WBA IN INDIVIDUALS WITH CENTRAL AND MARGINAL TYPE OF TYMPANIC MEMBRANE PERFORATION WITHOUT ACTIVE DISCHARGE

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(Audiology)

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MANASAGANGOTRI, MYSORE- 570006

SEPTEMBER 2023

CERTIFICATE

This is to certify that this dissertation, entitled **“WBA in individuals with central and marginal type of Tympanic membrane perforation without active discharge”** is a bonafide work submitted in part fulfilment for the degree of Master of Science (Audiology) of the student Registration number P01II21S0051. This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysore

September 2023

Dr. M. Pushpavathi

Director

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Manasagangothri, Mysore- 570006

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Mysore

September 2023

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DECLARATION

This is to certify that this dissertation entitled **"WBA in individuals with central and marginal type of Tympanic membrane perforation without active discharge"** is the result of my own study under the guidance of Dr. Animesh Barman, Professor in Audiology, Department of Audiology, All India Institute of Speech and Hearing, Mysore and has not been submitted earlier to any other University for award of any other Diploma or Degree.

Mysore **Registration Number:** P01II21S0051

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தெய்வத்தான் ஆகா தெனினும் முயற்சிதன்

மெய்வருத்தக் கூலி தரும்.

Although fate divine may make your labour in vain, efforts will surely be rewarded with the fruit of your labour.

Guided by passion, driven by dreams.

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LIST OF ABBREVIATIONS

WBT - Wideband Absorbance/Reflectance Tympanometry

WBA - Wideband Absorbance

WBTavg. - Wideband Average Tympanometry

TM-Tympanic Membrane

ECV- Ear Canal Volume

SD- Standard Deviation

CI- Confidence Interval

ABSTRACT

Aim and Objectives: This study aims to examine the impact of two different types of tympanic membrane perforations (central and marginal) on WBA measures. Additionally, the study aims to compare the effects of central and marginal perforations with those of a normal ear, as well as to make a comparison between the two types of perforations.

Methods: Two groups in the age range of 18 to 50 years were considered in the study. Group I consisted of ears with central perforation (n=65 ears), and Group II consisted of ears with marginal perforation (n=13 ears). Normative data were taken from the investigation of Karuppannan and Barman (2021). All the participants have undergone WBA measurements across frequencies in both pressure conditions.

Results and Discussion: The WBA measured in Group I across the frequencies and the comparison with the normal ear group revealed a significant difference across all the frequencies. It shows a maximum WBA at 5000 Hz. Individuals with a central perforation displayed a significant decreased absorbance at low frequencies and increased absorbance at high frequencies compared to the control group with normal ears. WBA in Group II across the frequencies and its comparison with the normal ear group revealed a significant difference only at specific frequencies. WBA pattern shows three maxima at 600, 4000, and 6000 Hz and a significant dip at 2000 Hz. Individuals with marginal perforation exhibited near-normal absorbance at lower frequencies. In comparison between the central and marginal perforation, a significant difference was found only in a few frequencies. Central perforation showed lower absorbance than marginal perforation at lower frequencies and decreased absorbance for marginal perforation at mid and high frequencieses. All these findings could be due to the complexity of the tympanic membrane vibration pattern and also could be due to differences in wavelength of the different frequencies.

Conclusion: The results of this study offer information about how the TM functions in transmitting sound and its clinical implications. By utilizing WBT to confirm what is observed during an ear examination, audiologists can guide patients. These measurements prove useful in distinguishing between normal ears and those with perforations, emphasizing their importance for diagnosis.

Keywords: Wideband absorbance tympanometry, Tympanic membrane, central perforation, marginal perforation, Peak pressure, and ambient pressure.

CHAPTER 1

INTRODUCTION

The function of the middle ear is to transfer sound energy from the low-impedance air of the ear canal to the high-impedance fluid of the inner ear. The primary purpose of the TM is to transmit sound waves from the external auditory canal through the ossicular chain to the oval window. This is accomplished because of its vibratory nature. The foremost and most crucial step in transduction occurs at the tympanic membrane (TM); it converts the ear canal's sound pressure to the ossicles' vibrations (Fay et al., 2006).

Tonndorf and Khanna (1972) studied the vibratory characteristics of the cat's tympanic membrane (TM) using Time-Averaged Holography across frequencies where they found that TM vibrates uniformly below 2000Hz. Above which, the vibratory pattern changes significantly in terms of amplitude in the posterior region, which vibrates three times more than other regions; above 3000Hz vibrations tend to be more on anterior regions and finally, above 4000Hz vibrations tend to be more on anterior and posterior regions of the TM than the malleolar tip. With a further increase in frequency, the posterior portion's amplitude peak shifts postero-superiorly. Thus, any abnormality, including perforation in the tympanic membrane, can lead to frequency-specific alterations in sound transmission.

TM perforations can be classified according to the perforation site, whether on pars tensa or flaccida. Pars tensa plays an important role in sound transmission, and the type of TM perforation is basically classified based on the shape, size and place of perforation. In pars tensa, perforation is further classified into central, subtotal, and marginal perforation. The tympanic membrane can be divided into four quadrants using two imaginary lines: one vertical line along the manubrium of the malleus and another line passing through the umbo at a right angle to the first line. The quadrants are anterosuperior, anteroinferior, posteroinferior, and posterosuperior (Szymanski A, 2023).

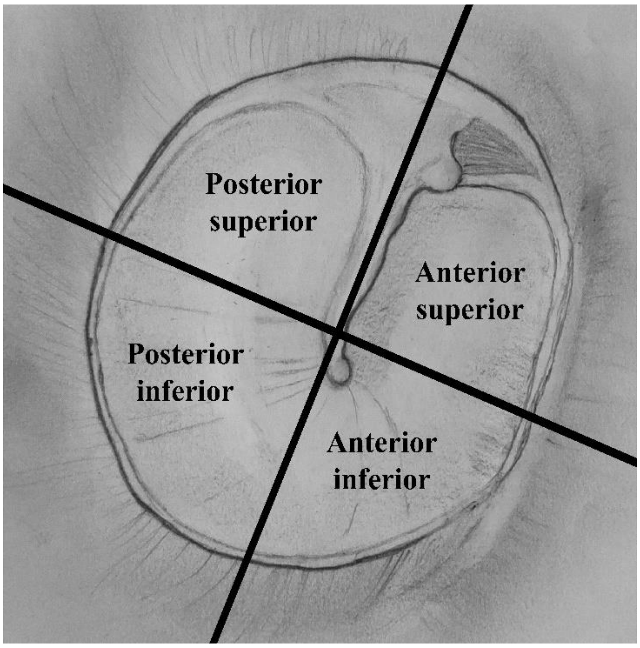

Figure 1.1 – *The right ear tympanic membrane and the quadrants are depicted.*

Central perforation involves different quadrants. If the perforation is situated in the anterior quadrant, it runs from the anterior to the malleus handle. Conversely, if it is in the posterior quadrant, it extends from the posterior to the handle of the malleus tympanicus. Subtotal perforation refers to a significant and extensive perforation of the pars tensa. In cases of marginal perforations, there is a lack of tympanic membrane borders in certain segments.

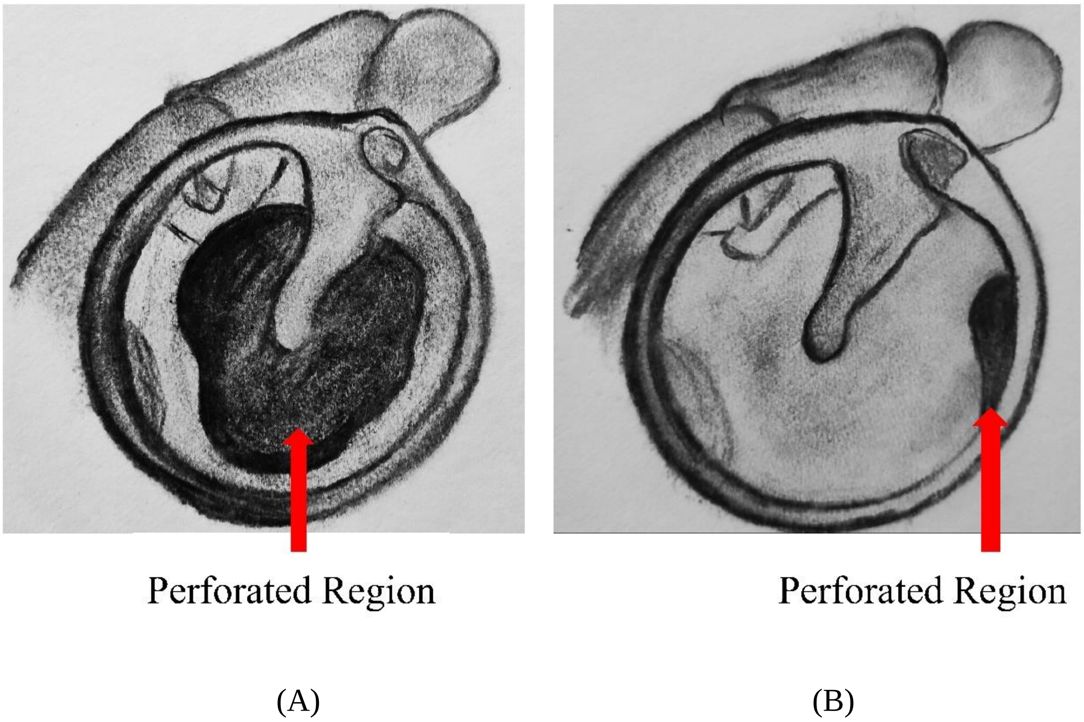

Figure 1.2- *Appearance of the perforated tympanic membrane (A) Central Perforation; (B) Marginal perforation.*

Marginal perforation is often encountered in the posterosuperior quadrant (Faris, 2011). The most common perforation site is the central region of TM, followed by the posterior and anterior areas (Nahata et al., 2014).

The ‘gold standard’ classification to identify the status of TM is defined by trained otolaryngologists, who independently classified each otoscopic image as with or without a tympanic membrane perforation (Habib et al., 2020). There are various methods for identifying middle ear pathologies, including both subjective and objective tests. Subjective tests involve procedures like the tuning fork test and pure-tone audiometry. On the other hand, objective tests encompass immittance audiometry, which consists of tympanometry and acoustic reflex measurement.

The principle behind immittance is either admittance or impedance. Standard immittance measures typically focus on a single frequency. The most common audiological findings that correlate with tympanic membrane (TM) perforation include flat or variable admittance. This means observing a 'B' type tympanogram with a large ear canal volume during conventional 226 Hz tympanometry (Hunter & Shanaz, 2013; Silman & Silverman, 1997). However, in cases with marginal perforations, it's possible to encounter an 'A' or 'As' type of tympanogram.

1.1 NEED FOR THE STUDY

The most common diagnostic method for assessing middle ear transmission function is single-frequency tympanometry with a probe tone of 226 Hz (Ibraheem, 2014). Even though 226 Hz is a commonly used diagnostic tool for evaluating the middle ear system, some studies have reported low accuracy in identifying middle ear pathologies (Hunter et al., 2013; Shahnaz & Polka, 1997). This is because middle ear disorders produce a significant change in the middle ear structures, including the ossicular mass, stiffness of the tympanic membrane, and supporting structures, which leads to frequency-specific attenuation or filtering (Norrix et al., 2013). Many studies showed that single probe frequency has poor sensitivity and specificity for diagnosing middle ear pathologies, particularly in specific middle ear pathologies, which may result in changes in the mechanical aspects of the tympanic membrane (Kaf, 2011). Thus, the single-frequency tympanometry limits the audiologist to see the frequency-specific effect of middle ear pathology and hence reducing the sensitivity and specificity.

To overcome the limitations of standard 226 Hz tympanometry, multi-frequency tympanometry came into existence. Even though multi-frequency tympanometry way much superior to standard 226 Hz tympanometry, it still has some limitations, such as Standing waves above 1500 Hz, which result in a significant difference in sound pressure level within the ear canal, thus can interfere with and obstruct accurate readings at high frequencies (Feeney et al., 2014; Margolis et al., 1999; Sanford et al., 2009). While considering all the disadvantages, therefore, there is a need for an alternative measure that reliably detects middle ear pathology with improved sensitivity and specificity is required, even for mild pathology.

A broadband measure of the middle-ear function provides a more thorough understanding of the middle ear's acoustic response qualities over a broad frequency range. Thus, Wideband acoustic immittance (WAI) tests offer a comprehensive outlook on middle-ear function and are considered valuable methods for assessing effective sound transmission in the middle ear (Margolis et al., 1999).

There are many advantages of WBT over MFT and Single frequency tympanometry, as there is no interference from myogenic noise generated by patient movements (Prieve et al., 2013). WBT can also be recorded even without applying pressure to the ear canal (Keefe & Levi., 1996). The positioning of the probe tip in the ear canal does not influence the WBT measurements (Feeney et al., 2014; Voss et al., 2008). Whereas standard 226 Hz tympanometric measurements are strongly influenced by the depth of the probe tip insertion (Margolis et al., 1999). Therefore, the WBT is emerging as a promising tool for identifying middle ear pathologies with high accuracy and possibly replacing the single probe tone and multi-frequency tympanometry (Hunter et al., 2013; Sanford et al., 2009).

