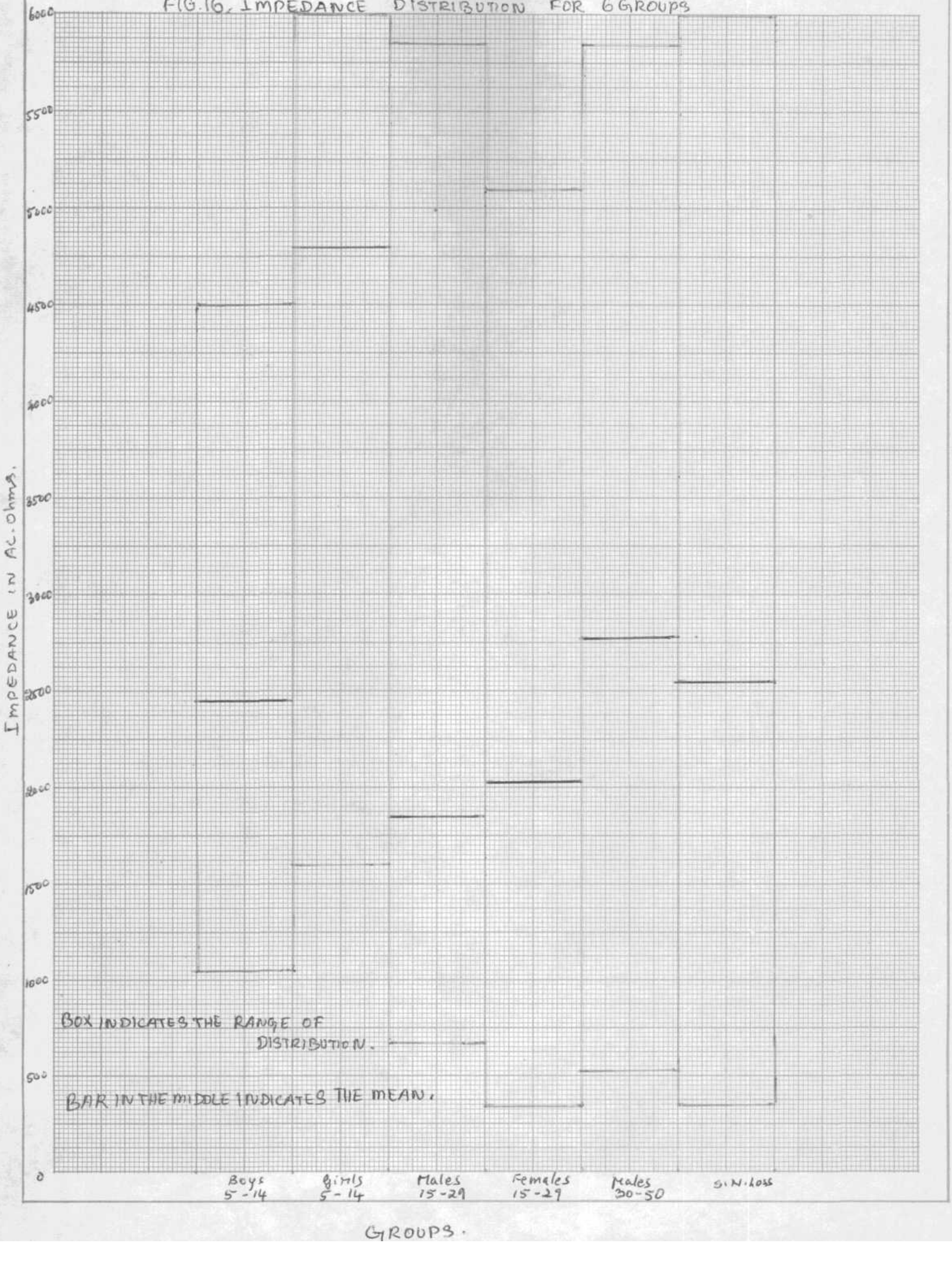


Fig. 16 represents the distributions of the acoustic impedance for the 6 groups. The verticle box encompasses the whole range of the impedance distribution. The solid horizontal bar in the box is the mean impedance value. From the Fig. 16 it is evident that the girls (5-14 years) group shows maximum mean impedance and wider variation than the other groups. This group shows a variation from 1610 to 10782 acoustic ohms. For the younger age groups (5-14 years Boys and Girls) high impedance scores are consistent with the 'B' type tympanograms. The occurrence of high impedance value consistent with 'B' type tympanogram is in agreement with the findings of Jerger (1970).

From Table 7 it can be inferred that the adults of normal middle ears will give impedance scores in the range from 632-5840 acoustic ohms.

This finding has greater range to that of Jerger's (1972) reported range of impedance scores for normal middle ears (800-4200 acoustic ohms).

Table 11 gives the frequency distribution of acoustic impedance for different groups.

TABLE 11

Frequency distributation of acoustic Impedance for the normal ears of 6 groups

Impedance in acoustic ohms	5-14 yrs Boys		5-14 yrs Girls		15-29 yrs Males		15-29 yrs Females		30-50 yrs Males		Sensori Neural Loss	
	No.of ears	% of ears	No.of ears	% of ears	No.of ears	% of ears	No.of ears	% of ears	No.of ears	% of ears	No.of ears	% of ears
500 and below	-	-	-	-	-	-	1	3.12	-	-	1	4.54
600	-	-	-	-	-	-	-	-	1	3.33	-	-
900	-	-	-	-	4	8.50	3	9.37	2	6.66	1	4.54
1200	2	15.38	-	-	9	19.14	4	12.50	3	9.99	2	9.09
1500	-	-	-	-	11	23.40	3	9.37	-	-	2	9.09
1800	3	23.07	2	18.18	5	10.63	4	12.50	2	2.66	2	9.09
2100	-	-	2	18.18	3	6.38	3	9.37	1	3.33	3	13.63
2400	2	15.38	-	-	3	6.38	4	12.50	2	6.66	4	18.18
2700	1	7.69	-	-	2	4.25	3	9.37	5	16.66	-	-
3000	1	7.69	-	-	5	10.63	3	9.37	2	6.66	-	-
3300	1	7.69	1	9.09	-	-	-	-	1	3.33	-	-
3600	2	15.38	-	-	2	4.25	-	-	3	9.99	-	-
3900	-	-	1	9.09	1	2.12	1	3.12	1	3.33	2	9.09
4200	-	-	-	-	-	-	1	3.12	1	3.33	1	4.54
4500	1	7.69	-	-	1	2.12	1	3.12	4	13.33	1	4.54
4800	-	-	-	-	-	-	-	-	1	3.33	1	4.54
5100 & above	-	-	5	45.45	1	2.12	1	3.12	1	3.33	2	9.09

Table 9 gives the results of statistical significance of the difference between the means of the groups with regard to acoustic impedance.

From the results, the following are apparent:

1) there is significant difference between girls and boys with regard to acoustic impedance indicating sex difference in early age groups (5-14 years). The former groups shows higher impedance than the latter.

2) there is no significant difference between males and females for the same age group (15-29 years).

3) there is significant difference between two male age groups viz., 15-29 years and 30-50 years indicating age difference with regard to acoustic impedance.

The older group shows higher impedance than the younger group. This is in agreement with the compliance results that it declines with age.

Acoustic Reflex Thresholds

The reflex threshold data: Mean, range, number of ears and percentage af ears responded far different frequencies of the 6 groups, 5-14 years boys, 8-14 years girls, 15-29 years males, 15-29 years females, 30-50 yeard males and Sensori-neural Hearing Loss, are given in the Tables 12A, 12B, 12C, 12D, 12E and 12F respectively.

Table 12A shows that 100% reflex response is observed for frequencies 1000 and 2000 Hz only. The mean range for acoustic reflex threshold for this group is 72.27 to 83.08 dB sensation levels

Table 12B also shows that 100% reflex response is observed at 1000 and 2000 Hz only. The mean range of acoustic reflex threshold for this group is 75 to 92.73 dB sensation level.

Table 12C indicate that 100% reflex is observed at 3 frequencies: 500, 1000 and 2000 Hz. This group has mean acoustic reflex threshold range of 86.07 dB sensation level.

100% reflex is observed for 5 frequencies 250-4000 Hz with female group (15-29 years) - Table 12D. The mean acoustic reflex threshold range is 69.57 to 85.37 dB sensation level.

Males (30-50 years) group shows 100% reflex response for frequencies 500, 1000 and 2000 Hz. Their mean acoustic reflex threshold ranges from 64.25 to 76.26 dB sensation level. (12E).

Table 12F shows that 100% reflex is not present in any frequency. This is quite reasonable as the results belong to sensori-neural loss group. The mean acoustic reflex threshold ranges from 12.5 dB sensation level to 44.58 dB sensation level. The upper mean limit of this range is well below the lower limit for the normal groups.

Table 13 gives the detailed acoustic reflex threshold data obtained for this sensori-neural hearing loss group.

The above findings suggest the importance of variables such age and sex while considering the acoustic impedance measures.

Table 12A-F: Showing Mean, and Range of Acoustic Reflex Threshold. and Number of ears and percentage of ears responded

Table 12A 5-14 yrs. Boys No. of ears - 13

	Frequency in Hz						
-	250	800	1000	2000	4000	6000	8000
No. of ears responded	11	11	13	13	7	5	1
% of ears responded	84.61	84.61	100	100	53.84	38.46	7.69
Mean in dB	72-27	78.08	83.08	81.93	81.43	79	80
Range in dB	65-90	65-95	70-95	70-90	75-90	65-85	

Table 12B 6-14 yrs. Girls No. of ears - 11

	Frequency in Hz						
	250	500	1000	2000	4000	6000	8000
No. of ears res-ponded	5	10	11	11	5	1	0
% of ears responded	45.48	90.90	100	100	45.45	9.09	0
Mean indB	75	84.50	89.10	92.73	92.00	80	0
Range in dB	70-80	75-95	75-95	80-110	85-105		

Table 12C 15-30 yrs. Males No. of ears - 47

	Frequency in Hz 250	500	1000	2000	4000	6000	8000
No. of ears responded	44	47	47	47	44		
% of ears responded	93.61	100	100	100	93.61	53.17	29.78
Mean in dB	77.05	77.97	86.20	79.25	83.30	36.07	80.36
Range in dB	60-90	65-95	70-100	60-100	70-100	65-90	65-90

Table 12D 15-30 yrs. Females No. of ears - 32

	Frequency in Hz 250	600	1000	2000	4000	6000	8000
No. of ears responded	33	38	32	32	32	17	12
% of ears responded	100	100	100	100	100	53.12	37.50
Mean in dB	69.57	80.00	85.37	78.91	82.81	79.11	80.41
Range in dB	65-90	60-95	75-110	65-100	70-95	70-90	75-85

Table 12E 30-50)yrs. Males No. of ears-30

	Frequency in Hz						
		500	1000	2000	4000	6000	8000
No. of ears responded	27	30	30	22	16	13	13
% of ears responded	90	100	100	100	53.33	43.33	43.33
Mean in dB	64.25	69.80	68.44	67.17	74.55	76.26	70.05
Range in	46-75	50-85	60-85	60-85	66-85	60-80	60-80

Table 12F Sensori-neural loss No. of ears - 22

	Frequency in Hz						
	880	500	1000	2000	4000	6000	8000
No. of ears responded	11	12	12	11	6	2	3
%of ears responded	50	54.54	54.54	50	27.27	9.09	13.63
Mean in dB	36.37	39.59	44.58	39.54	31.36	12.50	25
Range in dB	20-75	25-65	25-85	5-65	20-50	0-25	5-45

No.	Age	RT	)PT	D	RT	PT	D	RT	PT	D	RT	PT	D	RT	PT	D	RT	PT	D	RT	PT	D
1	12	85	10	75	90	30	60	95	30	65	90	25	65	NR								
2	14	—	NR	-	NR	105	—	NR	95	—	NR	85	_	NR	85	—	NR	75 —		NR	80	—
3	18	80	60	20	85	60	25	90	65	25	85	65	80	90	70	20	80	80	0	85	80	5
4	18	NR	90	—	NR	95	—	NR	85	—	NR	90	—	NR	95	NR	NR	105	—	NR	NR	—
5	18	90	65	25	100	60	40	110	65	45	—	75	—	—	70		—	75	—	—	70	-
6	20	NR	80	--	NR	90	—	NR	95	—	NR	110	—	NR	110	—	NR	110	—	NR	---	
7	29	110	35	75	110	45	65	110	45	65	110	45	65	NR	40	—	NR	70	—	NR	80	—
8	32	75	40	35	75	50	25	95	60	35	105	80	25	NR	105		NR	105	—	NR	NR	—
9	35	65	40	25	70	35	35	90	45	45	80	60	30	85	55	90	NR	75	—	NR	60	—
10	38	NR	25	—	100	20	80	110	25	85	100	25	75	NR	30	—	NR	40	—	NR	40	—
11	41	NR	60	—	NR	80	—	NR	85	—	NR	90	-—	NR	105	—	NR	_	-	NR	_	—
12	45	90	70	20	95	60	35	80	55	25	75	70	5	100	75	25	NR	90	--	NR	90	—
13	33	NR	40	—	NR	35	NR	NR	40	—	NR	45	--	NR	75	--	NR			NR	—	—---.

