The Journal of International Advanced Otology

J Int Adv Otol 2024; 20(2): 158-163 • DOI: 10.5152/iao.2024.231048

Original Article

Wideband Absorbance Pattern and its Diagnostic Value in Adults with Middle Ear Effusions and Tympanic Membrane Perforation

Arunraj Karuppannan[1], Animesh Barman[2], Nerale Maraiah Mamatha[2]

[1]Department of Audiology and Prevention of Communication Disorders, All India Institute of Speech and Hearing, Manasagangothri, Karnataka, India
[2]Department of Audiology, All India Institute of Speech and Hearing, Manasagangothri, Karnataka, India

ORCID iDs of the authors: A.K. 0000-0001-6965-8677, A.B. 0000-0001-8158-7584, N.M.M. 0000-0001-9934-0862.

Cite this article as: Karuppannan A, Barman A, Mamatha NM. Wideband absorbance pattern and its diagnostic value in adults with middle ear effusions and tympanic membrane perforation. *J Int Adv Otol.* 2024;20(2):158-163.

BACKGROUND: Middle ear effusion (MEE) and tympanic membrane perforation (TMP) are difficult to distinguish using existing immittance techniques, necessitating the use of a separate test battery. Wideband absorbance (WBA) tympanometry is a new enhanced technique, and studies have shown a reliable WBA pattern to identify middle ear disorders. Thus, the study was performed to determine the WBA across the frequencies in ears with MEE, TMP, and compared with normal hearing individuals.

METHODS: A total of 109 ears with TMP and 122 ears with MEE in the age range of 22-50 years were compared with 150 normal hearing ears. Otoscopic examination, middle ear fluid monitor, pure tone audiometry, and immittance measurements were performed to categorize the subject ears into groups. The absorbance levels at peak and ambient pressure across one-third octave frequencies in each group were statistically evaluated at $\alpha = 0.05$.

RESULTS: Wideband absorbance for the normal ear group was lowest at low (<800 Hz) and high frequencies (>3000 Hz) and highest at mid-frequency regions (800-3000 Hz). The MEE group had significantly lower WBA at all frequencies, and TMP group showed reduced WBA at low and mid-frequencies (<2500 Hz). Wideband absorbance at peak pressure was slightly higher than ambient pressure in all the groups. Receiver operating characteristic analysis demonstrated a high diagnostic value in the mid-frequency region for both the TMP and MEE groups.

CONCLUSION: Wideband absorbance provides high reliability in discriminating between MEE and TMP and has a unique WBA pattern. Thus, WBA can be a useful diagnostic tool for the identification of middle ear disorders.

KEYWORDS: Absorbance, middle ear disorders, tympanometry, peak pressure, ambient pressure

INTRODUCTION

The human middle ear system is important in effectively transmitting sound to the inner ear and acting as an impedance balancer between the outer ear, i.e., low impedance of air, and the inner ear of high impedance fluid.[1] Any change or alteration in the middle ear system would change the mechno-acoustic properties of the middle ear and affect sound transmission.[2] Thus, the physical state of the tympanic membrane and the middle ear structures is critical in determining the middle ear status and effective sound transmission.

Sound transmission varies depending on the etiology, severity, and location of the lesion within the middle ear structure. This would result in variable degrees of conductive hearing loss.[3] Conditions such as middle ear effusion (MEE) and tympanic membrane perforation (TMP) reduce the impedance-matching capacities of the middle ear, which degrade hearing acuity, resulting in minimal to moderate conductive hearing loss.[4] Middle ear effusion is the most frequent type of middle ear infection resulted from Eustachian tube dysfunction or inflammation of the middle ear mucosa due to bacterial or viral infection. This generally goes unnoticed in its early stages due to the absence of symptoms. If left untreated, it can progress to hearing loss and more serious disorders

Corresponding author: Arunraj Karuppannan, e-mail: nahularun@gmail.com

Received: January 3, 2023 • **Revision requested:** August 7, 2023• **Last revision received:** August 21, 2023 • **Accepted:** October 4, 2023 • **Publication Date:** March 27, 2024
Available online at www.advancedotology.org

such as chronic otitis media.[4] Further, the amount and viscosity of the fluid may both have effects on the tympanic membrane and affects the middle ear function.

