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Wideband Absorption for Diagnosing Conductive Hearing Loss: Insights from Middle Ear Pathologies

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ABSTRACT

Objective: This study aimed to investigate the relationship between air-bone gap (ABG) and wideband absorbance (WBA) values in patients with conductive hearing loss resulting from four middle ear pathologies: Tympanic membrane perforation, middle ear effusion, ossicular chain discontinuity, and otosclerosis.

Methods: Air and bone conduction thresholds and WBA values were measured at 0.25, 0.5, 1, 2, and 4 kHz under ambient pressure. Correlations between ABG and WBA were analyzed in each pathology group to explore diagnostic relevance.

Results: Significant correlations were identified for specific frequencies and pathologies. In the middle ear effusion group, ABG was negatively correlated with WBA at 0.25 kHz in the right ears (r=-0.570, p=0.022), whereas a positive correlation was observed in the otosclerosis group at the same frequency (r=0.570, p=0.048). Additionally, a negative correlation was noted at 4 kHz for the left ears across all groups (r= -0.270, p= 0.034).

Conclusion: Preoperative WBA measurements provide valuable insights into middle ear function, offering diagnostic and surgical planning advantages for patients with conductive hearing loss. These findings suggest incorporating frequency-specific WBA evaluations into clinical practice can enhance the precision of middle ear pathology assessments.

Keywords: Hearing loss, middle ear pathologies, wideband tympanometry, absorbance, diagnostic audiology

Introduction

Wideband tympanometry (WBT) is a clinically valuable method for evaluating middle ear function, providing detailed insight into the diagnosis and treatment planning of conductive hearing loss. The WBT evaluates middle ear function with a transient stimulus (click or chirp) between 226 Hz and 8000 Hz and provides important information about middle ear functions (1). Because of the presence of multiple frequencies in transient stimuli, WBT is less sensitive to myogenic noise in patient movements (1-3). Comparing to traditional tympanometry, which measures at a standard 226 Hz frequency, it can provide results in a single measurement over a wide frequency range. This approach allows more specific investigation and diagnostics of middle ear problems and conductive hearing loss. The use of WBT in clinical practice can thus significantly enhance the accuracy of middle ear pathology detection and contribute to more precise treatment decisions (4-7).

Wideband absorbance (WBA), a parameter derived from WBT, measures the proportion of sound energy absorbed from the ear canal into the middle ear. This property has been found promising as a diagnostic marker, with studies indicating its ability to differentiate between various middle ear pathologies (8). Characteristic absorbance curves have been described for conditions like otosclerosis, negative middle ear pressure, middle ear effusion, ossicular chain discontinuity, excessive flaccidity or stiffness of the tympanic membrane, and perforation. These findings highlight the potential of WBA as a diagnostic marker for various stages of middle ear diseases, therefore helping with personalized treatment approaches (9).

Conductive hearing loss is a form of auditory impairment that results from pathological conditions in either the outer ear, the middle ear, or both. The condition can be caused by earwax, infection, or trauma to the external auditory canal, or by perforation of the tympanic membrane, ossicular chain discontinuity, middle ear effusion, or otosclerosis. The pure-tone audiometry test is

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a useful tool for diagnosing conductive hearing loss (10). The diagnostic criteria include a bone conduction threshold of 20 dB HL or better and an air-bone gap (ABG) of 10 dB or more, which can range between 10 and 60 dB in conductive hearing loss (11).

Wideband acoustic absorbance measures the middle ear system's ability to absorb sound waves over a wide frequency range (8). In WBT, WBA measurements can be conducted with or without pressure, displaying absorbance results across specific frequency ranges. Non-pressure absorbance refers to measurements at ambient pressure (0 daPa), while pressure absorbance values are obtained at the peak pressure of the tympanogram (12,13).

This study addresses this gap by analyzing the relationship between ABG and WBA at specific frequencies in patients with tympanic membrane perforation, otosclerosis, middle ear effusion, and ossicular chain discontinuity. Therefore, we aimed to enhance the clinical relevance of WBA in diagnosing and managing conductive hearing loss. This investigation is novel in its focus on frequency-specific correlations across multiple pathologies, offering new perspectives on the diagnostic utility of WBA in middle ear assessments.

METHODS

Participants

The study included 78 patients (107 ears) aged 18-65 years (mean age ± SD: 38.24±12.6 years). Participants were selected based on pathological severity, which was explicitly defined in alignment with clinical diagnostic guidelines. For instance, patients with otosclerosis had an ABG ≥20 dB, which was confirmed by radiological imaging.