Table 13 - contd.

No.	Age	RT	PT	D	RT	PT	D	HT	PT	D	RT	PT	D	RT	PT	D	RT	PT	D	RT	PT	D
14	56	85	45	40	90	65	25	95	60	35	90	70	20	90	65	25	85	60	25	70	35	35
15		NR			NR	—		NR			NR			NR	-	-	NR			MR		
16		NR			NR	—		NR			NR			NR	-	-	NR			NR		
17		70	45	25	75	SO	25	100	60	40	110	60	50	NR	110	-	NR	105		NR	NR	
18		35	60	20	90	55	33	96	55	40	35	45	40	95	45	50	NR	70		90	55	45
19		NR	90		NR	100		NR	95		NR	90		NR	100	-	NR	NR		NR	NR	
20		NR	65		NR	75		NR	80		NR	90		NR	95	-	NR	NR		NR	NR	
20		90	55	35	35	60	28	90	60	30	90	50	40	90	50	40	NR	65		NR	55	
21		NR	50		NR	60		NR	70		NR	70		NR	70	-	NR	80		NR	80	

RT = Reflex Threshold
PT = Pure Tone Threshold
NR = No Response
D = Difference between PT and RT

Impedance Measurements in Pathological Groups

Suspected Otosclerosis:- Otosclerosis was suspected on the basis of family history, ENT findings, audiogram and other investigations (Appendix 2). Table 14A gives the results of compliance at various pressure values for 18 ears (9 cases).

The results show A type pressure compliance relation (A type curve) except for 2 ears which show B type (No.3 and 4 in Table 14A). The maximum compliance at middle ear pressures appears to be less than that of the normals. An average static compliance for this group is .34 cc (Table 14B) where as the normal group around same age range has an average of more than 0.7 cc.

Table 14B shows the acoustic impedance findings for the group (9 cases, 16 ears). It ranges from 1174 to 7652 acoustic ohms and has a mean value of 4060 acoustic ohns which is well above the normal mean value for the same age group (Mean for males = 1848 acoustic ohms and Mean for females = 2013).

Acoustic reflex was absent in all these cases.

Table 14A

Pressure Compliance Values for Suspected Otosclerosia Ears

No.	-400	-360	-320	-280	-240	-200	-180	-120	-80	-40	-20	0	20	40	80	120	160	200
1	1.38	1.37	1.36	1.34	1.33	1.32	1.31	1.30	1.30	1.32	1.34	1.41	1.52	1.49	1.36	1.30	1.27	1.24
2	1.32	1.32	1.30	1.28	1.27	1.26	1.26	1.25	1.26	1.27	1.28	1.33	1.44	1.40	1.29	1.24	1.22	1.19
3	1.82	1.80	1.78	1.77	1.75	1.75	1.73	1.73	1.73	1.73	1.74	1.74	1.74	1.73	1.69	1.65	1.61	1.59
4	2.30	2.28	2.22	2.22	2.20	2.19	2.19	2.20	2.20	2.20	2.20	2.20	2.20	2.20	2.12	2.05	2.00	1.95
5	1.78	1.76	1.79	1.82	1.86	1.90	1.94	1.96	1.98	1.98	1.97	1.94	1.94	1.83	1.82	1.79	1.78	1.80
6	1.75	1.75	1.75	1.75	1.77	1.78	1.79	1.79	1.80	1.74	1.73	1.72	1.69	1.67	1.65	1.63	1.61	1.58
7	2.37	2.40	2.40	2.40	2.40	2.30	2.22	2.18	2.19	2.12	2.20	2.30	2.10	2.18	2.05	1.93	1.87	1.83
8	1.32	1.31	1.31	1.31	1.32	1.32	1.33	1.33	1.33	1.34	1.36	1.39	1.43	1.43	1.37	1.32	1.28	1.25
9	1.38	1.42	1.44	1.46	1.47	1.48	1.50	1.50	1.50	1.52	1.55	1.58	1.57	1.54	1.47	1.44	1.41	1.38
10	1.44	1.42	1.40	1.40	1.40	1.40	1.40	1.40	1.41	1.42	1.44	1.43	l.60	1.50	1.46	1.44	1.41	1.37
11	1.41	1.39	1.38	1.37	1.37	1.37	1.36	1.37	1.37	1.38	1.41	1.45	1.51	1.70	1.48	1.37	1.33	1.32
12	1.80	1.79	1.79	1.80	1.80	1.83	1.80	1.90	2.08	2.35	2.15	2.00	1.88	1.83	1.72	1.87	1.83	1.71
13	1.70	1.71	1.73	1.70	1.73	1.73	1.75	1.79	1.92	2.18	2.50	2.65	2.33	2.12	1.85	1.75	1.70	1.63

Table 14B

Impedance, Static compliance, Middle ear pressure, Difference and Reflex values for suspected Otosclerotic Ears

SI. No.	Case No.	Z_1	Z_2	Z_x	C_1	C_2	C_s	MP	DMT.	Reflex
1	2838	860	720	4422	1.52	1.34	0.28	20	0.14	Absent
2		825	660	3300	1.44	1.19	0.25	20	0.13	"
3	2935	800	720	7200	1.74	1.59	0.15	0	0.23	"
4		640	690	7552	2.20	1.95	0.25	0	0.35	"
5	8055	530	470	4151	1.98	1.80	0.18	-40	-0.02	"
6		640	530	3083						
7	6738	650	580	5385	1.80	1.58	0.22	80	0.17	"
8	6523	550	475	3483	2.30	1.83	0.47	0	0.50	"
9	2414	820	700	4783	1.43	1.25	0.18	20	0.07	"
10		850	740	5718	1.58	1.38	0.20	20	0	"
11	2876	750	690	6625	1.50	1.37	0.13	-20	0.03	"
12		790	620	2881	1.70	1.32	0.38	-40	0.08	"
13	6839	630	430	1354	2.35	1.79	0.56	40	0.01	"
14		630	410	1174	2.65	1.63	1.02	0	0.07	"
15	7100	825	600	2200	1.70	1.25	0.35			"
16		1080	650	1032	1.55	0.96	0.59			"

Conductive Loss

25 conductive loss ears (15 cases) have been tested. The data are given in Tables 15A and 15B.

Pressure compliance relation is represented in Table 15A. 4 ears (4, 8, 8 and 9 in Table ISA) show Btype pressure compliance. The remaining ears show A type pressure compliance relation.

A point of interest with regard to A type preaaure compliance relation is that A type in normals is characterized by slight decrease in the beginning and gradual increase in compliance up to a maximum around atmospheric pressure and gradual decrease as the pressure is varied from -400 mm H_2O to +200 mm H_2O, whereas the , conductive and Mixed loss ears show a slightly different 'A' type characterized by a greater amount of decrease in compliance extending for greater pressure range, gradually increasing around atmospheric pressure and gradual decrease as the pressure is varied from -400 to +200 mm Hg

It is apparent from Table 15B that there is a wide variation in impedance for this group. As this may be due to heterogenous group.

Table 15A

Pressure Compliance Values for Conductive Loss Group

No.	-400	-360	-320	-280	-240	-200	-160	-120	-a0	-40	-20	0	20	40	80	120	160	200
1	1.77	1.77	1.74	1.72	1.71	1.68	1.70	1.72	1.75	1.88	2.10	2.22	1.98	1.88	1.77	1.63	1.64	1.59
2	1.99	1.97	1.97	1.96	1.95	1.95	1.95	1.97	2.00	2.12	2.18	2.12	2.04	1.98	1.90	1.84	1.8)	1.77
3	1.96	1.95	1.93	1.93	1.92	1.92	1.91	1.91	1.91	1.93	1.96	2.02	2.06	2.01	1.91	1.83	1.77	1.74
4	1.12	1.11	1.10	1.09	1.07	1.06	1.05	1.03	1.03	1.01	1.01	1.00	1.00	0.99	0.97	0.96	0.94	0.94
5	1.03	1.01	1.01	1.01	0.99	0.98	0.98	0.97	0.96	0.95	0.94	0.92	0.92	0.91	0.90	0.83	0.87	0.86
6	1.55	1.53	1.53	1.51	1.50	1.49	1.48	1.48	1.46	1.48	1.49	1.55	1.75	1.72	1.53	1.44	1.38	1.36
7	1.42	1.41	1.40	1.39	1.38	1.38	1.37	1.37	1.38	1.39	1.44	1.63	1.65	1.51	1.43	1.37	1.33	1.32
8	1.36	1.34	1.33	1.33	1.32	1.32	1.32	1.31	1.30	1.32	1.34	1.34	1.36	1.29	1.27	1.25	1.23	1.21
9	1.44	1.42	1.41	1.41	1.41	1.39	1.39	1.38	1.38	1.39	1.40	1.43	1.43	1.39	1.37	1.34	1.32	1.31
10	1.81	1.80	1.79	1.79	1.79	1.81	1.83	1.87	1.93	1.93	2.00	2.02	2.04	1.99	1.86	1.76	1.67	1.65
11	2.00	2.00	2.00	2.00	2.02	2.06	2.07	2.12	2.16	2.22	2.27	2.35	2.50	2.68	2.10	2.00	1.95	1.91
12	2.02	2.02	2.02	2.05	2.10	2.10	2.14	2.16	2.19	2.32	2.44	2.80	2.65	2.55	2.18	2.10	2.03	1.95
13	1.92	1.92	2.10	2.10	2.11	2.11	2.13	2.20	2.23	2.40	3.20	5.00	3.80	2.70	2.25	2.67	1.95	1.85
14	1.62	1.62	1.62	1.62	1.63	1.65	1.66	1.70	1.80	1.95	2.10	3.10	2.45	2.30	2.04	1.35	1.70	1.65
15	1.92	1.94	2.00	2.00	2.00	1.86	1.85	1.80	1.76	1.72	1.70	1.69	1.67	1.66	1.64	1.62	1.60	1.58
16	2.25	2.25	2.25	2.22	2.18	2.18	2.18	2.18	2.22	2.40	3.00	3.80	3.20	2.62	2.25	2.19	2.00	1.95

Sl. No.	Z_1	Z_2	Z_x	C_1	C_2	Cs	MP	Diff.	Reflex
1	650	490	1990	2.22	1.59	0.63	0	0.18	Absent
2	580	480	2784	2.18	1.77	0.41	-20	0.22	
3	590	520	4382	2.06	1.74	0.32	20	0.22	
4	B type compliance relation - very high impedance								
5			-do-					-do-	
6	770	560	2053	1.75	1.36	0.39	20	0.19	Absent
7	780	630	3276	1.65	1.32	0.33	20	0.10	
8	850	760	7177	1.34	1.21	0.13	0	0.15	"
9	790	710	7011	1.43	1.31	0.12	0	0.13	"
10	630	520	2978	2.04	1.65	0.39	20	0.16	".
11	530	320	807	2.68	1.91	0.77	40	0.09	Present
12	525	275	577	2.80	1.95	0.95	0	0.07	
13	530	200	321	5.00	1.85	3.15	0	0.07	Absent
14	600	330	733	3.10	1.65	1.55	0	-0.03	
15	670	600	5742	B type T curve					
16	535	250	469	3.80	1.95	1.45	0	0.30	Absent
17	550	200	314	5.00	1.36	3.14	0		
18	600	300	600	3.41	1.71	1.70	0		
19	825	500	1269	2.03	1.23	0.80			
20	820	620	2542	1.65	1.25	0.40			
21	580	510	4225	2.00	1.76	0.25			
22	375	275	1031	3.80	2.67	1.13			
23	350	275	1283	3.80	2.90	0.90			

This groupshows no reflex - is usually expected.