The diagnosis of MEE and TMP is normally based on the findings of otoscopy, pneumatic otoscopy, and immittance, along with pure tone audiometry.[5] Otoscopic examination can detect TMP; however, MEE can be detected only when signs of effusion are evident.[6] Pneumatic otoscopy is used to detect the presence of MEE. However, the accuracy of detecting disorders is largely dependent on physician expertise and has been reported to range between 40% and 70%.[7]

Tympanometry has been used as a routine tool for several decades to measure the admittance properties of the middle ear with changes in pressure, indicating middle ear functioning. These conditions are typically distinguished by a large air-bone gap in pure tone audiometry, conductive hearing loss, and a "B" type tympanogram in 226 Hz probe tone tympanometry with absent acoustic reflexes.[8] However, there is insufficient information to distinguish between conditions, i.e., TMP and MEE. Though ear canal volume (ECV) may provide some information between the 2 (high ECV in TMP and lower ECV in MEE than normal ECV), acute otitis media may also produce a high ECV secondary to tympanic membrane perforation.[9] Additionally, early stages of MEE may go undetected in immittance findings, especially when fluid levels are below or in the effective area of the tympanic membrane. Thus, it is essential to identify the condition early and take the necessary steps to cure.

The wideband absorbance (WBA) overcomes those limitations of conventional tympanometry by showing promising clinical utility. The WBA tympanometry is a recent advanced technique used to assess the middle ear status across frequencies.[10-15] The click stimuli used as a probe tone comprise a wide range of frequencies with flat spectrum, which resolves many limitations of clinically utilized single-tone tympanometry at 226 Hz. Studies have shown that WBA helps in the differential diagnosis of conductive hearing loss conditions[11,16-18] with higher sensitivity than that of 226 Hz tympanometry.[19] However, the studies reported in the literature on identifying MEE and TMP are in infants and children, and they are primarily concerned with measuring WBA at ambient pressure conditions.[11,12] Middle ear effusion has been linked to lower power absorbance across all frequencies,[19-21] while only a few studies have been published for ears, with TMP[3,12,22,23] showing reduced absorbance at low and mid-frequencies.

MAIN POINTS

- The human middle ear plays a crucial role in sound transmission, balancing air and fluid impedance
- Changes in the middle ear's physical state, especially the tympanic membrane, affects the sound transmission.
- Middle ear conditions such as effusion (MEE) and perforation (TMP) can lead to hearing loss, and thus early detection is crucial.
- Diagnosis relies on methods like pneumatic otoscopy, and immittance testing. Wideband absorbance (WBA) tympanometry is a promising tool for distinguishing these conditions, offering higher sensitivity than traditional tests, though more research is needed.

Although research has shown that WBA at tympanometric peak pressure (TPP) is more sensitive to middle ear disorders in children and adults,[13,16,17,24,25] none of the studies on MEE and TMP have compared the results of WBA at ambient pressure and TPP for differential diagnosis. Furthermore, to the best of our knowledge, no study has been conducted to investigate the effect of MEE and TMP on WBA measurement in the adult population. In addition, the sensitivity and specificity measurements are not adequately studied in these conditions. Thus, the purpose of this study was to determine the WBA pattern to distinguish between MEE and TMP, and how both conditions differ from normal middle ear. The WBA measured was compared to ambient pressure and TPP, and the diagnostic value (sensitivity and specificity) was calculated for each disorder at varied frequencies.

MATERIAL AND METHODS

A total of 328 adults in the age range of 22-50 years (mean age 35.35 ± 9.09 years) were randomly recruited. The study groups were divided into 3 groups: the TMP group (n = 96) with 109 ears; the MEE group (n = 102) with 122 ears; and the normal ear (control) group (n = 130) with 150 ears. The details of the participants are shown in Table 1.

The TMP group included patients diagnosed with isolated or dry tympanic membrane perforation without any active ear discharge. The MEE group includes patients with otitis media with effusion without any TMP. Both groups of pathological ears had conductive hearing loss (air-bone gap >10 dB) of less than 70 dB HL pure-tone average and no measurable peak in the 226 Hz probe tone, i.e. "B" type tympanogram with absent acoustic reflexes between the octaves 500 Hz and 4000 Hz. Participants with any other confirmed middle ear pathologies such as cholesteatoma, tympanosclerosis, ossicles-related disorders, and congenital malformations, as assessed by an experienced and proficient otorhinolaryngologist, were excluded from the study. Further, participants with a near total TMP were also excluded due to the difficulty in measuring WBA, especially at TPP. The control group includes participants with normal hearing sensitivity (≤ 15 dB HL between 0.25 and 8 kHz octave frequencies) and no air-bone gap; an "A" type tympanogram for 226 Hz probe tone tympanometry; and the presence of acoustic reflexes.

