COMPARISON OF TRADITIONAL AND WIDEBAND TYMPANOMETRY BETWEEN THE MASTOIDECTOMY POSTERIOR TYMPANOTOMY APPROACH (MPTA) AND TRANSCANAL WALL (VERIA) SURGICAL APPROACH IN CHILDREN WITH COCHLEAR IMPLANTATION

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CERTIFICATE

This is to certify that this dissertation entitled "**Comparison of Traditional and Wideband Tympanometry between the Mastoidectomy Posterior Tympanotomy Approach (MPTA) and Transcanal wall (Veria) surgical approach in children with Cochlear Implantation**" is a bonafide work submitted in part-fulfilment for the degree of Master of Science (Audiology) of the student with Registration Number: P01II21S0079. 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.

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This is to certify that this dissertation entitled "**Comparison of Traditional and Wideband Tympanometry between the Mastoidectomy Posterior Tympanotomy Approach (MPTA) and Transcanal wall (Veria) surgical approach in children with Cochlear Implantation**" has been prepared under my supervision and guidance. It is also certified that this dissertation has not been submitted to any other University for the award of any other Diploma or Degree.

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This is to certify that this dissertation entitled "**Comparison of Traditional and Wideband Tympanometry between the Mastoidectomy Posterior Tympanotomy Approach (MPTA) and Transcanal wall (Veria) surgical approach in children with Cochlear Implantation**" is the result of my own study under the guidance of Dr. Mamatha N M, Assistant Professor in Audiology, Department of Audiology, All India Institute of Speech and Hearing, Mysuru, and has not been submitted earlier to any other University for the award of any Diploma or Degree.

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"CULTIVATION OF MIND SHOULD BE THE ULTIMATE AIM OF HUMAN EXISTENCE……"

-Dr. B. R. Ambedkar

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ABSTRACT

Aim: The current study aimed to find and compare the effect of cochlear implantation (CI) on middle ear mechanics in terms of wideband absorbance (WBA) and resonance frequency (RF) using wideband tympanometry in children who underwent different surgical approaches, i.e., mastoidectomy posterior tympanotomy approach (MPTA) and transcanal wall (Veria) approach. The study also compared the WBA across frequencies and RF between Normal and MPTA group, Normal and Veria group and MPTA and Veria group. Further, it also compared the conventional 226 Hz tympanometry and wideband tympanometry (WBA & resonant frequency) between MPTA and Veria groups.

Methods: The present study was conducted using a standard group comparison design. A total of 40 participants ranging from 3 to 10 years were involved in the present study, which was separated into three groups: Group I had 20 normal-hearing children, Group II, comprised 10 children with CI operated with MPTA, and Group III involved 10 CI children operated with the Veria technique. All the participants underwent the wideband tympanometry testing across frequencies at peak pressure and ambient pressure. Furthermore, 226 Hz tympanometry was performed only on the MPTA group and the Veria group.

Results: The results of the present study indicated that a comparison of WBA between the Normal and MPTA groups showed a significant difference in WBA at 1000 Hz and 1250 Hz frequencies for both peak pressure and ambient pressure. Further, a comparison of WBA between the Normal and Veria groups showed a significant difference in WBA at 2000 Hz, 3000 Hz, 4000 Hz, 5000 Hz, 6000 Hz, and 1000 Hz, 2000 Hz, 3000 Hz, 4000 Hz, 5000 Hz,6000 Hz frequencies at peak pressure and ambient pressure respectively. Also, a comparison of WBA between the MPTA and Veria groups showed a significant difference for frequencies 1250 Hz, 1500 Hz, 3000 Hz, 4000 Hz, and 5000 Hz at peak pressure and 3000 Hz and 4000 Hz frequencies at ambient pressure. A comparison of resonance frequency showed that the mean resonance frequency was found to be higher in MPTA group compared to Veria group and Normal group. However, there was no significant difference noted for resonance frequency between Normal and MPTA, Normal and Veria, and MPTA and Veria group. Further, a comparison of 226 Hz tympanometry and WBT between the MPTA and Veria groups revealed that the conventional 226 Hz tympanometry did not exhibit any significant difference among the MPTA and Veria groups. However, there were significant differences noted in WBA at certain frequencies (1250 Hz, 1500 Hz, 3000 Hz, 4000 Hz, & 5000 Hz at peak pressure and 3000 Hz & 4000 Hz at ambient pressure) between MPTA and Veria groups.

Conclusions: From the results of the study it can be concluded that cochlear implantation has an effect on the middle ear mechanics, which can be measured in terms of WBA using wideband tympanometry. These differences are also noted differently across frequencies for different types of cochlear implant surgical approaches (MPTA & Veria approaches). However, resonance frequency did not show any difference between MPTA and Veria groups. It can also be concluded that conventional 226 Hz tympanometry has limitations in showing the differences between the MPTA and Veria surgery approaches. Thus, compared to 226 Hz tympanometry, WBT has the potential to study the effect of cochlear implantation on middle ear mechanics across frequencies.

Keywords: Wideband tympanometry, WBA, 226 Hz tympanometry, MPTA and Veria surgery, RF, peak pressure and ambient pressure.

CHAPTER 1

INTRODUCTION

In a clinical setting, a single probe tone of 226 Hz is frequently used to assess middle ear function. Additionally, multiple-frequency tympanometry is used, comprising a frequency range of 200 to 2000 Hz (Colletti, 1976; Stieve et al., 2008). However, a more recent technique called Wideband Tympanometry (WBT) has emerged as an alternative way of assessing middle-ear function. WBT involves using a brief wideband stimulus, click, to assess middle ear function across a broader range of frequencies. Research has shown that WBT is more effective and precise for middle ear assessment compared to using a single probe tone. It has demonstrated higher sensitivity in identifying middle ear diseases and evaluating middle ear functioning, surpassing the standard 226 Hz tympanometry (Hein et al., 2017).

Traditional tympanometry asses the functioning of middle ear using a 226 Hz probe tone. Moreover, multi-frequency tympanometry uses frequencies between 226 and 2000 Hz for middle ear assessment (Iacovou et al., 2013). So, conventional and multi-frequency tympanometry limits the assessment at other frequency ranges tested behaviourally. Furthermore, some research shows various advantages of WBT over traditional tympanometry in assessing various middle ear disorders. Wideband tympanometry (WBT) uses transient stimuli containing a range of frequencies, making it less susceptible to myogenic noise arising from the patient's activity (Prieve et al., 2013).

Additionally, Shanks & Lilly (1981) found that the depth at which the probe tip is inserted significantly impacts traditional tympanometry measurements but has no effect on WBT measurements Voss et al. (2008). Even without pressure on the ear canal, WBT can be recorded (Keefe & Levi, 1996; Keefe & Simmons, 2003).

WBT and traditional tympanometric parameters assess absorption and resonance frequency, static acoustic admittance, tympanometric peak pressure, equivalent ear canal volume, and tympanogram width (Kaya et al., 2020). WBT can, therefore, assess normal middle ear functions (Liu et al., 2008), assess various middle ear pathologies (Prieve et al., 2013), measure middle ear development (Hunter et al., 2016), and also helpful in studying functions of the middle ear through pressure variations in the ear canal (Keefe et al., 2015). As a result, the WBT is promising for accurately diagnosing middle ear diseases and may eventually replace the traditional 226 Hz probe tone frequency tympanometry (Sanford et al., 2013).

It is also becoming clear that wideband tympanometry (WBT) offers insightful new perspectives in investigating loss of conductive hearing, especially cases resulting from problems in the middle and inner ear. This is especially important for people who have a superior semicircular canal dehiscence, confirmed by the CT scans. (Merchant et al., 2015), In the study, patients with superior canal dehiscence showed different and distinctive wideband tympanometry (WBT) data, particularly manifesting as a reflectance notch near 1000 Hz. However, no differences in static compliance, tympanometric peak pressure, or tympanogram type were noted when employing traditional tympanometry compared to normal. The absence of differences was explained by this lack of sensitivity to post-implantation mechanical alterations. Additionally, it was shown that the wideband tympanometric patterns in cochlear implant recipient's ears differed from normal hearing individuals, with a drop in absorbance up to 1200 Hz frequencies. (Merchant et al., 2015; Zhang et al., 2020).

The classic CI surgery known as the mastoidectomy posterior tympanotomy approach (MPTA), which was first described by William House in 1961, is normally used during cochlear implantation (CI) while the patient is under general anesthesia (Fouad, 2020). Several other surgy techniques were described for CI. The most common are the suprameatal approach (Kronenberg et al., 2001), the pericanal approach (Ha & Usler, 2002), the transcanal (Veria) approach (Kiratzidis et al., 2002), the transattic approach (Vaca et al., 2015), and the transcanal wall ("Veria") technique (Kiratzidis et al., 2002) which is a non-mastoidectomy technique for cochlear implantation.

Despite taking precautions to prevent damage to structures of the middle ear during these surgical procedures, there is still an integral risk of trauma, which may be unavoidable, especially in cases involving unusual anatomy (Balkany et al., 1999; Cohen & York, 1999).In certain cases, a cochleostomy is performed to create a pathway for inserting the cochlear implant (CI) electrode, essentially forming a temporary "third window" in the cochlea. As a result, cochlear implantation alters the transfer function of the middle ear (Merchant et al., 2020; Scheperle & Hajicek, 2020).

Furthermore, middle ear dysfunction that is not related to any cause of hearing loss or the individual response to CI can directly impact the integrity of the system. Consequently, it affects the functioning of the auditory conduction mechanism (Saki et al., 2022). The present study focuses on whether the auditory conduction mechanism is affected in different surgical technique approaches, i.e., between mastoidectomy posterior tympanotomy approach (MPTA) and the transcanal (Veria) approach with the help of traditional tympanometry and wideband tympanometry.

1.1 NEED FOR THE STUDY

For bilateral severe to profound sensorineural hearing loss (SNHL), cochlear implants (CI) are thought to be the preferred course of action. Subjects having residual hearing are included in the CI candidature criteria (Gantz et al., 2005; Nguyen et al., 2016). Cochlear implantation has been proposed to potentially lead to an air-bone gap, which might be due to an increase in stiffness of the middle and inner ear. (Attias et al., 2022). However, in people with residual hearing, post-cochlear implantation audiograms frequently show greater air-bone gap with typical tympanogram and no evident middle ear disease (Attias et al., 2022). After cochlear implantation, higher air-conduction thresholds were observed, but bone-conduction thresholds remained stable; it has been hypothesized that the electrodes in cochlea enhance the stiffness of the inner ear and are found to impair sound transmission (Raveh et al., 2015). These findings suggest that normal middle ear transfer function can be affected in children who have undergone cochlear implantation surgery.

Based on animal model studies (Attias et al., 2016), it has been observed that cochlear implants have caused an air-conduction threshold shift of 15 dB but only a 3 to 5 dB change in bone conduction threshold. After the electrode array was implanted, there was an observed increase in air-bone gaps (ABGs) one week later. This suggests that the presence of the electrodes and after-implant events, like fibrosis, might have been a reason for the deterioration of air-conduction thresholds. However, there was only a minor and statistically insignificant impact on bone-conduction thresholds and inner-ear mechanics.

Studies done by several authors in cochlear implant adults (18-34 years) using wideband tympanometry have shown a reduction in WBA at lower frequencies (400–

800 Hz) and an elevation in WBA at 1600 Hz (Attias et al., 2022). These frequency ranges are above the traditional tympanometry, which uses the only probe tone of 226 Hz, which limits identification of the influence of cochlear implantation on the middle-ear mechanism, which may have an effect on wide ranges of frequency required for the conduction of the sound through the middle ear. This will be made possible by using wideband tympanometry, which uses the broad-spectrum stimulus to assess the middle ear status.

Another study observed no substantial differences between the pre-implantation and post-implantation conditions using traditional 226 Hz tympanometry both in the ear with and without the implant in children less than 24 months. However, children with cochlear implants showed significantly lower absorbance from 1260 to 3175 Hz and also from 5040 to 8000 Hz frequency ranges. In contrast, smaller variations were noticed at lower frequencies on wideband tympanometry. However, their research found no appreciable variations between pre- and post-implantation conditions in ears without implantation (Saki et al., 2022).

The earlier Studies done on adult CI subjects noted a difference in absorbance between low and mid frequencies on WBT (Attias et al., 2022); studies done on children reported lower absorbance in 1260 to 3175 Hz and 5040 to 8000 Hz frequency ranges (Saki et al., 2022). In contrast, few changes were detected in the low frequencies on wideband tympanometry. From these results, it can be observed that there is a difference and variation noted in absorbance values in low, mid, and high frequencies in both children and adults. The literature has also reported that there is variation in wideband absorbance (WBA) in various ethnic groups due to differences in middle ear acoustical properties (Shahnaz & Bork, 2006). Hence, it is important to study WBA values in the Indian population to compare with the clinical population.

Also, cochlear implantation (CI) is done using different surgical approaches, such as the traditional surgical procedure (transmastoid approach) (Freni et al., 2020). In recent years, various cochlear implant techniques (excluding mastoidectomy approaches) have been developed. These methods prove especially beneficial in situations with anatomical limitations, where executing the facial recess approach poses challenges. (Freni et al., 2020). In these cases, alternative techniques are used to lessen complications, which involve (1) the suprameatal approach (SMA), (2) the middle fossa approach, (3) the transcanal ("Veria") technique, and (4) the trans-mastoid labyrinthectomy technique (Dubey et al., 2020).

Attias et al. (2022) proposed that various aspects of the CI surgery procedure itself, including mastoidectomy and posterior tympanotomy, as well as subsequent post-operative factors, like fibrosis, may influence middle and inner stiffness. It has been demonstrated that cortical mastoidectomy and the facial recess approach increased middle ear cavity volume and WBA (Merchant, 1998). Cochleostomy could function as a third window opening and may influence the stiffness and WBA of the middle ear cleft. An alternative possible explanation was put forward by Wasson et al. (2018), suggesting that the creation of bone dust while performing mastoid drilling might lead to an increase in the mass of ossicles. These changes might differ in different surgical approaches used for cochlear implantation surgery, which may affect the middle ear mechanics differently.

From the review, it is evident that the previous research that has used wideband tympanometry to study the influence of cochlear implant on the middle ear cleft have not considered the effect of different surgical approaches used in CI surgery. Hence, it is important to study whether or not different surgical approaches of CI surgery [the mastoidectomy posterior tympanotomy approach (MPTA) and transcanal wall (Veria)] have a similar or different effect on middle ear mechanics using wideband tympanometry.

1.2 AIM OF THE STUDY

The present study aims to find and compare the effect of cochlear implantation on the middle ear mechanics in terms of WBA and resonance frequency using wideband tympanometry in children operated with different surgical approaches, i.e., the mastoidectomy posterior tympanotomy approach (MPTA) and transcanal wall (Veria) approach.

1.3 OBJECTIVES OF THE STUDY

1. To compare the WBA across frequency and resonance frequency between normal individuals and CI children operated with the MPTA approach.
2. To compare the WBA across frequency and resonance frequency between normal individuals and CI children operated with the Veria approach.
3. To find and compare the effect of mastoidectomy posterior tympanotomy approach (MPTA) and transcanal wall (Veria) surgical approaches in terms of wideband absorbance across frequency and resonance frequency in children with CI using WBT and to find the most affected frequency range.
4. To compare the traditional 226 Hz tympanometry and wideband tympanometric measures (WBA & resonance frequency) between MPTA and Veria surgical approach in CI children.

CHAPTER 2

REVIEW OF LITERATURE

The three primary components of the human auditory system are the outer ear, which contains the auricle and auditory canal; the middle ear, which contains the eardrum and three tiny bones; and the inner ear, which contains the cochlea and semicircular canals. Sound waves travel from the outer ear to the eardrum, which vibrates. This vibration is then transmitted through the three tiny bones to the oval window. Sensory hair cells in the cochlea transform vibrations into electrical signals, which are sent to the brain through the auditory nerve (Hawkins, 2023).

Transmission of the sound energy to the inner ear is carried out by the middle ear. Because of the difference in the impedance characteristics of the middle ear and inner ear, the middle ear is responsible for pressure adjustment and compensating for sound energy loss. Any problems with the middle ear can interfere with signal transmission, causing a loss of energy and leading to hearing loss (Norrix et al., 2013).

The alteration in sound transmission can occur due to various factors, for instance, the existence of various pathologies of the tympanic cavity or variances in anatomy influenced by gender, ethnicity, and maturation. These factors can result in reducing the transmission of specific frequencies of sound (Beers et al., 2010; Mazlan et al., 2015; Shahnaz & Davies, 2006). These transmission changes in sound energy in the middle ear can be evaluated using a middle ear analyzer with a test evaluation called tympanometry that examines how well the middle ear transfers acoustic energy from the external auditory meatus to the inner ear.

Different types of middle ear pathologies are found to affect the function in distinct ways, with each pathology having its own unique impact. Through tympanometry, the changes in the energy transfer function can be measured and documented and hence enables the diagnosis of various middle ear disorders based on their specific characteristics (Biswas & Dutta, 2018). Currently, tympanometry is typically conducted using a standard frequency of 226 Hz. The use of this frequency has been found to be effective in accurately detecting different types of middle ear disorders (Lilly et al., 1984).

The examination of a 226 Hz tympanometry involves several quantitative components, such as static compliance, tympanometric width, tympanometric peak pressure, and volume of the ear canal. These measurements help establish standardized norms for analysis and ensure consistent tympanometric data across different clinics. Tympanometry is a fast and non-invasive test suitable for patients of all ages, including infants and adults. The test usually takes less than a minute to perform and does not require the patient to respond behaviourally (Alaerts et al., 2007).

But, conventional 226 Hz tympanometry frequently struggles to differentiate between middle ears with normal hearing and those affected by pathologies that specifically impact the ossicular chain (Lilly Good Samaritan, 1984; Shanaz Polka, 2009). Moreover, in newborn infants and infants below the age of 6 months, standard 226 Hz tympanometry can also struggle to differentiate between middle ears with normal hearing and those with pathologies (Hunter & Margolis, 1992). Hence, traditional single-frequency reflectance tympanometry has several limitations (Biswas & Dutta, 2018).

Moreover, when it comes to multi-frequency tympanometry, which is a technique that examines tympanograms at different frequencies, typically between 226 and 2,000 Hz, it helps to assess the middle-ear system's response to acoustic energy through acoustic immittance, which consists of impedance and admittance components like mass susceptance, stiffness susceptance, and conductance and resonance frequency. This method provides valuable insights into the middle ear's characteristics and how it interacts with sound at various frequencies, which is more precise and specified information about the middle ear dynamics than standard tympanometry (Shahnaz, 2007).

Wideband tympanometry (WBT), an enhancement over conventional and multifrequency tympanometry, has recently grown in prominence. In contrast to conventional tympanometry, which concentrates on absorbance rather than admittance, WBT is a useful technique for identifying and tracking a variety of middle ear problems since it offers extra information on absorbance and resonance frequency due to the use of wideband stimulus and resonance frequency. These middle ear conditions include effusion in the tympanic cavity, damage to TM, and otosclerosis (Keefe et al., 2010; Kim et al., 2019; Terzi et al., 2015).

3.1 WIDEBAND TYMPANOMETRY

To overcome the limitations of traditional tympanometry, wideband tympanometry (WBT) has gained increasing use. WBT test procedure deviates from conventional tympanogram by employing absorbance instead of admittance. It has been utilized for the diagnosis and monitoring of various middle ear conditions, such as newborn middle ear lesions, otosclerosis, discontinuity in the ossicular chain, tympanic membrane perforations, effusion of middle ear (Shahnaz et al., 2009).

In addition to measuring sound absorption by the middle ear, wideband tympanometry (WBT) also measures sound reflection (reflectance). This thorough technique offers insightful information about middle ear function and associated diseases, with variable impacts on reflectance and absorbance at various frequencies. Traditional tympanometry, which measures reflectance at a single frequency and is unable to capture middle ear function in a variety of diseases accurately, is outperformed by WBT. WBT's multi-frequency data, which typically ranges from 226 to 8,000 Hz or higher, allows for accurate and extensive middle ear diagnosis. (Biswas & Dutta, 2018).

There are now two well-known device families for wideband tympanometry (WBT) measurements available in the market. The first consists of American-made Mimosa Acoustics Otostat and Hear ID systems. The Titan system created by Interacoustics in Denmark makes up the second family. The main distinction is that Titan requires a PC for WBT measurements, whereas Mimosa devices operate without one. The Titan gadget from Interacoustics also displays WBT data in a 3D manner as opposed to the conventional 2D depiction. This spinning 3D graph provides a rotating perspective that enables users to spot intriguing patterns in the 3D contour. It shows pressure on the y-axis, frequency on the x-axis, and absorbance on the z-axis (Hein et al., 2017).