Mixed Loss

Table 16A gives the results of compliance at different pressures for 18 ears (11 cases). Out of 16 ears, 12 ears show A type pressure compliance relation (Maximum compliance around atmospheric pressure). 3 ears Serial Nos. 4, 5 and 10 in Table 16A) snow B type pressure compliance relation(almost same compliance at all pressure values or gradual slight decrease in Compliance from negative pressure to positive pressure) and one ear (Sl.No.11) shows C type pressure compliance relation (maximum compliance at negative pressure).

Data of acoustic impedance and other results are shown in Table 16B. The average impedance of this group is 4669 acoustic ohms and the average compliance is + 3 CC.

In all the ears the acoustic reflex was absent.

Fig. 17 shows the distribution of acoustic impedance for normals, otosclerosis, Mixed loss and Sensori-neural loss groups.

Table 16A

Pressure Compliance Values for Mixed Group

No.	-400	-360	-320	-280	-240	-200	-160	-120	-80	-40	-20	0	20	40	a0	120	160	200
1	1.78	1.76	1.74	1.75	1.75	1.76	1.77	1.80	1.87	1.97	2.18	2.04	1.95	1.86	1.75	1.69	1.64	1.61
2	1.70	1.69	1.69	1.70	1.70	1.72	1.74	1.78	1.83	1.96	2.16	2.23	2.00	1.86	1.72	1.63	1.58	1.53
3	1.52	1.49	1.48	1.47	1.47	1.45	1.44	1.43	1.43	1.46	1.50	1.58	1.53	1.47	1.41	1.37	1.35	1.33
4	1.63	1.61	1.59	1.58	1.56	1.55	1.54	1.53	1.53	1.53	1.53	1.53	1.56	1.54	1.48	1.45	1.42	1.39
5	1.83	1.81	1.80	1.78	1.77	1.76	1.76	1.76	1.75	1.76	1.76	1.77	1.76	1.78	1.78	1.74	1.70	1.65
6	2.16	2.16	2.16	2.14	2.12	2.13	2.13	2.15	2.17	2.19	2.21	2.25	2.28	2.31	2.44	2.36	2.30	2.23
7	1.21	1.22	1.24	1.24	1.25	1.27	1.28	1.29	1.30	1.31	1.30	1.30	1.30	1.28	1.27	1.26	1.23	1.22
8	1.69	1.69	1.66	1.65	1.64	1.62	1.61	1.60	1.59	1.59	1.59	1.63	1.71	1.93	1.85	1.60	1.55	1.52
9	1.37	1.35	1.34	1.33	1.32	1.31	1.31	1.31	1.31	1.33	1.36	1.42	1.64	1.50	1.36	1.33	1.30	1.29
10	1.67	1.63	1.60	1.62	1.62	1.62	1.62	1.62	l.$2	1.62	1.62	1.63	1.62	1.62	1.62	1.59	1.58	1.56
11	1.62	1.61	1.62	1.63	1.67	1.70	1.74	1.83	1.72	1.67	1.63	1.62	1.60	1.60	1.57	1.55	1.55	1.55
12	1.98	1.98	1.98	1.93	1.98	1.97	1.96	1.96	1.95	1.97	1.97	2.02	2.10	2.02	2.97	1.92	1.88	1.85
13	1.40	1.37	1.36	1.36	1.34	1.33	1.33	1.32	1.32	1.35	1.35	1.37	1.42	1.56	1.46	1.39	1.35	1.31
14	1.24	1.22	1.22	1.21	1.20	1.20	1.19	1.19	1.19	1.21	1.24	1.28	1.36	1.29	1.22	1.18	1.17	1.15
15	1.27	1.25	1.24	1.23	1.23	1.22	1.21'	1.21	1.21	1.21	1.22	1.24	1.28	1.32	1.26	1.22	1.18	1.16
16	1.84	1.83	1.81	1.81	1.81	1.81	1.80	1.80	1.81	1.84	1.70	2.10	2.15	1.95	1.83	1.76	1.70	1.67
17	1.99	2.02	2.18	2.45	2.58	2.32	2.15	2.03	1.96	1.90	1.87	1.84	1.82	1.80	1.76	1.73	1.70	1.66
18	2.00	2.00	2.00	2.00	2.00	2.00	2.01	2.04	2.10	2.17	2.22	2.25	2.30	2.32	2.26	2.10	2.00	1.98

Table 16B

Impedance, Static compliance. Middle ear pressure and Difference values for Mixed Loss Group

Sl. No.	Z_l	Z_2	Z_X	C_l	C_2	C_S	MP	Diff.	Reflex
1	640	500	2285	2.18	1.61	0.69	20	0.17	Absent
3	670	470	1574	2.23	1.53	0.70	0	0.17	"
4	670	475	2146	2.15	1.67	0.48	20	0.17	"
4	775	650	4030	1.58	1.33	0.25	0	0.19	"
5	725	670	8831	1.56	1.39	0.17	20	0.25	"
	620	565	5389	1.78	1.65	0.13	40	0.18	"
7	460	420	4830	2.44	2.23	0.21	80	-0.07	"
8	840	750	7000	1.31	1.22	0.09	40	-0.01	"
9	675	495	1856	1.93	1.52	0.41	40	+0.17	"
10	790	670	4410	1.64	1.29	0.35	20	0.08	"
11	630	590	9292	B type T curve					
12	650	550	3575	1.83	1.55	0.28	-120	0.07	C type curve
13	550	490	4491	2.10	1.85	0.25	20	0.13	Absent
14	780	640	3565	1.56	1.31	0.25	40	0.09	"
15	890	750	4767	1.36	1.15	0.21	20	0.09	"
16	880	780	6864	1.23	1.16	0.16	40	0.09	"

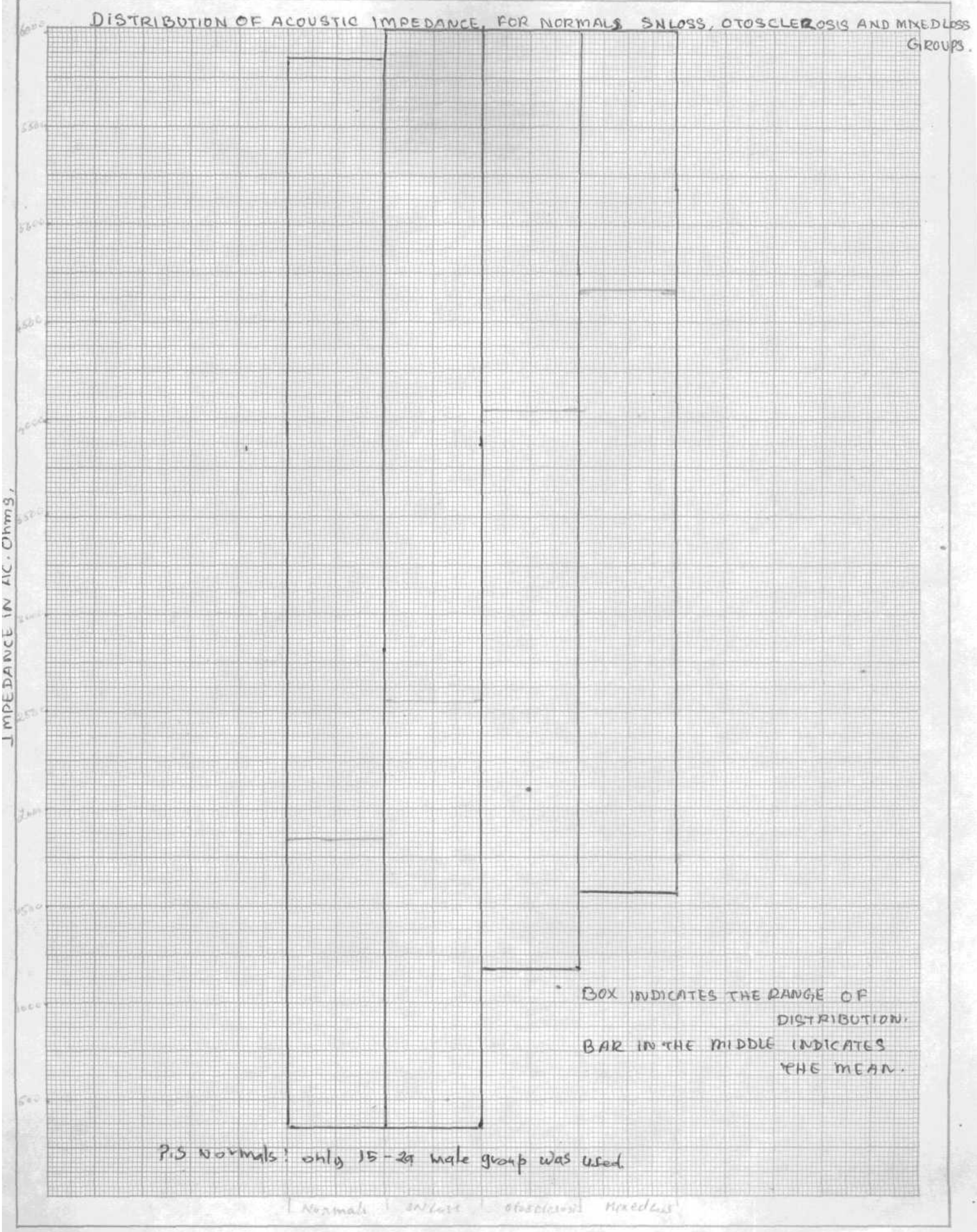
Total Impedance = 74704

Average = 4669

Total Compliance = 4.53

Average = 0.30

FIG 17.



Groups

Case Reports

Case (7096) - Mr. C, aged 23 years, having cleft palate was tested. The Impedance measures were suggestive of middle ear fluid. This was later confirmed by x-ray investigation.

Z_2 was measured at various pressures as middle ear pressure could not be exactly measured.

$Z_1 = 700$

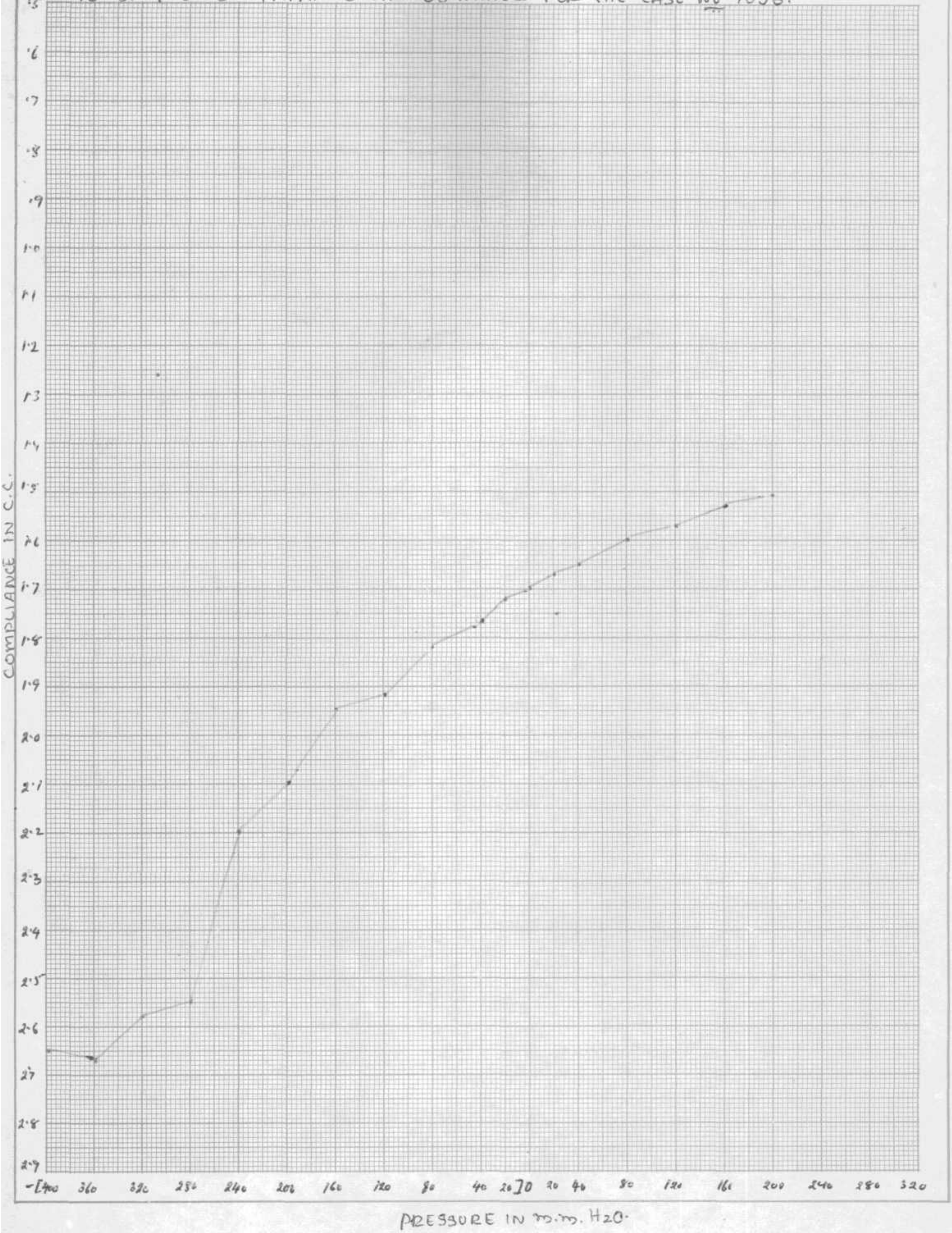
Z_2 at	100 mm	H_2O	=	670
	0	"	"	=	640
	-100	"	"	=	610
	-200	"	"	=	590
	-300	"	"	=	570
	-400	"	"	=	520

Fig. 18 represents B type tympanogram of the case.