The impact of tympanic membrane perforation on WBA measures has only been evaluated in a few studies (Ibraheem, 2014; Karuppannan & Barman, 2021; J. Kim & Koo, 2015; Voss et al., 2012). There is a lack of consistency in the frequencies showing highly variable energy reflectance/absorbance patterns in individuals with TM perforations, highlighting a research gap. Currently, no studies have compared the perforation sites on WBA measures. Therefore, it is important to investigate how the site of perforation influences the frequency-specific transmission of the tympanic membrane.

Tonndorf and Khanna (1972) studied the vibratory characteristics of the cat's tympanic membrane (TM) using Time-Averaged Holography. They observed that at frequencies below 2000Hz, the TM vibrates uniformly, but above 3000Hz, the vibratory pattern changes significantly, with the posterior region vibrating three times more than other regions. Whereas frequencies above 4000Hz, vibrations tend to be more on both the anterior and posterior regions of the TM compared to the malleolar tip. Additionally, as frequency increases further, the amplitude peak of the posterior portion shifts postero-superiorly. Thus, this also suggests that the location of perforation or size of the perforation might influence the frequency-specific absorbance in WBA measurements, thus justifying the need to explore this condition. Hence, a systematic study on absorbance patterns on different types of TM perforation would help to confirm the frequency-specific importance of TM vibratory patterns and is an academic interest.

1.2 AIM OF THE STUDY

Thus, the present study aimed to investigate the effect of different types of tympanic membrane perforation (central and marginal) on WBA measures.

1.3 OBJECTIVES:

1. To compare the absorbance between normal and central perforation groups across the frequencies.
2. To compare the absorbance between normal and marginal perforation groups across the frequencies.

3. To compare the absorbance between marginal and central perforation groups across frequencies.

CHAPTER 2

REVIEW OF LITERATURE

The tympanic membrane serves as the boundary separating the external auditory canal from the middle ear. The primary purpose of the TM is to transmit sound waves from the external auditory canal through the ossicular chain to the oval window. This is accomplished because of its vibratory nature. The foremost and most crucial step in transduction occurs at the tympanic membrane (TM); it converts the ear canal's sound pressure to the ossicles' vibrations (Fay et al., 2006).

It has been shown in the literature that the tympanic membrane shows frequency-specific transmission(Fay et al., 2006; Møller, 2006; Robert & Funnell, 1983; Tonndorf & Khanna, 1972). Thus, any abnormality, including perforation in the tympanic membrane, can show frequency-specific alterations in sound transmission. WBA can assess any abnormality in the tympanic membrane. A study conducted by Gan in 2016 on chinchillas investigated the relationship between impulse pressure waveform and mechanical damage to the tympanic membrane. The authors explain that peak energy absorbance (EA) occurs when the pressure of the middle ear is equal to that of the external ear in a normal ear with an intact TM. When there is a perforation, the EA is low and flat. However, the authors observed that when the TM didn't rupture after the blast, there was not a significant difference in the EA measurements before and after exposure. From the study, it has been seen that even a tiny split or rupture in the TM significantly influences the EA measurement (Gan et al., 2016).

Wideband tympanometry (WBT) is a technique used to measure the amount of energy absorbed or reflected by the ear. It works by introducing a controlled and diverse range of sounds into an ear canal and then analysing how much of that energy is absorbed or reflected by the eardrum at frequencies. This helps us better understand how the middle ear functions and provides insights into its characteristics (Hunter & Shanaz, 2013; Liu et al., 2008; Margolis et al., 1999). Wideband acoustic immittance (WAI) is another way to refer to Wideband Tympanometry (WBT), which encompasses both Wideband Absorbance (WBA) and Wideband Reflectance (WBR) measurements (Feeney et al., 2014). Wideband acoustic immittance (WAI) tests are highly valuable in assessing middle ear function as they offer a wide range of frequencies for evaluation. These tests have proven to be tools for determining the condition of the ear (Feeney & Keefe, 2012).

There are many advantages of WBT over MFT and Single frequency tympanometry, as there is no interference from myogenic noise generated by patient movements (Prieve et al., 2013). WBT can also be recorded without applying pressure to the ear canal (Keefe & Levi., 1996). The positioning of the probe tip in the ear canal does not influence the WBT measurements (Feeney et al., 2014; Voss et al., 2008). Whereas standard 226 Hz tympanometric measurements are strongly influenced by the depth of the probe tip insertion (Margolis et al., 1999). Therefore, the WBT is emerging as a promising tool for identifying middle ear pathologies with high accuracy and possibly replacing the single probe tone and multi-frequency tympanometry (Hunter et al., 2013; Sanford et al., 2009).

WBT has emerged as an evolving field with numerous applications. It proves valuable in the identification and differential diagnosis of middle-ear disorders, monitoring middle-ear outcomes, and assessing Eustachian tube function (Araújo et al., 2022; Feeney et al., 2003a, 2022; Karuppannan & Barman, 2021; Nakajima et al., 2013; Pan & Yang, 2018; Prieve et al., 2013; Pucci et al., 2017; Sanford et al., 2013; Shahnaz et al., 2023; Turanoglu et al., 2022; Zhang et al., 2023). Additionally, it plays a significant role in paediatric audiology and has been found to be crucial in neonatal hearing screening and assessment (Aithal et al., 2014), as recommended by the Joint Committee on Infant Hearing (JCIH),2019.

The impact of tympanic membrane perforation on WBA measures has only been discussed in a few studies (Allen, 1994; Ellison et al., 2012; Feeney et al., 2003a, 2003b; Gan et al., 2016; Ibraheem, 2014; Karuppannan, 2021; Kim et al., 2019a; Nakajima et al., 2013; Park et al., 2020; Park, 2017; Sanford et al., 2023; Voss et al., 2001a, 2001b, 2001c, 2012). However, the impact of the location of TM perforation on WBA has not been explored extensively.

The study by Karuppannan (2021) compared WBA across various pathological conditions in ambient and peak pressure conditions. For individuals with tympanic membrane perforation, absorbance values were lower in low and mid frequencies, and the high absorbance was observed beyond 4000Hz in peak pressure conditions (Karuppannan, 2021).

A study by Kim et al. (2019) demonstrated lower absorbance values (higher energy reflectance) at ambient pressure conditions in the low and mid-frequency region, significantly below 1000 Hz. So far, only one data demonstrates average absorbance measured at ambient (Kim et al., 2019). Although the TPP was reported, the study measured the WBT average only at ambient pressure, indicating a 'B' type pattern without any measurable peaks and absorbance. A flat absorbance curve without apparent peaks, or a tympanogram of type "B," was seen in ears with TM perforations. In some of the subjects, the study also found measurable peak pressure. WBT_{avg} readings at those peak pressures were not reported. They demonstrated low absorbance in the low and mid-frequency regions, mostly below 1000 Hz.

Park et al. (2020) compared wideband absorbance measures before and after the tympanoplasty surgery, where participants were enrolled due to CSOM and TM perforation. The study found important distinctions in wideband absorbance (WBA) among normal ears, ears with chronic suppurative otitis media (CSOM), and reconstructed ears, particularly at middle to high frequencies. At frequencies of 800 Hz and above, the absorbance in the normal ear was notably higher than in ears with CSOM. Over time, post-operative measures absorbance decreased at low frequencies but increased at middle to high frequencies. Furthermore, a significant positive relationship was observed between changes in air-bone gaps (ABG) and absorbance at corresponding frequencies in the low to middle range (Park et al., 2020).

Contrary, several studies have reported increased absorbance (Allen et al., 2005a; Feeney et al., 2003; Sanford et al., 2023; Voss et al., 2001, 2012). Voss et al. (2001) conducted a study on middle ear function using perforated tympanic membranes (TM). The researchers observed the impact of perforation size and location on sound transmission in cadaveric specimens. They discovered that as the perforation size increased, there was a significant decrease in sound transmission between 1000-2000 Hz. However, for frequencies below 1000 Hz, they observed an increase in sound transmission regardless of the size of the perforation. Additionally, the researchers noted the frequency dependence of loss with perforation. They observed that the increase in loss is directly proportional to the perforation size, but this relationship is evident only in the low-frequency range. In other words, as the perforation size increases, the loss of sound transmission also increases, but this effect is specifically observed at lower frequencies. At higher frequencies, the loss does not show a direct correlation with perforation size.

Feeney et al. (2003) investigated the wideband energy reflectance (ER) at ambient pressure in adults with various types of middle-ear disorders. They found that energy reflectance was minimal at lower frequencies and almost similar to normal across mid-frequencies, and more reflectance was observed between 2000-3500 Hz in individuals with TM perforations (Feeney et al., 2003).

Allen in 2005 evaluated the human middle ear system and acoustic power assessment using a reflectance measurement system. In their study, researchers observed the differences between perforated and intact eardrums in terms of sound reflectance and transmission. They observed that at lower frequencies, specifically below 1500 Hz, perforated eardrums showed lower reflectance than intact eardrums. This lower reflectance indicates that sound is transmitted more effectively through the perforated eardrums than intact eardrums. At higher frequencies, the transmittance of the perforated ear remains high, while that of the normal ear. Additionally, the presence of perforation may alter the ear's impedance (Allen et al., 2005).

Voss et al. (2012) have investigated in depth to see the impact of various-sized tympanic membrane perforations on energy reflectance in cadaveric specimens. The study showed an increase in WBA at low frequencies up to 2000 Hz, i.e., a reduction in energy reflectance up to 2000 Hz. Further, the effect of perforation showed a large variation, with the smallest perforation showing a large effect on absorbance. The authors explained that this significant effect is caused by low-frequency mass created in the perforation zone due to air accumulation. This lowers the resistance and permits low-frequency sound transmission into the middle ear (Jeng et al., 2008). As the size of the TM perforation increases, the resonant frequency moves relatively towards the high-frequency region.

Ibraheem (2014) assessed energy reflectance in patients with tympanic membrane perforation with high ear canal volumes who had a 'B' type tympanogram with high ear canal volume. The results were compared to those of the control adult group with an ‘A’ type tympanogram. Individuals with TM perforations have shown reduced energy reflectance (High absorbance) at low frequencies and increased energy reflectance (Low absorbance) at high frequencies above 1000 Hz (Ibraheem, 2014).

Sanford et al. (2023) have examined wideband acoustic immittance (WAI) across different pathologies such as otitis media with effusion (OME), tympanic membrane (TM) perforation, otosclerosis, excessive middle ear pressure, disarticulation of the ossicular chain, patulous Eustachian tube, tympanosclerosis, cholesteatoma. They found increased WBA across frequencies. The researcher concluded that a perforation in the tympanic membrane results in energy dissipation because sound vibrations are not properly transferred to the ossicular chain and into the oval window. As a result, a large portion of the sound vibrations interact with the expanded air volume and are absorbed within the tympanic cavity. Therefore, the observed wideband acoustic (WBA) patterns reflect the acoustic characteristics of the enlarged air-filled cavity rather than the standard middle ear system (Sanford et al., 2023).

Overall, there is no uniformity in the frequencies with highly variable energy reflectance/absorbance patterns reported on individuals with TM perforations, which leads to the research gap. The research gap led to the need for the study based on the above review of the literature. Most of the studies have been done in the cadaver, and they did not specify any type of perforation, emphasising only the perforation size. In addition, these studies were conducted with a limited sample size. Further, there is a lack of research on absorbance measurements in ears with TM perforations.

CHAPTER 3
METHODS

This study attempted to investigate the effect of different types of tympanic membrane perforation on WBA measures. It is a standard group comparison research (Miri & Shahrokh, 2019) conducted in an academic institute. The participants were recruited through a purposive non-random sampling method (Pope & Mays, 1995), wherein all eligible and interested participants were enrolled for the study.

3.1 Participants

Two groups of participants in the age range of 18 to 60 years were recruited. Thus, participants in Group I with central perforation and participants in Group II with marginal perforation were included in the study. For comparison with the Normal data, the data reported by Karuppannan and Barman (2021) were used, as suggested by the panel of examiners during the presentation of the research proposal.

3.2 Criteria for Inclusion:

3.2.1 Group I:

- Ears with Central perforation.
- This group consisted of ears with isolated dry Central TM perforations and no active ear discharge. The perforation was concentrated around the umbo or malleolar handle (pars tensa region), with intact TM around the bony canal.
- These findings were confirmed by an experienced Otologist.
- Ears had conductive hearing loss (air-bone gap>10 dB)
    - Pure-tone average of less than 60 dB HL in PTA
    - No measurable peak in 226 Hz probe tone tympanogram, i.e., ‘B’ type tympanogram with absent acoustic reflexes between the octave’s

frequencies of 500 Hz and 4000 Hz. High ear canal volumes of >2.0 ml was considered.

- Other middle ear disorders include tympanosclerosis, myringosclerosis, cholesteatoma, ossicle-related disorders, or ears with granulation tissue, hypoplastic mucosa, polypoid degeneration, or otorrhea, as well as the inner ear and neural disorders were excluded from the study.