Wideband tympanometry (WBT) measurements encompass various parameters, including reflectance or absorbance. These parameters are commonly referred to as Wideband absorbance (WBA) or Wideband reflectance (WBR) (Margolis et al., 1999). In the literature, alternative terms such as acoustic reflectance/acoustic absorbance (Margolis et al., 1999), power reflectance/power absorbance (Nakajima et al., 2013), and energy reflectance (Wang et al., 2019)/energy absorbance (Hougaard et al., 2020) are also used. Additionally, "Wideband acoustic immittance (WAI)" is an alternative term for WBT and encompasses both WBA and WBR measurements (Feeney et al., 2013). The WBA measurements are represented by an actual number between 0 and 1, and they only indicate the magnitude of the measurement without considering any dimension or phase (Feeney et al., 2013; Liu et al., 2008; Stinson, 1990). A value of one means absorption of all the sound energy, while a value of zero means that all the sound energy is reflected back to the ear canal (Liu et al., 2008; Stinson, 1990).

3.1.1 Wideband Tympanometry In Middle Ear Disorders

Research has indicated that the WBA can effectively identify middle ear disorders compared to both multi-frequency and single-frequency tympanometry (Kim et al., 2019b; Shahnaz et al., 2009). It also has the ability to differentiate between different types of conductive hearing loss and offer supplementary information. Individuals with tympanic membrane perforation exhibited reduced absorbance at lower frequencies, while those with issues related to the ossicular chain showed decreased absorbance at higher frequencies (Kim et al., 2019).

Additionally, when investigating people with otosclerosis, it was discovered that their average wideband absorbance (WBA) at standard atmospheric pressure was lower, at 0.35, and that their resonance frequency was higher, at 1350.33 Hz, compared to the group of people with healthy, normal ears. The healthy ear group, on the other hand, had a resonance frequency of 930.14 Hz and an absorbance of 0.60. These findings suggest that average WBA when applied to WBA values in the 250–1550 Hz range, can reliably detect otosclerosis in ears and efficiently separate it from healthy normal ears. With over 90% sensitivity and specificity, this technique shows excellent diagnostic accuracy, especially at frequencies around 1000 Hz. (Karuppannan & Barman, 2021). Also, the data analysis demonstrated a distinct pattern in average wideband absorbance (WBA) for individuals with ossicular chain discontinuity, indicating higher absorbance at 750 Hz compared to normal ears. On the other hand, the otosclerosis individuals exhibited a drop in WBA (with statistical significance, $p < 0.05$) at lower frequencies ranging from 250 Hz to 1500 Hz.

Additionally, when comparing resonance frequencies, individuals with ossicular chain discontinuity had a significantly lower resonance frequency (674 Hz) compared to healthy individuals (901 Hz). In contrast, otosclerosis individuals had a shift of resonance frequency upwards in frequency (1445 Hz). These findings suggest that average wideband absorbance (WBA) also has the potential to distinguish between pathologies related to the ossicles and normal ears, as well as differentiate between ears with otosclerosis and ossicular chain discontinuity (Karuppannan & Barman, 2021).

3.1.2 Wideband Tympanometry In Inner Ear Disorders

It is well known that problems with the middle or outer ear can impair how sound travels through the ear, resulting in an air-bone gap (ABG) on audiograms. It's important to understand that abnormalities in the inner ear can lead to the formation of the ABG. The superior semicircular canal dehiscence (SSCDS) is one of the typical inner-ear conditions that can cause an ABG. (Mikulec et al., 2004; Minor et al., 2003).

Research conducted on semicircular canal dehiscence revealed a distinct feature in energy reflectance, specifically a notch or dip in absorbance occurring between approximately 750 Hz and 1000 Hz, which differed from the absorbance at other frequencies (Nakajima et al., 2012). Comparable observations have been reported in animal models regarding the presence of a third window in semi-circular canals (Attias et al., 2011; Preis et al., 2009.). When people have an expanded vestibular aqueduct (EVA) disorder, this is another instance in inner ear air-bone gap (ABG). A low-frequency ABG may be present in EVA patients without causing any middle-ear problems. (Merchant et al., 2007). The reported WBA values showed slight abnormalities, particularly in the right ear, with a significant reduction near 1200 Hz. On the other hand, the WBA values in the left ear fell within the normative range but exhibited unusual peaks around 500 Hz and 1500 Hz. The differences observed in the WBA pattern were attributed to potential abnormalities in the cochlea, while the middle ear remained intact (Olszewski et al., 2017). These variations in the WBA pattern were found to closely resemble the values obtained in individuals with superior semicircular canal dehiscence disorder (Nakajima et al., 2013).

In cases of inner-ear anomalies, the threshold for bone conduction may show improvement. This improvement can be attributed to the cochlea's altered response resulting from the presence of the third window phenomenon (Merchant & Rosowski, 2008). The Research done by Kaya et al. (2020), examined the wideband average absorbance (WBA) in ears with various inner ear malformations, including hypoplastic cochlea, incomplete partition I and II, aplasia of cochlea, and labyrinthine aplasia. These conditions were related to SNHL, and the results were compared to WBA measurements obtained from individuals with normal hearing.

The study found distinct effects of inner ear malformations on WBA measurements at peak and ambient pressure. The WBA measurements in all malformation groups were lower compared to the normal hearing group, indicating reduced absorbance. However, the group with complete labyrinthine aplasia exhibited a significantly larger difference. Notably, there was a significant difference in WBA values between complete labyrinthine aplasia and other malformation groups for frequencies ranging from 226 Hz to 1000 Hz. At higher frequencies, specifically between 4237 Hz and 6535 Hz, a significant difference was observed between the normal hearing group and the other malformation groups. In contrast, no significant difference was found among the different malformation groups themselves.

Studies investigating wideband average absorbance (WBA) measurements in cases of endolymphatic hydrops have provided valuable information about the condition of the inner ear, particularly when the tympanic cavity remains intact. A cross-sectional study was conducted to examine WBA in ears affected by symptomatic and asymptomatic Meniere's disease, comparing them to ears with normal hearing. The study assessed WBA at two pressure conditions, ambient and peak. The findings indicated reduced absorbance at lower frequencies, up to 1000 Hz, for symptomatic cases. In asymptomatic cases, the reduced absorbance extended up to 1260 Hz, with the lowest absorbance observed in symptomatic individuals.

Conversely, increased absorbance was observed at higher frequencies, specifically at 2520 Hz, 3175 Hz, and 4000 Hz, with the maximum change in absorbance reported in symptomatic cases. Both the symptomatic and asymptomatic groups exhibited maximum absorbance at higher frequencies between 2520 Hz and 3175 Hz. This reduction in absorbance at lower frequencies may be ascribed to increased pressure in an inner ear, leading toward increased stiffness of cochlear windows and influencing the stiffness of the ossicles. As a result, the transmission of low-frequency sounds to the inner ear is reduced, while maximum sound energy is observed at frequencies above 2000 Hz (Tanno et al., 2022).

3.2 WIDEBAND TYMPANOMETRY IN COCHLEAR IMPLANT INDIVIDUALS

Some studies have hypothesized a connection between cochlear implantation and the development of an air-bone gap, which may be linked to an increase in middle ear and inner ear stiffness. For people with severe to profound SNHL in both ears, cochlear implants (CIs) tend to be considered the best course of action (Attias et al., 2022). The criteria for cochlear implant candidacy have changed over time to now allow patients with significant residual hearing, particularly in the lower frequency range. Even if they have good tympanometry results and no obvious middle ear problems, people with residual hearing who received cochlear implants frequently show increased air-bone gaps (ABGs) in their post-implantation audiograms. (Gantz et al., 2005; Nguyen et al., 2016).

Raveh et al. (2015), found that cochlear implantation increased air-conduction thresholds but had no effect on bone-conduction thresholds. According to their theory, inserting solid electrodes into the scala tympani causes the inner ear to become stiffer, potentially obstructing sound transmission.

Recent studies have aimed to investigate the influence of cochlear implantation on the middle ear using utilizing wideband tympanometry (WBT). Studies have involved individuals with normal hearing as well as those with severe-profound SNHL who have undergone CI in one ear or both ears. Analysis of wideband tympanometry (WBT) indicated a notable reduction in WBA at 400-800 Hz and an increased WBA at 1600 Hz in the ears that underwent cochlear implantation. These findings can be attributed to the surgical procedure and the presence of the implant, leading to increased stiffness in the inner ear (Attias et al., 2022).

Research conducted by Orhan et al., (2021), showed that the average ratio of WBA decreases, and the average resonant frequency (RF) rises following cochlear implantation. The average resonance frequency for the implanted ears was 846.7±(333.8) Hz, while for the non-implanted ears, it was 815.05±(249.7) Hz. This difference was found to be statistically significant ($p<0.001$). The authors suggested that these findings may be attributed to an increase in stiffness within the middle and inner ear systems. Consistent with previous reports by (Merchant et al., (2020); Raveh et al., (2015); and Saoji et al., 2020), the observation aligns with the notion that the existence of a CI in the cochlea can cause a decrease in absorbance at low frequencies, potentially due to an increase in stiffness within the inner ear.

However, it is vital to note that cochlear implant surgery, including MPTA, as well as post-operative developments like fibrosis, can also impact the stiffness of both the middle and inner ear (Attias et al., 2022). Merchant et al., (2020) and Whittemore et al. (1998) conducted studies that showed cortical mastoidectomy and the facial recess approach can result in an increase in the volume and WBA of the tympanic cavity cleft.

3.3 COCHLEAR IMPLANT SURGERIES

3.3.1 Mastoidectomy Posterior Tympanotomy Approach (MPTA)

The typical method for cochlear implantation (CI) involves administering general anesthesia and employing the traditional surgical technique known as the mastoidectomy posterior tympanotomy approach (MPTA), which was initially introduced by William House in 1961 (Fouad, 2020). The first "true" cochlear implantation procedure was carried out by William House and John Doyle on January 9, 1961. The surgery involved making a post-auricular incision and utilizing the mastoidectomy posterior tympanotomy approach (MPTA) to access the middle ear. Once the round window (RW) membrane was exposed, an electrode's lead was implanted into the scala tympani (Blume, 1999). While the mastoidectomy posterior tympanotomy approach (MPTA) remains the traditional and widely used method for cochlear implantation (Zeitler & Balkany, 2010), various alternative approaches have been described. Among these, the suprameatal approach (Kronenberg et al., 2001), the pericanal approach (Ha & Usler, 2002), the transcanal (Veria) approach (Kiratzidis et al., 2002), and the transattic approach (Vaca et al., 2015) are some of the most common alternatives used for CI.

While the transmastoid facial recess is the technique used for cochlear implant surgery the most frequently throughout the world, several additional methods have been documented in scientific literature. Possible reasons for the need for these alternative techniques include anatomical limitations, surgeon preference, and training. However, it's crucial to make sure that safety and effectiveness, with an emphasis on reducing complications, are key in CI surgery (Zeitler & Balkany, 2010).

3.3.2 The Suprameatal Approach (SMA)

By avoiding the mastoid cavity, the suprameatal approach (SMA) provides a more effective route to access the middle ear. By using this method, the surgery can be completed in about an hour. The outer aural canal's bony portion and suprameatal region of the SMA are both drilled to insert the electrode. The danger of surgical drill injuries, such as injury or heating of the chorda tympani or facial nerves, is decreased because of this cautious technique, which ensures a safe distance from the location of the facial nerve (Kronenberg et al., 2001).

3.3.3 "Veria" Technique (The Transcanal Wall Approach)

The transcanal wall technique, also known as the "Veria" technique, is a non-mastoidectomy approach utilized for cochlear implantation, involving accessing the middle ear and cochlea through the transcanal approach ((Kiratzidis et al., 2002). The surgery entails raising a typical tympanomeatal flap to access the tympanic cavity by an endaural or retroauricular route. The posterosuperior bony canal wall is straightened after analyzing the middle ear's structure, including the cochlea, fallopian canal, and round window niche. The suprameatal hollow is then drilled after the creation of the cochleostomy. The transcanal wall is cut through directly, aligning the cochleostomy with it. Skin and subperiosteal flaps are prepared, and the skin incision is lengthened. The electrode is implanted after creating an implant bed to hold the device in place. After regulating any extra electrode in the suprameatal hollow, the incision is eventually stitched up (Zeitler & Balkany, 2010).

3.3.4 The Transattic Approach

A mastoidectomy and a transmeatal cochleostomy are included in the simple transattic technique. This technique avoids the need to enter the facial recess by inserting the electrode into the middle ear through the attic. This method offers a clear and straightforward solution to overcome specific constraints and contraindications related to the traditional method (Vaca et al., 2015).

3.3.5 The Middle Cranial Fossa (MCF) Approach

The middle cranial fossa (MCF) approach for cochlear implantation was initially introduced by Chouard in 1908, involving the use of multiple independent electrodes inserted through various labyrinthectomy sites. However, it was only in recent years that Colletti et al., (2000) presented an updated version of the MCF approach for surgery in patients with various indications, including chronic ear disease, those with unsatisfactory results from promontory stimulation, and those requiring dual electrode array insertion to enhance spatial selectivity and improve outcomes, particularly in cases of proximal labyrinth ossification (Zeitler & Balkany, 2010).

A recent study conducted by Nagaraj et al. (2023) investigated the surgical outcomes in children undergoing cochlear implantation using two different techniques: Posterior Tympanotomy (MPTA) and the modified Veria technique. The results revealed that the mean surgical duration for patients undergoing MPTA was 139.67 ±

16.53 minutes, while those undergoing the Veria technique had a significantly shorter mean surgical duration of 84.67 ± 11.72 minutes ($p < 0.05$). During the study, only one patient who underwent cochlear implantation through MPTA surgery experienced an intraoperative complication, specifically a House Brackman grade 4 facial nerve injury. However, this complication was identified postoperatively and resolved over a period of three months. On the other hand, the group that underwent the Veria technique did not encounter any intraoperative complications. Statistical analysis showed that the p-value for intraoperative complications was greater than 0.05, indicating no significant difference between the two groups in terms of intraoperative complications.

Although several authors have given reasons for changes in WBT pattern after CI implantation, Saoji et al. (2020) in their study's findings regarding decreased low-frequency absorbance, which are similar to disorders like otosclerosis or stapes fixation, lack an explanation of the underlying causes. Possible influences on the ossicular chain’s movement and middle ear absorption include changes in middle ear volume, electrode presence, placement, and growth of fibrous tissue following surgery.

Other authors like Attias et al. (2022) suggested that various stages of cochlear implant (CI) surgery, like mastoidectomy with posterior tympanotomy, along with post-operative processes like fibrosis, could impact middle and inner ear stiffness. Additionally, some the studies have shown that cortical mastoidectomy and the facial recess approach can increase tympanic cavities volume and WBA (Merchant, 1998). On the other hand, cochleostomy, might create a third window and influence WBA and stiffness properties. An additional aspect, proposed by Wasson et al. (2018), is that bone dust generated during the drilling of mastoid could increase the ossicular mass. These factors might vary depending on the specific surgical approach used for cochlear implantation, leading to differential effects on middle ear mechanics.

From the review it is evident that Recent research using wideband tympanometry (WBT) in individuals with cochlear implants showed reduced absorbance at low frequencies and increased absorbance at higher frequencies, suggesting increased inner-ear stiffness (Attias et al., 2022). Another study by Orhan et al. (2021) found that cochlear implantation led to a decrease in absorbance ratio and an increase in resonance frequency, supporting the idea of increased stiffness in the middle and inner ear systems due to the presence of the implant.

In summary, cochlear implantation may lead to an increase in stiffness characteristics of both the middle and inner ear, potentially contributing to larger air-bone gaps and altered absorbance at different frequencies, which suggests that there is an effect of CI on middle ear mechanics. Wideband tympanometry (WBT) is a more advanced technique than traditional tympanometry and multifrequency tympanometry (Kim et al., 2019; Shahnaz et al., 2009), offering additional information about the middle ear's conductive mechanism and its interaction with sound at various frequencies. WBT provides valuable insights into various middle ear conditions (Karuppannan & Barman, 2021; Kim et al., 2019), inner ear disorders (Kaya et al., 2020) and post-cochlear implantation (Attias et al., 2022; Raveh et al., 2015) outcomes. Compared to conventional tympanometry, WBT offers more accurate precise diagnostic information and has the potential to improve the assessment and management of patients with hearing-related issues.

The current study aims to examine and compare wideband tympanometry measures between two different cochlear implant surgery approaches, namely the mastoidectomy posterior tympanotomy approach (MPTA) and the Veria CI surgery approach. The focus of current research is to investigate and analyze the differences in wideband tympanometry test results between these two surgical techniques.

CHAPTER 3

METHODS

The aim of the study was to explore the effect of cochlear implantation on the middle-ear mechanics in terms of WBA and resonance frequency using wideband tympanometry in children who had undergone two different cochlear implant (CI) surgery techniques, i.e., mastoidectomy posterior tympanotomy approach (MPTA) and transcanal wall (Veria) surgical approaches. To fulfill the aim and objectives, the following method was followed. Wideband tympanometry (WBT) and traditional tympanometry were carried out in children with implanted ears who had undergone mastoidectomy posterior tympanotomy approach (MPTA) and transcanal wall (Veria) surgical approaches. Additionally, these tests were performed in normal-hearing individuals with normal middle ear functioning to compare the absorbance and resonance frequency values obtained with the implanted ear. The present study was conducted using a standard group comparison design.

3.1 Participants

A total of 40 participants ranging from 3 to 10 years were involved in this study, which was divided into three groups: Group 1 comprised 20 normal hearing children, Group 2 included 10 CI children operated with MPTA, Group 3 comprised 10 CI children operated with the Veria technique, and. All these participants included in the study were selected from the AIISH Listening Training Unit & Speech Department.

Informed written consent was taken from the parents before carrying out the study. The current study followed the bio-behavioral ethical principles established by Venkatesan and Basavaraj (2009) at the All-India Institute of Speech and Hearing, Mysore.

3.1.1 Inclusive / Exclusive Criteria

Group 1

In group 1, twenty normal-hearing participants (n = 20) were included.

Subjects with the following conditions were excluded from the present study.

- Subjects having any type and degree of hearing loss.
- The subjects with impacted wax and abnormal Tympanic Membrane on Otoscopic Examination.
- Subject with a present middle ear infection and a history of middle ear infections.
- Subjects with B, C, Ad, and E type tympanogram.

Group 2

Participants (n=10) selected in group 1 for the present study were based on the following conditions:

- Subject with a unilateral cochlear implant operated with mastoidectomy posterior tympanotomy approach (MPTA).
- Subjects with no previous history of external and middle-ear pathologies in the implanted ear.
- Subjects with bilateral severe to profound SNHL with an implant in one ear.
- Subjects with a clear ear canal and normal tympanic membrane on otoscopic examination.

Group 3

Participants (n=10) selected in group 2 for the present study were based on the following conditions:

- Subject with a unilateral cochlear implant operated with transcanal wall (Veria) surgical approaches.
- Subjects with no history of external and middle ear pathologies in the implanted ear.
- Subjects with bilateral severe to profound SNHL with an implant in one ear.
- Subjects with a clear ear canal and normal tympanic membrane on otoscopic examination.

3.2 Instrumentation

The following equipment was utilized to carry out the study:

- Video-Otoscope H Inventis was used to carry out the otoscopy.
- Interacoustics Titan Suite IMP440/WBT440 version 3.3.1 was used to carry out 226 Hz Tympanometry and wideband Tympanometry.

3.3 Test Environment

All the participants in this study underwent testing in an environment that had been treated for acoustics and had ambient noise levels that complied with ANSI S3.1-1999 (R2008).

3.4 Procedure

Children with cochlear implantation involved in this study were diagnosed with severe to profound hearing loss by Department of Audiology, AIISH and selected children were ear-matched (only the right ear was considered) for further evaluation. The diagnosis for the cases was confirmed by referring to their case files from the record section. Further, by referring to their discharge summary report, the type of surgical approach children have undergone were noted. The CI children were separated into two groups on the basis of type of surgery they have undergone i.e., CI children operated with MPTA and CI children operated with the Veria approach.

Individuals with ear-matched (right ear) normal hearing were taken from by referring case files from the audiology and speech department. Further, siblings of the children taking therapy in the Listening Training Unit and Speech department were considered in the normal hearing group after testing with pure tone audiometry, tympanometry, and otoacoustic emissions (OAEs) test, and they were classified as normal hearing sensitivity based on the hearing loss classification system given by Clark in 1981 (Clark, 1981).