No acoustic reflex was present at all frequencies.

On ENT examination, Mr. S (8010), aged 22 years, showed the following for the right ear:

FIG.18. TYPE B TYMPANOGRAM OBTAINED FOR THE CASE NO 7096.



Appearance of the tympanic membrane

There is not much bulging of the drum

Slightly congested

Shiny - reddish

Light reflex absent

Lateral process of malleus prominent

Fluid level not seen

Case history revealed:

Frequent attacks of cold

Fullness in the ear

Tinnitus

Loss of hearing

Pain not much marked

No discharge

Audiogram was found to be unilateral (right) conductive lOSS.

Pressure compliance relation showed B type. Acoustic impedance determined using three values of Z_2:

$Z_1 = 1150$

Z_2 at 0 = 1075 Z_X

-100 = 1040

-200 = 1010

Reflex was absent at all frequencies for this ear.

The results were suggestive of serous otitis media. This was confirmed by myringotomy.

A girl (8029), aged 11 years, was tested. ENT examination revealed adenoid growth. Hearing was within normal limits. Impedance measurements shoved the following for right ear.

C type tympanogram - Fig. 19

Acoustic impedance - 11650 acoustic ohms

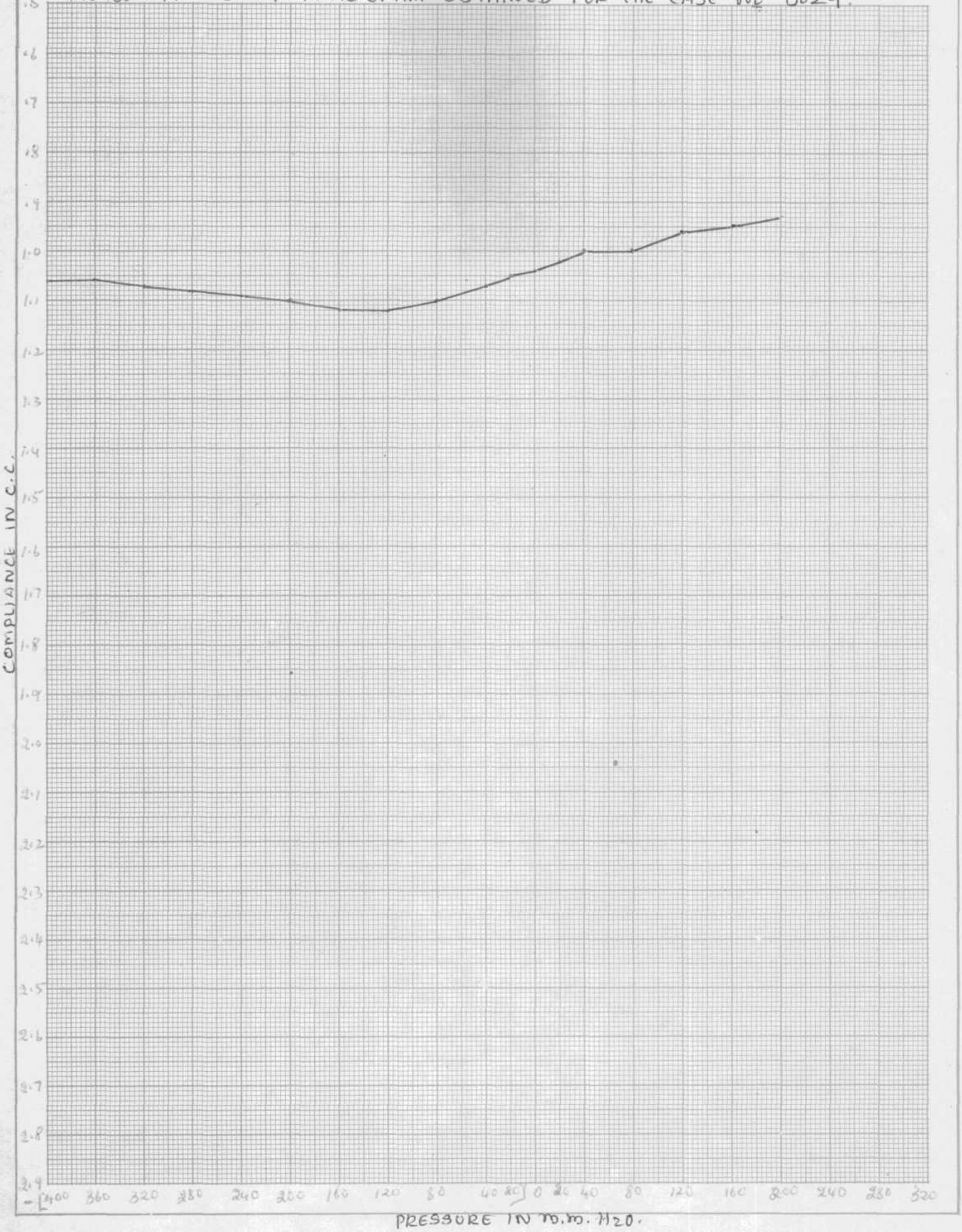
Acoustic reflex was present at 4 frequencies:

	Left		Right	
	PT	RT	FT	RT
280	20	85	20	90
800	15	90	20	98
1 K	15	95	20	95
2 K	5	90	15	90

Functional Hearing Loss

A 35 year old female (Case No.7054) reported at the Institute with a complaint of sudden hearing loss

FIG.19. TYPE C TYMPANOGRAM OBTAINED FOR THE CASE NO 8029.



bilaterally (since 4 daya), after an attack of flu and severe headache. ENT findings revealed nothing abnormal except for her hearing loss.

Psychological evaluation reveals IQ of 124 (Performance tests). During the interview with the patient it was observed that the patient was preoccupied, as if she was depressed - the case is a second wife. She has step children and she has no issues.

Speech evaluation shoved no apparent defects:

N-eurological examination report is as follows:

1) Tfo focal neurological deficit to account for sudden loss of hearing

2) C.V.S. - N.A.D.

3) suspects - functional hearing los%r

Radiological evaluation -

Pure tone audiometry showed no responses for all the frequencies in the left ear, and responses at maximum levels were observed in the right ear (280 - 90 dB

500 - 110
1000 - 110
2000 - 110
4000 - 110)

Lambard test was administered and the reflex (slight raise in her voice) occurred when the noise level was aboat 100 dB.

Impedance audiometry: acoustic reflex was observed in the right (tone to left ear). The reflex thresholds are:

Right ear -	250 Hz	-	90 dB
	500 Hz	-	85 "
	1 K	-	80 "
	2 K	-	85 "
	4 K	-	90 "

On the basis of audiological evaluation the case was diagnosed as bilateral functional hearing loss.

Speech audiometry could not be done as she failed to repeat the words even at maximum levels of the audiometer. (110 dB).

In this case acoustic thresholds are well below the admitted pure tone thresholds at different frequencies in the right ear. Left ear was not tested for acoustic reflex because of air tight problem.

Abnormal Impedance Measures in Normals

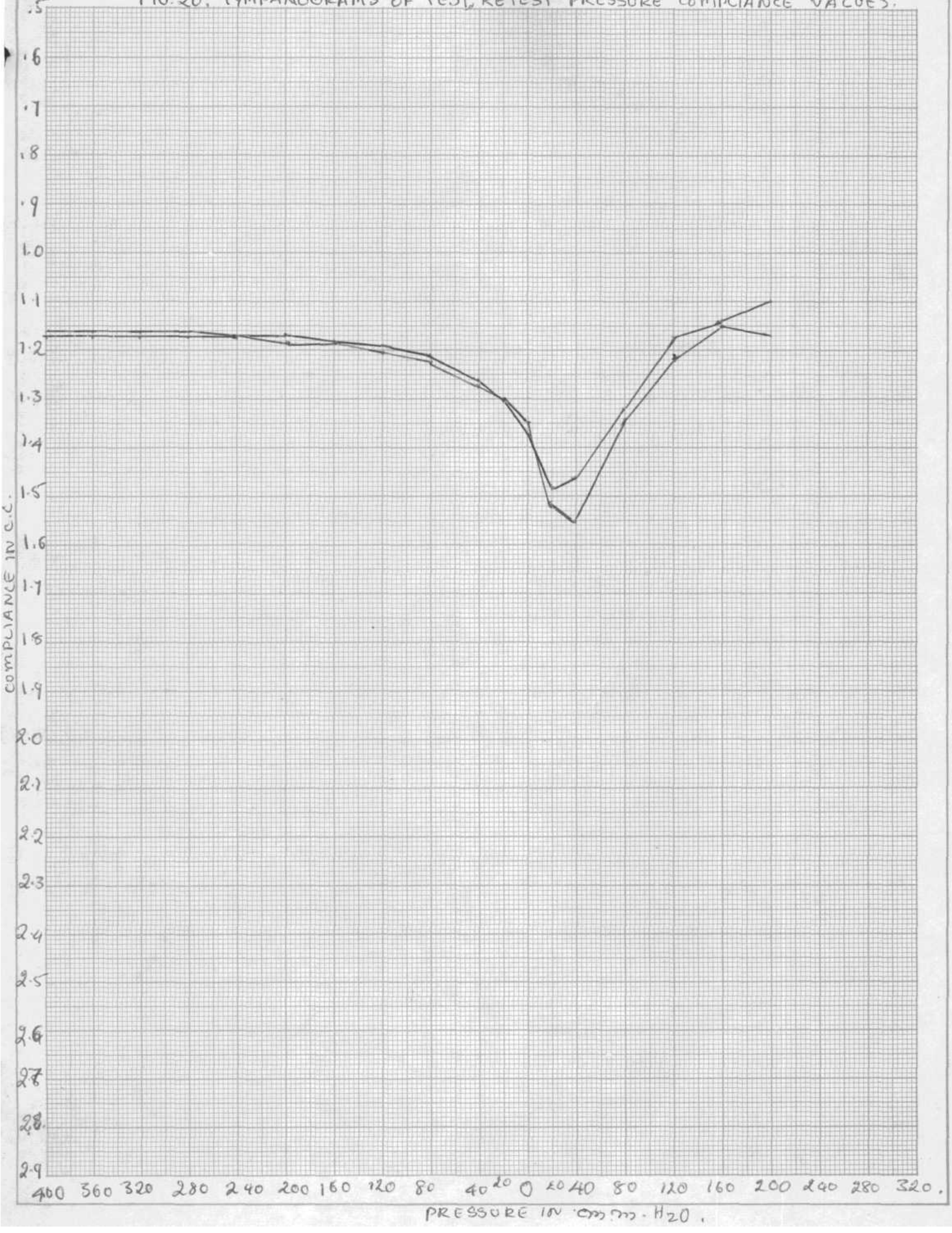
2 (l male and 1 female) normal hearing adult subjects exhibited no acoustic reflex at all frequencies. Tympanograms were of A type and acoustic impedance values were around mean normal values.