3.2.2 Group II:

- Ears with marginal perforation.
- This group consisted of ears with isolated dry marginal perforation in the TM, confirmed by the experienced Otologist.
- All the participants in this group had conductive hearing loss (air-bone gap>10 dB)
    - Pure-tone average of less than 60 dB HL in PTA
    - No measurable peak in 226 Hz probe tone tympanogram, i.e., ‘B’ type/ measurable peak with lesser compliance, i.e., ‘A_S’ tympanogram with absent acoustic reflexes between the octave’s frequencies of 500 Hz and 4000 Hz. There is either a normal or high ear canal volume of >2.0 ml in the tympanometric measure.
- The study excluded ears with inner ear and neural disorders, as well as those with tympanosclerosis, myringosclerosis, ossicle-related disorders, granulation tissue, hypoplastic mucosa, polypoid degeneration, or otorrhea.

3.3 Instrumentation

1. GSI AudioStar ProTM dual-channel clinical audiometer (Grason-Stadler et al., USA) was used to estimate the hearing thresholds, speech identification scores and Uncomfortable level.
2. Titan Suite IMP440 Ver 3.0 was used to measure 226 Hz probe tone tympanogram and acoustic reflex thresholds.
3. The Titan Suite IMP440/WBT440 advanced research analyser (Interacoustics A/S, Middelfart, Denmark) connected to a laptop was used to measure wide band absorbance tympanometry.

3.4 Test environment

The tests were conducted in a sound-treated audiometric room with the background permissible noise levels as per ANSI/ASA S3.1-1999 (R2018) standards (ANSI, 2018). During the data collection period, the audiological equipment- GSI AudioStar ProTM dual-channel clinical audiometer, Titan Suite IMP440 Ver 3.0, used for the study was calibrated once in every three months, following the guidelines of ANSI/ASA S3.6-2004 (R2010) and ANSI/ASA S3.39-1987 (R2012) standards as recommended by ANSI (2010, 2012). Whereas Titan Suite IMP440/WBT440 advanced research analyser had to be calibrated daily by inserting the probe assembly into a calibration unit with a volume of 2 cc.

3.5 Test Procedure:

Before the experimental phase, all participants underwent the following audiological examinations to check whether they met the participant's eligibility requirements.

3.5.1 Preliminary evaluations

3.5.1.1 Structured Case History:

A structured case history interview regarding the status of the ear and hearing, along with clinical signs and symptoms, was collected. Also, the participant's medical records indicating any confirmed tympanic membrane perforation diagnosed by the Otologist were recorded.

3.5.1.2 Otoscopic examination:

An otoscopic examination was performed on all participants. The purpose was to check the status of the ear canal and tympanic membrane, identifying any abnormalities, including cerumen accumulation. Additionally, the examination aimed to ascertain whether the perforation was dry or not.

3.5.1.2 Pure tone and speech audiometry:

All the participants underwent pure-tone audiometry and speech audiometry. A modified version of the Hughson and Westlake approach (Carhart & Jerger, 1959)was used to estimate the air conduction (0.25, 0.5, 1, 2, 4, & 8 kHz) and bone conduction (0.25, 0.5, 1, 2, & 4 kHz) thresholds. Speech identification scores were measured at the most comfortable level, i.e., 40 dB SL, with reference to the Speech Recognition Threshold. The degree of hearing loss was decided based on Clark's classification (Clark, 1981) by averaging four frequency hearing thresholds (0.5, 1, 2 and 4 kHz).

3.5.1.3 Immittance Audiometry:

To assess each participant's middle ear status, a tympanogram at 226 Hz probe tone and acoustic reflex thresholds (Ipsi/contralateral at 0.5, 1, 2 and 4 kHz) were measured. Participants were made to sit comfortably and instructed to be quiet while the test was being performed. Ear canal volume, static admittance, and tympanometric peak pressure were recorded for all the participants.

The participants were enrolled to carry out experimental test procedures, i.e., Wideband absorbance tympanometry based on the results of the preliminary audiological evaluations.

Table 3.1

Summary of the Audiological test results used for grouping the participants

GROUPS	**AUDIOMETRIC FINDINGS**	**IMMITTANCE FINDINGS**
Group I	**Conductive hearing loss (Abnormal)**	**Abnormal**
Central Perforation Group	>26 dB HL and < 70 dB HL across all octaves ABG > 10 dB HL No active discharge	B type tympanogram with ECV more than 2.0 ml Absent Ipsi/Contra acoustic reflexes
Group II	**Conductive hearing loss (Abnormal)**	**Abnormal** ‘A_S ’or ‘B’ type
Marginal Perforation Group	>26 dB HL and < 70 dB HL across all octaves ABG > 10 dB HL No active discharge	tympanogram with ECV more than or less than 2.0 ml Absent Ipsi/Contra acoustic reflexes

3.5.2 *Experimental test procedures-Wideband absorbance tympanometry:*

Before initiating the WBA procedure, instrument calibration was done daily by placing the probe assembly in a calibration unit of 2 cc volume. For the purpose of carrying out the WBA measurements, the source reflectance and incident pressure were determined. As recommended by the manufacturer, it was made sure that the reflectance value stays below 15% up to 2 kHz and below 30% above 2000 Hz (Interacoutics, 2016; Liu et al., 2008).

Participants who met the inclusion criterion were subjected to the experimental procedure. The participants were made to sit comfortably during the time of the experiment without any active movement. Each participant was informed of the testing technique, which involved inserting a probe tip into the ear canal to create an airtight seal, generating pressure, and presenting click stimuli. The test participants were given guidance to abstain from swallowing, coughing, talking, and making unnecessary body or head movements throughout the test duration. The probe with a suitable size was firmly placed in the participant's ear canal and the correct probe fit was ensured.

The wideband click stimulus of 100 dBpeSPL was delivered. The pressure was automatically swept between +200 daPa and -400 daPa at the medium-level pump speed of 200 daPa/sec. By averaging the click stimulus response over 32 sweeps, the WBA values were calculated automatically for 1/24th octave frequencies between 226 Hz and 8000 Hz (121 frequencies). Out of the 121 frequencies, absorbance values of 16 frequencies (1/3rd octave frequencies) were considered. The 3-dimensional graph was used to display the WBA values that include frequency on the x-axis (226Hz to 8000Hz), pressure on the y-axis (200 daPa & -400 daPa), and the absorbance values on the z-axis (0 to 100%). WBA values across the frequency typically fall between 0.0 and 1.0, with '1' denoting that the middle ear absorbs all sound energy and '0' indicating that the middle ear reflects all sound energy(Stinson, 1990). The Titan IMP/WBT440 module displays WBA readings across the frequencies at two pressure situations: ambient pressure (0 daPa) and tympanometric peak pressure (TPP). The ear canal volume (ECV) and tympanometric peak pressure (TPP) were also measured as part of the wideband tympanogram.

All the tests were performed automatically by Titan suit and displayed in the 3-dimensional graph (Interacoutics, 2016). WBA measurements were done thrice to check for consistency and eliminate artifacts.

3.6 Statistical analysis:

Statistical analysis was carried out to compare the absorbance values measured across frequencies in ears with TM perforation and the absorbance with the normal ear group. Absorbance values were measured at each frequency (1/3rd octave frequencies from 226 to 8000 Hz), and a comparison was done.

Descriptive statistics (Mean, median, SD and range) were calculated to study the mean absorbance values across the frequencies from 226 Hz to 8000 Hz (16 frequencies) for all the groups. Further, inferential statistics were carried out to study any significant difference between the groups in median absorbance values measured across the frequencies. Within the group comparison was also made to study the difference in median absorbance values obtained at peak pressure and ambient pressure conditions across the frequencies.

The normality of the distribution of WBA measurements acquired across various frequencies under different pressure conditions was evaluated using the Shapiro-

Wilks test. The results have shown that data were not normally distributed for both groups. Significant levels were mostly less than 0.05 for both groups. Values are given in the table 3.2. Similar results were also obtained using the Kolmogorov-Smirnov normality test. Hence non-parametric tests were used to investigate the main effect and their interactions.

The One-Sample Wilcoxon Signed Rank Test was used to analyse the data of normal and perforation ear groups. Normative data reported by Karuppannan and Barman (2021) were considered for the comparison between the normal ears and perforated TM groups. In this procedure, the median of each frequency was taken from the Karuppannan and Barman study and compared with the median of the central and marginal perforation groups.

Mann-Whitney U test was used to compare between the groups. It was used to compare the absorbance values of central and marginal perforation groups. This test was done to determine the frequency range over which significant differences existed between the groups.

Wilcoxon Signed Rank Test was used to compare the absorbance values within groups between peak and ambient pressure. This test was done to determine the frequency range over which significant differences existed within the groups. It was used to study the difference in median absorbance values obtained at peak and ambient pressure conditions across the frequencies.

In this study, the effect size for a non-parametric test, specifically the correlation coefficient (r), was determined by dividing the Z value by the square root of the sample size. The interpretation of the correlation coefficient (r) was as follows: a value between 0.1 and less than 0.3 was considered a small effect, a value between 0.3 and

0.5 was regarded as a moderate effect, and a value of 0.5 or greater was classified as a large effect (Cohen, 1992).

Table 3.2

Shapiro-Wilks test statistical results for normality of WBA obtained at peak and ambient pressure conditions.

Frequency (Hz)	**Peak Pressure**		**Ambient Pressure**	
	Statistic	**p-value**	**Statistic**	**p-value**
250	0.181	<0.001	0.228	<0.001
300	0.215	0.102*	0.268	0.001
400	0.195	<0.001	0.238	<0.001
500	0.165	0.200*	0.237	0.004
600	0.171	<0.001	0.144	0.002
800	0.238	0.043	0.170	0.200*
1000	0.182	<0.001	0.146	0.002
1250	0.301	0.002	0.168	0.200*
1500	0.218	<0.001	0.104	0.078
2000	0.199	0.167*	0.180	0.200*
2500	0.231	<0.001	0.118	0.026
3000	0.176	0.200*	0.218	0.092*
4000	0.194	<0.001	0.084	0.200*
5000	0.245	0.031	0.200	0.159*
6000	0.233	<0.001	0.124	0.015
8000	0.204	0.143*	0.167	0.200*

(*Note*. *Not Significant difference, p>0.05)

Chapter 4

RESULTS

The present study aimed to investigate the effect of two types of tympanic membrane perforation (central and marginal) on WBA measures. To address the objectives of the current study, the data were studied quantitatively and qualitatively and are given under the following headings.

1. Comparison of absorbance between normal and central perforation groups.
2. Comparison of absorbance between normal and marginal perforation groups.
3. Comparison of absorbance between marginal and central perforation groups.

WBA data reported by Karupannan (2021) in normal middle ears were considered for the comparison, as mentioned in the method section.

4.1 Comparison of absorbance between normal and central perforation groups:

Descriptive statistics were made to determine the mean, median, SD, and range of WBA on central and marginal perforation across frequencies in both pressure conditions. Table 4.1 shows the data obtained by Karuppannan and Barman (2021) and table 4.2, and Table 4.6 depicts the data obtained in the Central perforation ears and marginal perforation ears, respectively. A median was also obtained as most of the data did not fall into a normal distribution.

Table 4.1

Mean, SD, median and range of WBA measured in Normal ear across frequencies at TPP and Ambient pressure (Normative data from Karuppannan & Barman study (2021) Taken with permission from the Authors)

Pressure conditions	Frequency (Hz)	Mean	SD	Median	Range
Peak Pressure	250	0.14	0.04	0.14	0.02-0.28
	300	0.17	0.05	0.16	0.03-0.33
	400	0.24	0.06	0.23	0.04-0.45
	500	0.33	0.07	0.33	0.07-0.65
	600	0.45	0.07	0.44	0.12-0.80
	800	0.66	0.07	0.65	0.24-0.96
	1000	0.81	0.08	0.77	0.44-0.99
	1250	0.85	0.08	0.82	0.55-0.99
	1500	0.85	0.09	0.84	0.58-0.99
	2000	0.87	0.08	0.87	0.41-0.99
	2500	0.80	0.13	0.79	0.29-0.99
	3000	0.67	0.16	0.62	0.00-0.80
	4000	0.41	0.15	0.38	0.00-0.59
	5000	0.23	0.09	0.22	0.00-0.42
	6000	0.15	0.07	0.14	0.01-0.54
	8000	0.15	0.10	0.13	0.33-0.82
Ambient Pressure	250	0.14	0.04	0.14	0.00-0.28
	300	0.17	0.05	0.16	0.02-0.33
	400	0.24	0.06	0.24	0.04-0.45
	500	0.33	0.07	0.33	0.05-0.45
	600	0.45	0.07	0.45	0.08-0.80
	800	0.66	0.07	0.66	0.17-0.94
	1000	0.81	0.08	0.81	0.36-0.99
	1250	0.85	0.08	0.86	0.36-0.99
	1500	0.85	0.09	0.86	0.58-0.99
	2000	0.87	0.08	0.88	0.51-0.99
	2500	0.80	0.13	0.82	0.40-0.99
	3000	0.67	0.16	0.67	0.29-0.98
	4000	0.41	0.15	0.40	0.00-0.78
	5000	0.23	0.09	0.22	0.00-0.59
	6000	0.15	0.07	0.14	0.01-0.41
	8000	0.15	0.10	0.12	0.01-0.57

Note- Extracted from the thesis with author’s permission.