The study was carried out in accordance with the Ethical Principles for Medical Research Involving Human Subjects outlined in the Helsinki Declaration (2013) and also approved by the Institutional Ethical Committee for Bio-Behavioral Research Involving Human Subjects of the All India Institute of Speech and Hearing (Approval No: WOF-0404). Informed consent was obtained for their voluntary participation.

Table 1. Details of the Number of Participants/Ears in Each Group Along with Mean Age and SD

Groups	No. of Participants (No. of ears)			Mean age ± SD (in years)
	Males (Right/Left)	Females (Right/Left)	Total (Ears)	
Normal Ear	68 (42/33)	62 (47/28)	130 (150)	34.40 ± 9.01
Tympanic Membrane Perforation	49 (28/28)	47 (27/26)	96 (109)	34.22 ± 9.04
Middle Ear Effusion	52 (31/31)	50 (30/30)	102 (122)	37.53 ± 8.91

Table 2. Descriptive Statistics [Mean (SD)] of Wideband Absorbance Obtained at Tympanometric Peak Pressure and Ambient Pressure in Normal Ear and Pathological Ear Groups

Frequency (Hz)	Normal Ear Group		Tympanic Membrane Perforation Group		Middle Ear Effusion Group	
	Tympanometric Peak Pressure	Ambient	Tympanometric Peak Pressure	Ambient	Tympanometric Peak Pressure	Ambient
250	0.14 (0.04)	0.13 (0.04)	0.08 (0.04)	0.07 (0.05)	0.08 (0.06)	0.07 (0.06)
300	0.17 (0.05)	0.16 (0.05)	0.1 (0.06)	0.09 (0.06)	0.09 (0.07)	0.09 (0.07)
400	0.24 (0.06)	0.22 (0.06)	0.17 (0.1)	0.15 (0.09)	0.13 (0.09)	0.13 (0.1)
500	0.33 (0.07)	0.3 (0.07)	0.25 (0.16)	0.22 (0.15)	0.17 (0.1)	0.15 (0.11)
600	0.45 (0.07)	0.42 (0.08)	0.37 (0.23)	0.33 (0.22)	0.2 (0.1)	0.18 (0.11)
800	0.66 (0.07)	0.62 (0.09)	0.51 (0.24)	0.48 (0.23)	0.24 (0.11)	0.22 (0.11)
1000	0.81 (0.08)	0.79 (0.09)	0.59 (0.2)	0.57 (0.19)	0.29 (0.13)	0.28 (0.13)
1250	0.85 (0.08)	0.85 (0.08)	0.6 (0.17)	0.6 (0.17)	0.34 (0.14)	0.33 (0.14)
1500	0.85 (0.09)	0.85 (0.09)	0.57 (0.16)	0.57 (0.16)	0.37 (0.14)	0.36 (0.15)
2000	0.87 (0.08)	0.87 (0.08)	0.56 (0.22)	0.58 (0.21)	0.42 (0.14)	0.4 (0.14)
2500	0.8 (0.13)	0.8 (0.13)	0.64 (0.21)	0.65 (0.21)	0.41 (0.11)	0.4 (0.11)
3000	0.67 (0.16)	0.67 (0.16)	0.63 (0.18)	0.64 (0.17)	0.36 (0.09)	0.35 (0.09)
4000	0.41 (0.15)	0.41 (0.16)	0.4 (0.17)	0.41 (0.18)	0.24 (0.11)	0.23 (0.11)
5000	0.23 (0.09)	0.23 (0.09)	0.35 (0.18)	0.35 (0.18)	0.17 (0.09)	0.16 (0.09)
6000	0.15 (0.07)	0.15 (0.07)	0.34 (0.21)	0.33 (0.21)	0.11 (0.06)	0.1 (0.05)
8000	0.15 (0.1)	0.16 (0.1)	0.18 (0.15)	0.18 (0.15)	0.19 (0.2)	0.21 (0.22)

Test Procedure

The participants were first examined by the otorhinolaryngologist using otomicroscopy, followed by administration of pure-tone audiometry (Inventis Piano Clinical audiometer), a middle ear fluid monitor (Ear Check, Innovia Medical-Lenexa), and 226 Hz tympanometry with acoustic reflex thresholds (Interacoustics Titan IMP440 Ver. 3.1.024). Wideband absorbance measurements were performed on all study participants using Interacoustics Titan IMP440/WBT440, version 3.1.024, and it was calibrated on a daily basis.[26] The probe was inserted into the ear canal with an appropriate airtight probe tip, and a click stimulus of 100 dB peSPL was presented at a constant rate of 21.5 Hz. Pressure was swept from +200 daPa to −600 daPa with a medium pump speed of 200 daPa/sec, and WBA was measured across the frequencies ranging from 226 to 8000 Hz. The WBA values were extracted at TPP and ambient pressure at one twenty-fourth-octave band (121 frequency data points), which were averaged into one-third-octave bands (16 frequency data points) for analysis. The MATLAB software version 9.7 (Math Works, Inc., Natick, US) was used to extract the data, which was then uploaded to Statistical Package for Social Sciences Statistics software for Windows version 21.0 (IBM SPSS Corp.; Armonk, NY, USA) for statistical analysis.