The inclusion criteria were as follows:

- Patients aged 18-65 years with conductive hearing loss due to
  - ○ Tympanic membrane perforation (Griffin classification grade 2-3) (14),
  - ○ Middle ear effusion persisting for 3 months,
  - ○ Ossicular chain discontinuity,
  - ○ Otosclerosis,
- Diagnosis confirmed by radiological imaging.

Exclusion criteria were as follows:

- Diagnosis of sensorineural or mixed hearing loss.
- Presence of mastoid or external ear disease (e.g., cholesteatoma).
- History of otological surgery.

Study Protocol

Data Collection and Physical Examination

Demographic data such as age, gender, and medical history related to hearing loss were collected from all participants. A comprehensive physical examination was conducted by an otolaryngologist, including an otoscopic evaluation of the external auditory canal and tympanic membrane. Temporal bone computed tomography scan was used to confirm pathological severity and identify potential confounders, such as undiagnosed conditions (15).

Participant Grouping

Participants were divided into four groups according to their diagnosed middle ear pathologies:

- **Group I:** Tympanic membrane perforation (n=27 ears)
- **Group II:** Middle ear effusion (n=31 ears)
- **Group III:** Ossicular chain discontinuity (n=25 ears)
- **Group IV:** Otosclerosis (n=24 ears)

Measurement Procedures

To minimize variability and ensure consistency, all measurements were conducted in a single session for each participant. Audiological evaluations, including pure tone audiometry and WBT, were performed in a soundproof room compliant with the American National Standards Institute standards. The equipment was calibrated according to the manufacturer's instructions before each test session.

Data Management and Ethical Considerations

Data were recorded electronically and securely stored to protect participant confidentiality and to comply with data protection regulations. This study was approved by Ankara University Clinical Research Ethics Committee (decision no: 09-710-19, date: 13.05.2019). and written informed consent was obtained from all participants. The study was conducted in accordance with the Declaration of Helsinki and Good Clinical Practice guidelines.

Audiological Evaluation

Pure-tone Audiometry

Pure-tone audiometry was performed to determine air- and bone-conduction thresholds using the Interacoustics AC-40 audiometer. Air-conduction thresholds were measured at frequencies of 0.25, 0.5, 1, 2, 4, 6, and 8 kHz, while bone-conduction thresholds were assessed at 0.25, 0.5, 1, 2, and 4 kHz. Pure-tone thresholds for both air and bone conduction were obtained using the modified Hughson-Westlake procedure (16).

Criteria for The Diagnosis of Conductive Hearing Loss

Conductive hearing loss was diagnosed if an ABG of 10 dB or more was present at least 3 out of 5 frequencies tested (0.25, 0.5, 1, 2, and 4 kHz) (17).

Classification of ABG Amounts

The audiograms were classified into two categories based on the amount of ABG delivered at each frequency:

- **Less-ABG audiogram:** An average ABG of ≤25 dB at least 3 frequencies among 0.25, 0.5, 1, 2, and 4 kHz.

- **More-ABG audiogram:** The average ABG of ≥26 dB at the same frequencies (18).

WBT Test

WBT absorbance tests were conducted bilaterally using the Interacoustics Titan 3.5 system with the Version 3.7 Research Module (Interacoustics A/S, Denmark). Absorbance measurements were performed using a click stimulus at ambient pressure over the frequency range 226-8000 Hz. The stimulus had a duration of 2 ms, and measurements were taken at 107 frequency points with a resolution of 21.5 Hz. The intensity level was set at 94-dB peak equivalent SPL (peSPL).

The tests were conducted in a quiet room using a sealing probe to occlude the external ear canal. Participants were instructed to avoid activities such as swallowing, coughing, yawning, or talking during the test to prevent artifacts.

Statistical Analysis

Statistical analyses were performed using IBM SPSS 22.0 (SPSS Inc., Chicago, IL, USA). The normality of the numerical data was assessed using the Shapiro-Wilk test. Normally distributed variables were expressed as mean ± standard deviation, non-normally distributed variables were expressed as min-max, and categorical variables were presented as frequency (percentage).

For group comparisons, the Mann-Whitney U test was used for two groups, while the Kruskal-Wallis test and Dunn's post-hoc test with Bonferroni correction were used for three or more groups. Relationships between categorical variables were assessed using the Pearson Chi-square test or Fisher's exact test, depending on the sample size.