Normative data were taken from the investigation of Karuppannan and Barman (2021). It can be observed that the mean WBA data at peak pressure was slightly higher than ambient pressure at the lower frequencies from 250 Hz to 1000 Hz, whereas, at higher frequencies above 1000 Hz, and the differences were negligible. They have observed a significant difference in WBA measures between the ambient and peak pressure conditions at certain frequencies. This difference is particularly pronounced in the low-frequency region, as well as the 3000 Hz and 4000 Hz regions, showing higher absorbance at peak pressure compared to ambient pressure. Graph of normative data from the investigation of Karuppannan and Barman (2021), displayed in Figure 4.1. The pattern showed two (double) relatively non-evident broad peaks at 1250 and 2000 Hz.

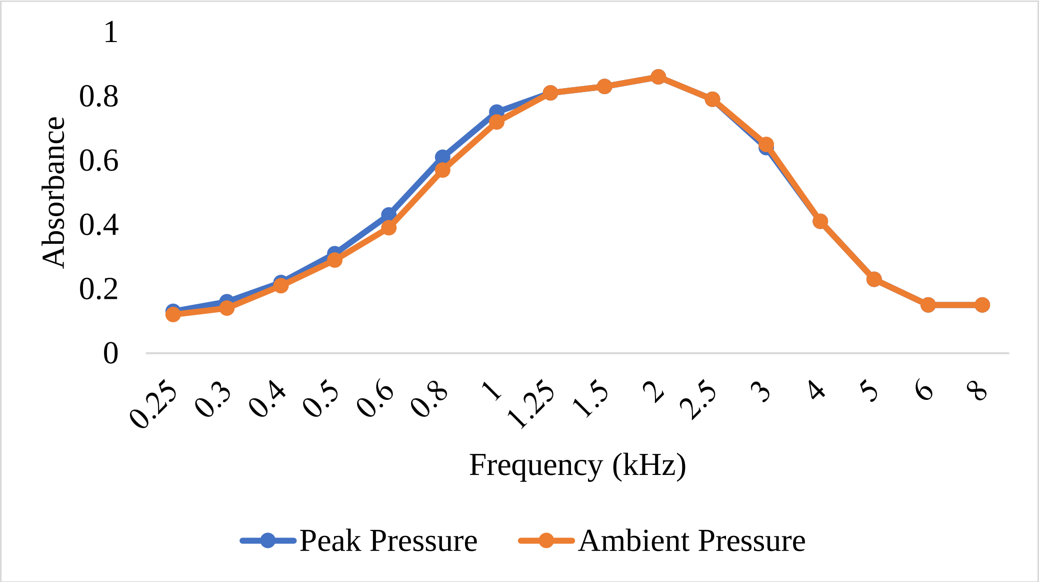

Figure 4.1 *Graphical representation of mean WBA measured at peak and ambient pressure across frequencies in the Normal ear (Depicted with permission from the Authors).*

Similar descriptive statistics were carried out for the data obtained in participants with central perforation. All the individuals in this group showed a ‘B’ type tympanogram and an average ear canal volume of 3.29 +/-1.03 (Range=2.01 to 6.12). Even the ears with central perforation showed tympanometric peak pressure (TPP), and their mean TPP was -260.77+/-35.5(range: -121 to -294 daPa). The reason might be the usage of wide-frequency stimulus. Since the instrument is measuring automatically, the exact method for this measurement is unclear.

Consequently, WBA at this peak pressure, i.e., TPP, and the ambient pressure (0 daPa) were considered for analysis in ears with the central perforation. The measurement method of the WBT avg. in peak pressure is unknown since the instrument operates automatically, and its results are unknown. It was absent for individual with the central perforation.

Table 4.2

Mean, SD, median and range of the WBA obtained across frequencies at peak and ambient pressure conditions in the central perforation group.

			Central Perforation Group		
Pressure conditions	**Frequency (Hz)**	**Mean**	**SD**	**Median**	**Range**
	250	0.09	0.09	0.06	0.00-0.51
	300	0.12	0.13	0.09	0.06-0.65
	400	0.17	0.16	0.14	0.01-0.58
	500	0.21	0.18	0.17	0.00-0.93
	600	0.25	0.21	0.21	0.00-0.58
	800	0.26	0.24	0.20	0.00-0.49
	1000	0.28	0.31	0.16	0.00-0.49
	1250	0.31	0.35	0.10	0.00-0.58
	1500	0.33	0.35	0.13	0.00-0.99

Peak Pressure	2000	0.34	0.36	0.14	0.00-0.93
	2500	0.34	0.32	0.24	0.00-0.98
	3000	0.44	0.28	0.49	0.00-0.98
	4000	0.56	0.22	0.54	0.00-0.97
	5000	0.60	0.16	0.57	0.24-0.99
	6000	0.48	0.19	0.44	0.50-0.99
	8000	0.44	0.23	0.43	0.22-0.95
Ambient Pressure	250	0.09	0.10	0.07	0.07-0.51
	300	0.13	0.12	0.10	0.06-0.65
	400	0.19	0.16	0.16	0.01-0.58
	500	0.22	0.18	0.20	0.00-0.83
	600	0.25	0.21	0.20	0.00-0.58
	800	0.26	0.25	0.16	0.00-0.49
	1000	0.30	0.32	0.16	0.00-0.49
	1250	0.34	0.35	0.19	0.00-0.58
	1500	0.35	0.36	0.28	0.00-0.99
	2000	0.36	0.36	0.21	0.00-0.93
	2500	0.36	0.32	0.31	0.00-0.98
	3000	0.45	0.27	0.47	0.00-0.98
	4000	0.56	0.21	0.54	0.00-0.97
	5000	0.61	0.18	0.59	0.24-0.99
	6000	0.49	0.17	0.47	0.50-0.93
	8000	0.43	0.23	0.40	0.22-0.97

WBA was measured across frequencies at peak pressure, and the ambient pressure showed one maximum at 5000 Hz, as shown in Figure 4.2. A mean minimum absorbance value was observed at 250 Hz, whereas this peak pattern was not seen in the normal group; it was a double and smooth broad peaked pattern for the normal group. Overall, the mean WBA observed in central perforation ears was lower for low and mid frequencies up to 2500Hz. As the frequency increased above

2500 Hz, mean absorbance values also increased. It reached a maximum value at 5000 Hz.

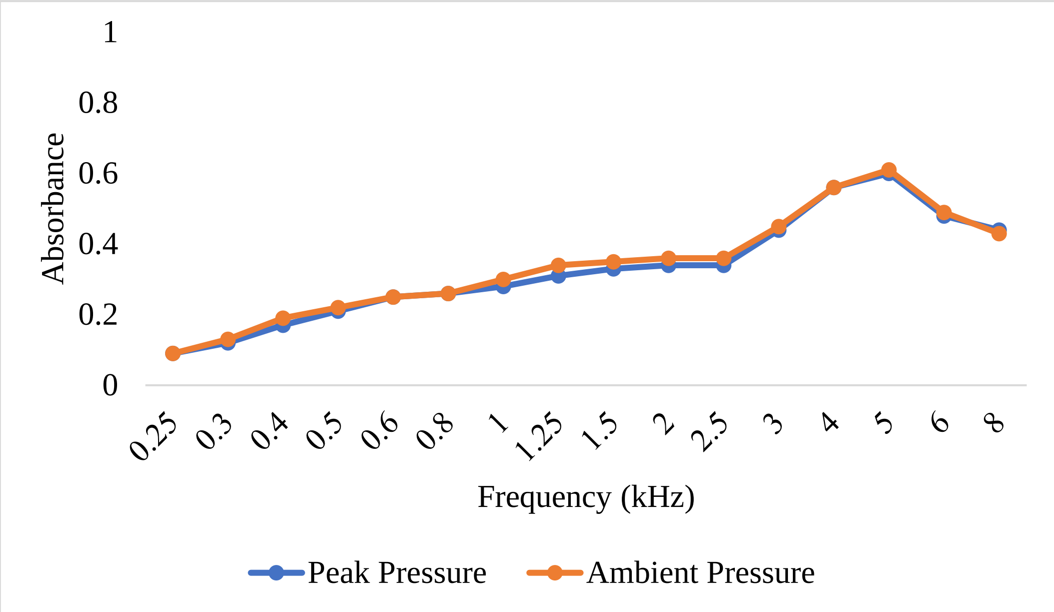

Figure 4.2 *Graphical representation of mean WBA measured at peak and ambient pressure across frequencies in the central perforation group.*

In comparison to the normal ear group, it was seen that the mean absorbance was lesser for the central perforation group at low and mid frequencies that are up to 2500Hz. The absorbance of central perforation has an identical value near 4000 Hz. Absorbance was higher at 5000 Hz, 6000 Hz, and 8000 Hz than the normal group, as shown in Table 4.2 and Figure 4.3.

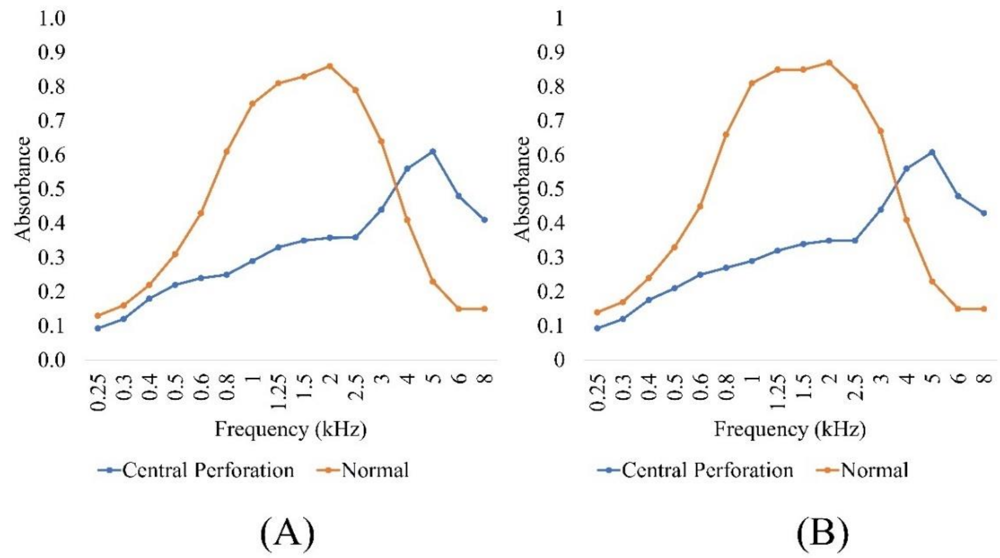

Figure 4.3 *Mean WBA of the central perforation and Normal ear groups obtained at (A) peak pressure and (B) ambient pressure across frequencies.*

A one-sample Wilcoxon signed-rank test was conducted between the normal and central perforation groups. This test was used to determine whether there was any significant difference between the groups. Since our data fall into a non-normal distribution and normative values were taken from previous data, the one-sample Wilcoxon signed-rank test was chosen as the appropriate statistical test.

In one-sample Wilcoxon signed-rank test, the results showed a significant difference ($p<0.05$) between the normal ear group and the central perforation group across all frequencies and in both pressure conditions. The effect size was also considered for the analysis, and it showed a large effect size from 800 to 2500 Hz and also from 5000 to 8000 Hz for peak pressure conditions. Additionally, some frequencies showed a moderate effect size at 250 to 600 Hz, 3000 Hz, and 4000 Hz. In ambient pressure, the large effect size was seen at 800 Hz and from 1500 to 8000 Hz. The moderate effect size was observed at 500 Hz, 600 Hz, 1000 Hz, and 1250

Hz. Apart from the above-mentioned frequencies, others showed a small effect size. The results of the one-sample Wilcoxon signed-rank test are displayed in Table 4.3.

Table 4.3

One-sample Wilcoxon signed rank test results and its significant level of WBA obtained across frequencies between the central perforation group and Normal ear group at peak and ambient pressure conditions.

Pressure	Frequency (Hz)	Median	H. Median	|z|	p	r
Peak Pressure	250	0.06	0.14	4.66	<0.01**	0.35
	300	0.09	0.16	3.10	<0.01**	0.23
	400	0.14	0.23	4.34	<0.01**	0.33
	500	0.17	0.33	4.74	<0.01**	0.36
	600	0.21	0.44	5.28	<0.01**	0.40
	800	0.20	0.65	6.60	<0.01**	0.50
	1000	0.16	0.77	6.62	<0.01**	0.50
	1250	0.10	0.82	6.80	<0.01**	0.51
	1500	0.13	0.84	6.69	<0.01**	0.51
	2000	0.14	0.87	6.92	<0.01**	0.52
	2500	0.24	0.79	6.53	<0.01**	0.50
	3000	0.49	0.62	4.98	<0.01**	0.38
	4000	0.54	0.38	4.46	<0.01**	0.34
	5000	0.57	0.22	6.97	<0.01**	0.53
	6000	0.44	0.14	6.95	<0.01**	0.53
	8000	0.43	0.13	6.87	<0.01**	0.52
	250	0.07	0.14	4.13	<0.01**	0.31
	300	0.10	0.16	3.21	<0.01**	0.24
	400	0.16	0.24	3.49	<0.01**	0.26
	500	0.20	0.33	4.59	<0.01**	0.35
	600	0.20	0.45	5.25	<0.01**	0.40
	800	0.16	0.66	6.60	<0.01**	0.50

Ambient Pressure	1000	0.16	0.81	6.07	<0.01**	0.46
	1250	0.19	0.86	5.09	<0.01**	0.38
	1500	0.28	0.86	6.65	<0.01**	0.50
	2000	0.21	0.88	6.73	<0.01**	0.51
	2500	0.31	0.82	6.47	<0.01**	0.50
	3000	0.47	0.67	6.68	<0.01**	0.51
	4000	0.54	0.40	6.24	<0.01**	0.47
	5000	0.59	0.22	6.95	<0.01**	0.53
	6000	0.47	0.14	6.98	<0.01**	0.53
	8000	0.40	0.12	6.70	<0.01**	0.51

Note- H median- Hypothetical Median; |z| - Standardized Test Statistic; p- Significant level, ** The actual *p*-value was not depicted as the initial three values after the decimals were zero. The shaded region indicates a significant difference with medium to large effect size.