All of these participants initially underwent an otoscopic examination to confirm the presence of a normal tympanic membrane with a clear ear canal and rule out the presence of ear wax, discharge, and any foreign body. Then, WBT, and 226 Hz tympanometry were performed in one single run. Before conducting measurements, calibration of the Interacoustic Titan Suit IMP440/WBT440 was done on every day of testing by placing the probe assembly in each of 4 metal calibration units of 0.2cc, 0.5cc, 2cc, and 5 cc volumes. The source reflectance and incident pressure were determined to carry out WBA measurements. It was also ensured that the reflectance value remained below 15% up to 2 kHz and below 30% thereafter, as per the recommendations of the manufacturer (Interacoustics, 2016).

Participants were comfortably seated and instructed to remain silent and still during the entire testing process. An appropriately sized ear tip was used to ensure an airtight seal in the ear canal for performing wideband tympanometry. A suitable-sized probe tip was firmly inserted into each participant's ear canal. The wideband tympanometry was conducted using a 100 dBpeSPL wideband click stimulus delivered at a constant rate of 21.5 Hz (Interacoustics, 2017). By averaging the click stimulus response over 32 sweeps, the Wideband Absorbance (WBA) values were automatically calculated for 1/24th octave frequencies ranging from 226 Hz to 8000 Hz (121 frequencies) from which 16 frequencies were taken for further analysis.

These WBA values were presented in a 3-dimensional graph with frequency (226 Hz to 8000 Hz) on the x-axis, pressure (in daPa from +200 to -600 daPa) on the y-axis, and absorbance values (in percentage from 0 to 100%) on the z-axis. Typically, WBA values range between 0.0 and 1.0, where '1' indicates that the middle ear absorbs all sound energy, and '0' indicates that all sound energy is reflected from the middle ear (Stinson, 1998). Absorbance values for each participant were recorded for low, mid, and high frequencies, as well as resonance frequencies.

Simultaneously, 226 Hz tympanometry was also carried out in the same run. Static compliance, tympanometric peak pressure (TPP), and ear canal volume (ECV) were recorded for each participant.

The wideband tympanometry and 226 HZ tympanometry were performed on all three groups, and wide band absorbance (WBA) at 16 frequencies, i.e., 250 Hz, 300 Hz, 400 Hz, 500 Hz, 600 Hz, 800 Hz, 1000 Hz, 1250 Hz, 1500 Hz, 2000 Hz, 2500 Hz, 3000

Hz, 4000 Hz, 5000 Hz, 6000 Hz, 8000Hz and resonance frequency, were recorded and noted down for each participant, and additionally, 226 Hz tympanometry measures, i.e., static admittance, TPP, and ECV were also recorded and noted down.

3.5 STATISTICAL ANALYSIS:

The IBM Statistical Package for Social Sciences (SPSS) version 26.0 was used for the statistical analysis.

CHAPTER 4

RESULTS

The current study was planned to compare the effects of two different cochlear implantation surgical procedures, transcanal wall (Veria) and the mastoidectomy posterior tympanotomy approach (MPTA), on the middle ear mechanics using wideband tympanometry (WBT)in children aged 3 to 10 years. To fulfill the objectives of the present study, qualitative and quantitative statistical analyses were conducted. All analyses were carried out using Statistical Package Social Sciences (SPSS), version 26.0 (IBM Corp., Armonk, NY, USA).

Initially, the Shapiro-Wilk test of normality was performed to see if the data were normally distributed. This was done for data obtained for 226 Hz tympanometric measures (compliance, tympanometric peak pressure, &ear canal volume) and WBT measures (resonance frequency and WBA at peak & ambient pressure conditions). The Shapiro-Wilks test statistics for the normality of wideband absorbance at peak pressure condition and ambient pressure condition in the Normal group, MPTA group, and Veria group are given in Table 4.1. It was found that data was normally distributed ($p>0.05$) for measures such as 226 Hz compliance, 226 Hz tympanometric peak pressure (TPP), 226 Hz ear canal volume, resonance frequency, and wideband absorbance at peak pressure for frequencies 250 Hz, 300 Hz, 400 Hz, 500 Hz, 600 Hz, and 800 Hz and wideband absorbance at ambient pressure for frequencies 400 Hz, 500 Hz, 600 Hz, 800 Hz, and 1000 Hz.

And the data was normally distributed ($p<0.05$) for measures such as wideband absorbance at peak pressure for frequencies 1000 Hz, 1250 Hz, 1500 Hz, 2000 Hz, 2500 Hz, 3000 Hz, 4000 Hz, 5000 Hz, 6000 Hz,8000 Hz and wideband absorbance at ambient pressure for frequencies 250 Hz, 300 Hz, 1250 Hz, 1500 Hz, 2000 Hz, 2500 Hz, 3000 Hz, 4000 Hz, 5000 Hz, 6000 Hz, and 8000 Hz.

Table 4.1

Shapiro-Wilks test statistics for normality of WBA obtained at peak and ambient pressure across the Normal, MPTA, and Veria groups

	WBA at peak pressure									WBA at ambient pressure								
	Statistics			df			p-value			Statistics			df			p-value		
Freq (in Hz)	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III
250	0.95	0.85	0.91	20	10	10	0.37	0.05	0.28	0.97	0.82	0.99	20	10	10	0.75	0.03*	0.99
300	0.94	0.87	0.94	20	10	10	0.25	0.10	0.59	0.97	0.82	0.99	20	10	10	0.81	0.03*	0.10
400	0.10	0.89	0.95	20	10	10	0.09	0.19	0.62	0.98	0.87	0.96	20	10	10	0.88	0.09	0.75
500	0.92	0.91	0.95	20	10	10	0.10	0.29	0.63	0.97	0.92	0.97	20	10	10	0.72	0.37	0.10
600	0.94	0.92	0.89	20	10	10	0.27	0.33	0.17	0.97	0.94	0.94	20	10	10	0.76	0.60	0.50
800	0.94	0.90	0.92	20	10	10	0.20	0.21	0.34	0.96	0.85	0.95	20	10	10	0.48	0.06	0.64
1000	0.88	0.94	0.90	20	10	10	0.02*	0.57	0.23	0.93	0.87	0.93	20	10	10	0.13	0.09	0.45
1250	0.73	0.97	0.77	20	10	10	0.00*	0.92	0.06	0.80	0.94	0.92	20	10	10	0.00*	0.58	0.36
1500	0.74	0.97	0.77	20	10	10	0.00*	0.85	0.01*	0.76	0.95	0.81	20	10	10	0.00*	0.61	0.02*
2000	0.74	0.96	0.74	20	10	10	0.00*	0.76	0.00*	0.77	0.92	0.80	20	10	10	0.00*	0.36	0.02*
2500	0.69	0.90	0.89	20	10	10	0.00*	0.24	0.15	0.68	0.93	0.91	20	10	10	0.00*	0.46	0.29
3000	0.64	0.90	0.90	20	10	10	0.00*	0.26	0.08	0.66	0.94	0.84	20	10	10	0.00*	0.51	0.05
4000	0.74	0.91	0.86	20	10	10	0.00*	0.26	0.08	0.87	0.92	0.89	20	10	10	0.00*	0.36	0.15
5000	0.86	0.87	0.87	20	10	10	0.01*	0.09	0.09	0.87	0.88	0.92	20	10	10	0.01*	0.15	0.39
6000	0.95	0.86	0.66	20	10	10	0.41	0.80	0.00*	0.94	0.86	0.75	20	10	10	0.22	0.07	0.00*
8000	0.94	0.84	0.78	20	10	10	0.21	0.05	0.01*	0.93	0.83	0.80	20	10	10	0.16	0.04*	0.07

*Note: *- significant difference at p<0.05, df-degrees of freedom, I-Normal group, II-MPTA group, III-Veria group*

The following statistical analyses were carried out to analyse the data:

- The descriptive statistical analysis (mean, median & standard deviation) were performed for all three groups, i.e., normal, MPTA, and Veria group for all measures, i.e., 226 Hz tympanometry (compliance, tympanometric peak pressure, ear canal volume) and Wideband tympanometry (wideband absorbance at 16 center frequency for peak pressure condition and ambient pressure condition &resonance frequency)
- A Parametric Independent t-test was used to compare 2 independent samples for data having normal distribution.
- A Non-parametric Mann-Whitney U test was used to compare between 2 independent samples for non-normally distributed data.

The results of the study are compared and elaborated under the following headings.

1. Comparison of wideband absorbance and resonance frequency between Normal hearing children and MPTA groups.
2. Comparison of wideband absorbance and resonance frequency between Normal hearing children and Veria groups.
3. Comparison of wideband absorbance and resonance frequency between MPTA and Veria groups.
4. Comparison of 226 Hz Tympanometry and wideband tympanometry across all three groups, i.e., Normal hearing, MPTA, and Veria groups.

4.1 Comparison of Wideband absorbance (WBA) and Resonance (RF) Frequency between Normal and MPTA groups

The descriptive statistics were performed to obtain the Mean, Median, and Standard Deviation values for wide band absorbance (WBA) for 16 center frequencies for both the pressure conditions, i.e., peak pressure and ambient pressure for normal and MPTA groups. Table 4.2 depicts the Mean, Median, and Standard deviation of WBA measured across frequencies at peak pressure and Ambient pressure in the Normal group. Table 4.3 shows the Mean, Median, and Standard Deviation of WBA values measured across frequencies at TPP and Ambient pressure in the MPTA group.

Table 4.2

The Mean, Median, and Standard deviation of WBA across frequencies at peak and Ambient pressure in the Normal group

	Peak Pressure			Ambient Pressure		
Frequency	**Mean**	**Median**	**SD**	**Mean**	**Median**	**SD**
250	0.15	0.15	0.05	0.14	0.14	0.06
300	0.18	0.17	0.06	0.17	0.17	0.07
400	0.25	0.23	0.09	0.24	0.22	0.10
500	0.33	0.29	0.11	0.30	0.28	0.13
600	0.41	0.38	0.14	0.39	0.35	0.16
800	0.57	0.54	0.17	0.52	0.49	0.20
1000	0.69	0.68	0.17	0.64	0.63	0.20
1250	0.71	0.78	0.17	0.69	0.75	.017
1500	0.68	0.71	0.16	0.67	0.71	0.16
2000	0.67	0.70	0.16	0.69	0.71	0.17
2500	0.81	0.87	0.19	0.82	0.88	0.19
3000	0.83	0.89	0.19	0.83	0.80	0.19
4000	0.78	0.80	0.21	0.77	0.87	0.21
5000	0.67	0.67	0.20	0.67	0.68	0.19
6000	0.49	0.49	0.14	0.49	0.48	0.13
8000	0.35	0.31	0.21	0.36	0.31	0.21

From Table 4.2 it can be noted that WBA at peak pressure is found to be high compared to WBA at ambient pressure at frequencies from 250 Hz to 1500 Hz. For frequencies from 1500 Hz to 8000 Hz, the WBA values were found to be almost equal for both peak pressure and ambient pressure conditions for the normal group.

Figure 4.1 shows the mean WBA values across frequencies measured at peak pressure and ambient pressure for the normal group. From Figure 4.1, it can be seen that mean WBA is lower at 250 Hz, increased gradually with increasing frequency, reaching a maximum at 1250 Hz and, increased further at 3000 Hz, and thereafter decreased till 8000 Hz. Thus, maximum absorbance was observed at mid frequencies between 1000 Hz and 3000 Hz, and lower absorbance was seen at low and high frequencies. Also, it is evident that absorbance at peak pressure is slightly higher than the WBA at ambient pressure for frequencies from 250 Hz to 1500 Hz and the absorbance is almost equal for both peak an ambient pressure for frequencies from 1500 Hz to 8000 Hz.

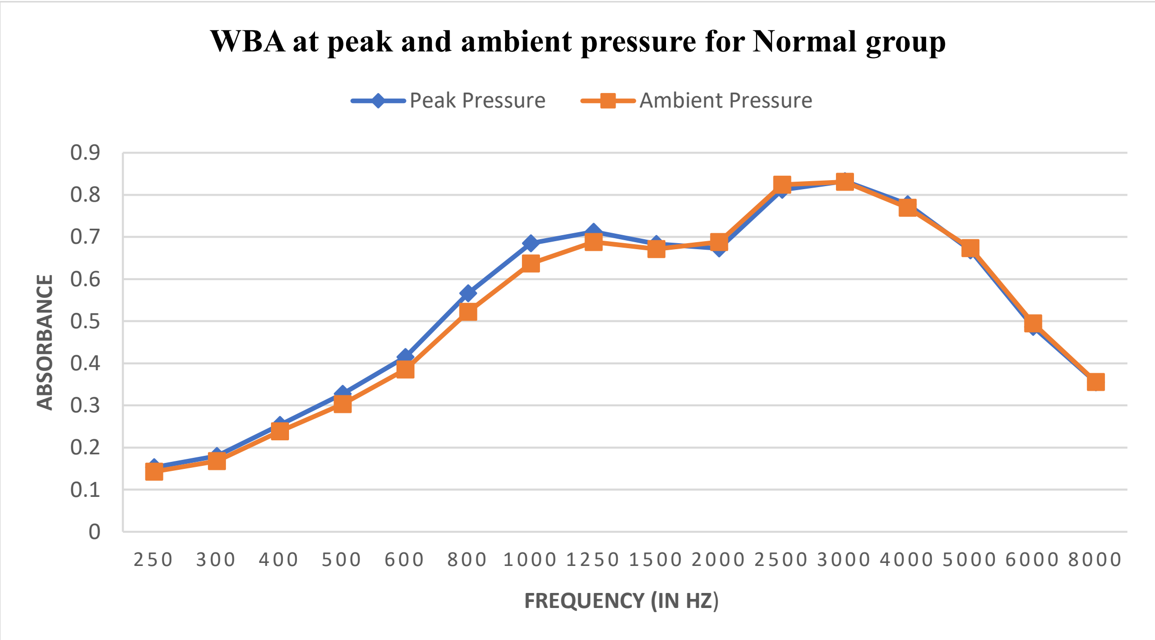


Figure 4.1. *Graphical representation of mean WBA at peak and ambient pressure across frequencies in the Normal group*

Similarly, the descriptive statistics were carried out for the MPTA group (CI children operated with MPTA surgery approach). Table 4.3 and Figure 4.2 shows the Mean, Median, and Standard Deviation values of WBA across all 16 frequencies at peak pressure and ambient pressure for the MPTA group. From Table 4.3 it can be seen that WBA at peak pressure is slightly more than ambient pressure conditions at frequencies from 250 Hz to 3000 Hz and for frequencies from 4000 Hz to 8000 Hz the WBA values were found to be almost equal for both peak and ambient pressure conditions.

Table 4.3

The Mean, Median, and Standard Deviation of WBA across frequencies at TPP and Ambient pressure in MPTA group

	Peak Pressure			Ambient Pressure		
Frequency	**Mean**	**Median**	**SD**	**Mean**	**Median**	**SD**
250	0.12	0.10	0.05	0.11	0.09	0.05
300	0.14	0.12	0.06	0.13	0.11	0.06
400	0.20	0.18	0.07	0.19	0.17	0.07
500	0.25	0.24	0.07	0.24	0.22	0.08
600	0.32	0.32	0.09	0.30	0.37	0.09
800	0.44	0.42	0.16	0.42	0.41	0.17
1000	0.52	0.48	0.17	0.47	0.49	0.19
1250	0.59	0.61	0.12	0.52	0.56	0.16
1500	0.64	0.66	0.15	0.57	0.56	0.17
2000	0.73	0.71	0.13	0.70	0.70	0.13
2500	0.81	0.83	0.12	0.80	0.84	0.13
3000	0.84	0.85	0.10	0.83	0.85	0.12
4000	0.78	0.82	0.16	0.78	0.82	0.15
5000	0.66	0.73	0.20	0.66	0.72	0.19
6000	0.46	0.53	0.16	0.46	0.54	0.15
8000	0.32	0.28	0.20	0.33	0.28	0.20

Figure 4.2 shows that the mean WBA at peak pressure was noted to be high for frequencies 250 Hz to 3000 Hz compared to that of absorbance at ambient pressure and

WBA was found to be almost equal for both peak and ambient pressure from 4000 Hz to 8000 Hz.

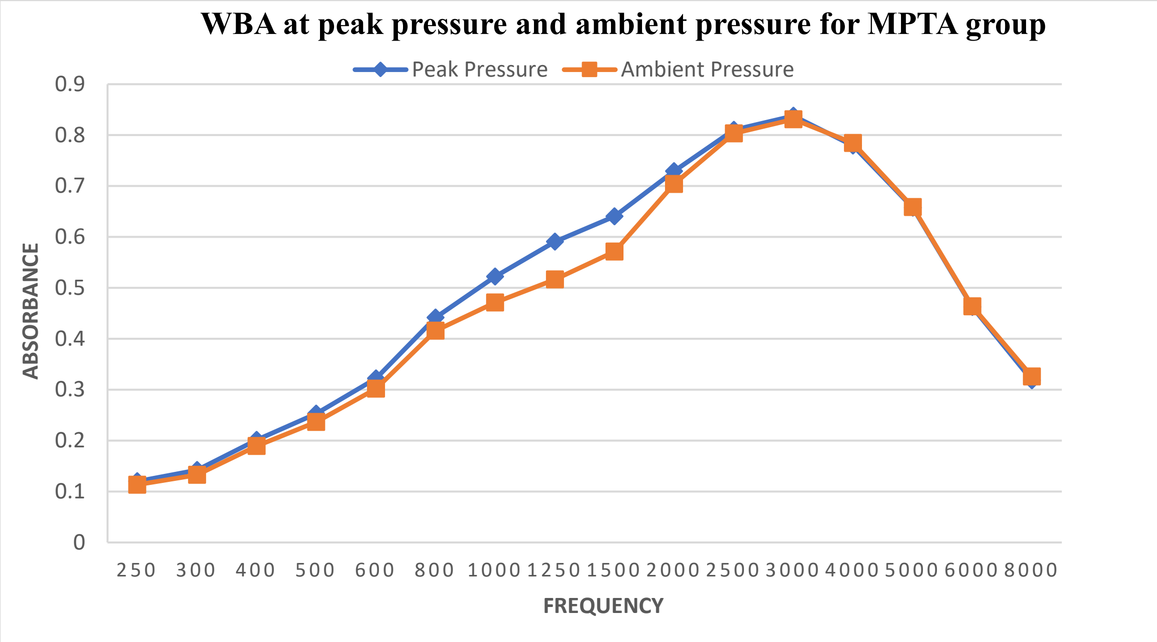
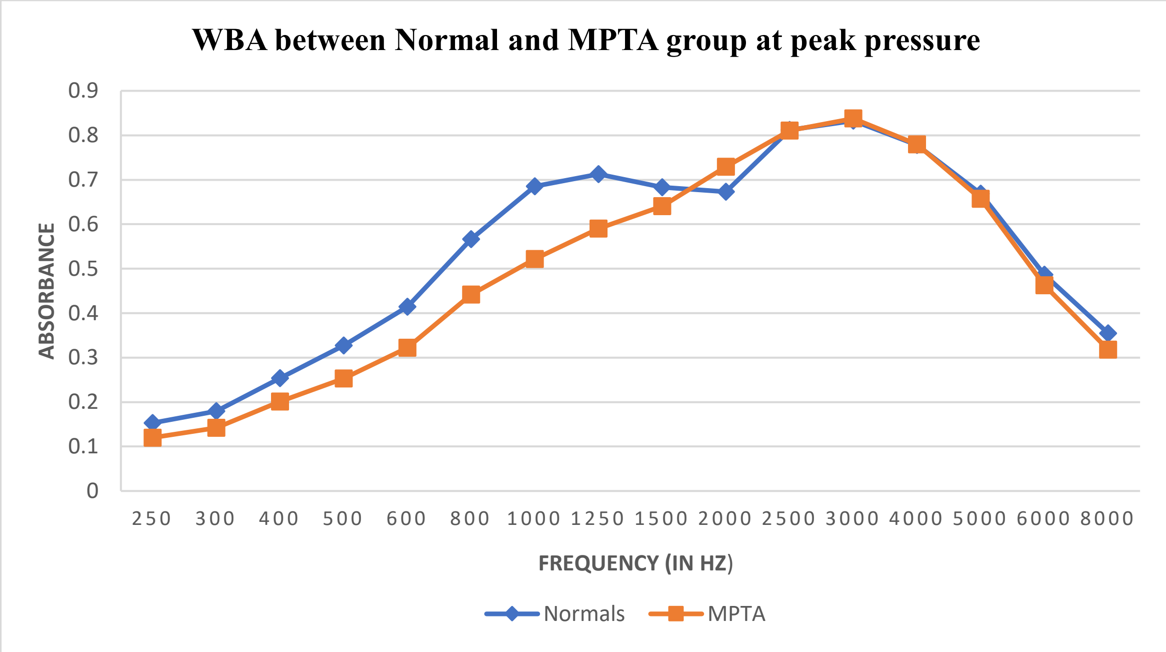
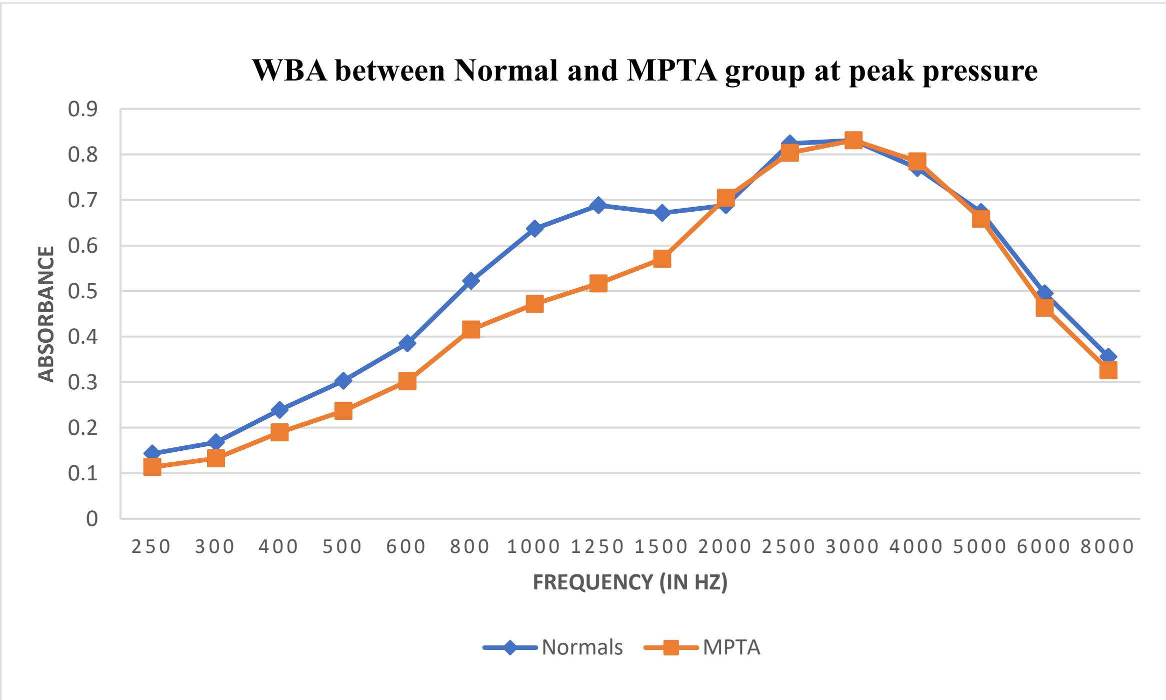