A boy aged 13 years (Case No.8040) was tested. ENT examination revealed nothing abnormal. Audiogram vas well within normal limits. Impedance results were very interesting. When tested for compliance the balance meter needle exceeded the balance meter value at middle ear pressures for both the ears. He obtained very low acoustic impedance scores. Acoustic reflex threshold values are:

Frequency	Left		Right	
	PT in dB	RT in dB	PT in dB	RT in dB
250 Hz	0	80	-5	75
500 Hz	5	85	0	80
1 K Hz	0	90	0	100
2 K Hz	0	85	-5	95
4 K Hz	-5	90	0	95
6 K Hz	0	NO	0	NO
8 K Hz	-5	NO	-5	NO

Reliability

FIG. 20. TYMPANOGRAMS OF TEST, RETEST PRESSURE COMPLIANCE VALUES.



Randomly selected 14 normal ears vere tested twice for all the impedance measures. The results were . consistent.

The results of acoustic impedance and static compliance were analyzed for computing coefficient of correlation between test-retest scores. A correlation of .9 for static compliance and a correlation of .9 for acoustic impedance were obtained.

Coefficient computed from the present data is a good Agreement with the previous results of Tillman et al (1964) and Jerger et al (1972).

Test-retest data for these subjects is given in Appendix 3.

Fig. 20 shows the tympanometry curves for the two mean pressure compliance values (test-retest values) obtained for the 14 ears.

Effect of air pressure on acoustic reflex threshold

Usually acoustic reflex threshold is measured at middle ear pressure. To study how air pressure variation in the external auditory meatus affects the acoustic reflex threshold for different frequencies, 20 normal ears were studied at +100 mm H_2O and -100 mm H_2O. Data is given in Appendix 4.

Results were analyzed using Wilcoxon paired signed Tank test to find the statistical significance between different acoustic reflex thresholds measured at different pressure values.

The results showed that there was significant difference between the reflex threshold measured at 0 mm H_2O and 100 mm H_2O air pressure in the external auditory meatus.

Comparison of the results at -100 and 0 mm H_2O showed no significant difference at .01 level and there was significant difference at .025 level.

The magnitude of deflection of the needle of the balance meter was reduced when tested at -100 and +100 mm HgO - suggesting that pressure variation in this range does not abolish the reflex but it affects the magnitude of the reflex. Further, it can be stated that the positive pressure has more effect than the negative pressure.

However, it would be worth studying more number of subjects at different pressure values.

CHAPTER V

SUMMARY AND CONCLUSIONS

Impedance audiometry is becoming a popular diagnostic clinical tool. However it is useful only as a complete battery and the inferences must depend on the overall results of tympanometry, acoustic impedance and the acoustic reflex threshold. The present study deals with the results of impedance measurements on normals and pathological groups in India. It is quite essential to know how the results of the normal and the pathological . groups vary. The results obtained could be helpful in using the impedance bridge for diagnostic purposes. With this view the present study was undertaken. A total of 136 subjects (191 ears) were included in this study.

The following conclusions can be drawn.

1. Comparison of the two groups (boys and girls) in the age range 5-14 years shows no significant difference with regard to static compliance indicating no sex difference in younger age groups. This is in agreement with the other studies.

2. Comparison of the two adult groups (males and females) in the age range 15-29 years shows significant difference with regard to static compliance indicating sex difference. The males show higher compliance than the females. This agrees with the reported studies.

3. Comparison of the two male groups in the age range of 15-29 and 30-50 years respectively, shows significant difference In compliance indicating age difference. Compliance declines as a function of age. This conforms with the previous reports.

4. The average compliance and the variance in compliance are more with females than males. This finding is in contrary to Jerger's (1972) report that "....Women consistently show a lower average compliance and less variance than men at all ages".

5. With regard to acoustic impedance there is significant difference between girls and boys indicating aex difference in early age groups. The former groups shows higher impedance than the latter. This result is not in agreement with the conclusion number one. It needs further investigations.

6. There is no significant difference with regard to acoustic impedance between males and females for the same age group (15-29 years). This result also is not in agreement with the conclusion number 2. Further investigations are needed.

There is significant difference with regard to acoustic impedance between two male age groups, viz., 15-29 years and 30-50 years, indicating age difference in acoustic impedance. The older age group shows higher impedance than the younger group. This is in agreement with the compliance results that it declines with age.

8. l00% acoustic reflex responses were Observed only at 1 K and 2 K Hz for all the normal ears.

9. Reflex threshold declines with increase in hearing loss with sensori-neural loss cases (Table 7).

10. Any conclusion regarding the norms for acoustic impedance cannot be drawn as there is overlapping of pathological and normal ears with regard to acoustic impedance. The normals obtained a wide range of 682-5840 acoustic ohms.

11. All conductive and mixed loss cases showed absence of acoustic reflex.

12. Suspected otosclerotlc ears (16) obtained impedance score in the range 1032-7552 . The mean value is well above the mean for normal ears.

13. The case reports mentioned illustrate the diagnostic value of impedance audiometry.

Recommendations for further research

1. As the present study has not included young children (below 5 years), study could be carried out on very young children.

2. As the present study has not included older group (above 50 years), study could be carried out on older group.

3. Further work could be carried out on more number

of subjects, normal as well as pathological* ^
,y^-:r,;,,,,.:,.ryr; ^ ^ ^:,,-..; .; ,, ,,;., ,

^ ^3+^ Preliminary investigation on the effect of the pressure on acoustic reflex threshold shows positive . results. Further work could be carried out on this line.

5. Due to the non-availability of acoustic neuroma, brain stem tumors, 50% reflex decay could not be studied. This can be explored.

6. The present study and the reported studies reveal age and sex differences in static compliance and acoustic impedance values, and hence it would be of interest to explore this in greater detail.

BIBLIOGRAPHY

Alberti and Kristenson, 1970. The clinical application of Impedance Audiometry. Laryngoscope, 80, pp 735-746

Alexander Efron, 1968. Sound, Basic Science series; Vakils, Feffer & Simons Private Ltd.

Anderson, H., and Barr, B., 1971. Conductive high torn hearing loss. Arch, of Otolaryn. 93, pp 599-605

Anderson, H., and Barr, B., 1968. Conductive recruitment Int. Audiol. 7, pp 48-54

Anderson, H., and Wedenberg, E., 1968. Audiometric identification of normal hearing carries of genes for deafness, Acta. Otolaryng. 65, pp 535-54

Ballantyne, J., and Groves, J. (editors) 1971. Diseases of the ear, nose and throat, 3rd edition, Butter-worths

Bauer, B.B. et al. 1968. External ear replica for acoustical testing. J. International Audiology. 7 pp 77-84

Berenek, 1967. Acoustic Measurements; 7th printing, John Wiley & Sons, Inc.

Bicknell, M.R. et al, 1968. A clinical evaluation of the Zwislocki Acoustic bridge, Laryngology, 82, pp 673-93

Blair Simmons, 1964. Middle ear muscle acoustic reflex as index of cochlear sensitivity in auditory experiments; J.A.R. 4, pp 255-260

Brasher, P.F., et al, 1969. Middle ear muscle activity and Temporary Threshold Shift. International Audiology. 8, pp 579-84

Brooks, D.N., 1968. An objective method of detecting fluid in the middle ear, J. Int. Audiology. 7, pp 282-86

Brooks, D.N., 1968. The use of the Electroacoustic impedance bridge in the assessment of middle ear function. J. Int. Audiology. 8, pp 563-69

BraceMer, S., et al. 1967. Fiheroptic Endotoscopes for examining the middle ear. Arch. Oto. 85, pp

Burke, K.R., et al. 1970. Middle ear impedance measurements, J.S.H.R. 13, pp 317-325

Dallos, P.J., 1964. Dynamics of the acoustic reflex: Phenomenological aspects, JASA. 36, pp 2175-83

Davis and Silverman (editors) 1970. Hearing and Deafness, Holt, Rinehart and Winston, Inc.

De Reueck, A.V.S., and Jalie Knight, 1968. Hearing Mechanisms in vertebrates, A Ciba Fonndation Symposium

Djupesland, 6., 1969. Use of impedance indicator in deafness of middle ear pathology. J. Int. Audiol. 8, pp 570-78

Djupesland, G., and Flottosp, 1970. Correlation between the Fowler Loudness Balance Test, the Metz's Recruitment Test and the Flottosp-Ophelm's Aural Harmonic Test in various types of hearing impairment. Int.Aud. 9, 1970, pp 156-175

Djupesland, G. and Zwislocki, J.J., 1971. Effect of temporal summation of the human stapedius reflex. Acto. Oto. 71, pp 262-65

Farrant, et al. 1966. Measuring the acoustic impedance of severely deaf ears to test for conductive component. J. Acto. Soc. of Aust. 2, pp 49-53

Feldman, A.S., 1963. Impedance measurement at the ear drum as an aid to diagnosis. JSHR, pp 315-27

Feldman, A.S., 1967. Acoustic Impedance Studies of the Normal Ear. JSHR 10, 00 pp 165-76

Feldman, A.S., 1969. Acoustic impedance measurements of post stapedectomized ears. Laryngoscope, 79, pp 1132-55 .

Feldman, A.S., 1965. Effect of the acoustic reflex on the impedance at the ear drum. JSHR 8, pp 213-22

Flottorp, G. et al. 1970. Diphasic impedance change and its applicability to clinical work. Acto. Oto. Suppl. 263

Fulton, R.T., and Lamb, L.E., 1972. Acoustic Impedance and tempanometry with the retarded: a normative study. Aud. 11, pp 199-208

Greisen, O., et al. 1970. Stapedius muscle reflexes and otoneurological examinations in brain stem tumors, Act. Oto. 70, pp 366-70

Harford, E.R., 1973. Tympanometry for Estachian tube evaluation. Arch, of Oto. 97, pp 17-20

Henning Sorenson, et al. 1967. Clinical experience with tone decay test. Int. Audio. 6, pp 411-14

Iagelstedt, S., et al., 1967. Mechanics of the human middle ear. Acta. Oto. Suppl. 228

Jepsen, et al. 1962. Ossicular chain defects. Acto* Oto. 54, pp 393-402

Jerger (editor) 1963. Modern Developments in Audiology. Academic Press Inc.

Jerger, 1970. Clinical experience with Impedance Audiometry. Arch, of Oto. 92, pp 311-24

Jerger______1972. Studies in impedance audiometry. Arch, of Otolaryngol. 96, 1972.

Johansen, 1967. Acoustic reflexes as a test of suspectability to noise. Acto. Oto. 64, pp 256-62

Johnson, E.W., 1973. Clinical applicability of special hearing tests. Arch. Oto. 9, pp 92-95

Kinsler, L.E., and Frey, A.R., 1962. Fundamentals of acoustics. John Wiley & Sons, Inc.

Lamb, et al. 1968. Application stapedius muscle reflex. J. Int. Audio. 7, pp 188-189

Liden, et al, 1970. Tympanometry. Acto. Oto. Suppl. 263

Lilly, D.J., 1964. A rebalance technique for the measurement of acoustic balance. Changes in acoustic impedance due to the acoustic reflex. ASHA 6, 380.

Lilly, D.J., 1970. Comparison of acoustic impedance data obtained with Madsen and Zwislocki instruments. ASHA 12, 441

Littler, 1965. The physics of the ear. Pergamon Press Ltd.

Madsen Model Z070. Electro-acoustic impedance bridge. Applications and instructions for use

McRobertson, et al. 1969. The effect of middle ear muscle contractions on sound transmission through the human ear. Int. Audio. 8

Miller, 1965. Eastachian tube - function in normal and diseased ears. Arch. Oto. 81, pp 41-48

Nager, 6.T., 1969. Histopathology of otosclerosis. Arch. Oto. 89, pp 341-63

Nair, K.R., 1973. Personal Communication. "Otosclerosis with particular reference to its etiology and secretion of urinary neutral 17 ketosteroids".

Newby, Hayes, A., 1965. Audiology. London: Vision

Nilges, T.S., et al. 1969. Zwislocki acoustic bridge: clinical correlation. Arch, of Oto. 89, pp 727-44 .

Nixon, J.C. and Glorig, A. 1964. Reliability of acoustic impedance measures of the eardram. JAR 4, pp 261-76

Peterson, S.L., and Liden, G., 1970. Tympanometry in human temporal bones, Arch, of Oto. 92, pp 258-366

Priede, V.M., 1970. Acoustic impedance in 2 cases of ossicular discontinuity. Int. Audiol. 9, pp 127-336.

Psychoacoustics - Audiology. Grason-Stadler Catalogue

Robertson, et al. 1968. Relative impedance measurements in young children. Arch, of Oto. 88, pp 162-68

Stevens, et al. 1970, Editors of Time Life Books, Sound and Hearing Time, Inc.