Within the group comparison was made between the two pressure conditions. The WBA measured at ambient pressure was higher than peak pressure for frequencies 1000Hz, 1250Hz, 1500Hz, 2000Hz and 2500 Hz, as shown in Figure 4.2. Further analysis was done using the Wilcoxon-signed rank test. Analysis using the Wilcoxon signed rank test with corrections for the central perforation group showed a significant difference between peak and ambient pressure ($p<0.05$) only for specific frequencies from 250 to 500 Hz and 2500 Hz, as shown in Table 4.4. In the effect size analysis, none of the frequencies showed a moderate to strong effect size.

A median 95% confidence interval (CI) was calculated to estimate the range of values that were likely to encompass the true population parameter within a certain level of confidence. Usually, the mean CI would be calculated, but since our data followed a non-normal distribution, the median was the reliable measure. Data of the median 95% confidence interval is displayed in Table 4.4

Table 4.4

Wilcoxon signed rank results and its significant level; 95% confidence intervals of WBA obtained across frequencies between the pressure conditions (peak, ambient) in the central perforation group

Frequency	**|z|**	**P**	**R**	**95% CI**	
				Peak Pressure	**Ambient Pressure**
250	1.89	0.05*	0.23	0.06,0.09	0.05,0.09
300	2.13	0.03*	0.26	0.07,0.10	0.08,0.11
400	1.94	0.05*	0.24	0.11,0.18	0.12,0.20
500	2.40	0.01*	0.29	0.14,0.20	0.16,0.23
600	0.80	0.42	0.09	0.17,0.23	0.17,0.24
800	1.00	0.31	0.12	0.15,0.22	0.12,0.22
1000	0.46	0.64	0.05	0.08,0.26	0.09,0.28
1250	1.90	0.05*	0.23	0.04,0.25	0.06,0.40
1500	1.07	0.28	0.13	0.00,0.44	0.04,0.50
2000	0.31	0.75	0.03	0.00,0.58	0.02,0.58
2500	2.11	0.03*	0.26	0.14,0.38	0.17,0.24
3000	1.59	0.11	0.19	0.27,0.56	0.32,0.54
4000	1.09	0.27	0.13	0.48,0.60	0.50,0.60
5000	1.36	0.17	0.16	0.54,0.61	0.57,0.64
6000	1.70	0.08	0.21	0.40,0.53	0.42,0.62

8000	0.35	0.72	0.04	0.30,0.50	0.28,0.48

Note- |z| - Standardized Test Statistic; p- Significant level, *Indicates a significant difference, $p<0.05$.

In summary, the WBA measured at the peak and ambient pressure was lesser at low and mid-frequencies up to 2500 Hz for ears with central perforation compared to the normal ears. The pattern observed for WBA measurements across the frequencies showed one evident maximum for the central perforation group, compared to two relatively non-evident maximum peaks for the Normal ears. The summary of findings for the central perforation is displayed in Table 4.5

Table 4.5

Summary of the findings of the central perforation group and its comparison with the normal ear group

Parameters	**Central Perforation Group (In comparison to the normal ear)**
WBA across frequencies from 250 Hz to 8000 Hz	Lower absorbance value up to 2500 Hz and higher at 5000, 6000 and 8000 Hz.
WBA pattern	Showed a maximum at 5000 Hz compared to the smooth broad and double-peaked pattern in normal ears. WBA between the pressure in ears with CP are identical

4.2 Comparison of absorbance between normal and marginal perforation groups:

Similar descriptive statistics were carried out for the data obtained in participants with marginal perforation. All the individuals in this group either showed an ‘A_s’ or ‘B’ type tympanogram and an average ear canal volume of 2.49 +/-0.82 (Range=1.41 to 3.81). Tympanic peak pressure was also measured as part of data collection), and their mean TPP was -162.00+/-45.0 (Range=-95 to -221 daPa). Similar to the central perforation group, here also, the individuals who had the ‘B’ type also got the tympanic peak pressure. Table 4.6 depicts the details of the results obtained in the descriptive statistics.

Table 4.6

Mean, SD, median, and range of the WBA obtained across frequencies at peak and ambient pressure conditions in the marginal perforation group.

		Marginal Perforation Group			
Pressure conditions	**Frequency (Hz)**	**Mean**	**SD**	**Median**	**Range**
Peak Pressure	250	0.13	0.12	0.06	0.00-0.44
	300	0.17	0.17	0.09	0.00-0.63
	400	0.26	0.26	0.14	0.00-0.98
	500	0.32	0.24	0.17	0.11-0.96
	600	0.36	0.21	0.21	0.17-0.91
	800	0.29	0.25	0.20	0.00-0.85
	1000	0.28	0.28	0.16	0.00-0.83
	1250	0.21	0.23	0.10	0.00-0.61
	1500	0.19	0.22	0.13	0.00-0.59
	2000	0.19	0.24	0.14	0.21-0.51
	2500	0.33	0.34	0.24	0.23-0.95

	3000	0.42	0.25	0.49	0.05-0.85
	4000	0.52	0.18	0.54	0.16-0.74
	5000	0.44	0.21	0.57	0.08-0.73
	6000	0.54	0.22	0.44	0.24-0.95
	8000	0.37	0.17	0.43	0.09-0.69
Ambient Pressure	250	0.14	0.12	0.07	0.00-0.44
	300	0.18	0.16	0.10	0.00-0.63
	400	0.27	0.26	0.16	0.10-0.98
	500	0.38	0.23	0.20	0.10-0.95
	600	0.41	0.24	0.20	0.16-0.90
	800	0.34	0.29	0.16	0.20-0.91
	1000	0.28	0.28	0.16	0.00-0.77
	1250	0.20	0.23	0.19	0.14-0.59
	1500	0.18	0.23	0.28	0.15-0.59
	2000	0.12	0.20	0.21	0.00-0.51
	2500	0.24	0.32	0.31	0.00-0.95
	3000	0.36	0.22	0.47	0.09-0.84
	4000	0.49	0.17	0.54	0.16-0.69
	5000	0.43	0.21	0.59	0.08-0.79
	6000	0.54	0.21	0.47	0.34-0.95
	8000	0.36	0.16	0.40	0.09-0.61

WBA was measured across frequencies at peak pressure, and the ambient pressure showed three maxima at 600 Hz, 4000 Hz, and 6000 Hz and a dip at 2000 Hz, as shown in Figure 4.4. Mean minimum absorbance values were observed at 250 Hz and 2000 Hz, whereas this peak pattern was not seen in the normal group; instead, it exhibited a double and smooth broad peaked pattern. Overall, the mean WBA observed increased sharply until 600 Hz, followed by a steeper decrease in absorbance until 2000 Hz. As the frequency increased above 2000 Hz, mean absorbance values also increased sharply, reaching a maximum at 4000 Hz, then slightly decreased WBA value at 5000 Hz and again increased to have a maximum absorbance value at 6000 Hz. The WBA pattern in marginal perforation exhibited variations under different pressure conditions. At frequencies ranging from 250 to 800 Hz and at 1500 Hz, the absorbance was higher in the ambient pressure condition compared to the peak pressure condition. Conversely, between 2000 and 3000 Hz, the absorbance was greater in the peak pressure condition than in the ambient pressure condition. The absorbance remained identical at 1000, 1250, 4000, and 6000 Hz.

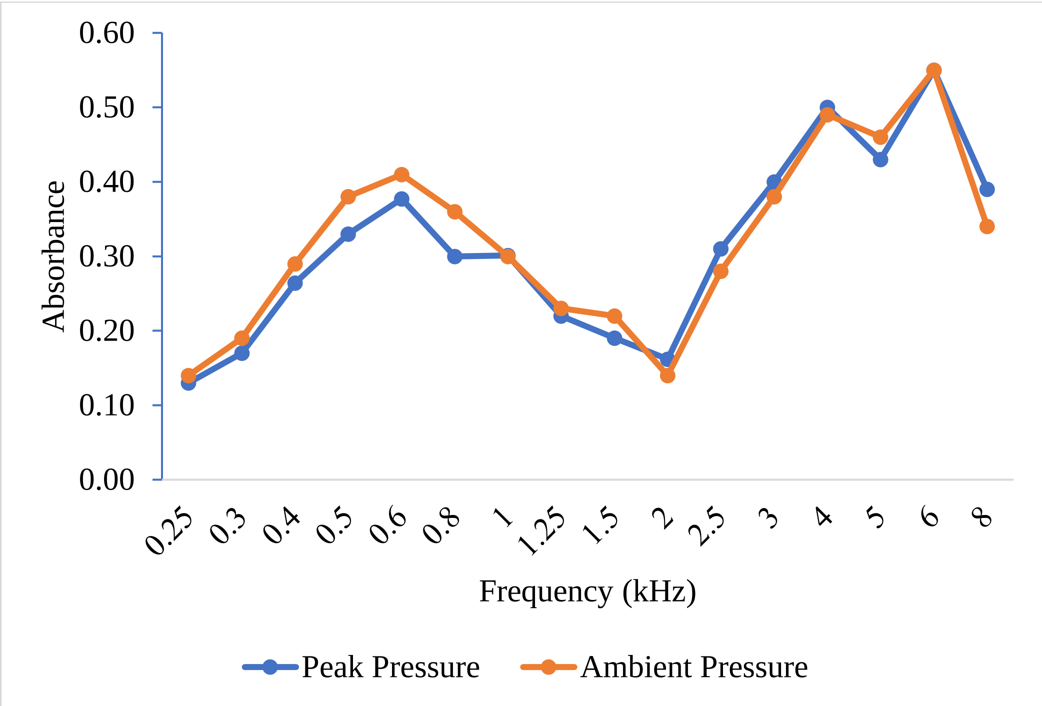

Figure 4.4 *Graphical representation of mean WBA measured at peak and ambient pressure across frequencies in the marginal perforation group.*

In comparison to the normal ear group, it was seen that the mean absorbance was lesser for the marginal perforation group at mid frequencies from 600 Hz to 3000 Hz. The absorbance of marginal perforation was identical at low frequencies from 250 Hz to 600 Hz. WBA of marginal perforation was higher at 4000 Hz,5000 Hz,6000 Hz and 8000 Hz than the normal group for peak and ambient pressure, as shown in Figure 4.5.

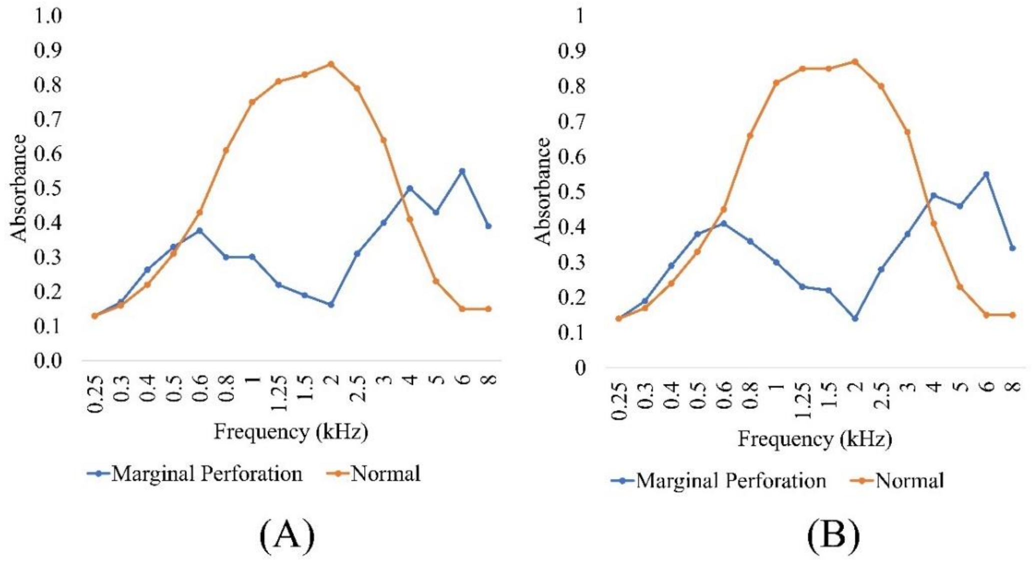

Figure 4.5. *Mean WBA of the marginal perforation and Normal ear groups obtained at (A) peak pressure and (B) ambient pressure across frequencies.*

In a one-sample Wilcoxon signed-rank test, the results showed a significant difference ($p<0.05$) between the normal ear group and the marginal perforation group in specific frequencies in both pressure conditions. The frequencies that exhibited significant differences were mid-frequencies from 800 to 2500 Hz, WBA values being lesser for marginal perforation groups and high frequencies from 4000 to 8000 Hz in peak pressure, WBA being more in marginal perforation groups, whereas, in ambient pressure, significant differences were observed in mid and high frequencies from 800 to 8000 Hz. In peak pressure, higher frequencies from 4000 to 8000 Hz showed a medium to large effect size, whereas from 800 to 3000 Hz showed a small effect size. In ambient pressure, the moderate to large effect size was seen only at 800 Hz. Apart from the above-mentioned frequency, others showed a small effect size. The results of the one-sample Wilcoxon signed-rank test are displayed in Table 4.7.