Figure 4.2. *Graphical representation of mean WBA at peak and ambient pressure across frequencies in the MPTA group*

From Tables 4.2 and 4.3 it can be observed that the mean wide absorbance values for the normal group were different from that of the MPTA group. The differences noted in mean wide absorbance values of normal and MPTA group is also clearly shown in Figure 4.3 (a) and (b). Figure 4.3 (a) shows the mean WBA between Normal and MPTA groups across frequencies at peak pressure, and Figure 4.3 (b) shows the mean WBA between Normal and MPTA groups across frequencies at ambient pressure. It can be observed from both figures 4.3 (a) and 4.3 (b) that there are differences between Normal and MPTA group in mean WBA across frequencies from 250 Hz to 2000 Hz and thereafter from 2500 Hz WBA values were found to be almost equal from 2500 Hz to 8000 Hz for both at peak pressure and ambient pressure.



(a)



(b)

Figure 4.3. *Graphical representation of WBA between Normal and MPTA groups across frequencies at a) peak pressure and b) ambient pressure*

Further, to see if there is any significant difference in WBA values between the Normal group and the MPTA group at peak pressure and ambient pressure, the Independent t- test utilized for data exhibited normal distribution and Mann Whitney U test was employed for data did not follow normal distribution.

First, the comparison of WBA between the Normal and MPTA groups was performed at peak pressure conditions using an Independent t- test that was performed for WBA at frequencies 250 Hz, 300 Hz, 400 Hz, 500 Hz, 600 Hz, and 800 Hz at peak pressure which were normally distributed as per the Shapiro-Wilk test of normality. The results of the Independent t-test and their significant level of WBA across frequencies between the Normal and MPTA group at peak pressure are given in Table 4.4. From Table 4.4, it can be seen that there is no significant difference (p>0.05) between the Normal and MPTA groups for WBA at frequencies 250 Hz, 300 Hz, 400 Hz, 500 Hz, 600 Hz, and 800 Hz at peak pressure.

Table 4.4

Independent t-test results and their significant level of WBA across frequencies between Normal and MPTA groups at peak pressure

Frequency	**| t |**	***p***
250	1.80	0.08
300	1.72	0.10
400	1.67	0.11
500	1.90	0.07
600	1.93	0.06
800	1.95	0.06

Note- | t | - Test Statistic; p-<0.05 Significant level

Fuhrer, non-parametric Mann Whitney U test was employed for non-normally distributed parameters, i.e., WBA for frequencies 1000 Hz, 1250 Hz, 1500 Hz, 2000 Hz, 2500 Hz, 3000 Hz, 4000 Hz, 5000 Hz, 6000 Hz, and 8000 Hz at peak pressure between Normal and MPTA group. Mann Whitney U test results and their significant level of WBA across frequencies between Normal and MPTA groups at peak pressure condition is given in Table 4.5.

Table 4.5

Mann Whitney U test results and their significant level of WBA across frequencies between Normal and MPTA groups at peak pressure

Frequency	**| z |**	***p***
1000	2.23	0.02*
1250	2.60	0.01*
1500	1.14	0.25
2000	0.70	0.48
2500	0.75	0.45
3000	0.66	0.51
4000	0.35	0.73
5000	0.13	0.90
6000	0.13	0.90
8000	0.48	0.63

*Note- |z | - Test Statistic; p-<0.05 Significant level; *-significant difference*

It can be seen from Table 4.2 and Table 4.3 that, there was a difference noted for WBA values at frequencies from 250 Hz to 2000 Hz. The differences noted for WBA values were significantly different (p<0.05) for WBA only at frequencies 1000 Hz and

1250 Hz at peak pressure. And for frequencies 1500 Hz, 2000 Hz, 2500 Hz, 3000 Hz, 4000 Hz, 5000 Hz, 6000 Hz, and 8000 Hz, there was no significant difference (p>0.05) found for WBA at peak pressure.

To summarize, a comparison of WBA values between Normal and the MPTA group at peak pressure revealed that there was no significant difference (p>0.05) found for WBA values at peak pressure for all frequencies except at 1000 Hz and 1250 Hz frequencies.

In a similar way, a comparison between the Normal group and the MPTA group was carried out for WBA values across frequencies at the ambient pressure condition. Independent t-test was performed for frequencies 400 Hz, 500 Hz, 600 Hz, 800 Hz, and 1000 Hz at ambient pressure, which were normally distributed as per the Shapiro-Wilk test of normality. Independent t-test results and their significant level of WBA across frequencies between Normal and MPTA groups at ambient pressure conditions are given in Table 4.6.

Results from Table 4.6 showed that there was no significant difference (p>0.05) for the 400 Hz, 500 Hz, 600 Hz, and 800 Hz frequencies except for 1000 Hz frequency where there was a significant difference (p<0.05) found at ambient pressure between Normal and MPTA group.

Table 4.6

Independent t-test results and their significant level of WBA across frequencies between Normal and MPTA groups at ambient pressure

Frequency	**| t |**	***p***
400	1.40	0.17
500	1.50	0.14
600	1.53	0.14
800	1.45	0.16
1000	2.17	0.04*

*Note: | t | - Test Statistic; p-<0.05 Significant level; *-significant difference*

Fuhrer, non-parametric Mann Whitney U test was performed for non-normally distributed parameters, i.e., WBA for frequencies 250 Hz, 300 Hz, 1250 Hz, 2000 Hz, 2500 Hz, 3000 Hz, 4000 Hz, 5000 Hz, 6000 Hz, and 8000 Hz at ambient pressure between Normal and MPTA group. Mann Whitney U test results and their significant level of WBA across frequencies between Normal and MPTA groups at ambient pressure conditions are given in Table 4.7.

Table 4.7

Mann Whitney U test results and their significant level of WBA across frequencies between Normal and MPTA groups at ambient pressure

Frequency	**| z |**	***p***
250	1.45	0.15
300	1.41	0.16
1250	2.66	0.01*
1500	1.85	0.07
2000	0.26	0.79
2500	0.86	0.39
3000	0.59	0.55
4000	0.20	0.84
5000	0.35	0.73
6000	0.00	1.00
8000	0.33	0.74

*Note- | z | - Test Statistic; p- (<0.05) Significant level; *-significant difference*

It can be seen from Table 4.7 that although there were differences noted for WBA at frequencies from 250 Hz to 2000 Hz, these differences were significantly different ($p<0.05$) for WBA at frequency 1250 Hz at peak pressure. And for frequencies 250 Hz, 300 Hz, 2000 Hz, 2500 Hz, 3000 Hz, 4000 Hz, 5000 Hz, 6000 Hz, and 8000 Hz, there was no significant difference ($p>0.05$) was found for WBA at peak pressure.

To summarize, a comparison of WBA between the Normal and MPTA groups at ambient pressure revealed that a significant difference ($p<0.05$) was found for1250Hz ($p<0.05$) frequency, and for other frequencies 250 Hz, 300 Hz, 2000 Hz, 2500 Hz, 3000 Hz, 4000 Hz, 5000 Hz, 6000 Hz, and 8000 Hz there was no significant difference (*p*>0.05) was found.

In brief, it can be concluded that a comparison of mean WBA values between the Normal group and the MPTA group revealed that there was a difference noted in mean WBA values between the Normal group and the MPTA group for frequencies from 250 Hz to 2000 Hz. However, a significant difference in WBA was found at 1000 Hz and 1250 Hz frequencies for both peak pressure and ambient pressure. And there was no significant difference found for other frequencies: 250 Hz, 300 Hz, 400 Hz, 500 Hz, 600 Hz, 800 Hz, 1500 Hz, 2000 Hz, 2500 Hz, 3000 Hz, 4000 Hz, 5000 Hz, 6000 Hz, and 8000 Hz (Figure 4.3 (a) & (b)).

Further, for Comparison of Resonance Frequency (RF) between Normal and MPTA groups, the descriptive statistic was carried out to obtain the Mean, Median, and Standard Deviation values of RF measured for the normal and MPTA groups, and results are shown in Table 4.8.

Table 4.8

The Mean, Median, and Standard deviation of Resonance Frequency for Normal and MPTA groups

Frequency	**Groups**	**Mean**	**Median**	**SD**
Resonance Frequency	Normal	843.05	892.50	236.10
	MPTA	890.50	871.50	328.59

It can be seen from Table 4.8 that the mean resonance frequency values were high for the MPTA group compared to the Normal group. Figure 4.4 also depicts that there is a difference in resonance frequency between the Normal and MPTA groups.

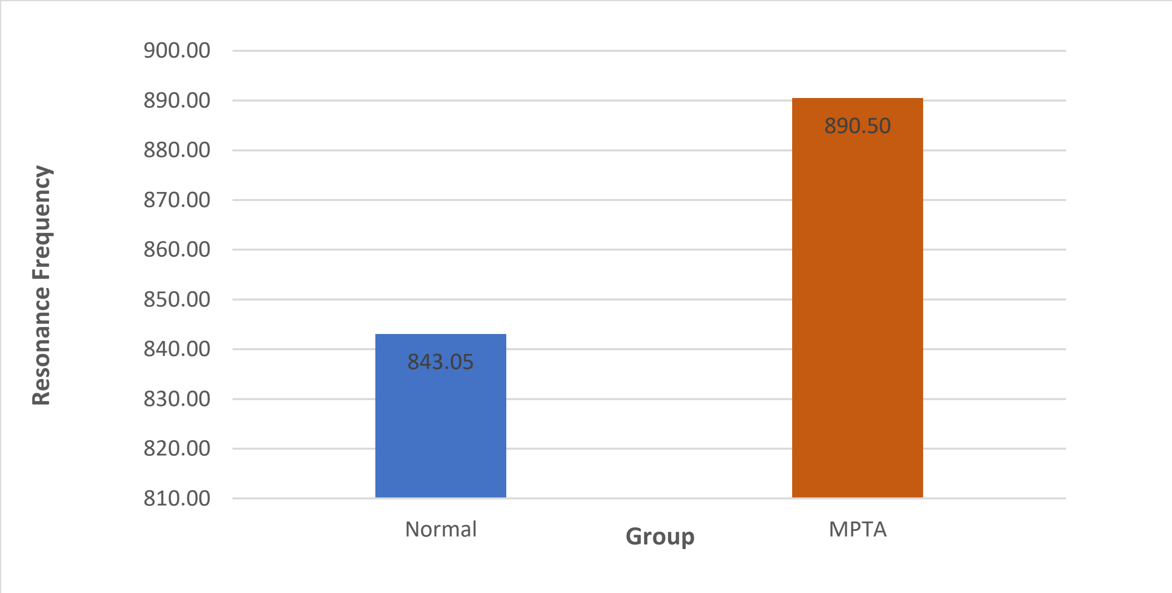


Figure 4.4. *Graphical representation of a comparison of Resonance Frequency between Normal and MPTA group*

To analyze further, is there any significant difference in RF between the normal and MPTA groups, an Independent t-test was performed as the resonance frequency value was normally distributed as per the Shapiro-Wilk test of normality. Independent t-test results and their significant level of Resonance Frequency revealed that although there was a difference noted in mean resonance frequency value between the Normal and MPTA group, this difference in RF was not statistically significant [|t| (28) = 045, p = 0.65] between Normal and MPTA group. Hence, it can be concluded that there is no significant difference in RF between the Normal and MPTA groups (p>0.05).

4.2 Comparison of Wideband absorbance (WBA) and Resonance Frequency between Normal and Veria groups

The descriptive statistics were performed to obtain the Mean, Median, and Standard Deviation values of WBA for 16 center frequencies for both peak and ambient pressure in the Veria group. Table 4.9 depicts the Mean, Median, and Standard deviation of WBA values measured across 16 different frequencies at peak and ambient pressure in the Veria group.

Table 4.9

The Mean, Median, and Standard deviation of WBA across 16 frequencies at peak pressure and Ambient pressure in the Veria group

	Peak Pressure			Ambient Pressure		
Frequency	**Mean**	**Median**	**SD**	**Mean**	**Median**	**SD**
250	0.14	0.14	0.04	0.13	0.12	0.04
300	0.18	0.17	0.05	0.15	0.15	0.05
400	0.26	0.25	0.09	0.22	0.22	0.09
500	0.33	0.32	0.10	0.27	0.29	0.12
600	0.39	0.35	0.14	0.34	0.34	0.12
800	0.49	0.43	0.19	0.40	0.40	0.18
1000	0.58	0.63	0.18	0.47	0.49	0.23
1250	0.70	0.78	0.21	0.63	0.69	0.23
1500	0.75	0.82	0.19	0.71	0.82	0.27
2000	0.81	0.87	0.19	0.78	0.88	0.24
2500	0.77	0.82	0.21	0.72	0.75	0.23
3000	0.66	0.64	0.16	0.62	0.60	0.13
4000	0.54	0.59	0.13	0.53	0.56	0.12
5000	0.43	0.40	0.22	0.41	0.42	1.15
6000	0.35	0.29	0.22	0.33	0.29	0.16
8000	0.29	0.19	0.23	0.28	0.18	0.22

From Table 4.9, it can be noted that WBA at peak pressure is found to be slightly higher compared to WBA at ambient pressure at all frequencies from 250 Hz to 8000

Hz in the Veria group. Figure 4.5 also shows the mean WBA values at peak pressure and ambient pressure for the Veria group. It can be seen from Table 4.9 and Figure 4.5 that the mean WBA value is lower at 250 Hz, increased gradually with increasing frequency, reaching a maximum at 2000 Hz, and thereafter decreased gradually till 8000 Hz. Thus, maximum absorbance was observed at 2000 Hz frequency, and lower absorbance was seen at lower (less than 2 K Hz) and high (more than 2 K Hz) frequencies. Also, it is evident that the absorbance at peak pressure is slightly higher than absorbance at ambient pressure for all frequencies from 250 Hz to 8000 Hz.

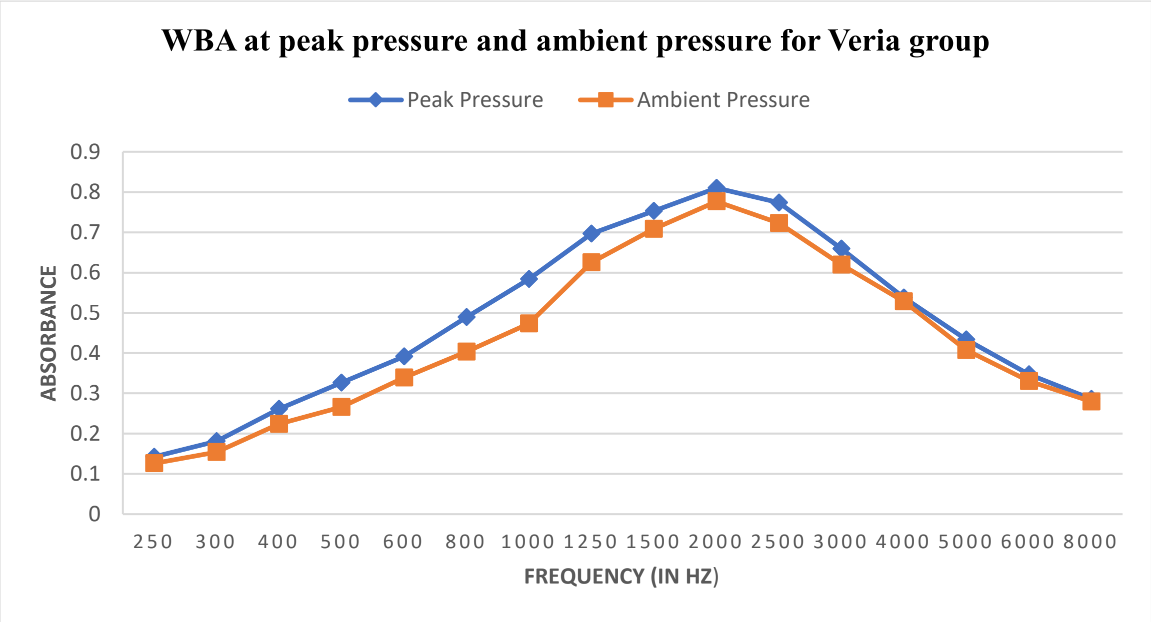
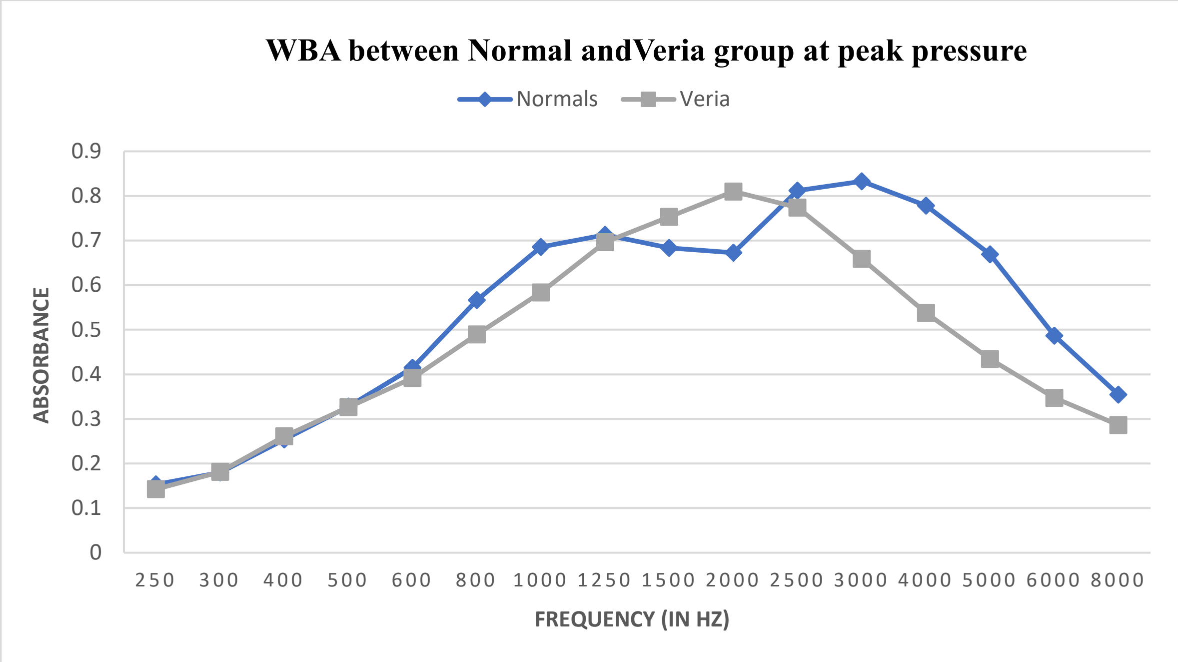