Statistical Analysis

Multivariate analysis was used to distinguish the WBA obtained across the groups as a function of one-third octave frequencies ranging from 250 Hz to 8000 Hz. A Pairwise multiple comparison using the Bonferroni post-hoc test was used to differentiate between the groups across the frequencies. Within the group, a paired T-test with Bonferroni corrections ($P < .003$) was used to determine the difference in WBA obtained by TPP and ambient pressure. The diagnostic value (sensitivity and specificity) of the WBA measurement was calculated using receiver operating characteristic (ROC) analysis.

RESULTS

The WBA data obtained in 2 pressure conditions at one-third-octave frequencies (16 frequencies) across the study groups (3 groups) were analyzed using mixed analysis of variance. The results indicated a significant main effect of groups ($P < .001$, $\eta_p^2 = 0.75$), pressure conditions ($P < .001$, $\eta_p^2 = 1.4$), and frequencies ($P < .001$, $\eta_p^2 = 1.4$). Further, a significant interaction effect was seen only for pressure conditions: frequencies ($P < .001$, $\eta_p^2 = 0.07$); and groups: frequencies ($P < .001$, $\eta_p^2 = 0.37$).

Tympanometric peak pressure was obtained even in ears with TMP (−269.22 ± 113.80 daPa) and MEE (−244 ± 179.83 daPa). This could be due to the use of a wider frequency range stimulus for WBA measurement, which would cause some variation in the transmission of sound energy at high frequencies. The instrument probably considers this variation as a peak and displays it as peak pressure. Table 2 shows the descriptive statistics (mean ± SD) for WBA measured at TPP and ambient pressure in the normal ear and pathological ear groups across the frequencies.

The mean WBA obtained in the normal ear group (Figure 1A) was maximum at mid-frequency region (1250 Hz-2000 Hz), having broader and less obvious peaks and reduced absorbance for frequencies below 1000 Hz and above 2000 Hz in both pressure conditions. The WBA in ears with TMP (Figure 1B) revealed reduced absorbance at low and mid frequencies up to 2500 Hz compared to the normal ear group; identical at 3000 Hz, 4000 Hz, and 8000 Hz; and higher at 5000 Hz and 6000 Hz. Furthermore, the TMP group had 3 maxima at 1000, 3000, and 6000 Hz. Pair-wise multiple comparisons using Bonferroni post-hoc analysis between the normal ear and TMP groups showed significant differences ($P < .01$) for all frequencies except at 3000 Hz, 4000 Hz, and 8000 Hz ($P > .05$). The MEE group revealed a substantial decline in absorbance values at all frequencies (Figure 1C), compared

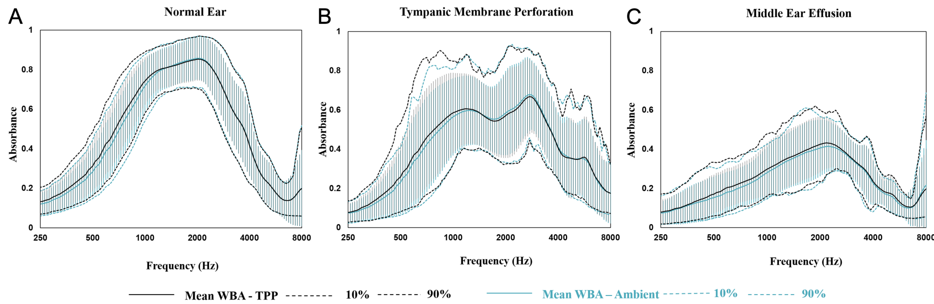

Figure 1. Graphical representation of mean wideband absorbance and 10%-90% range measured at tympanometric peak pressure and ambient pressure across frequencies in the (A) normal ear group; (B) tympanic membrane perforation group; and (C) middle ear effusion group.

to the normal ear group and TMP group. Post-hoc Bonferroni analysis showed a significant difference ($P < .01$) between the normal ear and MEE groups for all frequencies except at 8000 Hz ($P > .05$). Similarly, a significant difference was observed between the TMP group and MEE group across all frequencies ($P < .01$), except for 250 Hz, 300 Hz, and 8000 Hz ($P > .05$).