Travis - Handbook of Speech Pathology

Venkateshatnurthy, 1973. The acoustic reflex and its clinical application. Ind. J. Otol. 25, pp 39-46

Wolstenholme, G.E.W., and Julie Knight, 1970; Editors Sensorineural Hearing Loss, A Ciba Foundation , . Symposium. J & A. Churchill

Zwislocki, J.J., 1963. An acoustic method for ellnieal examination of the ear. JSHR 6, pp 302-14

Zwislocki, J.J., 1965. Summary by the modernator: the acoustic impedance of the ear. JIA 4, pp 13-19

Awislocki, J.J., 1968. On acoustic research and its clinical applications. Acto. Oto. 65, pp 86-96

Zwisloeki, J.J., and Feldman, A.S., 1973. Acoustic impedance of pathological ears. ASHA monograph 15.

APPENDICES

Impedance is measured in acoustic ohms

Compliance in equivalent volume cc

Pressure in mm H_2O

Reflex threshold and pure tone thresholds are measured in dB - re: 0.0002 dyne/cm^2

Z_1 - Impedance measured at a positive pressure of 200 mm H_2O in the external auditory meatus

Z_2 - Impedance measured at middle ear pressure

Z_X - Absolute acoustic impedance

C^ - Compliance measured at middle ear pressure

Cg - Compliance measured at a positive pressure of 200 mm HgO in the external auditory meatus

C_S - Static compliance

MP - Middle ear pressure

Difference- Difference in compliance between high negative and high positive pressures

RT - Reflex threshold

PT - Pure tone threshold

- Difference between RT and PT

-(400...20)-indicate applied negative pressure in mm H_2O

TABES I

Males - 16-30 years

Sl. No	Age	Z_1	Z_2	Z_X	C_1	C_2	C_S	MP	Difference
1	20	640	350	772	3.00	1.55	1.45	0	0.06
2	22	760	630	3683	1.63	1.35	0.28	0	0.17
3.	20	550	390	1390	2.60	1.37	0.73	20	0.12
4	23	690	410	1010	2.52	1.49	1.03	20	0.13
5	19	850	540	1980	1.93	1.20	0.73	-10	0.09
6	20	590	450	1896	2.30	1.75	0.55	0	0.14
7	19	840	560	1680	1.85	1.22	0.63	0	0.09
8	19	880	660	2690	1.52	1.16	0.36	-40	0.14
9	21	680	450	1330	2.35	1.51	0.84	0	0.07
10	19	680	450	1330	2.30	1.52	0.78	0	0.08
11	19	670	410	1056	2.50	1.53	0.97	20	-0.16
12	23	680	500	1214	2.05	1.53	0.52	-10	0.10
13	24	650	380	914	2.80	1.57	1.23	0	-0.07
14	24	820	550	1670	1.88	1.25	0.63	30	0.07
15	18	760	430	990	2.30	1.36	0.94	0	0.03
16	18	1000	700	2333	1.46	1.03	0.43	20	0.09
17	18	820	540	1581	1.90	1.25	0.65	20	0.06
18	19	950	705	2733	1.46	1.08	0.38	-20	0.10

...contd

TABLE 1 - contd.

81. No.	Age	Z_1	Z_2	Z_X	C_1	C_2	C_S	MP	Difference
19	26	900	670	2621	1.83	1.16	0.67	-20	0.04
20	18	920	540	1307	1.86	1.12	0.74	30	0.06
21	20	780	360	720	3.40	1.42	1.98	-60	0.13
22	23	675	365	795	3.12	1.52	1.60	60	-0.03
23	29	760	540	1165	1.90	1.34	0.56	0	0.13
24	28	740	580	2683	1.78	1.38	0.40	0	0.18
25	29	1110	79p	27400	1.16	0.99	0.17	30	0.06
26	17	740	560	2302	1.90	1.37	0.53	-20	0.14
27	26	730	580	2230	1.89	1.40	0.49	20	0.12
28	18	590	450	4425	2.25	1.75	0.50	-60	0.80
29	21	720	440	1131	2.00	1.40	0.60	10	0.04
30		750	440	1064	2.60	1.35	0.25	0	0.10
31		475	350	1330	2.95	2.15	0.80	40	0.20
32		680	450	1330	2.25	1.51	0.74	0	0.09
33		870	530	1356	1.90	1.19	0.71	0	0.06
34		850	510	1275	2.00	1.20	0.30	20	0.11
35		820	660	3383	1.66	1.28	0.38	0	0.88
36		720	440	1131	2.20	1.40	0.80	20	0.04
37		600	320	685	3.20	1.65	1.55	20	1.45
38		620	420	1302	2.36	1.66	0.70	20	0.09
39		1125	775	2491	1.32	0.92	0.40	20	0.08

....contd

TABLE I - contd.

Sl. No	Age	Z_1	Z_2	Z_x	C_1	C_2	C_S	MP	Difference
40		790	530	1610	1.93	1.23	0.65	20	0.03
41		900	670	2621	1.75	1.16	0.59	-10	0.10
42		900	490	1075	2.04	1.14	0.90	40	0.03
43		670	420	1125	2.41	1.65	0.76	20	0.20
44		850	680	3400	1.80	1.20	0.30	20	0.13
45		1050	890	5840	1.30	0.93	0.37	40	0.10
46		980	550	1367	1.85	1.10	0.74	0	0.02
47		900	550	1414	1.86	1.13	0.73	20	0.07
Average	20.96			1848			0.71	7.02	0.13

APPENDIX I - TABLE II

No.	RT	PT	D	RT	PT	D	RT	PT	D	RT	PT	D	RT	PT	D	RT	PT	D	RT	PR	D
1	85	0	85	85	0	85	90	10	80	90	5	85	85	10	75	90	5	85	NR		
2	90	20	70	100	20	80	95	15	80	90	10	80	100	20	80	90	10	80	NR		
3	90	10	80	95	10	85	95	15	80	100	10	90	110	15	95	NR	NR		NR		
4	90	5	85	90	0	90	100	5	95	95	10	85	95	5	90	90	0	90	90	0	90
5	80	5	75	90	5	85	85	5	80	85	5	80	80	10	70	90	5	85	NR		
6	85	15	70	95	5	90	95	5	90	90	5	85	95	10	85	85	5	80	80	0	80
7	90	0	90	100	10	90	100	10	90	95	15	80	100	15	85	NR			NR		
8	80	0	80	85	0	85	85	5	80	85	5	80	95	10	85	90	5	85	90	5	85
9	NR			105	15	90	105	5	100	100	0	100	100	0	100	90	15	75	NR		
10	90	5	85	85	5	80	85	0	85	85	0	85	80	10	70	80	15	65	NR		
11	95	10	85	100	15	85	100	15	85	100	20	80	110	20	90	NR			NR		
12	95	5	85	105	10	95	105	5	100	100	10	90	NR		NR	NR			NR		
13	85	0	85	80	5	75	80	5	85	80	5	75	85	10	75	90	15	75	NR		
14	90	10	80	90	5	85	100	10	90	100	5	95	100	10	90	NR			NR		
15	85	15	70	90	10	80	95	5	90	90	5	85	95	15	80	NR			NR		
16	65	15	50	70	15	65	80	5	75	75	0	75	80	0	80	80	0	80	70	5	65
17	75	5	70	80	5	75	80	0	80	75	5	70	80	10	70	80	5	75	80	0	80

APPENDIX I - TABLE II - Coontd.

No.	RT	PT	D	RT	PT	D	RT	PT	D	RT	PT	D	RT	PT	D	RT	PT	D	RT	PT	D
18	90	10	80	95	10	85	100	5	95	90	0	90	100	15	85	90	10	80	90	5	85
19	85	5	80	85	5	80	90	10	80	80	10	70	95	10	85	NR			NR		
20	85	10	75	80	15	65	80	10	70	80	5	75	95	5	90	NR			NR		
21	NR			100	20	80	105	20	85	110	15	95	110	15	95	NR			NR		
22	85	5	80	80	5	75	90	5	85	85	10	75	85	5	80	90	10	80	NR		
23	85	20	65	90	15	75	90	15	75	80	20	60	95	20	75	NR			NR		
24	80	15	65	85	15	70	90	20	70	80	15	65	90	15	75	NR			NR		
25	90	10	80	95	5	90	95	5	90	85	0	85	100	5	95	NR			NR		
26	85	20	65	95	20	75	105	15	85	95	15	80	105	20	85	NR			NR		
27	NR			110	20	90	100	20	80	95	15	80	100	20	80	NR			NR		
28	85	15	70	85	15	70	90	10	80	85	10	75	95	15	80	90	10	80	90	10	80
29	95	20	75	105	20	85	105	5	100	95	10	85	90	10	80	90	10	80	90	15	75
30	85	0	85	90	0	90	85	5	80	85	5	80	85	10	75	85	10	75	85	5	80
31	90	0	90	90	5	85	85	5	80	85	0	85	85	10	75	90	5	85	NR		
32	90	5	85	95	5	90	90	0	90	80	-5	85	80	5	75	90	0	90	90	0	90
33	80	0	80	85	0	85	95	0	95	80	0	80	80	5	75	80	0	80	NR		
34	90	5	85	95	15	80	100	10	90	100	15	85	95	10	85	90	5	85	NR		

.....contd

APPENDIX I - TABLE II . Contd.

No.	RT	PT	D	RT	PT	D	RT	PT	D	RT	PT	D	RT	PT	D	RT	PT	D	RT	PT	D
35	80	10	70	85	5	80	85	5	80	95	15	80	85	10	75	95	5	85	NR		
36	90	10	80	105	15	90	105	5	100	95	0	95	90	0	90	90	15	75	90	15	75
37	90	5	85	95	5	90	95	0	95	100	10	90	100	5	95	NR			NR		
38	90	15	75	90	10	80	95	5	90	100	5	95	NR			NR			NR		
39	70	10	60	85	10	75	85	0	85	75	0	75	85	0	85	85	5	80	80	0	80
40	75	0	75	80	5	75	80	0	80	80	10	70	85	5	80	85	20	65	90	0	90
41	85	0	85	85	0	85	90	5	85	80	0	80	95	10	85	NR	NR		NR		
42	85	15	70	85	5	80	90	10	80	80	0	80	105	5	100	NR			NR		
43	80	15	65	90	15	75	95	10	85	85	15	70	100	15	85	NR			NR		
44	85	15	65	90	20	70	90	10	80	85	10	75	95	15	80	75	20	55	90	20	70
45	90	10	80	100	10	90	100	5	95	90	5	85	NR			NR			NR		
46	80	0	80	80	0	80	80	0	80	80	5	75	100	10	90	NR			NR		
47	90	5	85	95	5	90	95	10	85	85	15	70	105	15	90	NR			NR		
Average	85.45			86.80			92.37			86.59			93.52			86.80			86.07		

APPENDIX **I - TABLE** III

Pressure Compliance Values for the age group 15-29 yrs (Males)

No.	-400	-360	-320	-280	-240	-200	-160	-120	-80	-40	-20	0	20	40	80	120	160	200
1	1.61	1.60	1.60	1.60	1.60	1.60	1.60	l.63	1.70	1.88	2.12	3.00	2.18	1.93	1.72	1.66	1.60	1.65
2	1.52	1.50	1.48	1.48	1.47	1.46	1.46	1.47	1.50	1.52	1.59	1.63	1.62	1.58	1.48	1.42	1.37	1.35
3.	1.95	1.96	1.95	1.96	1.99	2.00	2.00	2.04	2.10	2.20	2.22	2.24	2.60	2.45	2.15	2.00	1.95	1.87
4	1.62	1.62	1.62	1.62	1.62	1.62	1.62	1.62	1.65	1.72	1.82	1.90	2.10	2.52	2,05	2.18	1.53	1.49
6	1.29	1.29	1.28	1.28	1.28	1.29	1.29	1.32	1.39	1.61	1.90	1.93	1.80	1.75	1.43	1.30	1.26	1.20
6	1.89	1.85	1.85	1.86	1.88	1.91	1.98	2.06	2.12	1.30	1.70	2.30	2.10	2.05	1.90	1.83	1.78	1.75
7	1.31	1.31	1.31	1.31	1.31	1.32	1.34	1.37	1.43	1.68	1.65	1.85	1.78	1.70	1.43	1.31	1.26	1.22
8	1.30	1.30	1.28	1.28	1.28	1.30	1.32	1.37	1.50	1.52	1.40	1.36	1.31	1.38	1.23	1.20	1.17	1.16
9	1.58	1.58	1.56	1.56	1.58	l.53	1.58	1.59	1.61	1.66	1.70	1.87	2.35	2.35	1.85	1.62	1.56	1.51
10	1.60	1.68	1.62	1.62	1.62	1.64	1.64	1.72	1.77	1.94	2.03	2.00	2.0a	2.00	1.65	1.60	1.53	1.52
11	1.38	1.38	1.38	1.38	1.88	1.40	1.44	1.501	1.60	1.74	1.89	3.28	2.50	2.31	2002	1.80	1.66	1.53
12	1.63	1.63	1.63	1.62	1.63	1.64	1.67	1.70	1.80	1.92	2.05	2.05	1.80	1.85	1.67	1.60	1.57	$,63
13	1.50	1.50	1.50	1.50	1.51	1.63	1.65	1.60	1.75	2.00	2.30	2.80	2.66	2.20	1.90	1.73	1.64	1.61
14	1.32	1.32	1.30	1.30	1.30	1.28	1.28	1.29	1.32	1.37	1.44	1.56	1.72	1.882	1.59	1.40	1.31	.1.25

contd.