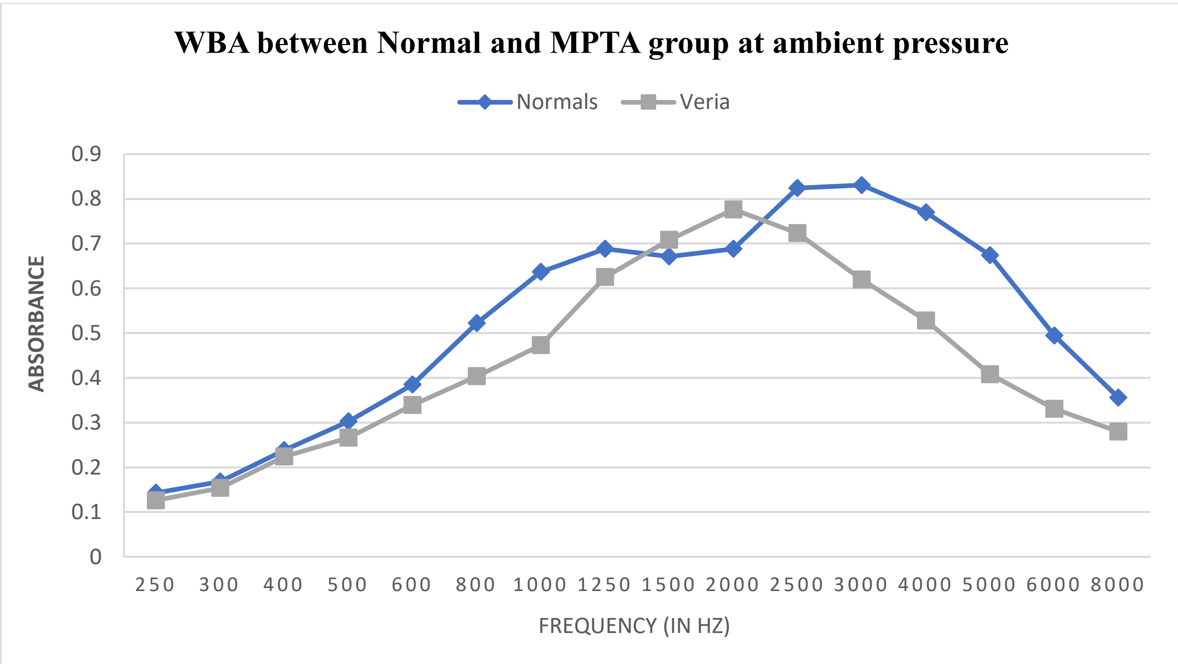
Figure 4.5. *Graphical representation of mean WBA at peak and ambient pressure across frequencies in the Veria group*

It was observed by looking at Tables 4.1 and 4.9 that the mean absorbance values for the normal group were different from those of the Veria group. The differences that was noted in the mean WBA values of the Normal and Veria group is also clearly visible in Figure 4.6 (a) & (b). Figure 4.6 (a) shows the mean WBA values between Normal and Veria groups across frequencies at peak pressure, and Figure 4.6

(b) shows the mean WBA values between Normal and Veria groups across frequencies at ambient pressure. It can be observed from Figure 4.6 (a) that there are differences noted between the Normal and Veria groups in WBA values across frequencies from 600 Hz to 8000 Hz and, from 250 Hz to 500 Hz the WBA values were almost similar at peak pressure. For ambient pressure it can be seen that there are diffrences in WBA values between Normal and Veria group for all frequencies from 250 Hz to 8000 Hz (Figure 4.6 (b).



(a)



(b)

Figure 4.6. *Graphical representation of WBA between Normal and Veria groups across frequencies at a) peak pressure and b) ambient pressure*

Further, to see if there is any significant difference in WBA values between the Normal group and Veria group at peak pressure and ambient pressure, the Independent t-test and Mann Whitney U test were performed for normally distributed data and non-normally distributed data, respectively.

First, an Independent t-test was performed for WBA values at frequencies 250 Hz, 300 Hz, 400 Hz, 500 Hz, 600 Hz, and 800 Hz at peak pressure, which were normally distributed as per the Shapiro-Wilk test of normality. The Independent t-test results and their significant level of WBA across frequencies between the Normal and Veria groups at peak pressure conditions are given in Table 4.10. From Table 4.10, it can be seen that the Independent t-test showed that there was no significant difference ($p>0.05$) between the Normal and Veria groups for WBA at frequencies 250 Hz, 300 Hz, 400 Hz, 500 Hz, 600 Hz, and 800 Hz at peak pressure condition.

Table 4.10

Independent t-test results and their significant level of WBA across frequencies between Normal and Veria groups at peak pressure condition

Frequency	**| t |**	***p***
250	0.58	0.56
300	0.07	0.94
400	0.21	0.83
500	0.03	0.98
600	0.44	0.67
800	1.13	0.27

Note- | t | - Test Statistic; p-<0.05 Significant level

Fuhrer, non-parametric Mann Whitney U test was performed for non-normally distributed measures, i.e., WBA for frequencies 1000 Hz, 1250 Hz, 1500 Hz, 2000 Hz, 2500 Hz, 3000 Hz, 4000 Hz, 5000 Hz, 6000 Hz, and 8000 Hz at peak pressure between Normal and Veria group. Mann Whitney U test results and their significant level of WBA across frequencies between Normal and Veria groups at peak pressure are given in Table 4.11.

Table 4.11

Mann Whitney U test results and their significant level of WBA across frequencies between Normal and Veria groups at peak pressure

Frequency	$\|z\|$	*p*
1000	1.45	0.15
1250	0.13	0.90
1500	1.56	0.12
2000	2.68	0.01*
2500	0.31	0.76
3000	2.91	0.00*
4000	3.61	0.00*
5000	2.86	0.00*
6000	2.82	0.01*
8000	1.17	0.24

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

It can be seen from Table 4.11 that there is a significant difference ($p<0.05$) seen in WBA at 2000 Hz, 3000 Hz, 4000 Hz, 5000 Hz, and 6000 Hz frequencies at peak pressure. And there was no significant (*p*>0.05) difference found for WBA at 1000 Hz, 1250 Hz, 1500 Hz, 2500 Hz, and 8000 Hz frequencies.

To summarize, a comparison of WBA at peak pressure between the Normal and Veria groups revealed that there was no statistically significant difference (p>0.05) found for frequencies 250 Hz, 300 Hz, 400 Hz, 500 Hz, 600 Hz, 800 Hz, 1000 Hz, 1250 Hz, 1500 Hz, 2500 Hz, and 8000 Hz. And there was a significant difference in WBA values found for frequencies 2000 Hz, 3000 Hz, 4000 Hz, 5000 Hz, and 6000 Hz.

In a similar way, the comparison of WBA between the Normal group and the Veria group was carried out for the ambient pressure condition. Independent t-test was performed for frequencies 400 Hz, 500 Hz, 600 Hz, 800 Hz, and 1000 Hz at ambient pressure, which were normally distributed as per the Shapiro-Wilk test of normality. Independent t-test results and their significant level of WBA across frequencies between Normal and Veria groups at ambient pressure are given in Table 4.12.

From Table 4.12, it can be seen that the Independent t-test showed that no significant difference (*p*>0.05) was found for the 400 Hz, 500 Hz, 600 Hz, and 800 Hz frequencies, And for 1000 Hz frequencies, there was significant difference (*p*<0.05) was noted between Normal and Veria group at ambient pressure condition.

Table 4.12

Independent t-test results and their significant level of WBA across frequencies between Normal and Veria groups at ambient pressure

Frequency	**| t |**	***p***
400	0.39	0.70
500	0.75	0.46
600	0.81	0.43
800	1.59	0.12
1000	2.02	0.05*

*Note: | t | - Test Statistic; p-<0.05 Significant level; *-significant difference*

Fuhrer, non-parametric Mann Whitney U test was performed for non-normally distributed parameters, i.e., absorbance for frequencies 250 Hz, 300 Hz, 1250 Hz, 2000 Hz, 2500 Hz, 3000 Hz, 4000 Hz, 5000 Hz, 6000 Hz, and 8000 Hz at ambient pressure between Normal and Veria group. Mann Whitney U test results and their significant level of WBA across frequencies between Normal and Veria groups at ambient pressure are given in Table 4.13.

Table 4.13

Mann Whitney U test results and their significant level of WBA across frequencies between Normal and Veria groups at ambient pressure

Frequency	| z |	*p*
250	0.77	0.44
300	0.62	0.54
1250	0.57	0.57
1500	1.58	0.11
2000	1.98	0.05*
2500	1.28	0.20
3000	3.57	0.00*
4000	3.56	0.00*
5000	3.35	0.00*
6000	3.17	0.00*
8000	1.32	0.19

*Note- | z | - Test Statistic; p-<0.05 Significant level; *-significant difference*

It can be noted that although there were differences noted for mean WBA for frequencies 250 Hz, 300 Hz, 1250 Hz, 2000 Hz, 2500 Hz, 3000 Hz, 4000 Hz, 5000 Hz, 6000 Hz, and 8000 Hz (table 4.2 & table 4.9) the significant difference ($p<0.05$) for WBA were found for only frequencies 2000 Hz, 3000 Hz, 4000 Hz, 5000 Hz, and 6000 Hz at ambient pressure condition between Normal and Veria group (Table 4.13).

To summarize, a comparison of WBA between the Normal and Veria groups at ambient pressure revealed a significant difference ($p<0.05$) found for 1000 Hz, 2000 Hz, 2500 Hz, 3000 Hz, 4000 Hz, 5000 Hz, and 6000 Hz frequencies and for other frequencies 250 Hz, 300 Hz, 400 Hz, 500 Hz, 600 Hz, 800 Hz, 1250 Hz, 1500 Hz, and 8000 Hz there was no significant difference (*p*>0.05) found.

In brief, it can be concluded that a comparison of WBA between the Normal group and the Veria group revealed that there was a significant difference found for WBA at frequencies 2000 Hz, 3000 Hz, 4000 Hz, 5000 Hz, 6000 Hz and 1000 Hz, 2000 Hz, 3000 Hz, 4000 Hz, 5000 Hz, 6000 Hz frequencies at peak pressure condition and ambient pressure condition respectively.

And there was no significant difference found for WBA for 250 Hz, 300 Hz, 400 Hz, 500 Hz, 600 Hz, 800 Hz, 1000 Hz, 1250 Hz, 1500 Hz, 2500 Hz, and 8000 Hz at peak pressure; for WBA at frequencies 250 Hz, 300 Hz, 400 Hz, 500 Hz, 600 Hz, 800 Hz, 1250 Hz, 1500 Hz, and 8000 Hz at ambient pressure (Figure 4.6 a & b).

Further, a Comparison of Resonance Frequency was carried out between the Normal and Veria group, for which descriptive statistic was carried out to obtain Mean, Median, and Standard Deviation values were obtained, which are shown in Table 4.14 and Figure 4.7.

Table 4.14

The Mean, Median, and Standard deviation of Resonance Frequency for the Normal and Veria group

Frequency	**Groups**	**Mean**	**Median**	**SD**
Resonance Frequency	Normal	843.05	892.50	236.10
	Veria	709.70	667.50	308.78

It can be seen from Table 4.14 that the mean resonance frequency values were high for the Normal group compared to the Veria group. Figure 4.7 also depicts that mean resonance frequency values were high in the Normal group compared to the Veria group.

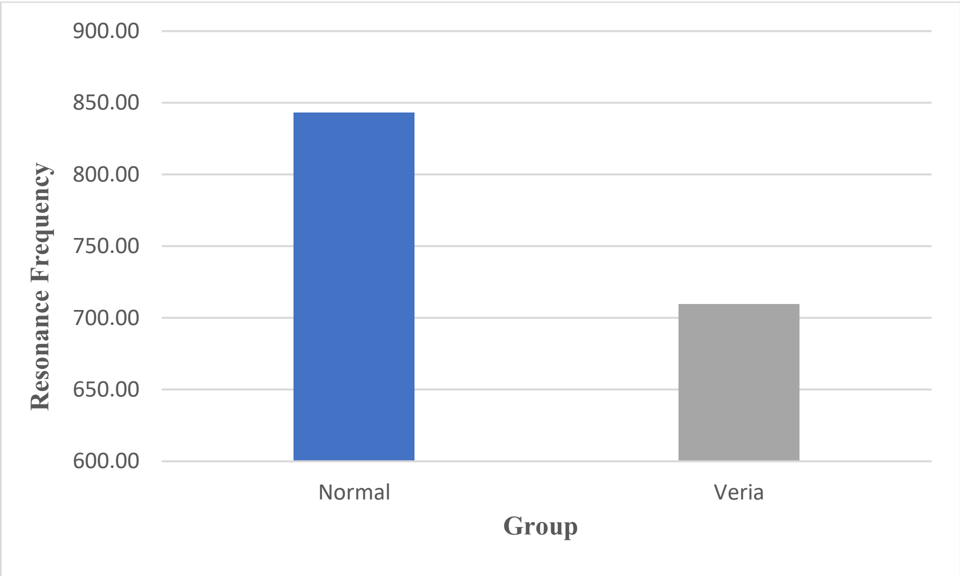


Figure 4.7. *Graphical representation of a comparison of Resonance Frequency between Normal and Veria group*

To analyze further whether there is any significant difference in RF between the normal and Veria group, an Independent t- test was performed as the resonance frequency was normally distributed as per the Shapiro-Wilk test of normality. Independent t-test results and their significant level of Resonance Frequency revealed that although there was a difference noted in mean RF between the Normal and Veria group (Table 4.14), there was no significant difference [$|t|$ (28) = 1.31, $p = 0.20$] between RF of Normal and Veria group. Hence, it can be concluded that the RF did not differ significantly between the Normal and Veria group ($p>0.05$).

4.3 Comparison of Wideband absorbance and Resonance Frequency between MPTA and Veria groups

The descriptive statistics were performed to obtain the Mean, Median, and Standard Deviation values for WBA for 16 centre frequencies at both the pressure conditions, i.e., peak pressure and ambient pressure for the MPTA group and Veria group. The Mean, Median, and Standard Deviation values are given in Table 4.15.

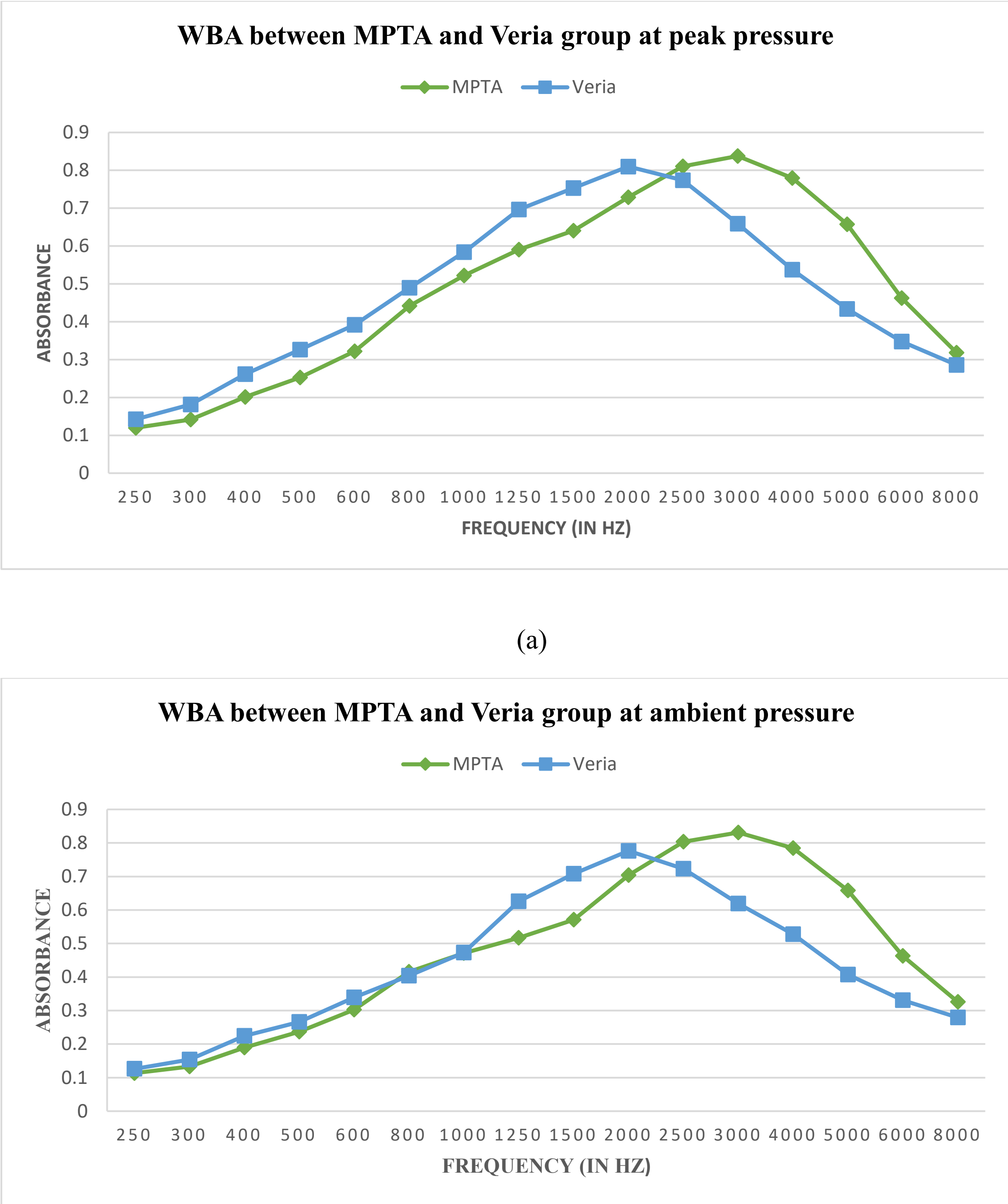
Table 4.15

The Mean, Median, and Standard deviation of WBA across frequencies at peak and Ambient pressure in MPTA and Veria group

Groups	MPTA group						Veria group					
Pressure	**Peak pressure**			**Ambient pressure**			**Peak pressure**			**Ambient pressure**		
Frequency	**Mean**	**Median**	**SD**	**Mean**	**Median**	**SD**	**Mean**	**Median**	**SD**	**Mean**	**Median**	**SD**
250	0.12	0.10	0.05	0.11	0.09	0.05	0.14	0.14	0.04	0.13	0.12	0.04
300	0.14	0.12	0.06	0.13	0.11	0.06	0.18	0.17	0.05	0.15	0.15	0.05
400	0.20	0.18	0.07	0.19	0.17	0.07	0.26	0.25	0.09	0.22	0.22	0.09
500	0.25	0.24	0.07	0.24	0.22	0.08	0.33	0.32	0.10	0.27	0.29	0.12
600	0.32	0.32	0.09	0.30	0.37	0.09	0.39	0.35	0.14	0.34	0.34	0.12
800	0.44	0.42	0.16	0.42	0.41	0.17	0.49	0.43	0.19	0.40	0.40	0.18
1000	0.52	0.48	0.17	0.47	0.49	0.19	0.58	0.63	0.18	0.47	0.49	0.23
1250	0.59	0.61	0.12	0.52	0.56	0.16	0.70	0.78	0.21	0.63	0.69	0.23
1500	0.64	0.66	0.15	0.57	0.56	0.17	0.75	0.82	0.19	0.71	0.82	0.27
2000	0.73	0.71	0.13	0.70	0.70	0.13	0.81	0.87	0.19	0.78	0.88	0.24
2500	0.81	0.83	0.12	0.80	0.84	0.13	0.77	0.82	0.21	0.72	0.75	0.23
3000	0.84	0.85	0.10	0.83	0.85	0.12	0.66	0.64	0.16	0.62	0.60	0.13
4000	0.78	0.82	0.16	0.78	0.82	0.15	0.54	0.59	0.13	0.53	0.56	0.12
5000	0.66	0.73	0.20	0.66	0.72	0.19	0.43	0.40	0.22	0.41	0.42	1.15
6000	0.46	0.53	0.16	0.46	0.54	0.15	0.35	0.29	0.22	0.33	0.29	0.16
8000	0.32	0.28	0.20	0.33	0.28	0.20	0.29	0.19	0.23	0.28	0.18	0.22

From Table 4.15, it can be noted that mean WBA values for the Veria group were slightly higher at 250 Hz to 2000 Hz and lower for 2500 Hz to 8000 Hz at peak pressure than that of WBA values for the MPTA group. And at ambient pressure also, the WBA values for the Veria group were slightly higher at 250 Hz to 2000 Hz and lower from 2500 Hz to 8000 Hz than that of WBA values for the MPTA group.