Correlations between ABG and WBA at various frequencies were evaluated using Pearson's or Spearman's correlations, depending on normality, with the results expressed as correlation coefficients (r) and 95% confidence intervals. Multiple regression analysis was used to analyze the ABG-WBA relationships while adjusting for confounding factors (e.g., age, pathology type, ear laterality), with interaction terms used to explore frequency-dependent effects. Statistical significance was set at p<0.05.

RESULTS

Participant Demographics

A total of 78 participants (107 ears) were included in the study, consisting of 51 females (68.38%) and 27 males (31.62%), with a mean age of 38.24±12.6 years (Table 1). Participants were distributed across the following four pathology groups: Tympanic membrane perforation (Group I), middle ear effusion (Group II), ossicular chain discontinuity (Group III), and otosclerosis (Group IV). No significant differences in age, gender, or ear laterality distribution were noted between the groups (p>0.05).

ABG Findings

The ABG was assessed at five frequencies (0.25, 0.5, 1, 2, and 4 kHz), and the trends were as follows:

- Group-specific findings:
- Group I (tympanic membrane perforation): The highest ABG was 0.25 kHz for both ears, with mean values of 30±9.4 dB in the right ear and 25.71±6.7 dB in the left ear.
- Group II (middle ear effusion): Similarly, the highest ABG was at 0.25 kHz (29.66±14.2 dB for the right ear and 29.58±12.3 dB for the left ear).
- Group III (ossicular chain discontinuity): Peak ABG occurred at 0.5 kHz, with values of 26.36±9.5 dB and 26.42±11.8 dB for the right and left ears, respectively.
- Group IV (Otosclerosis): ABG peaked at 0.5 kHz (30±11.9 dB for the right ear and 30.83±11.4 dB for the left ear; Table 2).
- **Frequency-specific trends:** Across all groups, ABG values decreased with increasing frequency, reaching their lowest values at 4 kHz.

• Gender and laterality comparisons:

- Female participants generally exhibited lower ABG values in the right ear than male participants, but the difference was not statistically significant (p>0.05).
- No significant differences in ABG were observed between the right and left ears in any group (p>0.05; Table 3).

Wideband Absorption (WBA) Findings

The WBA was measured across five frequencies, and the trends are summarized in Table 4:

• General trends:

- The absorbance was lowest at 0.25 kHz and highest at 2 kHz across all groups, consistent with known audiological patterns.
- Significant group differences were identified at 0.25 and 4 kHz (Kruskal-Wallis p<0.05).
- The post hoc analysis revealed that
- Middle ear effusion (Group II) had a significantly lower absorbance at 0.25 kHz than the other groups (p=0.022).
- Otosclerosis (Group IV) had a higher absorbance at 0.25 kHz than tympanic membrane perforation (Group I; p=0.048).
- Pathology-specific patterns:
- Tympanic membrane perforation and middle ear effusion show reduced absorbance at lower frequencies, reflecting impaired sound energy transfer.

Table 1. Gender and age distribution according to the groups

Groups	Age range	Mean ± SD	n		
			Male	Female	Total
Group I	18-61	38±11.2	10	11	21
Group II	19-65	37.5±14.4	9	12	21
Group III	21-47	33.1±8.9	4	14	18
Group IV	23-65	44.5±12.6	4	14	18
Total	18-65	38.24±12.6	27	51	78

SD: standard deviation

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Table 2. ABG values categorized according to pathology type, frequency, and ear laterality

Frequency	Group I		Group II		Group III		Group IV	
	Right ear mean ± SD	Left ear mean ± SD	Right ear mean ± SD	Left ear mean ± SD	Right ear mean ± SD	Left ear mean ± SD	Right ear mean ± SD	Left ear mean ± SD
250 Hz	30±9.4	25.71±6.7	29.66±14.2	29.58±12.3	25±9.4	25.71±12	28.88±11.9	29.16±12
500 Hz	22.72±9	20.71±7.8	28±13.3	24.58±13.3	26.36±.9.5	26.42±11.8	30±11.9	30.83±11.4
1000 Hz	23.63±11.6	17.14±9.9	28±9.9	25.41±10.5	24.5±11.5	26.42±11.8	27.22±13.7	28.33±8.7
2000 Hz	19.09±10.6	12.14±3.9	20±13.7	18.75±11.1	22.72±10.5	24.28±10.1	17.22±11.2	15.83±6.6
4000 Hz	23.63±10.7	18.57±5.5	23.33±12.3	22.5±12.1	24.09±11.3	25.42±8	23.88±13.6	20±9.4

SD: standard deviation

Table 3. ABG groups based on sex and laterality

		Left ear		Right ear	
		n	%	n	%
Female	Less ABG	21	56.8	9	32.1
	More ABG	16	43.2	19	67.9
	Total	37	100	28	100
Male	Less ABG	11	45.8	12	66.7
	More ABG	13	54.2	6	33.3
	Total	24	100	18	100

ABG: air-bone gap

- Otosclerosis exhibited higher absorbance at low frequencies, likely due to increased middle ear stiffness.