Figure 2 depicts the WBA measured at TPP and ambient pressure conditions for normal ear and pathological groups (TMP and MEE) across the frequencies. The WBA measured at ambient pressure was slightly lower than the TPP. Analysis using a paired *t*-test showed a significant difference between the TPP and ambient pressure for frequencies below 1000 Hz ($P < .05$), irrespective of the group. In addition, the MEE group showed lower absorbance at TPP for 2000 Hz and 3000 Hz ($P < .05$) compared to the ambient pressure.

The Area under the Receiver Operating Characteristic (AUROC) curve was used to estimate the diagnostic value for each pathological group by comparing it to the normal ear group for those significant frequencies ($P < .05$). The highest AUROC values were within 600 Hz-3000 Hz for the MEE group and 1250 Hz-2000 Hz for the TMP group, with high sensitivity and specificity at those frequencies. Table 3 shows the diagnostic values, sensitivity and specificity, and the cut-off criterion point for each frequency in both pressure conditions.

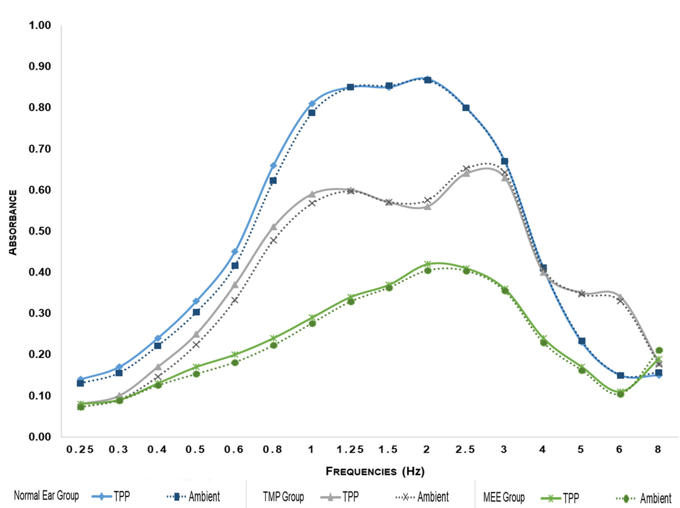

Figure 2. Graphical representation of mean wideband absorbance measured at tympanometric peak pressure and ambient pressure across frequencies in Normal ear group and Pathological ear group (tympanic membrane perforation and middle ear effusion)

DISCUSSION

The WBA measured across the frequencies and its pattern in the normal ear group are consistent with previous research showing that the WBA at TPP and ambient pressure reaches a maximum anywhere from 1000 Hz to 4000 Hz in adults and a minimum at the extreme low and high frequencies. This could be due to the mass and stiffness properties of the middle ear.[10,13,15] Two maxima around 1000 Hz and 2500 Hz were reported in the literature for both peak and ambient pressure conditions,[14,18] which is consistent with the current findings.

The TMP group showed lower absorbance at low and mid-frequencies with a significant reduction up to 2500 Hz and higher absorbance beyond 4000 Hz with 3 maxima at 1000 Hz, 3000 Hz, and 6000 Hz. The results are consistent with previous research showing reduced absorbance in the low and mid-frequency regions below 1000 Hz.[3,11,12] At high frequencies, studies have shown a wide range of variability, with few reporting near-normal absorbance above 1000 Hz[11,23] and few reporting increased absorbance above 4000 Hz.[27] None of the studies have specifically mentioned the number of maxima that they could observe. The rationale for having 3 maxima in this study, however, is unclear. One would expect either an increase in absorbance values at low or high-frequency region depending upon pathological changes, making the middle ear either mass dominated or stiffness dominated system. It is, however, a unique finding and WBA pattern observed in ears with TMP. The ROC analysis performed in the TMP group showed a high sensitivity (>74%) and specificity (>85%) for frequencies at 1250 Hz, 1500 Hz, and 2000 Hz in both pressure conditions with unique cut-off WBA values.