The Figure 4.8 represents a comparison of mean WBA values between MPTA and Veria groups across frequencies at (a) peak pressure and (b) ambient pressure. Figure 4.8 (a) and (b) also shows the differences in mean WBA curves of MPTA and Veria group at peak pressure and ambient pressure condition, respectively. From the figures 4.8 (a) and (b) it can be noted that the WBA values for Veria group were slightly higher at 250 Hz to 2000 Hz and lower for 2500 Hz to 8000 Hz than that of WBA values for MPTA group.



(b)

Figure 4.8. *Graphical representation of comparison WBA between MPTA and Veria groups across frequencies at a) peak pressure and b) ambient pressure*

Further, to see if there is any significant difference in WBA values between the MPTA group and Veria group at peak pressure and ambient pressure, the Independent t-test and Mann Whitney U test were performed for normally distributed data and non-normally distributed data, respectively.

First, an Independent t-test was performed for WBA at frequencies 250 Hz, 300 Hz, 400 Hz, 500 Hz, 600 Hz, and 800 Hz at peak pressure, which were normally distributed as per the Shapiro-Wilk test of normality. The Independent t-test results and their significant level of WBA across frequencies between MPTA and Veria group at peak pressure are given in Table 4.16. The results of the Independent t-test showed that there was no significant difference (p>0.05) for WBA between MPTA and Veria group at frequencies 250 Hz, 300 Hz, 400 Hz, 500 Hz, 600 Hz, and 800 Hz at peak pressure.

Table 4.16

Independent t-test results and their significant level of WBA across frequencies between MPTA and Veria group at peak pressure

Frequency	| t |	*p*
250	1.11	0.28
300	1.58	0.13
400	1.64	0.12
500	1.87	0.08
600	1.35	0.20
800	0.61	0.55

Note- | t | - Test Statistic; p-<0.05 Significant level

Fuhrer, non-parametric Mann Whitney U test was performed for non-normally distributed parameters, i.e., WBA for frequencies: 1000 Hz, 1250 Hz, 1500 Hz, 2000 Hz, 2500 Hz, 3000 Hz, 4000 Hz, 5000 Hz, 6000 Hz, and 8000 Hz at peak pressure between Normal and Veria group. Mann Whitney U test results and their significant level of WBA across frequencies between Normal and Veria groups at peak pressure are given in Table 4.17.

Table 4.17

Mann Whitney U test results and their significant level of WBA across frequencies between MPTA and Veria groups at peak pressure

Frequency	**| z |**	***p***
1000	0.64	0.52
1250	2.00	0.05*
1500	1.97	0.05*
2000	1.51	0.13
2500	0.04	0.97
3000	2.57	0.01*
4000	2.80	0.01*
5000	1.97	0.05*
6000	1.81	0.07
8000	076	0.45

*Note- | z | - Test Statistic; p-<0.05 Significant level; *-significant difference*

It can be seen from Table 4.17 that there is a significant difference ($p<0.05$) observed for WBA at 1250 Hz, 1500 Hz, 3000 Hz, 4000 Hz, and 5000 Hz frequencies at peak pressure. And there was no significant ($p>0.05$) difference found for WBA at 1000 Hz, 2000 Hz, 2500 Hz, 6000 Hz, and 8000 Hz frequencies.

To summarize, a comparison of WBA at peak pressure between MPTA and Veria groups revealed that there was no statistically significant difference ($p>0.05$) found for frequencies 250 Hz, 300 Hz, 400 Hz, 500 Hz, 600 Hz,800 Hz1000 Hz, 2000 Hz, 2500 Hz, 6000 Hz, and 8000 Hz. And there was a significant difference ($p<0.05$) for WBA at peak pressure for frequencies 1250 Hz, 1500 Hz, 3000 Hz, 4000 Hz, and 5000 Hz.

In a similar way, a comparison of WBA at ambient pressure between the MPTA group and the Veria group was carried out. Independent t-test was performed for frequencies 400 Hz, 500 Hz, 600 Hz, 800 Hz, and 1000 Hz at ambient pressure, which were normally distributed as per the Shapiro-Wilk test of normality. Independent t-test results and their significant level of WBA across frequencies between MPTA and Veria group at ambient pressure are given in Table 4.16. From Table 4.17, it can be seen that the Independent t-test showed that there was no significant difference ($p>0.05$) found for the 400 Hz, 500 Hz, 600 Hz, 800 Hz, and 1000 Hz frequencies at ambient pressure, which is also depicted in Table 4.18.

Table 4.18

Independent t-test results and their significant level of WBA across frequencies between MPTA and Veria group at ambient pressure

Frequency	**$\|t\|$**	***p***
400	0.99	0.34
500	0.65	0.52
600	0.77	0.45
800	0.15	0.88
1000	0.02	0.99

Note: $|t|$ - Test Statistic; p-<0.05 Significant level

Fuhrer, non-parametric Mann Whitney U test was performed for non-normally distributed parameters, i.e., WBA for frequencies 250 Hz, 300 Hz, 1250

Hz, 2000 Hz, 2500 Hz, 3000 Hz, 4000 Hz, 5000 Hz, 6000 Hz, and 8000 Hz at ambient pressure between MPTA and Veria group. Mann Whitney U test results and their significant level of WBA across frequencies between MPTA and Veria group at ambient pressure are given in Table 4.19.

Table 4.19

Mann Whitney U test results and their significant level of WBA across frequencies between MPTA and Veria group at ambient pressure

Frequency	**| z |**	***p***
250	0.91	0.36
300	0.95	0.35
1250	1.44	0.15
1500	1.74	0.08
2000	1.13	0.26
2500	0.53	0.60
3000	2.87	0.00*
4000	3.02	0.00*
5000	2.42	0.20
6000	1.89	0.06
8000	0.98	0.33

*Note- | z | - Test Statistic; p-<0.05 Significant level; *-significant difference.*

It can be seen from Table 4.19 that although there were differences noted for WBA at frequencies 250 Hz, 300 Hz, 400 Hz, 500 Hz, 600 Hz, 800 Hz, 1000 Hz, 1250 Hz, 1500 Hz, 2000 Hz, 2500 Hz 5000 Hz, 6000 Hz and 8000 Hz, but a significant difference ($p<0.05$) was found for WBA for frequencies 3000 Hz, and 4000 Hz at ambient pressure between MPTA and Veria group.

To summarize, a comparison of WBA between the MPTA and Veria groups at ambient pressure revealed that there was a significant difference ($p<0.05$) found for 3000 Hz, and 4000 Hz frequencies, and there was no significant difference ($p>0.05$) found for other frequencies 250 Hz, 300 Hz, 400 Hz, 500 Hz, 600 Hz, 800 Hz, 1000 Hz, 1250 Hz, 1500 Hz, 2000 Hz, 2500 Hz 5000 Hz, 6000 Hz and 8000 Hz.

In brief, it can be concluded that a comparison of WBA between the MPTA group and the Veria group revealed that there was a significant difference found for absorbance at frequencies 1250 Hz, 1500 Hz, 3000 Hz, 4000 Hz, and 5000 Hz at peak pressure and at ambient pressure significant difference was found for 3000 Hz and 4000 Hz frequencies.

And there was no significant difference found for WBA at peak pressure for frequencies: 250 Hz, 300 Hz, 400 Hz, 500 Hz, 600 Hz, 800 Hz, 1000 Hz, 2000 Hz, 2500 Hz, 6000 Hz, and 8000 Hz at condition; for WBA at ambient pressure for frequencies: 250 Hz, 300 Hz, 400 Hz, 500 Hz, 600 Hz, 800 Hz, 1000 Hz, 1250 Hz, 1500 Hz, 2000 Hz, 2500 Hz 5000 Hz, 6000 Hz and 8000 Hz (Figure 4.8 a & b).

Further, for comparison of Resonance Frequency between the MPTA and Veria groups, the descriptive statistic was carried out to obtain Mean, Median, and Standard Deviation values of resonance frequency for MPTA and Veria groups, and results are given in Table 4.8 and 4.13

It can be seen from Tables 4.7 and 4.13 that the mean resonance frequency value was high for the MPTA group compared to the Veria group. Figure 4.9 also depicts that the mean RF was higher in the MPTA group compared to the Veria group.

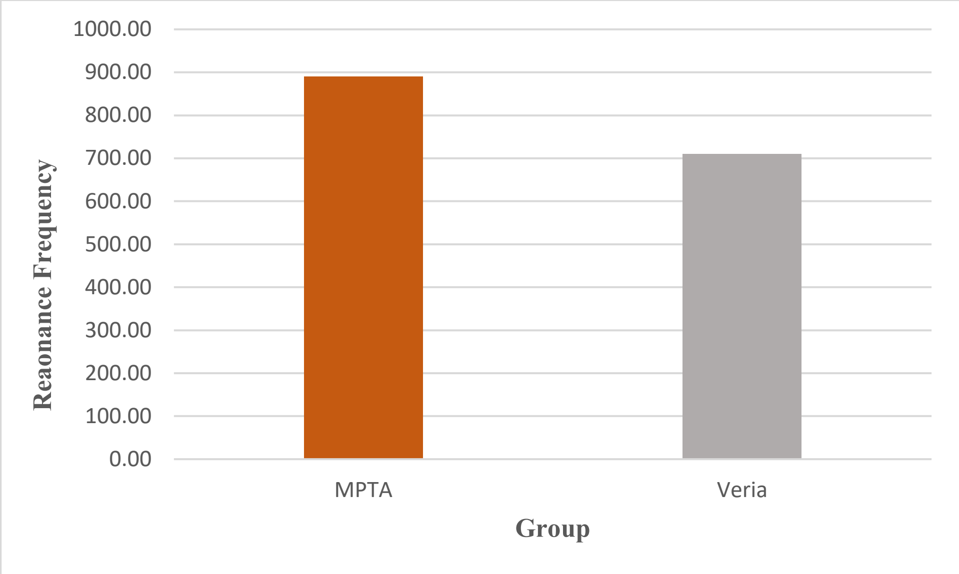


Figure 4.9. *Graphical representation of Resonance Frequency between MPTA and Veria group*

To analyse further whether there is any significant difference in RF between MPTA and Veria group Independent t- test was performed as the resonance frequency was normally distributed as per the Shapiro-Wilk test of normality. Independent t-test results and their significant level of Resonance Frequency between the MPTA and Veria group revealed that there was no significant difference [$|t|$ (18) = 1.27, p = 0.22] between the RF of the Normal and Veria groups. Hence, it can be concluded that RF did not differ between the MPTA and Veria groups statistically ($p>0.05$).

4.4 Comparison of 226 Hz Tympanometry and wideband tympanometry between MPTA and Veria group

The descriptive statistics were performed to obtain the Mean, Median, and Standard deviation values of 226Hz tympanometry (compliance, tympanometric peak pressure, ear canal volume) for two groups, i.e., MPTA and Veria, which are given in Table 4.20.

Table 4.20

The Mean, Median, and Standard Deviation of 226Hz tympanometry (compliance, tympanometric peak pressure, ear canal volume) in the MPTA and Veria group

Group	Parameters	Mean	Median	SD
MPTA	226 Hz c	0.38	0.33	0.17
	226 Hz tpp	-15.80	-7.00	32.28
	226 Hz ecv	0.74	0.75	0.18
Veria	226 Hz c	0.58	0.50	0.28
	226 Hz tpp	-10.20	-8.50	15.15
	226 Hz ecv	0.83	0.88	0.16

Note: c- compliance; tpp- tympanometric peak pressure; ecv- ear canal volume

It can be seen from Table 4.20 that mean values for compliance, tympanometric peak pressure, and ear canal volume are slightly higher for the Veria group compared to the MPTA group. The figure 4.10 also depicts that there are slighter differences in 226Hz tympanometry parameters (compliance, tympanometric peak pressure, ear canal volume) between MPTA and Veria groups

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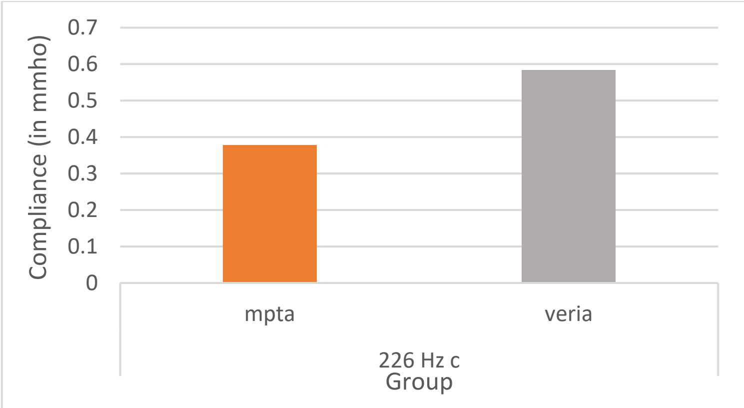
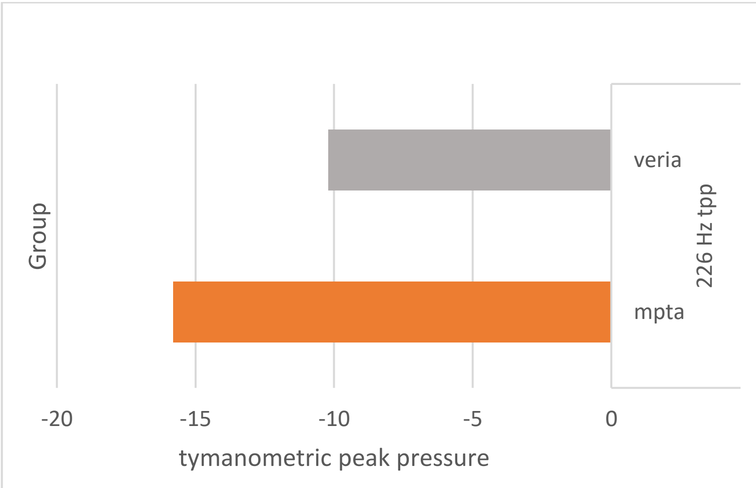
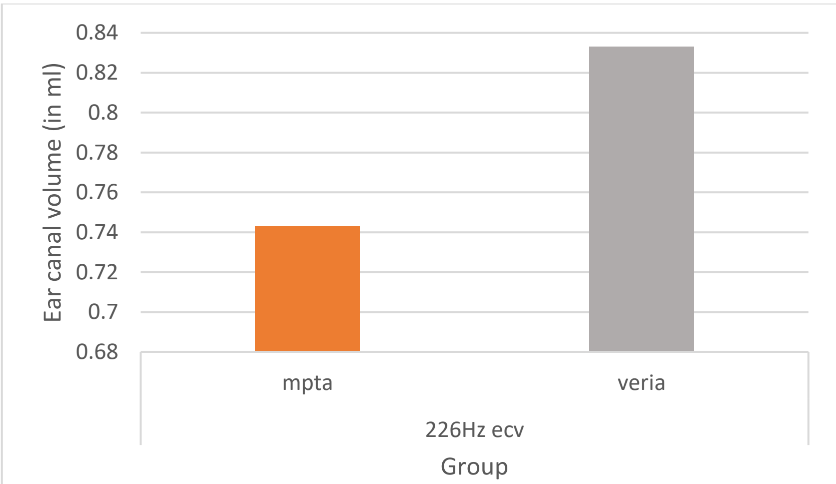


(a)



(b)



(c)

Figure 4.10. *Graphical representation of 226 Hz tympanometry: a) compliance b)tympanometric peak pressure c)ear canal volume between MPTA and Veria groups*

Further, to analyze if there is any significant difference between MPTA and Veria groups for compliance, tympanometric peak pressure, and ear canal volume, an independent t-test was used as the data was normally distributed for 226 Hz compliance, tympanometric peak pressure, and ear canal volume as per Shapiro-Wilk test of normality. Independent t-test results and significant level for 226 Hz tympanometry (compliance, tympanometric peak pressure, ear canal volume) between MPTA and Veria group are given in Table 4.21.

Table 4.21

Independent t-test results and significant level for 226Hz tympanometry (compliance, tympanometric peak pressure, ear canal volume) between MPTA and Veria group

226 Hz parameters	| t |	*p*
226 Hz c	1.95	0.07
226 Hz tpp	0.50	0.63
226 Hz ecv	1.18	0.25

Note: | t | - Test Statistic; p-<0.05 Significant level

Independent t-test results revealed that there was no significant difference (p<0.05) found for the 226Hz tympanometry parameters (compliance, tympanometric peak pressure, ear canal volume) between the MPTA and Normal group.

In summary, the 226Hz tympanometry (compliance, tympanometric peak pressure, ear canal volume) between MPTA and Veria did not show any significant difference. Further, WBT resonance frequency also did not show any significant difference between the MPTA and Veria groups. However, there was a significant difference found for WBA at peak pressure for a few frequencies, 1250 Hz, 1500 Hz, 3000 Hz, 4000 Hz, and 5000 Hz, and there was a significant difference found for WBA at ambient pressure for 3000 Hz and 4000 Hz frequencies.

In brief it can be seen that there are significant differences in WBA at certain frequencies (1250 Hz, 1500 Hz, 3000 Hz, 4000 Hz, and 5000 Hz at peak pressure condition and, 3000 Hz and 4000 Hz at ambient pressure condition) between MPTA and Veria group, whereas 226Hz tympanometry and resonance frequency did not show any significant differences.

CHAPTER 5

DISCUSSION

The present study aimed to find and compare the effect of cochlear implantation (CI) on the middle ear mechanics in terms of absorbance and resonance frequency using wideband tympanometry. Children who were operated with different CI surgical approaches, i.e., the mastoidectomy posterior tympanotomy approach (MPTA) and transcanal wall (Veria) approach were considered in the study. The objectives of the study were to compare middle ear wide band absorbance (WBA) across frequency and resonance frequency between normal individuals and CI children operated with the MPTA approach; compare middle ear WBA between normal individuals and CI children operated with the Veria approach; to compare the middle ear WBA across frequency and resonance frequency between CI children operated with the MPTA approach and CI children operated with the Veria approach, to compare the traditional 226 Hz tympanometry and wideband tympanometric measures (absorbance & resonance frequency) between MPTA and Veria surgical approach in CI children.

To meet these objectives, wideband tympanometry was performed on all three groups, i.e., Normal, MPTA, and Veria groups. Also, 226 Hz tympanometry was performed on the MPTA and Veria groups. Further, statistical analysis were performed using an independent t-test and Mann-Whitney U test for comparison purposes. The results obtained from the present study are discussed below

5.1 Comparison of Wideband absorbance and Resonance Frequency between Normal and MPTA groups

The results of the current study show that a comparison of WBA between the Normal and MPTA group revealed that there is a difference noted in mean WBA between the Normal and MPTA group for frequencies from 250 Hz to 2000 Hz, but a significant difference was found for absorbance at frequencies 1000 Hz and 1250 Hz for both peak pressure and ambient pressure (Table 4.5, 4.6 & 4.7). There was no significant difference in WBA found for frequencies 250 Hz, 300 Hz, 400 Hz, 500 Hz, 600 Hz, 800 Hz, 1500 Hz, 2000 Hz, 2500 Hz, 3000 Hz, 4000 Hz, 5000 Hz, 6000 Hz, and 8000 Hz.

Similar findings were reported in earlier prospective research by (Saoji et al., 2020) wherein they have compared preoperative and postoperative WBT absorbance measured at fixed pressure condition in 5 unilateral cochlear implantation individuals with four clients having > 70 years of age and one client with eight years of age. The results of their study showed significantly reduced WBA in ears with CI for frequencies that ranged from 600 Hz to 1100 Hz, and the maximum effect was noted at 1000 Hz frequency. The specific anatomical or physiological factors causing a reduction in WBA at lower frequencies in this study were not known. Such changes of lower absorbance at low frequencies were found to be consistent with otosclerosis, where low-frequency WBA significantly reduced for lower frequencies (Shahnaz, Bork, et al., 2009).

The other reasons reported in the literature for lower WBA at low frequencies could be due to the introduction of the facial recess, electrode array, positioning and closing of the electrodes at the cochleostomy, and/or buildup of bone dust that causes osteogenesis are some potential reasons that could affect ossicular chain mobility as a result of implantation. Other effects could include the development of fibrous tissue after surgery, limiting intrascalar fluid circulation in the basal end, and increasing impedance at oval window, in turn indirectly increasing ossicular chain stiffness and lowering middle ear absorption (Saoji et al., 2020).