APPENDIX I - TABLB III Contd.

NO.	-400	-360	-320	-280	-240	-200	-160	-120	-80	-40	-20	0	20	40	80	120	160	200
15	1.39	1.38	1.38	1.37	1.37	1.37	1.39	1.41	1.47	1.61	1.70	2.30	2.00	2.10	1.65	1.48	1.40	1.36
16	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.14	1.18	1.23	1.46	1.40	1.21	1.12	1.07	1.03
17	1.31	1.31	1.31	1.31	1.32	1.32	1.33	1.35	1.38	1.44	1.50	1.60	1.90	1.70	1.46	1.35	1.28	1.25
18	1.13	1.18	1.18	1.18	1.18	1.19	1.21	1.23	1.28	1.45	1.46	1.35	1.26	1.22	1.16	1.13	1.10	1.03
19	1.24	1.22	1.22	1.22	1.23	1.34	1.27	1.32	1.41	1.54	1.83	1.64	1.48	1.38	1.27	1.22	1.18	1.16
20	1.18	1.18	1.18	1.18	1.19	1.20	1.21	1.22	1.24	1.27	1.32	1.37	1.45	1.86	1.50	1.22	1.16	1.12
21	1.55	1.55	1.55	1.55	1.56	1.62	1.90	3.20	3.40	2.40	2.00	1.82	1.75	1.63	1.65	1.48	1.46	1.42
22	1.49	1.49	1.49	1.49	1.49	1.49	1.51	1.62	1.54	1.69	1.65	1.70	1.80	1.99	3.12	1.93	1.65	11.52
23	1.39	1.39	1.40	1.40	1.47	1.57	1.70	1.97	2.46	3.80	3.50	3.25	2.90	2.70	2.02	1.66	1.65	1.56
24	1.47	1.47	1.48	1.51	1.54	1.65	1.58	1.61	1.62	1.68	1.73	1.83	1.90	1.75	1.53	1.45	1.38	1.34
25	1.56	1.5$	1.54	1.64	1.54	1.54	1.55	1.57	1.59	1.65	1.69	1.74	1.78	1.75	1.60	1.48	1.43	1.38
26	1.08	1.04	1.04	1.04	1.04	1.04	1.05	1.07	1.08	1.10	1.11	1.12	1.13	1.16	1.11	1.06	1.02	0.99
27	1.51	1.49	1.48	1.47	1.48	1.49	1.53	1.61	1.83	1.82	1.90	1.85	1.70	1.58	1.50	1.44	1.42	1.37
28	1.52	1.50	1.48	1.48	1.47	1.47	1.47	1.48	1.61	1.72	1.80	1.82	1.89	1.82	1.63	1.49	1.44	1.40
29	1.15	1.90	1.94	1.95	1.96	2.00	2.15	2.20	2.25	2.05	2.00	1.95	1.87	1.35	1.82	1.80	1.77	1.75
30	1.44	1.44	1.42	1.42	1.44	1.44	1.44	1.47	1.50	1.61	1.63	1.85	2.00	1.75	1.53	1.47	1.43	1.40
31	1.45	1.45	1.44	1.44	1.44	1.44	1.44	1.46	1.52	1.81	2.25	2.60	1.85	1.70	1.52	1.45	1.40	1.36

APPENDIX I - TABLE III Contd.

No.	-400	-360	-320	-280	-240	-200	-160	-120	-80	-40	-20	0	20	40	80	120	160	200
	2.3b	2.35	2.30	2.30	2^.30	2.30	2.30	2.32	2.35	2.40	2.45	2.55	2.75	3.95	2.45	2.30	2.20	2.15
33	1.60	1.60	1.60	1.60	1.60	1.61	1.62	1.66	1.76	1.90	2.02	2.25	2.22	2.00	1.75	1.63	1.57	1.51
34	1.25	1.25	1.25	1.24	1.25	1.25	1.27	1.32	1.46	1.56	1.70	1.90	1.85	1.82	1.45	1.30	1.34	1.19
35	1.31	1.30	1.30	1.30	1.30	1.31	1.32	1.34	1.34	1.41	1.50	1.57	1.90	2.00	1.43	1.32	1.25	1.20
36	1.50	1.50	1.50	1.48	1.46	1.46	1.46	1.46	1.46	1.50	1.57	1.65	1.66	1.60	1.57	1.45	1.32	1.28
37	1.44	1.44	1.42	1.42	1.44	1.44	1.44	1.47	1.50	1.61	1.63	1.85	2.20	1.75	1.53	1.47	1.43	1.40
38	3.00	3.00	2.90	2.55	2.20	2.10	1.98	1.98	1.32	1.95	2.00	8.15	3.20	2.50	2.00	1.82	1.75	1.65
39	1.75	1.74	1.72	1.72	1.70	1.70	1.72	1.74	1.80	1.90	1.98	2.12	2.36	2.30	2.00	1.85	1.74	1.66
40	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.01	1.06	1.10	1.18	1.32	1.18	1.04	0.98	0.95	0.92
41	1131	1.32	1.32	1.32	1.33	1.34	1.35	1.38	1.41	1.46	1.52	1.61	1.93	1.80	1*50	1.39	1.32	1.28
42	1.26	1.25	1.26	1.27	1.27	1.28	1.30	1.33	1.41	1.55	1.65	1.75	1.53	1.37	1.27	1.22	1.18	1.16
43	1.17	1160	1.16	1.16	1.16	1.16	1.16	1.16	1.18	1.22	1.27	1.33	1.44	2.04	1.47	1.26	1.18	1.20
44	1.47	1.17	1.47	1.47	1.48	1.49	1.54	1.90	2.80	3.70	3.20	3.45	1.97	1.72	1.54	1.44	1.38	1.35
45	1.85	1.85	1.85	1.85	1.85	1.90	1.93	1.93	1.97	2.03	2.08	2.16	3.14	2.32	1.93	1.77	1.70	1.65
46	1.33	1.32	1.31	1.30	1.30	1.30	1.30	1.32	1.34	1.40	1442	1.48	1.50	1.48	1.37	1.28	1.24	1.20
47	1.03	1.02	1.02	1.02	1.02	.1.02	1.02	1.04	1.07	1.11	1.14	1.17	1.12	1.30	1.08	1.01	0.76	0.93
43	1.12	1.12	1.12	1.12	1.22	1.13	1.14	1.18	1.37	1.34	1.48	1.85	1.50	1.26	1.18	1.13	1.12	1.10
49	1.20	1.19	1.19	1.19	1.19	1.20	1.20	1.22	1.24	1.32	1.27	1.47	1.86	1.71	1.38	1.34	1.17	1.16

APPENDIX II

1) Caloric test
2) Blood grouping
3) Urinary 17 ketosteroids
4) Spontaneous nystagmus
5) Romberg test

Additional findings oF otosclerotic ears

		1	2	3	4	5
1.	K-2838	left ear not reactive	"A"		Absent	negative
2.	K-2935	Reavtive	"B"	14.4mg/day	"	"
3.	8055	inner ear was re-active	" O "	-	"	"
4.	6738	Reactive	"0"	-	"	"
	6623	Reactive	"0"	13.6mg/day	"	"
6.	2414	"	"A"	32.7mg/day		"
7.	K-2876	"	"B"	36.0mg/day	"	"
8.	6839	"	"AB"	20.0mg/day	"	"

Nair. 1973

APPENDIX III - A_1

1 Test Scores

Pressure Complianee Values

N$.	-400	-360	-320	-280	-240	-200	-160	-120	-80	-40	-20	0	20	40	80	120	160	180
1	1.12	1.12	1.12	1.12	1.12	1.13	1.14	1.18	1.27	1.34	1.48	1.85	1.50	1.26	1.18	1.13	1.12	1.10
2	1.20	1.39	1.19	1.19	1.19	1.20	1.20	1.22	1.24	1.32	1.39	1.47	1.86	1.71	1.38	1.24	1.17	1.13
3	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.14	1.18	1.23	1.46	1.40	1.21	1.12	1.07	1.04
4	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.01	1.06	1.10	1.18	1.32	1.18	1.04	0.98	0.95	0.92
5	1.31	1.31	1.31	1.31	1.32	1.32	1.33	1,35	1.38	1.44	1.50	1.60	1.90	1.70	1.46	1.35	1.28	1.25
6	1.18	1.18	1.18	1.18	1.18	1.19	1.21:	1.23	1.28	1.45	1.46	1.35	1.26	1.22	1.16	1.13	1.10	1.08
7	1.18	1.18	1.18	1.19	1.19	1.20	1.21	1.22	1.24	1.27	1.32	1.37	1.45	1.86	1.50	1.22	1.16	1.12
8	1.17	1.16	1.16	1,16	1.16	1.16	1.16	1.16	1.18	1.22	1.27	1.33	1.44	2.04	1.47	1.26	1.18	1.14
9	1.17	1.15	1.15	1.15	1.16	1.17	1.17	1.18	1.20	1.22	1.25	1.28	1.32	1.28	1.21	1.15	1.12	1.08
10	1.19	1.17	1.17	1.17	1.18	1.18	1.19	1.21	1.22	1.25	1.28	1.32	1.38	1.41	1.27	1.19	1.16	1.12
11	1.10	1.08	1.08	1.08	1.08	1.08.	1.08	1.09	1.11	1.13	1.16	1,20	1.73	1.48	1.18	1.14	1.14	1.08
l2	1.13	1.12	1.12	1.12	1.13	1.13	1.14	1.16	1.17	1.20	1.23	1.28	1.68	1.38	1.27	1.14	1.09	1.07
13	1.34	1.34	1.33	1.33	1.33:	1.33	1.34	1.35	1.38	1.41	1.45	1.53	1.65	1.43	1.30	1.30	1.26	1.22
14	1.18	1.17	1.17	1.17	1.17	1.17	1.17	1.17	1.18	1.22	1.24	1.28	1.37	1.42	1.38	1.22	1.11	1.08
Ave	1.16	1.16	1.17	1.16	1.17	1.17	1.18	1.39	1.21	1.26	1.30	1.37	1.48	1.46	1.32	1.18	1.14	1.10