In the current study, the MEE group had a reduced WBA across the frequencies, mostly seen below 3000 Hz, similar to the earlier studies.[19-21] Reduction in WBA depends on the amount of fluid filled in the middle ear.[23] Although the current study did not account for the amount of fluid present inside the middle ear cavity, a reduction was observed across all frequencies. The reduction in absorbance at low frequencies was attributed to fluid accumulation in the middle ear, which resulted in reduced tympanic membrane stiffness and umbo velocity. At high frequencies, the decrease in absorbance could be due to the increased mass caused by the fluid attached to the tympanic membrane and the decrease in umbo velocity.[28]

Earlier investigations on sensitivity and specificity were reported only in infants and children with middle ear effusion[19-21] demonstrating higher AUROC in the frequency range of 800 Hz-2000 Hz. A similar observation was made in the current investigation with high AUROC in the frequency range of 600 Hz-3000 Hz, with high sensitivity

Table 3. Summarize of the AUROC Values, Cut-off Criterion Point, Sensitivity (%), and Specificity (%) of Those Significant Frequency ($P < .01$) at Tympanometric Peak Pressure and Ambient Pressure

Frequency (Hz)	Peak Pressure				Ambient Pressure			
	AUROC	Cut-off Criterion point	Sensitivity (%)	Specificity (%)	AUROC	Cut-off Criterion point	Sensitivity (%)	Specificity (%)
Middle Ear Effusion								
250	0.84	≤0.11	78.69	85.33	0.80	≤0.07	64.75	94.00
300	0.84	≤0.12	75.41	88.67	0.80	≤0.08	64.75	95.33
400	0.84	≤0.17	74.60	89.33	0.80	≤0.13	63.93	96.00
500	0.88	≤0.21	73.77	95.33	0.86	≤0.23	78.70	86.00
600	0.96	≤0.30	86.07	92.67	0.95	≤0.30	86.07	92.67
800	1.00	≤0.52	100.00	97.33	1.00	≤0.45	100.00	98.00
1000	1.00	≤0.58	96.72	96.72	1.00	≤0.56	96.72	98.67
1250	1.00	≤0.66	97.54	99.33	1.00	≤0.64	97.54	99.33
1500	1.00	≤0.64	97.54	99.33	1.00	≤0.64	96.72	98.67
2000	1.00	≤0.70	100.00	97.33	1.00	≤0.68	99.18	96.00
2500	0.99	≤0.62	98.67	90.67	0.99	≤0.62	100.00	90.00
3000	0.96	≤0.48	92.62	88.67	0.96	≤0.49	93.44	88.00
4000	0.82	≤0.30	73.77	75.33	0.83	≤0.34	84.43	68.67
5000	0.70	≤0.16	52.46	80.67	0.75	≤0.18	65.57	74.00
6000	0.67	≤0.11	54.92	74.00	0.72	≤0.10	56.56	78.00
Tympanic Membrane Perforation								
250	0.86	≤0.10	68.81	90.00	0.82	≤0.07	60.55	94.00
300	0.82	≤0.11	64.20	90.00	0.80	≤0.09	58.72	95.33
400	0.73	≤0.15	55.05	92.00	0.75	≤0.13	56.80	93.33
500	0.69	≤0.26	63.39	83.33	0.72	≤0.20	55.05	93.33
600	0.66	≤0.30	49.54	96.67	0.68	≤0.30	53.21	93.33
800	0.71	≤0.53	58.72	96.67	0.72	≤0.48	56.88	93.33
1000	0.84	≤0.69	68.81	94.00	0.85	≤0.66	69.72	90.67
1250	0.90	≤0.69	76.15	97.33	0.89	≤0.66	74.31	98.67
1500	0.93	≤0.74	87.16	88.00	0.93	≤0.74	86.24	90.00
2000	0.88	≤0.74	76.15	93.30	0.87	≤0.74	74.31	92.67
2500	0.73	≤0.64	50.46	88.00	0.71	≤0.63	47.71	88.67
5000	0.69	>0.27	56.88	73.30	0.68	>0.26	63.30	68.67
6000	0.79	>0.25	55.05	93.33	0.78	>0.28	50.46	96.00

The closer to 1, the greater the diagnostic value.AUROC, area under the curve.

(>92%) and specificity (>88%) for both pressure conditions. The maximum sensitivity (100%) and specificity (97.3%) were seen for 800 Hz and 2000 Hz.