The results of the current study are supported by Attias et al. (2022) who compared WBT in adults aged 18-36 years having severe to profound hearing loss with and without CI. Their study results showed that in implanted ears there was significantly lower absorbance noted at lower frequencies from 400-800 Hz and also there was an elevation in WBA for 1600 Hz compared to normal hearing individuals. This is consistent with observations linking the reduction in WBA at lower frequencies to increased stiffness of the inner ear due to the existence of implant in the cochlear structure (Raveh et al., 2015; Merchant et al., 2020; Saoji et al., 2020). However, the middle- and inner-ear stiffness may be impacted by each step of the CI operation, such as the mastoidectomy and posterior tympanotomy, as well as by postoperative conditions like fibrosis (Attias et al., 2022).

Furthermore, a study done by Orhan et al. (2021) showed that the average absorption ratio at peak pressure for the implanted ear in individuals with a mean age of 8.2 (±4.4) years was found to be significantly lower in contrast to the control group at 226-1000 Hz, 1000- 2000 Hz, 2000- 4000 Hz and 4000 to 8000 Hz. Whereas in the current study, there were slight differences noted in mean WBA only at lower frequencies till 1500 Hz, but the significant difference was noted only for 1000 and 1250 Hz. The differences in the findings of the study could be due to the smaller number of subjects (n = 10) included in the present study, whereas the Orhan et al. study included 48 subjects (96 ears). Also, they compared implanted ears with non-implanted ears of the same individual which were having severe to profound hearing loss. However, the present study compared implanted ears with normal-hearing individuals. Additionally, subject with an implant age of at least 1 year was considered for Orhan's study. However, the present study did not consider the implant age of the CI children.

In the literature, it has been suggestsed that differences in WBA could be attributed to the common cochlear implantation surgical procedure involving cortical mastoidectomy with posterior tympanotomy (Attias et al., 2022). This surgical approach can lead to structural changes in the middle ear, such as electrode array obstructing the round window, scar formation in the middle ear and inner ear, and merging of the middle ear and mastoid cavity. These alterations may explain why implanted ears had lower absorbance ratio compared to control group.

The present study also compared resonance frequency between the Normal and MPTA groups. The mean resonance frequency values were found to be higher for the MPTA group, i.e., 890.50 (±328.59) Hz, compared to the normal group, i.e., 843.05 (±236.10) Hz. However, these differences were not found to be significantly different. In contrast to the current study, Orhan et al. (2021) found that in implanted ears, resonance frequency was shifted upwards; the average RF was 846.7 (±333.8) Hz in ears with an implant in contrast to normal group whose RF was 815.05(±249.7) Hz.

These findings of upward shift in RF are consistent with the theory that cochlear implantation increases middle ear stiffness. Otosclerosis, characterized by excessive stiffness dominating the pathology, causes the RF to move to high frequencies and ossicular chain discontinuities, characterized by mass, to lower frequencies (Feeney et al., 2009; Shahnaz, Longridge, et al., 2009). However, current study couldn't find any significant difference in RF between normal and MPTA group even though there was difference noted in mean RF. The difference noted with regard to RF between studies could be due to smaller number of subjects included in present study having normal (normal: n=20; MPTA: n=10) whereas Orhan et al study included 48 CI individuals. Furthermore, they have compared RF between implanted and non-implanted ears of the same individual.

5.2 Comparison of Wideband absorbance and Resonance Frequency between Normal and Veria groups

A comparison of WBA between the Normal group and the Veria group revealed that there were mean WBA differences noted from 250 Hz to 8000 Hz however, a significant difference found for WBA at peak pressure for frequencies 2000 Hz to 6000 Hz (Table 4.11) At ambient pressure 1000 Hz to 6000 Hz (Table 4.12 & 4.13) frequencies had significant difference.

There was no significant difference in WBA at peak pressure for 250 Hz, 300 Hz, 400 Hz, 500 Hz, 600 Hz, 800 Hz, 1000 Hz, 1250 Hz, 1500 Hz, 2500 Hz, and 8000 Hz; no significant difference in WBA at ambient pressure for frequencies 250 Hz, 300 Hz, 400 Hz, 500 Hz, 600 Hz, 800 Hz, 1250 Hz, 1500 Hz, and 8000 Hz between Normal and Veria group.

The outcomes of the current study show differences noted in mean WBA measured between the normal and Veria groups. A significant difference in WBA was noted between Normal and Veria group for frequencies 2000 Hz to 6000 Hz at peak pressure and for frequencies 1000 Hz, to 6000 Hz Hz at ambient pressure. This might be due to surgical procedures involved in cochlear implantation.

The “Veria” technique, also known as the transcanal wall approach (Kiratzidis et al., 2002), is a cochlear implantation method that avoids the mastoidectomy. It involves accessing the middle ear and cochlea through the ear canal. Key steps include creating a cochleostomy, drilling the supra meatal hollow, elevating the tympanomeatal flap, and inserting the electrode; this approach offers a less invasive alternative for cochlear implantation (Zeitler & Balkany, 2010).

Similar results were documented in a study conducted by Saki et al. (2022), where they have conducted a comparative analysis of Wideband Tympanometry

(WBT) in 35 unilaterally implanted children aged less than 24 months. The authors observed that when they compared the preoperative and postoperative WBT data, a significant reduction in WBT was identified in the implanted ears for frequencies 1260 Hz-3175 Hz and 5040 Hz-8000 Hz. They also noted that the low-frequency WBT remained unaffected, which aligns with the findings of our present study. The authors proposed that these findings might be due to variations in the placement of the probe tip in the ear canal and the approach used for round window insertion. These factors involve the manipulation of tissue around the round window, which can potentially alter the resistance to sound energy around a round window, thereby affecting peripheral sound transmission.

The present study also compared RF between the Normal and Veria groups. Results from the current study showed that the mean RF was lower (709.70±308.78 Hz) for the Veria group compared to the mean RF of the Normal group (843.05±236.10 Hz). However, these differences noted in RF were not significant between normal and Veria group.

The resonance frequency in otosclerosis, which is characterized by excessive stiffness, causes the RF to move towards high frequencies, whereas in ossicular chain discontinuities it is characterized by mass which shifts RF to lower frequencies (Feeney et al., 2009; Shahnaz, Longridge, et al., 2009). In a previous study by Orhan et al. (2021) found that implanted ears had resonance frequency that was shifted upwards; the average RF in implanted ears was 846.7 (±333.8 Hz) in contrast to 815.05 (±249.7) Hz in non-implanted group. These findings were consistent with the theory that cochlear implantation increases middle ear stiffness. But, in the present study, although RF did not show any significant difference between the Normal and Veria groups, the mean RF value was found to be lower for the Veria group (709.70±308.78) compared to that of the mean RF of the Normal group (843.05±236.1) which is in contrary to the results stated by (Orhan et al., 2021). These differences in RF between studies could be due to the that they have considered the implant age of at least less than one ear, whereas the present study did not consider the implant age. Furthermore, an increase in the time period after post-implant may reduce the impedance caused by fibrosis and osteospongesis.

5.3 Comparison of Wideband absorbance and Resonance Frequency between MPTA and Veria groups

When the WBA of the MPTA group and the Veria group were compared, it was found that the mean WBA for the Veria group was slightly higher at 250 Hz to 2000 Hz and lower for 2500 Hz to 8000 Hz at peak pressure than that of WBA values for the MPTA group. And at ambient pressure also, the WBA values for the Veria group were slightly higher at 250 Hz to 2000 Hz and lower from 2500 Hz to 8000 Hz than that of WBA values for the MPTA group. However, significant difference was noted in WBA at peak pressure for 1250 Hz, 1500 Hz, 3000 Hz, 4000 Hz, and 5000 Hz frequencies (Table 4.17) and significant difference noted in WBA at frequencies at ambient pressure for 3000 Hz and 4000 Hz frequencies (Table 4.19).

Additionally, no significant difference were observed for WBA at peak pressure for 250 Hz, 300 Hz, 400 Hz, 500 Hz, 600 Hz, 800 Hz, 1000 Hz, 2000 Hz, 2500 Hz, 6000 Hz, and 8000 Hz frequencies and no significant difference were observed for WBA at ambient pressure for 250 Hz, 300 Hz, 400 Hz, 500 Hz, 600 Hz, 800 Hz, 1000 Hz, 1250 Hz, 1500 Hz, 2000 Hz, 2500 Hz 5000 Hz, 6000 Hz and 8000 Hz frequencies between MPTA and Veria group.

These differences noted in WBA values between the MPTA and Veria groups could be due to the different surgical steps involved in these two different types of surgical approaches. The MPTA approach involves mastoidectomy, posterior tympanotomy aperture is created to reach middle ear. Middle ear components are exposed, allowing access to the cochlea. The electrode array is then inserted and secured, followed by the closure of incision (Blume, 1999.).

Whereas, in Veria (transcanal) technique (El-Anwar et al., 2016) middle ear is accessed through the ear canal which involves elevating a tympanomeatal flap, creating a cochleostomy, and drilling the suprameatal hollow. A direct tunnel through the transcanal wall is aligned with cochleostomy. The electrodes are inserted, and incision is closed. This technique differs from MPTA approach, and this difference in surgical procedures would have resulted in noting the variations in WBA between the MPTA and the Veria group.

The primary distinction between MPTA and Veria cochlear implantation procedure is that MPTA entails mastoidectomy, while Veria does not. Mastoidectomy involves drilling the mastoid bone to access the middle ear, generating bone dust that can increase the ossicular mass. This may have lead to more middle ear stiffness (Wasson et al., 2018), potentially lowering mean WBA at low frequencies in MPTA group, though it is not significantly different.

With regard to RF, the current study has indicated that no significant difference was found between MPTA and Veria groups. However, the mean RF of MPTA 890.50(±328.59) group was found to be higher than the mean RF of the Veria (709.70±308.78) group. The results of current study has been supported by Orhan et al. (2021), who has reported that in implanted ears the resonance frequency was shifted upwards i.e., the average RF was 846.7±(333.8) Hz in ear with CI in contrast to ear without CI whose RF was 815.05±(249.7) Hz. The results of the current study propose that cochlear implantation is found to raise middle ear stiffness, especially in MPTA group, whereas the Veria group had less stiffness compared to both MPTA and Normal group. This difference noted in RF between the two groups may be linked to lower absorbance at low frequencies in the MPTA group, potentially causing an upward shift in RF when compared to Veria group.

5.4 Comparison of traditional 226 Hz tympanometry and wideband tympanometric measures (absorbance & resonance frequency) between MPTA and Veria group

The present study also compared 226 Hz tympanometry parameters (compliance, tympanometric peak pressure, ear canal volume) between the MPTA and Veria group, and results indicated that no significant difference was found between the MPTA and Veria group for compliance, tympanometric peak pressure, and ear canal volume. The results of the current study are supported by Attias et al. (2022) who has found that there was no significant difference noted for static compliance, tympanometric peak pressure, and ear canal volume between implanted ears and normal hearing individuals in adults with age ranging from 18 to 36 years.

Based on the results obtained from the current study about traditional 226 Hz tympanometry results in children with cochlear implantation, it can be concluded that the middle ear function in cochlear implant children would be considered as having normal function when tested with conventional 226 Hz tympanometry which is currently practiced in most of the audiologic clinic.

In the current study, comparison of WBA using wideband tympanometry between the MPTA group and the Veria group showed a significant difference in WBA at peak pressure for 1250 Hz, 1500 Hz, 3000 Hz, 4000 Hz and 5000 Hz frequencies (Table 4.17), and significant difference in WBA at ambient pressure for 3000 Hz and 4000 Hz frequencies (Table 4.19). The results of the current study are supported by several other studies that have showed significant differences while studying the effect of CI on the middle ear mechanism using WBT. The WBT pattern showed significantly reduced lower frequency absorbance in the implanted ears in frequencies from 600 Hz to 1100 Hz in post-implant measurements (Saoji et al., 2020): significantly lower absorbance at lower frequencies 400-800 Hz and also showed an increase in WBA at 1600 Hz in implanted ears of adults compared to normal hearing individuals (Attias et al., 2022), average absorption ratio at peak pressure for implanted ear individuals with mean age 8.2±(4.4) for 226-1000 Hz, 1000-2000 Hz, 2000 to 4000, Hz and 4000 to 8000 Hz was significantly lower compared to the control group (Orhan et al., 2021).

However, when it comes to RF, current study did not show any significant difference between the MPTA and the Veria groups. In contrary to current study, Orhan et al. (2021) reported a significant difference in RF noted between CI individuals and normal hearing subjects. The implanted ears had a resonance frequency that was shifted upwards; the average RF was 846.7 (±333.8) Hz in ear with CI in contrast to the ear without CI, whose RF was found to be 815.05 (±249.7) Hz.

Hence, based on the findings of the current study and previous study, it can be noted that compared to traditional 226 Hz tympanometry, wideband tympanometry is more sensitive to middle ear changes in individuals who have undergone cochlear implantation.

CHAPTER 6

SUMMARY AND CONCLUSIONS

The human hearing system is composed of the external, middle, and inner ear. The middle ear helps in transmitting the sound energy into the inner ear. Any alterations in the middle ear structures are found to affect the transmission of sound energy. Presently, these alterations in anatomy and physiology are assessed using traditional 226 Hz tympanometry in terms of static compliance, tympanometric peak pressure (TPP), and ear canal volume (ECV). However, traditional tympanometry has several limitations when comparing normal and pathological ears. A more recent technique called Wideband Tympanometry (WBT) has emerged as an alternative way of assessing middle ear function. WBT assesses the middle ear functions and pathologies over a wide range of frequencies with more accuracy and precision. A recent literature review has suggested that cochlear implantation is one of the conditions that is found to affect middle ear mechanics.

The primary aim of the current study was to investigate and compare the impact of cochlear implantation (CI) on the middle ear mechanics in terms of absorbance and resonance frequency using wideband tympanometry. Children who were operated with different CI surgical approaches, i.e., the mastoidectomy posterior tympanotomy approach (MPTA) and transcanal wall (Veria) approach, were considered in the study. The objectives of the study included a comparison of the wide band absorbance (WBA) across frequency and resonance frequency between normal individuals and CI children operated with the MPTA approach, to compare middle ear WBA between normal individuals and CI children operated with the Veria approach, to compare the middle ear WBA across frequency and resonance frequency between CI children operated with the MPTA approach and CI children operated with the Veria approach, to compare the traditional 226 Hz tympanometry and wideband tympanometric measures (absorbance & resonance frequency) between MPTA and Veria surgical approach in CI children.

The present study was conducted using a standard group comparison design. A total of 40 individuals from 3 to 10 years of age were involved in this study, which was divided into three groups: Group I involved 20 normal-hearing children, Group II comprised 10 children with CI operated with MPTA, and Group 3 involved 10 CI children operated with the Veria technique. All the participants underwent the wideband tympanometry testing across frequencies at peak pressure and ambient pressure. Furthermore, 226 Hz tympanometry was performed only on the MPTA group and the Veria group. All data was tabulated, and analyses were performed with use of Statistical Package Social Sciences (SPSS), version 26.0 (IBM Corp., Armonk, NY, USA). Descriptive statistics was carried out to calculate mean, median and SD of WBA in normal group, MPTA and Veria group. Moreover, for data following normal distribution, statistical analysis was done through an independent t-test, while for non-normally distributed data, the comparison of WBA between groups was conducted using the Mann-Whitney U test.

First, A comparison of mean WBA values between the Normal group and the MPTA group revealed that there was a difference noted in mean WBA values between the Normal group and the MPTA group for frequencies from 250 Hz to 2000 Hz. However, a significant difference in WBA was found at 1000 Hz and 1250 Hz frequencies for both peak pressure and ambient pressure. However, RF did not show a significant difference between Normal and MPTA groups.

Second, a comparison of WBA between the Normal group and the Veria group revealed that there was a mean WBA difference noted for WBA frequencies from 600 Hz to 8000 Hz at peak pressure and from 250 Hz to 8000 Hz for ambient pressure.

However, a significant difference found for WBA at frequencies 2000 Hz, 3000 Hz, 4000 Hz, 5000 Hz,6000 Hz, and 1000 Hz, 2000 Hz, 3000 Hz, 4000 Hz, 5000 Hz,6000 Hz frequencies at peak pressure condition and ambient pressure condition respectively. However, the RF between the Normal and Veria groups did not show a significant difference.

Third, a comparison of WBA between the MPTA group and the Veria group revealed that there was a mean WBA difference noted for frequencies from 250 Hz to 8000 Hz for both peak pressure and ambient pressure. However, a significant difference found for WBA for 1250 Hz, 1500 Hz, 3000 Hz, 4000 Hz, and 5000 Hz frequencies at peak pressure, and a significant difference was found for 3000 Hz and 4000 Hz frequencies at ambient pressure. However, the RF between the MPTA and Veria groups did not show any significant difference.

Fourth, the 226 Hz tympanometry results, including compliance, tympanometric peak pressure, and ear canal volume, did not exhibit any significant difference between the MPTA and Veria groups. However, there were significant differences noted in WBA at certain frequencies (1250 Hz, 1500 Hz, 3000 Hz, 4000 Hz, and 5000 Hz at peak pressure and 3000 Hz and 4000 Hz at ambient pressure) between MPTA and Veria groups.

6.1 CONCLUSIONS

It can be concluded that the cochlear implantation has an effect on the middle ear mechanics, which can be measured in terms of WBA using wideband tympanometry. These differences are also noted differently for different types of surgery approaches in the present study, the MPTA and Veria approaches. However, resonance frequency did not show any differences. It can also be concluded that 226

Hz tympanometry has limitations in showing differences between the MPTA and Veria surgery approaches.

Thus, compared to conventional 226 Hz tympanometry, WBT has greater advantage to study the effect of cochlear implantation on middle ear mechanics. Furthermore, it can also be used to study the effect different types of cochlear implant surgical approaches on the middle ear mechanics.

6.2 IMPLICATIONS

- The outcomes of the study offer an understanding of effect of cochlear implantation on middle ear mechanics.
- The results of the study provides an insight into understanding of effect of different type of cochlear implantation surgical approaches on middle ear mechanics.
- The different types of cochlear implantation surgery affects the WBA differently, and this helps the clinicians in avoiding misdiagnosis of normal middle ear functioning from pathological ears using WBT in cochlear implant children.
- Compared to 226 Hz tympanometry, the use of WBT is better option to assess the middle ear functioning in post-implantation children.

6.3 FUTURE DIRECTIONS

- To investigate the impact of various methods employed for cochlear implantation in pediatric patients through the use of wideband tympanometry (WBT).

- To study the effect of different types of surgical approaches in the adult populations using WBT.
- To compare the effects of various types of surgery approaches in children and adult populations using WBT.

6.4 LIMITATIONS OF THE STUDY

- The present study did not compare the 226 Hz tympanometry between the normal group and the other two surgical approach groups, i.e., the MPTA and Veria groups.
- The number of participants included in the current study in each group were very small: normal group (n= 20), MPTA group (n=10), Veria group (n=10) and the sample size selected was uneven in all the three groups.

REFERENCES

A. Fouad, Y. (2020). Advances in Surgical and Anesthetic Techniques for Cochlear Implantation. *Advances in Rehabilitation of Hearing Loss*. 121-140. https://doi.org/10.5772/intechopen.88380

Alaerts, J., Luts, H., & Wouters, J. (2007). Evaluation of middle ear function in young children: clinical guidelines for the use of 226-and 1,000-Hz tympanometry. *Otology & Neurotology*, *28*(6), 727-732.

Attias, J., Hod, R., Raveh, E., Mizrachi, A., Avraham, K. B., Lenz, D. R., & Nageris, B. I. (2016). Hearing loss patterns after cochlear implantation via the round window in an animal model. *American Journal of Otolaryngology*, *37*(2), 162–168. https://doi.org/10.1016/J.AMJOTO.2015.12.004

Attias, J., Nageris, B. I., Shemesh, R., Shvero, J., & Preis, M. (2011). Superior canal dehiscence effect on hearing thresholds: Animal model. *Otolaryngology - Head and Neck Surgery*, *145*(4), 648–653. https://doi.org/10.1177/0194599811410535

Attias, J., Shahnaz, N., Efrat, C., Westerberg, B., Lea, J., David, E., Zavdy, O., & Hilly, O. (2022). Wideband Tympanometry in Adults with Severe to Profound Hearing Loss with and without Cochlear Implants. *Applied Sciences*, *12*(17), 8879. https://doi.org/10.3390/app12178879

Attias, †joseph, Preis, §michal, Shemesh, R., Hadar, §tuvia, Nageris, I., & Preis, M. (2010). Animal Model of Cochlear Third Window in the Scala Vestibuli or Scala Tympani. In *Otology & Neurotology* (Vol. 31). Otology & Neurotology, Inc. http://journals.lww.com/otology-neurotology

Balkany, T. J., Noel Cohen, F. L., York, N., & York Bruce Gantz, N. J. (1999). SURGICAL TECHNIQUE FOR THE CLARION® COCHLEAR IMPLANT. In *Ann Otol Rhinol Laryngol* (Vol. 108).