Table 4.7

One-sample Wilcoxon signed rank test results and its significant level of WBA obtained across frequencies between the marginal perforation group and Normal ear group at peak and ambient pressure conditions.

Pressure Conditions	**Frequency (Hz)**	**Median**	**H. Median**	**|z|**	**p**	**r**
Peak Pressure	250	0.08	0.14	0.94	0.34	0.08
	300	0.12	0.16	0.38	0.70	0.03
	400	0.20	0.23	0.59	0.55	0.05
	500	0.24	0.33	1.22	0.22	0.11
	600	0.30	0.44	1.78	0.07	0.11
	800	0.21	0.65	2.97	0.03*	0.16
	1000	0.22	0.77	3.11	0.02*	0.27
	1250	0.16	0.82	3.19	0.01*	0.28
	1500	0.17	0.84	3.2	0.01*	0.29
	2000	0.03	0.87	3.19	0.01*	0.29
	2500	0.23	0.79	2.97	0.03*	0.27
	3000	0.41	0.62	4.98	0.13	0.17
	4000	0.53	0.38	1.92	0.05*	0.45
	5000	0.54	0.22	6.95	<0.01**	0.62
	6000	0.50	0.14	3.18	0.01*	0.30
	8000	0.34	0.13	6.87	<0.01**	0.62
	250	0.14	0.14	0.31	0.75	0.02
	300	0.17	0.16	0.24	0.87	0.02
	400	0.20	0.24	0.10	0.91	0.09
	500	0.29	0.33	0.38	0.70	0.03
	600	0.32	0.45	1.78	0.07	0.16
	800	0.20	0.66	6.60	<0.01**	0.60

	1000	0.23	0.81	2.90	0.04*	0.26
Ambient	1250	0.16	0.86	3.21	0.01*	0.29
Pressure	1500	0.17	0.86	3.23	0.01*	0.29
	2000	0.19	0.88	3.26	<0.01**	0.29
	2500	0.27	0.82	2.97	0.03*	0.27
	3000	0.34	0.67	3.11	0.02*	0.28
	4000	0.51	0.40	3.18	0.01*	0.29
	5000	0.54	0.22	2.55	0.01*	0.23
	6000	0.48	0.14	3.18	<0.01**	0.29
	8000	0.34	0.12	3.04	0.02*	0.27

Note- H. Median- Hypothetical Median |z| - Standardized Test Statistic; p- Significant level, ** The actual *p*-value was not depicted as the initial three values after the decimals were zero. *Indicates a significant difference, p<0.05. The shaded region indicates a significant difference with medium to large effect size.

Within the group comparison was made between the pressure conditions; the mean WBA measured at ambient pressure was slightly higher for low frequencies from 250 to 2000 Hz than the peak pressure. However, it has been noted that the mean WBA at peak pressure is greater than ambient pressure for high frequencies. Other than the above-mentioned frequencies remaining frequencies of WBA were almost similar for both pressure conditions, as shown in Figure 4.4. Further analysis was done using the Wilcoxon-signed rank test. Analysis using the Wilcoxon signed rank test with corrections for the marginal perforation group showed a significant difference between peak and ambient pressure (p<0.05) only for 800 Hz and 2000 to 5000 Hz, as shown in Table 4.8. The effect size analysis revealed a moderate to strong effect size between 800 Hz as well as at higher frequencies ranging from

2000 to 5000 Hz. A 95% confidence interval was also measured as part of the analysis, and those values were displayed in Table 4.8.

In summary, the average WBA demonstrated a significant increase up to 600 Hz, followed by a decline in absorbance until 2000 Hz. Beyond 2000 Hz, the mean absorbance values exhibited a rapid rise, peaking at 4000 Hz, with a slight decrease at 5000 Hz and another peak at 6000 Hz. This distinctive trend in WBA across frequencies was evident both at peak pressure and ambient pressure conditions. Notably, the WBA pattern exhibited three prominent peaks at 600 Hz, 4000 Hz, and 6000 Hz, along with a trough at 2000 Hz. A summary of the findings for the marginal perforation can be found in Table 4.9.

Table 4.8

Wilcoxon signed rank results and its significant level of WBA obtained across frequencies between the pressure conditions (peak, ambient) in the marginal perforation group.

Frequency (Hz)	**|z|**	**p**	**r**	**95%CI**	
				Peak Pressure	**Ambient Pressure**
250	0.71	0.47	0.19	0.04,0.17	0.04,0.17
300	0.81	0.41	0.22	0.06,0.24	0.04,0.23
400	0.51	0.95	0.14	0.08,0.25	0.08,0.36
500	1.57	0.11	0.43	0.18,0.31	0.22,0.36
600	1.24	0.21	0.34	0.19,0.43	0.21,0.44
800	2.01	0.04*	0.55	0.10,0.44	0.13,0.44
1000	0.30	0.75	0.08	0.04,0.33	0.02,0.38
1250	0.59	0.55	0.16	0.00,0.36	0.00,0.26
1500	0.85	0.93	0.23	0.00,0.27	0.00,0.35
2000	1.68	0.03*	0.46	0.00,0.36	0.00,0.17

2500	2.49	0.01*	0.68	0.11,0.51	0.00,0.34
3000	2.43	0.01*	0.67	0.18,0.52	0.18,0.46
4000	2.43	0.01*	0.67	0.30,0.67	0.29,0.61
5000	1.86	0.05*	0.51	0.14,0.59	0.09,0.64
6000	0.05	0.95	0.01	0.35,0.69	0.35,0.69
8000	1.07	0.28	0.29	0.24,0.61	0.26,0.50

Note- |z| - Standardized Test Statistic; p- Significant level. *Indicates significant difference, p<0.05. The shaded region indicates a significant difference with medium to large effect size.

Table 4.9

Summary of the findings of the marginal perforation group and its comparison with the normal ear group

Parameters	**Marginal Perforation group (In comparison to the normal ear)**
WBA across frequencies from 250 Hz to 8000 Hz	Lower absorbance value up from 600 to 4000 Hz and higher at 5000, 6000 and 8000 Hz.
WBA pattern	Three maxima at 600, 4000 and 6000 Hz and a dip at 2000 Hz compared to the double and smooth broad peaked pattern in normal ears. WBA patterns in Marginal perforation in both pressures, conditions are almost identical.

4.3 Comparison of absorbance between marginal and central perforation groups:

The current study results have shown that there was a significant difference between the normal and the perforated Tympanic membrane groups, which includes both the central and marginal perforation. In the current section, an attempt has been made to compare the WBA data across frequencies obtained in two perforated tympanic membrane groups, i.e., central and marginal perforation. The WBA obtained across frequencies in central and marginal perforation were tabulated, and descriptive statistics are given in Tables 4.2 and 4.6.

Comparing the WBA pattern in peak pressure between the two groups revealed that the marginal perforation group exhibited higher absorbance at the low frequencies compared to the central perforation group. In the mid frequencies, ranging from 1250 to 3500 Hz, a difference in absorbance was observed between the marginal and central perforation groups, with higher absorbance measured in the central perforation group. This trend continued in the higher frequencies, where absorbance was also higher in the central perforation group, except at 6000 Hz. At 6000 Hz, the marginal perforation group exhibited slightly higher absorbance compared to the central perforation group. A similar pattern was observed in ambient pressure as well, as shown in Figure 4.6

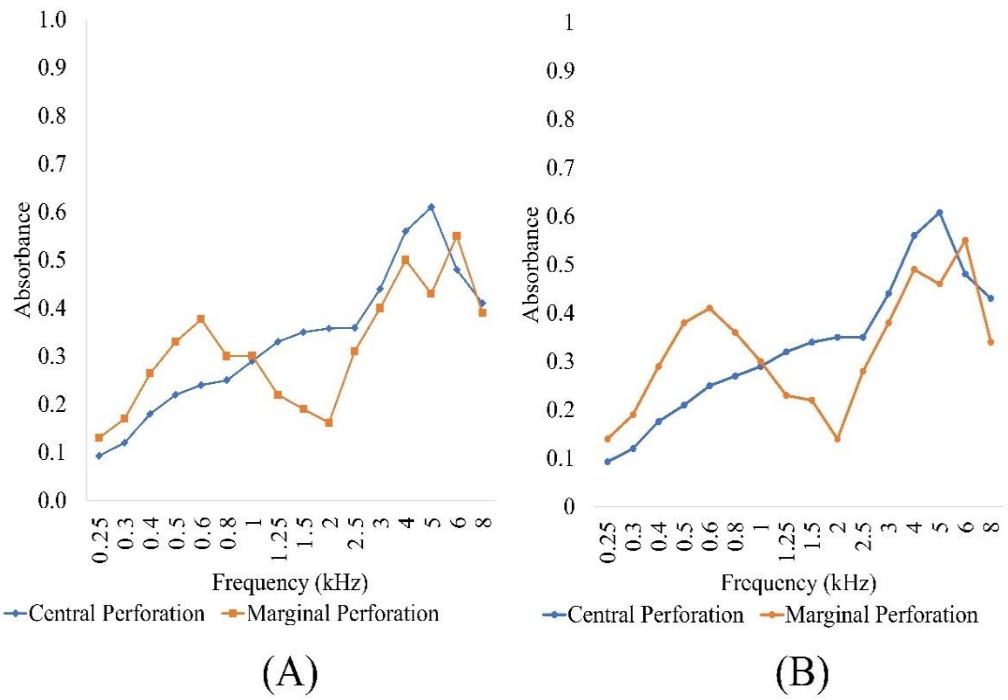

Figure 4.6. *Mean WBA of the central perforation and marginal perforation obtained at (a) peak pressure and (b) ambient pressure across frequencies.*

The Mann-Whitney U test was utilised to investigate whether there are significant differences in absorbance values across frequencies between the study groups (central and marginal perforations) under both peak and ambient pressure conditions. The findings showed that a statistically significant distinction between the groups was observed in just seven frequencies which includes both peak and ambient pressure conditions. Frequencies that exhibited significant differences in peak pressure are 500, 600 and 5000 Hz. Frequencies that exhibited significant differences in ambient pressure are 500, 600, 2000 and 5000 Hz.

The effect size was considered for the analysis, and it showed a moderate to large effect size at 500 and 600 Hz and 5000 Hz showed a small effect in pressure condition. In ambient pressure, the moderate to large effect size was seen at 500, 600 and 2000 Hz and a small effect size at 5000 Hz. The values of the Mann-Whitney U test are tabulated in Table 4.10

Table 4.10

Mann-Whitney U test results of WBA obtained between the central perforation and marginal perforation group with effect size at peak and ambient pressure conditions

Pressure Conditions	Frequency (Hz)	U	|z|	p	r
Peak Pressure	250	343.0	1.06	0.28	0.12
	300	323.0	1.33	0.18	0.15
	400	338.0	1.13	0.25	0.12
	500	251.5	2.29	0.02*	0.35
	600	261.5	2.15	0.03*	0.34
	800	405.0	0.23	0.81	0.02
	1000	419.5	0.04	0.96	0.00
	1250	372.5	0.68	0.49	0.07
	1500	341.5	1.12	0.26	0.12
	2000	343.0	1.10	0.27	0.12
	2500	422.0	0.00	0.99	0.00
	3000	405.5	0.22	0.82	0.02
	4000	399.5	0.30	0.75	0.03
	5000	265.5	2.10	0.03*	0.23
	6000	375.5	0.63	0.52	0.07
	8000	365.5	0.76	0.44	0.08
Ambient Pressure	250	321.5	1.35	0.17	0.15
	300	322.0	1.34	0.17	0.15
	400	348.5	0.99	0.32	0.11
	500	216.0	2.76	<0.01**	0.31
	600	217.0	2.75	<0.01**	0.31
	800	352.5	0.93	0.34	0.10

1000	419.5	0.04	0.96	0.00
1250	333.0	1.22	0.21	0.13
1500	296.0	1.74	0.08	0.19
2000	260.0	2.25	0.02*	0.35
2500	326.0	1.29	0.19	0.14
3000	347.0	1.01	0.31	0.11
4000	353.5	0.92	0.35	0.10
5000	246.0	2.36	0.01*	0.26
6000	375.5	0.63	0.52	0.07
8000	373.4	0.65	0.51	0.07

Note- |z| - Standardized Test Statistic; p- Significant level, ** The actual *p*-value was not depicted as the initial three values after the decimals were zero. *Indicates a significant difference, $p<0.05$. The shaded region indicates a significant difference with medium to large effect size.