Wideband absorbance obtained at TPP and ambient pressure indicated a substantial difference, notably at lower frequencies below 1000 Hz for both the normal ear group and pathological ear groups. Generally, no measurable peak exists in ears with TMP and/or MEE. The presence of TPP in the current study is most likely due to the use of a wider frequency range of stimulus in the WBA measurements. Relevant investigations measuring WBA at TPP in the pathological ear group, particularly in ears with MEE in children, have been reported, and the results are comparable to ambient pressure.[5,29] Most studies on TPP and ambient pressure conditions are performed in the normal ear and the findings are similar.[25,26] The presence of either positive or negative pressure induced in the ear canal in ambient pressure conditions with reference to the middle ear pressure[26] increases the stiffness, resulting in a larger impedance and thus reflecting sound energy into the ear canal. Regardless of the WBA differences, the pattern observed at peak and ambient pressure was comparable.[16,17,30]

While the study presented notable findings, it is imperative to acknowledge a certain limitation of the study—specifically, the inclusion of CT scan data could have improved the analysis. Despite the study's substantial sample size, the current study did not consider the location of the tympanic membrane perforation or the volume of fluid within the middle ear, both of which have an impact on sound transduction and consequently on hearing. Future research can focus on the absorbance at various tympanic membrane perforation sites and different stages of middle ear effusion (acute, serous, or chronic). In this study, comparisons were made between the normal and pathological ear groups (TMP and MEE). Wideband absorbance in ears with TMP and MEE were significantly different from that of a normal ear for both TPP and ambient pressure. The findings also show a distinct WBA pattern that distinguishes each pathological condition from the normal ear. Furthermore, high sensitivity and specificity were observed, demonstrating that WBA is an efficient testing technique for distinguishing middle ear disorders.

Ethics Committee Approval: This study was approved by the institutional ethical review committee of the All India Institute of Speech and Hearing (Approval No: WOF-0404, Date: 2014).

Informed Consent: Informed consent was obtained from the participants who agreed to take part in the study.

Peer-review: Externally peer-reviewed.

Acknowledgments: The authors acknowledge with gratitude to the All India Institute of Speech and Hearing, Mysuru, for permitting them to conduct the study. Dr. Vasanthalakshmi MS, Biostatistician, All India Institute of Speech and Hearing and Dr Vijay Kumar Narne, Research Fellowship, for their assistance in statistics and data extraction from MATLAB for the study. Special thanks to Interacoutics, Denmark, for providing the research module of the TITAN software. The authors would also like to acknowledge the participants for their cooperation.

Author Contributions: Concept – A.K., A.B.; Design – A.K., A.B.; Supervision – A.B.; Resources – A.K., A.B.; Materials – A.K., A.B.; Data Collection and/or Processing – A.K.; Analysis and/or Interpretation – A.K., A.B., N.M.M.; Literature Search – A.K., N.M.M.; Writing – A.K., N.M.M.; Critical Review – A.K., A.B., N.M.M.

Declaration of Interests: The authors have no conflict of interest to declare.

Funding: The authors declared that this study has received no financial support.