Beers, A. N., Shahnaz, N., Westerberg, B. D., & Kozak, F. K. (2010). Wideband reflectance in normal Caucasian and Chinese school-aged children and in children with otitis media with effusion. *Ear and hearing*, *31*(2), 221-233.

Biswas, A., & Dutta, N. (2018). Wideband Tympanometry. *Annals of Otology and Neurotology*, *01*(02), 126–132. https://doi.org/10.1055/s-0038-1676876

Blume, S. S. (1999). Histories of cochlear implantation. *Social Science & Medicine*, *49*(9), 1257-1268.

Clark, J. G. (1981). Uses and abuses of hearing loss classification. In *Asha: a journal of the American Speech-Language-Hearing Association*. https://www.researchgate.net/publication/16145943

Cohen, N. L. (1997). Cochlear implant soft surgery: fact or fantasy?. *Otolaryngology-Head and Neck Surgery*, *117*(3), 214-216.

Colletti, V., Fiorino, F. G., Carner, M., Sacchetto, L., & Giarbini, N. (2000). New approach for cochlear implantation: Cochleostomy through the middle fossa. *Otolaryngology - Head and Neck Surgery*, *123*(4), 467–474. https://doi.org/10.1067/mhn.2000.107406

Dubey, S., Singh, J., & Bhardwaj, B. (2020). Bhopal Technique of Cochlear Implantation: A Surgical Review of 50 Cases. *Indian Journal of Otolaryngology and Head and Neck Surgery*, *72*(3), 375–380. https://doi.org/10.1007/s12070-020-01889-8

El-Anwar, M. W., Elaassar, A. S., & Foad, Y. A. (2016). Non-mastoidectomy cochlear implant approaches: A literature review. In *International Archives of Otorhinolaryngology* (Vol. 20, Issue 2, pp. 180–184). Georg Thieme Verlag. https://doi.org/10.1055/s-0035-1558871

Feeney, M. P., Grant, I. L., & Mills, D. M. (2009). Wideband energy reflectance measurements of ossicular chain discontinuity and repair in human temporal bone. *Ear and hearing*, *30*(4), 391-400. 10.1097/AUD.0b013e3181a283ed

Feeney, M. P., Hunter, L. L., Kei, J., Lilly, D. J., Margolis, R. H., Nakajima, H. H., Neely, S. T., Prieve, B. A., Rosowski, J. J., Sanford, C. A., Schairer, K. S., Shahnaz, N., Stenfelt, S., & Voss, S. E. (2013). Consensus Statement. *Ear & Hearing*, *34*(Supplement 1), 78s–79s. https://doi.org/10.1097/AUD.0b013e31829c726b

Freni, F., Gazia, F., Slavutsky, V., Scherdel, E. P., Nicenboim, L., Posada, R., Portelli, D., Galletti, B., & Galletti, F. (2020). Cochlear implant surgery: Endomeatal approach versus posterior tympanotomy. *International Journal of Environmental Research and Public Health*, *17*(12), 1–9. https://doi.org/10.3390/ijerph17124187

Gantz, B. J., Turner, C., Gfeller, K. E., & Lowder, M. W. (2005a). Preservation of Hearing in Cochlear Implant Surgery: Advantages of Combined Electrical and Acoustical Speech Processing. *The Laryngoscope*, *115*(5), 796–802. https://doi.org/10.1097/01.MLG.0000157695.07536.D2

Gantz, B. J., Turner, C., Gfeller, K. E., & Lowder, M. W. (2005b). Preservation of hearing in cochlear implant surgery: Advantages of combined electrical and acoustical speech processing. In *Laryngoscope* (Vol. 115, Issue 5, pp. 796–802). https://doi.org/10.1097/01.MLG.0000157695.07536.D2

Ha, R., & Usler, È. (2002). Cochlear Implantation Without Mastoidectomy: The Pericanal Electrode Insertion Technique*. In *Acta Otolaryngol* (Vol. 122).

Hein, T. A. D., Hatzopoulos, S., Henryk Skarzynski, P., Colella-Santos, M. F., Hein, T. A. D., Hatzopoulos, S., Henryk Skarzynski, P., & Colella-Santos, M. F. (2017). Wideband Tympanometry. *Advances in Clinical Audiology*. https://doi.org/10.5772/67155

Hougaard, D. D., Lyhne, N. M., Skals, R. K., & Kristensen, M. (2020). Study on wideband tympanometry and absorbance within a Danish cohort of normal hearing adults. *European Archives of Oto-Rhino-Laryngology*, *277*(7), 1899–1905. https://doi.org/10.1007/s00405-020-05909-9

Hunter, L. L., Keefe, D. H., Feeney, M. P., Fitzpatrick, D. F., & Lin, L. (2016). Longitudinal development of wideband reflectance tympanometry in normal and at-risk infants. *Hearing Research*, *340*, 3. https://doi.org/10.1016/J.HEARES.2015.12.014

Hunter, L. L., & Margolis, R. H. (1992). Multifrequency Tympanometry. *American Journal of Audiology*, *1*(3), 33–43. https://doi.org/10.1044/1059-0889.0103.33

Iacovou, E., Vlastarakos, P. v., Ferekidis, E., & Nikolopoulos, T. P. (2013). Multi-Frequency Tympanometry: Clinical Applications for the Assessment of the Middle Ear Status. In *Indian Journal of Otolaryngology and Head and Neck Surgery* (Vol. 65, Issue 3, pp. 283–287). Springer. https://doi.org/10.1007/s12070-011-0470-9

Karuppannan, A., & Barman, A. (2021). Wideband absorbance pattern in adults with otosclerosis and ossicular chain discontinuity. *Auris Nasus Larynx*, *48*(4), 583–589. https://doi.org/10.1016/j.anl.2020.10.019

Kaya, Ş., Çiçek Çınar, B., Özbal Batuk, M., Özgen, B., Sennaroğlu, G., Genç, G. A., & Sennaroğlu, L. (2020). Wideband tympanometry findings in inner ear malformations. *Auris Nasus Larynx*, *47*(2), 220–226. https://doi.org/10.1016/j.anl.2019.09.001

Keefe, D. H., Fitzpatrick, D., Liu, Y. W., Sanford, C. A., & Gorga, M. P. (2010). Wideband acoustic-reflex test in a test battery to predict middle-ear dysfunction. *Hearing Research*, *263*(1–2), 52–65. https://doi.org/10.1016/j.heares.2009.09.008

Keefe, D. H., Hunter, L. L., Feeney, M. P., & Fitzpatrick, D. F. (2015). Procedures for ambient-pressure and tympanometric tests of aural acoustic reflectance and admittance in human infants and adults. *The Journal of the Acoustical Society of America*, *138*(6), 3625. https://doi.org/10.1121/1.4936946

Keefe, D. H., & Levi, E. (1996). Maturation of the middle and external ears: acoustic power-based responses and reflectance tympanometry. *Ear and Hearing*, *17*(5), 361–373. https://doi.org/10.1097/00003446-199610000-00002

Keefe, D. H., & Simmons, J. L. (2003). Energy transmittance predicts conductive hearing loss in older children and adults. *The Journal of the Acoustical Society of America*, *114*(6), 3217. https://doi.org/10.1121/1.1625931

Kim, S. Y., Han, J. J., Oh, S. H., Lee, J. H., Suh, M. whan, Kim, M. H., & Park, M. K. (2019a). Differentiating among conductive hearing loss conditions with wideband tympanometry. *Auris Nasus Larynx*, *46*(1), 43–49. https://doi.org/10.1016/j.anl.2018.05.013

Kim, S. Y., Han, J. J., Oh, S. H., Lee, J. H., Suh, M. whan, Kim, M. H., & Park, M. K. (2019b). Differentiating among conductive hearing loss conditions with wideband tympanometry. *Auris Nasus Larynx*, *46*(1), 43–49. https://doi.org/10.1016/j.anl.2018.05.013

Kiratzidis, T., Arnold, W., & Iliades, T. (2002). Veria operation updated. I. The trans-canal wall cochlear implantation. *ORL*, *64*(6), 406–412. https://doi.org/10.1159/000067578

Kronenberg, J., Migirov, L., & Dagan, T. (2001). Suprameatal approach: new surgical approach for cochlear implantation. In *The Journal of Laryngology & Otology* (Vol. 115).

Lilly Good Samaritan, D. J. (1984). *Multiple Frequency, Multiple Component Tympanometry: New Approaches to an Old Diagnostic Problem* (Vol. 5, Issue 5).

Liu, Y.-W., Sanford, C. A., Ellison, J. C., Fitzpatrick, D. F., Gorga, M. P., & Keefe, D. H. (2008). Wideband absorbance tympanometry using pressure sweeps: System development and results on adults with normal hearing. *The Journal of the Acoustical Society of America*, *124*(6), 3708. https://doi.org/10.1121/1.3001712

Margolis, R. H., Saly, G. L., & Keefe, D. H. (1999). Wideband reflectance tympanometry in normal adults. *The Journal of the Acoustical Society of America*, *106*(1), 265–280. https://doi.org/10.1121/1.427055

Mazlan, R., Kei, J., Ya, C. L., Yusof, W. N. H. M., Saim, L., & Zhao, F. (2015). Age and gender effects on wideband absorbance in adults with normal outer and middle ear function. *Journal of Speech, Language, and Hearing Research*, *58*(4), 1377–1386. https://doi.org/10.1044/2015_JSLHR-H-14-0199

Merchant, G. R., Roösli, C., Niesten, M. E. F., Hamade, M. A., Lee, D. J., McKinnon, M. L., Ulku, C. H., Rosowski, J. J., Merchant, S. N., & Nakajima, H. H. (2015).

Power Reflectance as a Screening Tool for the Diagnosis of Superior Semicircular Canal Dehiscence. *Otology & Neurotology : Official Publication of the American Otological Society, American Neurotology Society [and] European Academy of Otology and Neurotology*, *36*(1), 172. https://doi.org/10.1097/MAO.0000000000000294

Merchant, G. R., Schulz, K. M., Patterson, J. N., Fitzpatrick, D., & Janky, K. L. (2020). Effect of Cochlear Implantation on Vestibular Evoked Myogenic Potentials and Wideband Acoustic Immittance. *Ear and Hearing*, *41*(5), 1111–1124. https://doi.org/10.1097/AUD.0000000000000831

Merchant, S. N. (1998). Middle ear mechanics in normal, diseased and reconstructed ears. In *Journal of Laryngology and Otology* (Vol. 112, Issue 8, pp. 715–731). Cambridge University Press. https://doi.org/10.1017/s0022215100141568

Merchant, S. N., Nakajima, H. H., Halpin, C., Nadol, J. B., Lee, D. J., Innis, W. P., Curtin, H., & Rosowski, J. J. (2007). Clinical Investigation and Mechanism of Air-Bone Gaps in Large Vestibular Aqueduct Syndrome. In *Rhinology & Laryngology* (Vol. 116, Issue 7). https://doi.org/10.1177/000348940711600709

Merchant, S. N., & Rosowski, J. J. (2008). Conductive hearing loss caused by third-window lesions of the inner ear. *Otology & neurotology: official publication of the American Otological Society, American Neurotology Society [and] European Academy of Otology and Neurotology*, *29*(3), 282. 10.1097/mao.0b013e318161ab24

Mikulec, A. A., McKenna, M. J., Ramsey, M. J., Rosowski, J. J., Herrmann, B. S., Rauch, S. D., ... & Merchant, S. N. (2004). Superior semicircular canal dehiscence presenting as conductive hearing loss without vertigo. *Otology & Neurotology*, *25*(2), 121-129.

Minor, L. B., Carey, J. P., Cremer, D., Lustig, L. R., & Streubel, S.-O. (2003). *Dehiscence of Bone Overlying the Superior Canal as a Cause of Apparent Conductive Hearing Loss*. http://journals.lww.com/otology-neurotology

Nagaraj, S., Singhal, P., Singh, A. S., Sharma, S., Sharma, A. K., Jat, K. S., Agarwal, S., Harshvardhan, R., & Sharma, M. P. (2023). A Comparative Study of Surgical Outcomes in Children with Cochlear Implantation Using Posterior Tympanotomy & Modified Veria Technique. *Indian Journal of Otolaryngology and Head & Neck Surgery*, *75*(S1), 255–260. https://doi.org/10.1007/s12070-022-03399-1

Nakajima, H. H., Pisano, D. V, Roosli, C., Hamade, M. A., Merchant, G. R., Mahfoud, L., Halpin, C. F., Rosowski, J. J., & Merchant, S. N. (2012). *Comparison of Ear-Canal Reflectance and Umbo Velocity in Patients With Conductive Hearing Loss: A Preliminary Study*.

Nakajima, H. H., Rosowski, J. J., Shahnaz, N., & Voss, S. E. (2013). Assessment of Ear Disorders Using Power Reflectance. *Ear & Hearing*, *34*(Supplement 1), 48s–53s. https://doi.org/10.1097/AUD.0b013e31829c964d

Nguyen, S., Cloutier, F., Philippon, D., Côté, M., Bussières, R., & Backous, D. D. (2016). Outcomes review of modern hearing preservation technique in cochlear implant. *Auris Nasus Larynx*, *43*(5), 485–488. https://doi.org/10.1016/J.ANL.2016.02.014

Norrix, L. W., Burgan, B., Ramirez, N., & Velenovsky, D. S. (2013). Interaural multiple frequency tympanometry measures: Clinical utility for unilateral conductive hearing loss. *Journal of the American Academy of Audiology*, *24*(3), 231–240. https://doi.org/10.3766/jaaa.24.3.8

Olszewski, L., Jedrzejczak, W., Sliwa, L., Fabijanska, A., & Skarzynski, H. (2017). Use of wideband absorbance measurement to assess large vestibular aqueduct syndrome: a case study. *Journal of Hearing Science*, *7*(1), 52–55. https://doi.org/10.17430/904707

Orhan, K. S., Çelik, M., Polat, B., Dikici, T., & Güldiken, Y. (2021). Wideband absorbance outcomes of cochlear implantation: A comparative clinical study. *Journal of International Advanced Otology*, *17*(1), 9–12. https://doi.org/10.5152/iao.2020.4876

Preis, M., Attias, J., Hadar, T., & Nageris, B. I. (2009). Cochlear third window in the scala vestibuli: an animal model. *Otology & Neurotology*, *30*(5), 657-660.

Prieve, B. A., Werff, K. R. V., Preston, J. L., & Georgantas, L. (2013). Identification of conductive hearing loss in young infants using tympanometry and wideband reflectance. *Ear and Hearing*, *34*(2), 168–178. https://doi.org/10.1097/AUD.0B013E31826FE611

Raveh, E., Attias, J., Nageris, B., Kornreich, L., & Ulanovski, D. (2015). Pattern of hearing loss following cochlear implantation. *European Archives of Oto-Rhino-Laryngology*, *272*(9), 2261–2266. https://doi.org/10.1007/S00405-014-3184-2/METRICS

Saki, N., Shirani, M., Kardooni, M., Mirmoemeni, G., & Bayat, A. (2022). The effects of cochlear implantation on middle ear function: A prospective study. *International Journal of Pediatric Otorhinolaryngology*, *163*, 111368. https://doi.org/10.1016/j.ijporl.2022.111368

Sanford, C. A., Hunter, L. L., Patrick Feeney, M., & Nakajima, H. H. (2013). Wideband acoustic immittance: tympanometric measures. *Ear and Hearing*, *34 Suppl 1*(SUPPL. 1). https://doi.org/10.1097/AUD.0B013E31829C7250

Saoji, A. A., Shapiro, S. B., Finley, C. C., Koka, K., & Cassis, A. M. (2020). Changes in Wide-band Tympanometry Absorbance following Cochlear Implantation. *Otology and Neurotology*, *41*(6), e680–e685. https://doi.org/10.1097/MAO.0000000000002625

Scheperle, R. A., & Hajicek, J. J. (2020). Wideband Acoustic Immittance in Cochlear Implant Recipients: Reflectance and Stapedial Reflexes. *Ear and Hearing*, *41*(4), 883–895. https://doi.org/10.1097/AUD.0000000000000810

Shahnaz, N. (2007). Multi-Frequency Tympanometry and Evidence-Based Practice. *Perspectives on Hearing and Hearing Disorders Research and Diagnostics*, *11*(1), 2. https://doi.org/10.1044/hhd11.1.2

Shahnaz, N., & Bork, K. (2006). Wideband reflectance norms for Caucasian and Chinese young adults. *Ear and Hearing*, *27*(6), 774–788. https://doi.org/10.1097/01.AUD.0000240568.00816.4A

Shahnaz, N., Bork, K., Polka, L., Longridge, N., Bell, D., & Westerberg, B. D. (2009). Energy reflectance and tympanometry in normal and otosclerotic ears. *Ear and hearing*, *30*(2), 219-233. 10.1097/AUD.0b013e3181976a14

Shahnaz, N., & Davies, D. (2006). Standard and multifrequency tympanometric norms for Caucasian and Chinese young adults. *Ear and hearing*, *27*(1), 75-90. 10.1097/01.aud.0000194516.18632.d2

Shahnaz, N., Longridge, N., & Bell, D. (2009). Wideband energy reflectance patterns in preoperative and post-operative otosclerotic ears. *International Journal of Audiology*, *48*(5), 240–247. https://doi.org/10.1080/14992020802635317

Shanks, J., & Lilly, D. J. (1981). An Evaluation of Tympanometric Estimates of Ear Canal Volume. *Journal of Speech and Hearing Research*, *24*(4), 557–566. https://doi.org/10.1044/JSHR.2404.557

Stinson, M. R. (1990). Revision of estimates of acoustic energy reflectance at the human eardrum. *The Journal of the Acoustical Society of America*, *88*(4), 1773–1778. https://doi.org/10.1121/1.400198

Tanno, G. A. Y., Santos, M. A. de O., Sanches, M. T. D., Durante, A. S., Almeida, K. de, Gameiro, M. S., Roque, N. M. C. de F., & Sousa Neto, O. M. de. (2022). Analysis of wideband tympanometry in Ménière's disease. *Brazilian Journal of Otorhinolaryngology*, *88*(2), 194–203. https://doi.org/10.1016/j.bjorl.2020.05.029

Terzi, S., Özgür, A., Erdivanli, Coşkun, Z., Ogurlu, M., Demirci, M., & Dursun, E. (2015). Diagnostic value of the wideband acoustic absorbance test in middle-ear effusion. *Journal of Laryngology and Otology*, *129*(11), 1078–1084. https://doi.org/10.1017/S0022215115002339

Vaca, M., Gutiérrez, A., Polo, R., Alonso, A., & Álvarez, F. (2015). Long-term results of the transattical approach: an alternative technique for cochlear implantation. *European Archives of Oto-Rhino-Laryngology*, *272*(1), 35–41. https://doi.org/10.1007/s00405-013-2831-3

Voss, S. E., Horton, N. J., Woodbury, R. R., & Sheffield, K. N. (2008). Sources of variability in reflectance measurements on normal cadaver ears. *Ear and Hearing*, *29*(4), 651–665. https://doi.org/10.1097/AUD.0B013E318174F07C

Wang, S., Hao, W., Xu, C., Ni, D., Gao, Z., & Shang, Y. (2019). A Study of Wideband Energy Reflectance in Patients with Otosclerosis: Data from a Chinese Population. *BioMed Research International*, *2019*, 1–8. https://doi.org/10.1155/2019/2070548

Wasson, J. D., Campbell, L., Chambers, S., Hampson, A., Briggs, R. J. S., & O'Leary, S. J. (2018). Effect of cochlear implantation on middle ear function: A three-month prospective study. *Laryngoscope*, *128*(5), 1207–1212. https://doi.org/10.1002/lary.26840

Whittemore, K. R., Merchant, S. N., & Rosowski, J. J. (1998). Acoustic Mechanisms. *Otolaryngology–Head and Neck Surgery*, *118*(6), 751–761. https://doi.org/10.1016/S0194-5998(98)70264-5

Zeitler, D. M., & Balkany, T. J. (2010). Alternative approaches to cochlear implantation. *Operative Techniques in Otolaryngology - Head and Neck Surgery*, *21*(4), 248–253. https://doi.org/10.1016/j.otot.2010.10.001

Zhang, L., Wang, J., Zhao, F., & Li, Y. (2020). Inner ear pressure evaluation using wideband tympanometry in children with Large Vestibular Aqueduct Syndrome (LVAS): A pilot study. *International Journal of Pediatric Otorhinolaryngology*, *128*, 109690. https://doi.org/10.1016/J.IJPORL.2019.109690