In summary, the WBA characteristics differ significantly between the Central Perforation Group and the Marginal Perforation Group. For the Central Perforation Group, absorbance is lower up to 2500 Hz, increasing notably at 5000, 6000, and 8000 Hz. In the Marginal Perforation Group, absorbance rises from 250 to 600 Hz, drops steeply between 800 and 2000 Hz, rises distinctly from 2500 Hz to 4000 Hz, dips at 5000 Hz, and peaks again at 6000 Hz. The Central Perforation Group's pattern features a maximum at 5000 Hz, while the Marginal Perforation Group exhibits three maxima at 600 Hz, 4000 Hz, and 6000 Hz, with a dip at 2000 Hz. The summary table of statistical analysis is displayed in Table 4.12.

Table 4.11

Summary of the findings of the central perforation group and marginal perforation group.

Parameter	**Central Perforation Group**	**Marginal Perforation Group**
WBA across Frequencies from 250 Hz to 8000 Hz	Lower absorbance up to 2500 Hz Higher absorbance at 5000, 6000, and 8000 Hz	From 250 to 600 Hz: Absorbance increases. From 800 to 2000 Hz: There is a significant and steep decrease in absorbance. From 2500 Hz to 4000 Hz: Absorbance sharply rises. At 5000 Hz: There is a slight drop in absorbance. At 6000 Hz: Absorbance reaches its maximum point.
WBA pattern	A maximum at 5000 Hz.	Three maxima at 600 Hz, 4000 Hz, and 6000 Hz - Dip at 2000 Hz

To summarise, the One-sample Wilcoxon signed rank test revealed significant differences across frequencies between normal and central perforation ears under both pressure conditions. For marginal perforation ears, peak pressure showed significant differences at 800 Hz and 2000 to 5000 Hz. Comparing central and marginal perforation groups, the Mann-Whitney U test revealed significant differences, including 500, 600, and 5000 Hz under peak pressure and 500, 600, 2000, and 5000 Hz under ambient pressure. Within the group, the Wilcoxon signed-rank test demonstrated significant differences for central perforations only at specific frequencies: 250 to 500 Hz and 2500 Hz, without significant effect size. Similarly, marginal perforations exhibited a significant difference ($p<0.05$) only at specific frequencies: 800 Hz and 2000 to 5000 Hz, with a moderate to strong effect size.

Table 4.12

Summary of statistical analysis across frequencies carried out between the groups

Pressure	**Frequency (Hz)**	**Median**			**One sample Wilcoxon signed rank test**		**Mann-Whitney U test**
		Normal Ear Group	**GROUP I**	**GROUP II**	**GROUP I**	**GROUP II**	**-**
	250	0.14	0.09	0.08	S**	NS	NS
	300	0.16	0.12	0.12	S**	NS	NS
	400	0.23	0.17	0.20	S**	NS	NS
	500	0.33	0.21	0.24	S**	NS	S*
	600	0.44	0.25	0.30	S**	NS	S*
	800	0.65	0.26	0.21	S**	S**	NS
	1000	0.77	0.28	0.22	S**	S**	NS
	1250	0.82	0.31	0.16	S**	S**	NS
	1500	0.84	0.33	0.17	S**	S**	NS
	2000	0.87	0.34	0.03	S**	S**	NS

Peak pressure	2500	0.79	0.44	0.23	S**	NS	NS
	3000	0.62	0.44	0.41	S**	NS	NS
	4000	0.38	0.56	0.53	S**	S*	NS
	5000	0.22	0.60	0.54	S**	S**	S*
	6000	0.14	0.48	0.50	S**	S**	NS
	8000	0.13	0.44	0.34	S**	S**	NS
Ambient pressure	250	0.14	0.07	0.14	S**	NS	NS
	300	0.16	0.10	0.17	S**	NS	NS
	400	0.24	0.16	0.20	S**	NS	NS
	500	0.33	0.20	0.29	S**	NS	S*
	600	0.45	0.20	0.32	S**	NS	S*
	800	0.66	0.16	0.20	S**	S**	NS
	1000	0.81	0.16	0.23	S**	S**	NS
	1250	0.86	0.19	0.16	S**	S**	NS
	1500	0.86	0.28	0.17	S**	S**	NS
	2000	0.88	0.21	0.19	S**	S**	NS
	2500	0.82	0.31	0.27	S**	S**	NS
	3000	0.67	0.47	0.34	S**	S**	NS

4000	0.40	0.54	0.51	S**	S*	NS
5000	0.22	0.59	0.54	S**	S**	S*
6000	0.14	0.47	0.48	S**	S**	NS
8000	0.12	0.40	0.34	S**	S**	NS

Note- S*- significant difference at the level of $p<0.05$; S**- significant difference at $p<0.03$; NS- Not significant.

Chapter 5

DISCUSSION

The present study aimed to determine the wideband absorbance across frequencies in individuals with central and marginal perforation. This study assessed the wideband absorbance (WBA) in the ears of individuals with central and marginal tympanic membrane perforations (TM) under peak and ambient pressure conditions. The measurements were taken across various frequencies and compared to the normative data from Karupannan (2021). The statistical comparison and significance level were evaluated using the One-Sample Wilcoxon Signed Rank Test, the Wilcoxon Signed Rank Test, and the Mann-Whitney U Test to achieve the objectives. The results of the study are discussed under the following categories:

1. Comparison of absorbance between normal and central TM perforation groups.
2. Comparison of absorbance between normal and marginal TM perforation groups.
3. Comparison of absorbance between marginal and central TM perforation groups.

5.1 Comparison of absorbance between normal and central TM perforation groups:

The study compared the WBA across frequencies obtained at peak and ambient pressure in the central perforation group with the normal ear group. The central perforation group demonstrated lower absorbance values at low and mid-frequencies with significant reduction up to 2500 Hz and higher absorbance beyond 3000 Hz. The present study observed a significant difference between the normal ear group and the central perforation group across various frequencies. The normal ear group's wideband absorbance (WBA) pattern exhibited a smooth, broad, and double-peaked pattern typical of healthy ears. However, individuals within the central perforation group showed a reduction in absorbance up to 2500 Hz and a single peak at 5000 Hz. WBA pattern is identical in both pressure conditions for both groups.

The present study's findings are consistent with the outcomes of Kim et al. (2019) research, which demonstrated reduced absorbance values within the low and mid-frequency range, primarily concentrated below 1000 Hz. The results of the present study were found to be similar to that of the study conducted by Karuppannan and Barman (2021), which demonstrated reduced absorbance in the low and mid frequencies region. Additionally, they observed lower absorbance in the mid-frequency region also.

Contradictory results are also documented in the literature, where reduced reflectance – indicating increased absorbance – is noted for frequencies ranging from 250 Hz to 1000 to 2000 Hz in ears with perforations (Allen et al., 2005; Feeney et al., 2003; Ibraheem, 2014; Sanford et al., 2023; Voss et al., 2012). The authors explained this variation by pointing out that the middle ear's mass increases due to the perforation in the eardrum. This opening allows low-frequency energy to enter the middle ear (Kim & Koo, 2015). The greater absorption at low frequency i.e., lesser energy reflectance, is attributed to the considerable volume of the middle ear space, which includes both the ear canal volume and the middle ear, resulting from the tympanic membrane perforation (Ibraheem, 2014).

Some studies have compared the size of perforations and their effects on absorbance (Nakajima et al., 2013; Voss et al., 2012), which yielded various results. However, in our study, the size of the perforation was not considered when measuring WBA across frequencies in the central perforation group, which could have influenced the results.

Scientific literature demonstrates that the primary contributors to impedance matching are the advantageous eardrum-to-oval window area ratio and the buckling effect (Gelfand, 2016). The umbo, situated centrally in the tympanic membrane (TM), is vital in transmitting sound to the middle ear. When a central perforation affects the umbo, it triggers both the area ratio advantage and the curved membrane effect in sound transmission. This effect can also be viewed in accordance with Tonndorf and Khanna's study in 1972, which explored vibratory patterns. Below 2000 Hz, the tympanic membrane (TM) normally vibrates cohesively(Tonndorf & Khanna, 1972). However, individuals with a central perforation experience disrupted vibratory patterns, significantly diminishing the effectiveness of the area ratio mechanism and buckling effect. Consequently, low frequency requires a larger area due to its longer wavelength. This requirement could potentially result in decreased absorbance.

One reason for the increased impact at lower frequencies could be attributed to central perforation, which leads to a primary mechanism of transmission loss. This mechanism involves a decrease in the propagation of sound waves across the tympanic membrane. This phenomenon occurs because sound waves passing through the perforation are reflected back in the opposite direction, leading to a cancellation effect. This factor significantly contributes to the amplification of hearing loss, especially in cases of larger perforations. The greater the size of the perforation, the greater the proportion of the sound waves that pass through the perforation and cause the nullifying effect. Moreover, the perforation's margin introduces resistance to the passage of sound waves, and lower-frequency sounds encounter greater resistance compared to their higher-frequency counterparts. Thus, leading to a reduction in absorbance at low frequencies. Due to perforation, this may lead to a decrease in sound pressure across the tympanic membrane (TM), resulting in reduced sound transmission through the TM, and it can also impede middle ear propagation (Ahmad & Ramani, 1979; Voss et al., 2001a, 2001b, 2001c).

In relation to higher frequencies, significant variability in results has been observed across studies, with only a limited number of researchers reporting near-normal reflectance/absorbance patterns above 1000 Hz (Feeney et al., 2003; Voss et al., 2012) and a few others reporting absorbance were more above 4000 Hz (Allen et al., 2005; Jeng et al., 2008; Karuppannan & Barman, 2021a), as similar to the current finding. The reason for having a maximum at 5000 Hz is not clear.

Contradictory results have also been noted, stating a significant reduction in absorbance at the higher frequency region (Stomackin et al., 2019). In gerbils, as the size of the tympanic membrane perforation was expanded to surpass 25%, the reductions displayed a frequency-dependent alteration. More significant decreases were evident at higher testing frequencies, followed by a reversal in the pattern, ultimately reaching a plateau. It may be due to a decrease in the initial mechanical drive to the umbo accompanied by a minor reduction in sound transfer along the ossicular chain, which affects the transmission of higher frequencies.

The increased absorbance in the high-frequency region could be attributed to shorter wavelengths that can pass through a larger perforated tympanic membrane. Additionally, as the frequency increases, the vibratory pattern of the tympanic membrane changes from a uniform vibratory pattern up to 2000 Hz. Beyond this point, it transitions to a segmental vibration (Tonndorf & Khanna, 1972). In ears with a central perforation, these changes in vibratory behaviour could be further affected by the altered structural dynamics of the perforation. This interaction between the perforation and the shifting vibratory modes can contribute to the distinctive absorbance patterns observed in the high-frequency region. As the size of the perforation increases, most of the energies are absorbed into the middle ear cavity and further transmitted by the ossicles (Jeng et al., 2008). Thus, resulting in an increase in absorbance at high frequencies compared to normal ears.

In general, the presence of a measurable peak in the ears is not commonly observed when there is a tympanic membrane perforation. However, in the present study, WBA measurements were obtained at peak pressure for the central perforation group also. The reason might be the usage of wide-frequency stimulus. Since the instrument is measuring automatically, the exact method for this measurement is unknown. Until the current date, there is just one study that corresponds with our findings, highlighting the presence of peak pressure in cases of central perforation(Karuppannan & Barman, 2021a). The current study revealed a significant difference between the peak and ambient pressures at frequencies ranging from 250 to 500 Hz and 2500 Hz. However, none of these differences exhibited a moderate to strong effect size.

In conclusion, individuals with a central perforation displayed decreased absorbance at low frequencies and increased absorbance at high frequencies compared to the control group with normal ears, as discussed earlier with support from the literature. This phenomenon could be attributed to alterations in the area ratio and the buckling effect mechanism affecting sound transmission to the middle ear. Additionally, the pattern might arise from energy cancellation at low frequencies due to longer wavelengths and greater absorption of high frequencies due to their shorter wavelengths.

5.2 Comparison of absorbance between normal and marginal TM perforation groups:

The study compared WBA measurements across frequencies obtained under peak and ambient pressure conditions between the marginal perforation and normal ear groups. The marginal perforation group exhibited lower absorbance values at 250 Hz. From there, a sharp increase in absorbance was observed up to 600 Hz, followed by a significant reduction up to 2000 Hz. Beyond 3000 Hz, absorbance increased again, peaking at 6000 Hz. Compared to the normal ear group, ears with marginal perforations showed almost similar absorbance levels up to 500 Hz, lower absorbance at mid-frequencies up to 3000 Hz, and then higher absorbance at frequencies above 4000 Hz. WBA pattern of the marginal perforation group displayed three peaks: one at 600 Hz, a second peak at 4000 Hz, and a third at 6000 Hz. However, there was a dip in absorbance at 2000 Hz. In comparison between pressure conditions, the WBA pattern exhibited an almost identical pattern.