REFERENCES

1. Grais EM, Wang X, Wang J, et al. Analysing wideband absorbance immittance in normal and ears with otitis media with effusion using machine learning. *Sci Rep*. 2021;11(1):10643. [CrossRef]
2. Kim J. Koo M. Mass and stiffness impact on the middle ear and the cochlear partition. *Korean J Audiol*. 2015;19(1):1-6. [CrossRef]
3. Voss SE, Rosowski JJ, Merchant SN, Peake WT. How do tympanic-membrane perforations affect human middle-ear sound transmission? *Acta Otolaryngol*. 2001;121(2):169-173. [CrossRef]
4. Sinkkonen ST, Jero J, Aarnisalo AA. Tympanic membrane perforation. *Duodecim*. 2014;130(8):810-818.
5. Liang J, Xiao L, Sun XY, Zou B. Characteristics of the wideband absorbance of acoustic energy in children (3-7 years old) with otitis media with effusion. *Int J Pediatr Otorhinolaryngol*. 2021;140:110496. [CrossRef]
6. Sassen ML, van Aarem AV, Grote JJ. Validity of tympanometry in the diagnosis of middle ear effusion. *Clin Otolaryngol Allied Sci*. 1994;19(3):185-189. [CrossRef]
7. Blomgren K, Pitkäranta A. Current challenges in diagnosis of acute otitis media. *Int J Pediatr Otorhinolaryngol*. 2005;69(3):295-299. [CrossRef]
8. Shanks J, Shohet J. Tympanometry in clinical practice. In: Katz J, Medwetsky L, Burkard R, eds. *Handbook of Clinical Audiology*. 6th ed. Philadelphia: Lippincot Williams & Wilkins; 2009:157-188.
9. Onusko E. Tympanometry. *Am Fam Phys*. 2004;70(9):1713-1720. [CrossRef]
10. Shahnaz N, Bork K. Wideband reflectance norms for Caucasian and Chinese young adults. *Ear Hear*. 2006;27(6):774-788. [CrossRef]
11. Feeney MP, Grant IL, Marryott LP. Wideband energy reflectance measurements in adults with middle-ear disorders. *J Speech Lang Hear Res*. 2003;46(4):901-911. [CrossRef]
12. Kim SY, Han JJ, Oh SH, et al. Differentiating among conductive hearing loss conditions with wideband tympanometry. *Auris Nasus Larynx*. 2019;46(1):43-49. [CrossRef]
13. Margolis RH, Saly GL, Keefe DH. Wideband reflectance tympanometry in normal adults. *J Acoust Soc Am*. 1999;106(1):265-280. [CrossRef]
14. Feeney MP, Sanford CA. Age effects in the human middle ear: wideband acoustical measures. *J Acoust Soc Am*. 2004;116(6):3546-3558. [CrossRef]
15. Shahnaz N, Feeney MP, Schairer KS. Wideband acoustic immittance normative data: ethnicity, gender, aging, and instrumentation. *Ear Hear*. 2013;34(suppl 1):27S-35S. [CrossRef]
16. Karuppannan A, Barman A. Wideband absorbance tympanometry: a novel method in identifying otosclerosis. *Eur Arch Otorhinolaryngol*. 2021;278(11):4305-4314. [CrossRef]
17. Karuppannan A, Barman A. Wideband absorbance pattern in adults with otosclerosis and ossicular chain discontinuity. *Auris Nasus Larynx*. 2021;48(4):583-589. [CrossRef]
18. Wang S, Hao W, Xu C, Ni D, Gao Z, Shang Y. A Study of wideband energy reflectance in patients with Otosclerosis: data from a Chinese population. *BioMed Res Int*. 2019;2019:2070548. [CrossRef]
19. Ellison JC, Gorga M, Cohn E, Fitzpatrick D, Sanford CA, Keefe DH. Wideband acoustic transfer functions predict middle-ear effusion. *Laryngoscope*. 2012;122(4):887-894. [CrossRef]
20. Beers AN, Shahnaz N, Westerberg BD, Kozak FK. Wideband reflectance in normal Caucasian and Chinese school-aged children and in children with otitis media with effusion. *Ear Hear*. 2010;31(2):221-233. [CrossRef]
21. Terzi S, Özgür A, Erdivanli ÖÇ, et al. Diagnostic value of the wideband acoustic absorbance test in middle-ear effusion. *J Laryngol Otol*. 2015;129(11):1078-1084. [CrossRef]
22. Voss SE, Rosowski JJ, Merchant SN, Peake WT. Middle-ear function with tympanic-membrane perforations. II. A simple model. *J Acoust Soc Am*. 2001;110(3 Pt 1):1445-1452. [CrossRef]
23. Voss SE, Merchant GR, Horton NJ. Effects of middle-ear disorders on power reflectance measured in cadaveric ear canals. *Ear Hear*. 2012;33(2):195-208. [CrossRef]
24. Karuppannan A, Barman A. Evaluation of wideband absorbance tympanometry in adults with abnormal positive and negative middle ear pressure. *J Hear Sci*. 2020;10(4):40-47. [CrossRef]
25. Aithal S, Aithal V, Kei J, Manuel A. Effect of negative middle ear pressure and compensated pressure on wideband absorbance and otoacoustic emissions in children. *J Speech Lang Hear Res*. 2019;62(9):3516-3530. [CrossRef]
26. Liu YW, Sanford CA, Ellison JC, Fitzpatrick DF, Gorga MP, Keefe DH. Wideband absorbance tympanometry using pressure sweeps: system development and results on adults with normal hearing. *J Acoust Soc Am*. 2008;124(6):3708-3719. [CrossRef]
27. Allen JB, Jeng PS, Levitt H. Evaluation of human middle ear function via an acoustic power assessment. *J Rehabil Res Dev*. 2005;42(4)(suppl 2):63-78. [CrossRef]
28. Ravicz ME, Rosowski JJ, Merchant SN. Mechanisms of hearing loss resulting from middle-ear fluid. *Hear Res*. 2004;195(1-2):103-130. [CrossRef]
29. Aithal S, Kei J, Aithal V, et al. Normative study of wideband acoustic immittance measures in newborn infants. *J Speech Lang Hear Res*. 2017;60(5):1417-1426. [CrossRef]
30. Wali HA, Mazlan R, Kei J. Pressurized wideband absorbance findings in healthy neonates: A preliminary study. *J Speech Lang Hear Res*. 2017;60(10):2965-2973. [CrossRef]