Correlation Between ABG and WBA

The relationships between ABG and WBA were evaluated for all pathologies:

- **Middle ear effusion (Group II):**
- A significant negative correlation was observed between ABG and WBA at 0.25 kHz in the right ear (r=-0.570, p=0.022), suggesting reduced absorbance with increasing ABG. This is illustrated in Figure 1.
- **Otosclerosis (Group IV):**
- A positive correlation was noted at 0.25 kHz in the right ear (r=0.570, p=0.048), indicating that increased stiffness may enhance absorbance.
- **Across All Groups:**
- At 4 kHz, a significant negative correlation (r=-0.270, p=0.034) was observed in the left ear, suggesting that greater ABG values were associated with lower absorbance. This is illustrated in Figure 2.
- No statistically significant correlations were identified at other frequencies (p>0.05).

Multiple Regression Analysis

Multiple regression analysis was performed to assess the independent relationship between ABG and WBA. Age, sex, pathology type, and laterality were included as confounders based on theoretical and empirical evidence suggesting their influence on WBA. After verifying the model assumptions (linearity, independence, homoscedasticity, and absence of multicollinearity), the analysis showed that ABG was a significant predictor of WBA at 0.25 kHz (β=0.35, p=0.002) and 4 kHz (β=0.30, p=0.007). Interaction effects indicated that the strength of the ABG-WBA relationship varied according to pathology, with the strongest association observed in middle ear effusion at 0.25 kHz.

DISCUSSION

This study investigated the relationship between mean ABG and WBT absorbance values in patients with different middle ear pathologies. The findings indicate that the relationship between ABG and absorbance varies significantly depending on the specific pathology and the frequency measured, providing valuable insights into the diagnostic potential of WBT absorbance in clinical evaluations.

Key Findings and Their Interpretation

In the middle ear effusion group, a significant negative correlation was observed between ABG and absorbance at 0.25 kHz in the right ear (r=-0.570, p=0.022). This finding suggests that as the severity of middle ear effusion increases (reflected by higher ABG), the sound energy absorbance decreases, consistent with the presence of fluid in the middle ear cavity, which reduces sound transmission. This finding is consistent with previous studies that demonstrated an increase in energy reflectance in ears with middle ear effusion, particularly at lower frequencies (19,20).

In contrast, the otosclerosis group exhibited a significant positive correlation at 0.25 kHz in the right ear (r=0.570, p=0.048). This relationship indicates that increased stiffness in the middle ear system due to otosclerosis enhances sound absorbance at specific frequencies. This finding is consistent with studies by Shahnaz et al. (21) and Shahnaz and Davies. (22), which reported significantly higher energy reflectance in otosclerotic ears, particularly at low frequencies. These patterns suggest that otosclerosis induces stiffness-related changes in sound energy transfer, making WBT a useful tool for identifying such mechanical changes.

Additionally, a significant negative correlation was observed across all participants between ABG and absorbance at 4 kHz in the left ear (r=-0.270, p=0.034). This finding suggests that the ability of the middle ear to absorb sound energy diminishes with ABG levels at