To the best of our knowledge, until now, no studies have measured WBA in individuals with marginal perforation. The justification of the result can be viewed from the point of physiology of sound transmission of the tympanic membrane. The literature has cited that the vibration pattern of the tympanic membrane is uniform below 2000Hz. Above which, the vibratory pattern changes significantly in terms of amplitude in the posterior region, which vibrates three times more than other regions; above 3000Hz vibrations tend to be more on anterior regions, and finally, above 4000Hz vibrations tend to be more on anterior and posterior regions of the TM than the malleolar tip (Tonndorf & Khanna, 1972). Since most of the participants with marginal perforation had a perforation in the posterior quadrant, that might be one reason for having a dip at 2000 Hz. Research in the literature has indicated that the resonant frequency of the posterior quadrant of the tympanic membrane is approximately 2000 Hz (Tonndorf & Khanna, 1972). The impact on this particular quadrant can lead to a diminished efficiency in transmitting sound at 2000 Hz leading to a significant reduction in absorbance.

It has been shown in the literature that posterior perforations have a more pronounced impact on the malleus extrusion than anterior tympanic membrane perforations, and studies done with the Finite Element (FE) model simulations with a sealed tympanic cavity demonstrate that small perforations cause the tympanic membrane's rigidity to decrease and thus to an increase in oscillation amplitude of the TM. In contrast, the posterior perforation tends to decrease middle ear transfer function compared to small perforation in the anterior quadrant because perforation at the posterior part is situated closer to the round window. As a result, the pressure applied to the round window can more effectively cancel out the cochlear response compared to perforations in other locations (Bevis et al., 2022). Thus, because of the size of the perforation and its location in the TM, it could effectively reduce the sound transmission.

Most of the effective parts of the TM responsible for low-frequency transmission remained intact, similar to the normal condition, which leads to the absorbance pattern identical to the normal ears. The reduction in absorbance at 2000 Hz can be attributed to the loss of resonance properties and a shift in the vibratory pattern. Notably, the absorbance peaks at 4000 Hz and 6000 Hz may be attributed to the intricate vibratory pattern complexity of the TM, as discussed by Tondorff and Khanna in their 1972 work. This work suggests that the tympanic membrane exhibits uniform vibrations below 2000 Hz, with a significant increase in amplitude in the posterior region above this frequency. Furthermore, beyond 3000 Hz, the dominant vibrational area shifts to the anterior quadrant. Interestingly, above 4000 Hz, the anterior and posterior quadrants vibrate more than the malleolar tip.

The increased absorption of high frequencies associated with a marginal tympanic membrane perforation could be linked to their shorter wavelengths, which may help the sounds to pass through the perforation.

The comparison between the pressure conditions revealed a significant difference between ambient and pressure conditions at 800 Hz and 2000 to 5000 Hz, with medium to large effect sizes. In marginal perforation, the difference in pressure might depend on the perforation's size and the contact point between TM and the sulcus.

In summary, individuals with marginal perforation exhibited a unique and uneven absorption pattern. This pattern is characterised by a sharply increased absorbance at lower frequencies, up to around 600 Hz, followed by a decrease in absorbance until it reaches its minimum point at approximately 2000 Hz. Subsequently, there is a gradual increase in absorbance at higher frequencies, displaying three peaks and a dip in its pattern. This pattern is consistent with prior research, such as Tondorff and Khanna's 1972 work and this alignment is supported by relevant literature.

5.3 Comparison of absorbance between marginal and central TM perforation groups:

The study compared WBA measurements across frequencies obtained under peak and ambient pressure conditions between the central and marginal perforation ear groups. In this study, we found that the absorbance of lower frequencies is greater in marginal perforation till about 1000 Hz, whereas in mid and high frequencies, it has been found absorbance is greater in central perforation (except in 6000 Hz) in both peak and ambient pressure conditions. WBA pattern shows a significant difference between central and marginal perforation for three frequencies in the peak pressure condition and four in the ambient pressure condition. The central perforation is characterised by a maximum at 5000 Hz, whereas the marginal perforation is characterised by three maxima at 600, 4000, and 6000 Hz and a significant dip at 2000 Hz.

While the graph clearly illustrates a discrepancy between central and marginal perforations in the mid-frequency range around 2000 Hz, this disparity is not statistically significant. This lack of significance might be attributed to a higher standard deviation and an uneven distribution of participants between the two groups.

In central perforation, a decrease in absorbance at lower frequencies could be attributed to the involvement of the umbo as a crucial structure in facilitating the impedance-matching mechanism. This mechanism encompasses the eardrum-to-oval window area ratio and the buckling effect. This phenomenon aligns with Tonndorf and Khanna's 1972 study on vibratory patterns. Normally, the tympanic membrane (TM) maintains cohesive vibrations up to 2000 Hz. Beyond this frequency, amplitude significantly increases in the posterior region, and beyond 3000 Hz, the anterior quadrant becomes the dominant vibrational area. Above 4000 Hz, both anterior and posterior quadrants exhibit greater vibration than the malleolar tip. However, central perforations disrupt this pattern, diminishing the effectiveness of the area ratio mechanism and buckling effect. Consequently, due to the longer wavelength, low frequencies require a larger area, potentially resulting in decreased absorbance. On the other hand, in marginal perforation, the intact umbo preserves the impedance-matching mechanism, leading to better absorbance of low frequencies.

For the reduced absorbance in low frequencies regarding the central perforation, an explanation can be found in Bekesy's work (1941). According to his proposal, at a frequency of 2000 Hz, the tympanic membrane (TM) exhibits a disc-like vibrational pattern around its axis, leading to maximal displacement, particularly at the inferior edge of the TM. This phenomenon might be linked to our observations, in which we observed reduced absorbance in low frequencies for central perforations compared to marginal perforations. Beyond 2000 Hz, a more segmental vibration pattern becomes prominent. This could clarify the lower absorbance seen in individuals with marginal perforation.

With respect to higher frequencies, because of shorter wavelengths can penetrate through the central perforation, which results in higher absorbance for central perforation than the marginal perforation. Whereas in marginal perforation in our study, most participants had a perforation in the posterior quadrant, which resulted in reduced absorbance of higher frequencies than the central perforation group.

Existing literature indicates that smaller perforations exert a more substantial influence on absorbance than larger ones (Jeng et al., 2008; Nakajima et al., 2013). Interestingly, prior research had identified notable effects primarily within the lower frequencies. However, our study reveals significant effects in the mid frequencies, particularly around 2000 Hz. The resonant characteristics of the posterior quadrant of the tympanic membrane (Tonndorf & Khanna, 1972) and the precise location of the perforation, both of which could influence the movement of the stapes (Voss et al., 2001b), could be attributed to this outcome.

In summary, the study shows distinct WBA patterns for central and marginal tympanic membrane (TM) perforations. Central perforations are characterised by a singular peak at 5000 Hz, accompanied by minimal absorbance at 250 Hz. In contrast, marginal perforations display three peaks at 600, 4000, and 6000 Hz, alongside a trough at 2000 Hz. Marginal perforations also show minimum absorbance at 250 and 2000 Hz. While WBA proves effective for diagnosing middle ear pathologies, its ability to differentiate between central and marginal perforations is constrained. The analysis identifies differences in absorbance patterns across a few frequencies, accounting for various pressure conditions. This suggests potential limitations in WBA's capacity to discern between these two perforation types.

Chapter 6

SUMMARY AND CONCLUSION

The tympanic membrane plays an important role in transmitting sound waves from the external auditory canal through the ossicular chain to the oval window. Perforations in the tympanic membrane can lead to frequency-specific alterations in sound transmission. In recent days, Wideband Tympanometry (WBT) has been emerging as a promising tool for identifying middle ear pathologies with high accuracy, and the impact of tympanic membrane perforation on WBA measures has only been evaluated in a few studies. The literature review suggests that the location of the perforation or the size of the perforation might influence the frequency-specific absorbance in WBA measurements, thus justifying the need to explore this condition. The present study aimed to investigate the effect of different types of tympanic membrane perforation (central and marginal) on WBA measures.

To achieve this, the current study had three primary objectives:

1. To compare the absorbance between normal and central TM perforation groups across the frequencies.
2. To compare the absorbance between normal and marginal TM perforation groups across the frequencies.
3. To compare the absorbance between marginal and central TM perforation groups across the frequencies.

The present study used a cross-sectional research study design with standard group comparison. Two groups in the age range of 18 to 55 years were considered in the study. Group I consisted of individuals with central perforation (n=65 ears), and Group II consisted of individuals with marginal perforation (n=13 ears). And normative data for the comparison was taken from Karupannan (2021). All the participants had undergone WBA measurements across frequencies.

The study compared the WBA across frequencies obtained at peak and ambient pressure in the central perforation group with the normal ear group. The central perforation group demonstrated lower absorbance values at low and mid-frequencies with significant reduction up to 2500 Hz and higher absorbance beyond 3000 Hz. WBA patterns in individuals with central perforations have shown reduced absorbance at low frequencies up to 2500 Hz. After that, there is a gradual increase in absorbance until 5000 Hz, followed by a decline in absorbance, and it shows a maximum at 5000 Hz. WBA pattern is identical in both pressure conditions for both groups. Individuals with a central perforation displayed decreased absorbance at low frequencies and increased absorbance at high frequencies compared to the control group with normal ears. This phenomenon could be attributed to alterations in the area ratio and the buckling effect mechanism affecting sound transmission to the middle ear. Additionally, the pattern might arise from energy cancellation at low frequencies due to longer wavelengths and greater absorption of high frequencies due to their shorter wavelengths.

WBA measurement between the marginal perforation and normal ear group revealed that the marginal perforation group exhibited lower absorbance values at 250 Hz. From there, a sharp increase in absorbance was observed up to 600 Hz, followed by a significant reduction up to 2000 Hz. Beyond 3000 Hz, absorbance increased again, peaking at 6000 Hz. Compared to the normal ear group, ears with marginal perforations showed almost similar absorbance levels up to 500 Hz, lower absorbance at mid-frequencies up to 3000 Hz, and then higher absorbance at frequencies above 4000 Hz. WBA pattern of the marginal perforation group displayed three peaks: one at 600 Hz, a second peak at 4000 Hz, and a third at 6000 Hz. However, there was a dip in absorbance at 2000 Hz. In comparison between pressure conditions, the WBA pattern exhibited an almost identical pattern. Individuals with marginal perforation exhibited near normal absorbance at lower frequencies which could be due to marginal perforation; most of the structures responsible for lower frequencies were intact and decreased transmission at mid-frequencies which may be linked with the resonant frequency of the posterior quadrant of the TM which aligns with Tonndorf and Khanna's 1972 study on vibratory patterns and greater absorption of high frequencies due to their shorter wavelengths.

By comparing WBA between central and marginal perforation, it was found that the absorbance of lower frequencies is greater in marginal perforation till about 1000 Hz, whereas in mid and high frequencies, it has been found that absorbance is greater in central perforation (except in 6000 Hz) in both peak and ambient pressure conditions. The central perforation is characterised by a maximum at 5000 Hz, whereas the marginal perforation is characterised by three maxima at 600, 4000, and 6000 Hz and a significant dip at 2000 Hz. In low frequencies, marginal perforations displayed higher absorbance than central perforations. This could be attributed to the impact on the umbo, a crucial component for low-frequency transmission, in central perforations. Conversely, mid-frequency absorbance was lower in marginal perforations compared to central perforation, likely due to resonance effects within the posterior quadrant of the tympanic membrane.

6.1 CONCLUSION:

Although WBA demonstrates efficacy in diagnosing middle ear issues, its capability to distinguish between central and marginal perforations is limited, accounting for various pressure conditions. The examination reveals variations in absorbance patterns at specific frequencies, considering different pressure scenarios. This indicates potential constraints in WBA's ability to differentiate between the central and marginal types of perforations.

6.2 IMPLICATIONS OF THE STUDY:

1. One of the critical applications would be that this study's findings might help us understand the physiology of TM concerning frequency-specific sound transmission.
2. The results of the present study would also help clinicians verify and correlate the otoscopic findings with WBT on vibratory patterns of the tympanic membrane.
3. Results would help clinicians to counsel the patients with marginal TM perforations versus central TM perforations regarding the consequences of untreated disease and management of the same.
4. The study's findings suggest that wideband absorbance (WBA) measurements exhibit distinguishable patterns between cases of TM perforations and normal ears. Notably, the frequencies that prove most informative are predominantly within the low and mid-frequency spectrum, usually below 2000 Hz, while the behaviour of high-frequency measurements tends to be more variable.

6.3 STRENGTHS AND LIMITATIONS OF THE STUDY

1. This is one of the first studies to compare the WBA between central and marginal perforation.
2. The current study validated the wideband absorbance (WBA) outcomes within a clinical population and compared them with existing normative values. This research underscored the significance of WBA across different clinical groups, effectively distinguishing between central and marginal perforations using WBA measurements to accurately identify each condition.
3. Sample Size Disparity: The sample sizes of the central and marginal perforation groups are quite uneven (65 ears vs. 13 ears). This disparity could potentially skew the results and limit the statistical power of the smaller group.
4. In the current study, the data are grouped according to audiometric findings and diagnoses provided by otologists. However, the study did not account for potential associated factors, which could be verified through exploratory surgery. This lack of consideration could lead to variations in absorbance across different frequencies.
5. The study acknowledges the influence of perforation size in differentiating between central and marginal perforations. However, it does not address the assessment of perforation size within the central perforation group, which could also be a significant factor limiting the outcomes.
6. The study did not compare the single-component and multi-component tympanometry findings with the wideband absorbance (WBA) measurements, which could have allowed for a more comprehensive comparison of results.

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