No.	-400	-360	-320	-290	-240	-300	-160	-120	-80	-40	-20	0	30	40	80	120	160	180
1	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.14	1.15	1.16	1.23	1.30	1.88	1.58	1.3S	1.20'	1.14	1.11
3	1.18	1.18	1.19	1.20	1.19	1.22	1.23	1.25	1.28	1.37	1.46	1.56	1.95	1.68	1.36	1.26t	1.18	1.16
3	1.12	1.12	1.12	1.21	1.12	1.13	1.13	1.13	1.13	1.16	1.18	1.24	1.45	1.41	1.25	1.15'	1.08	1.04
4	1.03	1.03	1.03	1.03	1.03	1.04	1.04	1.03	1.06	1.12	1.16	1.36	1.38	1.26	1.1C	1.04=	0.97	0.85
5	1.31	1.32	1.32	1.32	1.32	1.34	1.35	1.37	1.41	1.46	1.52	1.61	1.93	1.80	1.5C	1.39	1.32	1.28
6	1.18	1.17	1.17	1. 18	1.18	1.19	1.21	1.23	1.28	1.46	1.52	1.61	1.93	1.80	1.50	1.13	1.10	1.08
7	1.18	1.17	1.17	1.17	1.17	1.18	1.18	1.18	1.20	1.24	1.28	1.86	1.43	1.83	1.42	1.23	1.16	1.12
8	1.18	1..18	1.18	1.18	1.18	1.18	1.18	1.19	1.21	1.24	1.28	1.34	1.44	2.18	1.53	1.33	1.33	1.17
9	1.17	1.16	1.16	1.16	1.17	1.18	1. 19	1.21	1.23	1.25	1.28	1.32	1.37	1. 38	1.41	1.28	1.25	1.14
10	1.18	1.16	1.16	1.17	1.18	1.19	1.21	1.23	1.25	1.28	1.32	1.37	1.38	1.43;	1.28	1.25	1.14	1.13
11	1.09	1.06	1.06	1.06	1.07	1.07	1.08	1.09	l.10	1.13	1.14	1.18	1.23	1.74	1.52	1.21	1.15	1.08
12	1.12	1.11	1.11	1.11	1.11	l.ll	1.12	1.13	1.14	1.13	1.19	1.35	1.69	1.36	1.35	1.22	1.14	1.07
13	1.35	1.35	1.33	1.33	1.33	1.33	1.34	1.34	1.34	1.39	1.42	1.46	1.53	1.66	1.46	1.34	1.28	1.24
14	1.19	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.19	1.23	1.26	1.32	1.41	1.44	1.30	1.16	1.12	1.08
Av.	1.17	1.17	1.17	1.17	1.17	1.18	1.18	1.20	1.22	1.27	1.30	1.35	1.52	1.55	1.34	1.22	1.15	1.11

Sl. No.	Z_1	Z_2	Z_x	C_1	C_2	C_S	MP	Difference
1	920	550	1367	1.85	1.10	0.74	0	0.02
2	900	550	1414	1.86	1.13	0.73	20	0.07
3	1000	700	2333	1.46	1.03	0.48	20	0.09
4	1125	775	2491	1.32	0.92	0.40	20	0.08
5	820	540	1581	1.90	1.25	0.65	20	0.06
6	950	708	2733	1.46	1.09	0.38	-20	0.10
7	920	540	1307	1.86	1.12	0.74	30	0.06
8	900	490	1075	2.04	1.14	0.90	40	0.03
9	950	780	4358	1.32	1.08	0.94	20	0.09
10	920	785	3420	1.41	1.12	0.29	40	0.07
11	960	590	1530	1.73	1.08	0.65	40	0.03
[illegible]	960	610	1673	1.63	1.07	0.61	20	0.06
13	840	620	2367	1.65	1.22	0.43	40	0.12
14	[illegible]	720	2973	1.42	1.08	0.34	40	0.10
Mean	....		2187			0.54	25	0.07

APPENDIX III- D_2

BeTest scores of impedance, compliance, etc.

Sl.No.	Z_1	Z_2	Z_x	C_1	C_2	C_s	MP	Difference
1	930	550	1346	1.38	1.11	0.77	20	0.02
2	880	530	1332	1.95	1.16	0.79	20	0.03
3	1000	710	2448	1.45	1.04	0.41	20	0.08
4	1080	740	2350	1.38	0.95	0.43	20	0.08
5	800	530	1570	1,93	1.28	0.65	+20	0.03
6	950	710	2810	1.47	1.08	0.39	-20	0.10
7	920	550	1367	1.83	1.12	0.71	40	0.06
8	880	480	1056	2.18	1117	1.01	40	0.01
9	940	750	3710	1.32	1.10	0.22	20	0.07
10	920	725	3420	1.41	1.13	0.28	40	0.05
11	950	590	1556	1.74	1.08	0.66	40	0.01
12	950	610	1704	1.69	1.07	0.62	20	0.05
13	830	620	2450	1.66	1.24	0.42	40	0.11
14	950	710	2810	1.44	1.08	0.36	40	0.11
Mean			2137			0.55	25.71	0.06

APPENDIX III - C_1

I Test scores of Acoustic Reflex Threshold

No.	RT	PT	D	RT	PT	D	RT	PT	D	RT	PT	D	RT	PT	D	RT	PT	D	RT	PT	D
1	80	0	80	80	0	80	80	0	80	80	5	75	100	10	90	NR	—	-	NR	--	
2	90	5	85	95	5	85	95	10	85	85	16	70	105	15	90	NR			NR		
3	65	15	50	70	15	55	80	5	75	75	0	75	80	0	80	80	0	80	70	5	65
4	70	10	60	85	10	75	85	0	85	75	0	75	85	0	85	85	5	80	80	00	80
5	75	5	70	80	5	75	80	0	80	75	5	70	80	10	70	80	5	75	80	0	80
6	85	10	75	80	15	55	80	10	70	80	5	75	95	5	90	NR			NR		
7	85	15	70	85	5	80	90	10	80	80	0	80	105	5	100	NR			NR		
8	80	15	65	85	10	75	85	15	70	85	15	70	NR			NR			NR		
9	NR			90	20	70	90	15	75	90	20	70	- NR			NR			NR		
10	85	20	65	80	15	55	85	15	70	70	6	65	95	30	75	80	15	65	80	10	70
11	85	20	65	85	20	65	80	10	70	70	5	65	- 85	15	70	85	15	70	80	10	70
12	80	0	80	80	5	76	80	5	75	75	0	75	80	5	75	85	30	55	85	20	65
13	80	5	75	85	5	80	90	5	85	80	5	75	90	0	90	85	25	60	85	13	75
14	90	10	80	95	10	85	100	5	95	90	0	90	100	15	85	90	10	80	90	5	85
AV	70.76			73.92			78.21			73.49			83.33			80.58			73.76		

APPENDIX III

Rretest scores of Acoustic Reflex Threshold

No.	RT	PT	D	RT	PT	D	RT	PT	D	RT	PT	D	RT	PT	D	RT	PT	D	RT	PT	D
1	80	0	80	80	0	80	80	0	80	75	5	70	90	10	80	NR			NR		
2	85	5	80	90	5	85	90	10	80	80	15	65	100	15	85	NR			NR		
3	70	15	55	70	15	55	80	5	75	70	0	70	75	0	75	75	0	75	70	5	65
4	75	10	65	85	10	75	85	0	85	80	0	80	85	0	85	80	5	75	75	0	75
5	80	5	75	80	5	75	80	0	80	75	5	70	80	10	70	80	5	75	80	0	80
6	90	10	80	90	10	80	95	5	90	85	6	85	100	15	85	90	10	80	90	10	80
7	80	10	70	75	15	60	80	10	70	75	5	70	95	5	90	NR			NR		
8	85	15	70	80	5	75	90	10	80	80	0	80	105	5	1000	NR			NR		
9	80	15	65	80	10	70	85	15	70	85	15	70	NR			NR			NR		
10	NR			85	20	65	90	15	75	90	20	70	NR			NR			NR		
11	85	20	65	80	16	65	80	15	65	70	5	65	90	20	70	75	15	60	75	10	65
12	85	20	65	90	20	70	85	10	75	70	5	65	85	15	70	90	15	75	80	10	70
13	80	0	80	80	5	75	80	5	75	75	0	75	80	5	75	80	35	55	85	20	65
14	80	5	75	85	5	80	90	5	85	80	5	75	90	0	90	85	25	60	85	10	75
Av.	66.07			72.14			77.50			72.86			81.25			68.12			71.78		

APPENDIX IV-A

Acoustic Reflex Threshold Values at 0 mm H_2O

No.	250	500	1 K	2 K	4K	6 K	8 K
1	NR	105	100	90	95	NR	NR
2	NR	105	100	95	105	NR	NR
3	75	80	80	75	80	75	70
4	80	75	80	75	85	NR	70
5	80	85	80	80	90	NR	85
6	80	80	80	75	80	NR	85
7	80	75	80	75	90	NR	80
8	85	80	80	75	90	NR	75
9	85	80	aS	75	90	NR	NR
10	85	90	85	80	85	NR	NR
11		90	90	90	100	NR	NR
12	85	85	85	80	90	NR	NR
13	90	90	85	75	100	NR	NR
14	70	80	80	85	NR	NR	NR
15	60		75	70	80	NR	75
16	90	95	90	95	NR	NR	NR
17	80	85	90	90	NR	NR	NR
18	80	85	85	80	90	NR	NR
19	85	85	90	80	95	NR	NR
20	80	90	95	85	100	NR	NR
21	85	90	90	80	95	NR	NR
22	80	90	90	85	95	75	NR
23	80	85	90	80	90	NR	NR
24	90	100	100	90	NR	NR	NR
25	90	95	95	95	100	NR	NR
	81.73	86.60	87.60	81.80	91.66	82.72	78.75

APPENDIX IV - B

Acoustic Reflex Threshold Values at 100 mm H_2O

No.	250	500	1 K	2 K	4 K	6 K	8 K
1	NR	105	105	100	100	NR	NR
2	NR	105	105	100	110	NR	NR
3	85	80	85	85	90	90	80
4	85	85	90	80	90	85	75
5	80	85	85	85	90	90	NR
6	85	85	85	80	90	90	NR
7	80	80	85	80	95	90	90
8	90	85	85	80	105	85	80
9	90	85	90	80	95	90	NR
10	85	95	95	90	105	NR	NR
11	85	90	90	85	95	NR	NR
12	90	90	90	85	95	NR	NR
13	NR	95	90	85	NR	NR	NR
14	75	80	85	85	NR	NR	NR
15	70	75	80	75	90	85	NR
16	90	95	95	100	NR	NR	NR
17	85	90	95	95	NR	NR	NR
18	80	85	85	m85	95	NR	NR
19	90	90	90	85	NR	NR	NR
20	90	100	105	105	NR	NR	NR
21	NR	110	110	110	NR	NR	NR
22	85	90	95	90	95	90	NR
23	85	90	95	85	95	NR	NR
24	90	105	100	90	NR	NR	NR
25	NR	100	100	90	NR	NR	NR
Average	84. 73	91.00	92.60	88.40	95.93	88.33	81.25

APPENDIX IV - C

Acoustic Reflex Threshold Values at -100 mm H_2O

No.	250	500	1 K	2 K	4 K	6 K	8 K
1	NR	90	95	80	85	NR	NR
2	NR	100	100	90	95	NR	NR
3	80	85	90	80	85	80	85
4	85	80	80	80	90	85	90
5	85	90	90	85	100	NR	NR
6	85	85	85	85	85	NR	NR
7	80	80	85	80	95	90	90
8	90	85	85	80	95	90	85
9	90	85	85	80	95	NR	NR
10	85	95	95	95	100	NR	NR
11	85	95	95	90	100	NR	NR
12	85	90	85	80	95	NR	NR
13	90	90	85	80	NR	NR	NR
14	75	85	85	85	NR	NR	NR
15	70	80	85	80	95	90	NR
16	90	90	90	95	NR	NR	NR
17	85	85	90	95	NR	NR	NR
18	80	85	85	85	95	NR	NR
19	80	90	90	80	90	NR	NR
20	NR	105	110	95	NR	NR	NR
21	85	90	95	90	NR	NR	NR
22	80	85	90	85	90	85	NR
23	80	90	90	85	90	NR	NR
24	90	100	100	85	NR	NR	NR
25	90	95	95	85	100	NR	NR
Average							
	83.40	89.20	86.96	81.40	98.88	86.66	85.00

APPENDIX IV - D

Comparison of the Results

		+100 mm	0	----	Ranks
1.	250	84.75	81.73	3.02	2
2.	500	91.00	86.60	4.40	4
3.	1000	92.60	87.60	5.00	5
4.	2000	88.40	81.80	6.60	7
5.	4000	95.93	91.66	4.37	3
6.	6000	88.33	82.72	5.61	6
7.	8000	81.25	78.75	2.50	1

T = o

H_0 is rejected

$G_{Table} = 2$

H_1 - +100 is greater than 0 mm H_2O

	-100	0		Ranks
1.	33.40	81.73	1.67	3
2.	89.20	86.60	2.60	4
3.	86.96	87.60	-0.64	-2
4.	81.40	81.80	-0.40	-1
5.	98.88	91.66	7.22	7
6.	86.66	82.73	3.94	5
7.	85.00	78.75	6.25	6

APPENDIX IV - D (contd)

	+100	-100		
1	84.73	83.40	1.35	1
2	91.00	89.20	1.80	3
3	92.60	86.96	5.64	6
4	83.40	81.40	7.00	7
5	95.93	98.88	-2.95	-4
6	88.33	86.66	1.67	2
7.	81.25	85.00	-3.75	-5

T = 9

H_0 is accepted at 0.01 level.

G_{Table} = 2