Table 4. Distribution of absorbance values among the groups

Right ear						Left ear				
	Frequency	n	Mean ± SD	Min.	Max.	Frequency	n	Mean ± SD	Min.	Max.
Group I	250 Hz	7	0.216±0.25	0.043	0.775	250 Hz	11	0.107±0.07	0.04	0.25
	500 Hz	7	0.371±0.25	0.075	0.745	500 Hz	11	0.258±0.15	0.07	0.55
	1000 Hz	7	0.520±0.23	0.196	0.85	1000 Hz	11	0.526±0.23	0.21	0.86
	2000 Hz	7	0.608±0.18	0.311	0.854	2000 Hz	11	0.630±0.17	0.32	0.95
	4000 Hz	7	0.501±0.14	0.256	0.63	4000 Hz	11	0.420±0.20	0.11	0.78
Group II	250 Hz	12	0.089±0.06	0.019	0.255	250 Hz	15	0.089±0.05	0	0.23
	500 Hz	12	0.176±0.10	0.062	0.4	500 Hz	15	0.210±0.08	0.01	0.35
	1000 Hz	12	0.445±0.24	0.167	0.857	1000 Hz	15	0.540±0.22	0.01	0.96
	2000 Hz	12	0.731±0.10	0.562	0.903	2000 Hz	15	0.601±0.27	0.06	0.96
	4000 Hz	12	0.446±0.12	0.281	0.602	4000 Hz	15	0.416±0.18	0.04	0.61
Group III	250 Hz	7	0.140±0.09	0.021	0.293	250 Hz	11	0.194±0.16	0.02	0.57
	500 Hz	7	0.324±0.31	0.03	0.947	500 Hz	11	0.424±0.28	0.06	0.79
	1000 Hz	7	0.463±0.27	0.165	0.978	1000 Hz	11	0.625±0.27	0.12	0.97
	2000 Hz	7	0.671±0.11	0.478	0.79	2000 Hz	11	0.689±0.16	0.36	0.94
	4000 Hz	7	0.593±0.22	0.357	0.943	4000 Hz	11	0.474±0.17	0.19	0.69
Group IV	250 Hz	6	0.140±0.09	0.021	0.293	250 Hz	9	0.125±0.11	0	0.37
	500 Hz	6	0.324±0.31	0.03	0.947	500 Hz	9	0.256±0.22	0.07	0.72
	1000 Hz	6	0.463±0.27	0.165	0.978	1000 Hz	9	0.596±0.24	0.26	0.87
	2000 Hz	6	0.671±0.11	0.478	0.79	2000 Hz	9	0.664±0.12	0.39	0.87
	4000 Hz	6	0.593±0.22	0.357	0.943	4000 Hz	9	0.512±0.14	0.07	0.54

SD: standard deviation, min.: minimum, max.: maximum

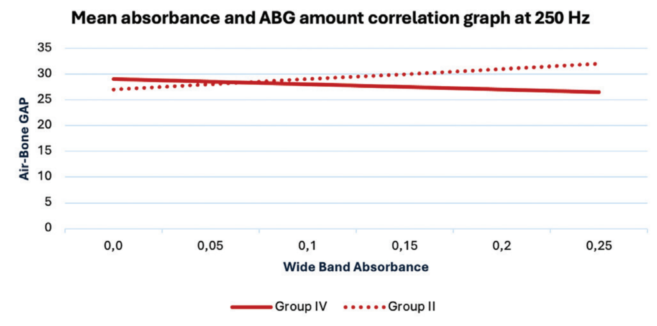

Figure 1. Scatter plot of ABG and absorbance correlation in the middle ear effusion group (0.25 kHz, right ear)
ABG: air-bone gap

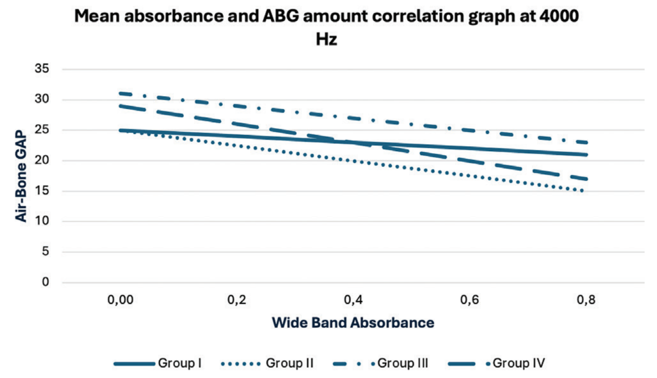

Figure 2. Scatter plot of ABG and absorbance correlation across all participants (4 kHz, left ear)
ABG: air-bone gap

higher frequencies. This result extends previous research that has predominantly focused on low-frequency changes in absorbance (23,24).

Consistency with Literature

The ABG values measured in this study for various middle ear pathologies were consistent with previously published values. Tympanic membrane perforation exhibited mean ABG values of 30.5 dB in the right ear and 25.5 dB in the left ear, consistent with the findings of Anthony and Harrison. (25). Similarly, the middle ear effusion group had an average ABG of 29 dB, which is consistent with the results reported by Dempster and Swan (26). The ABG values for ossicular chain discontinuity (mean: 25 dB) and otosclerosis (mean: 28 dB for the right ear and 29 dB for the left ear) were comparable to those reported by Ayache et al. (27).

The absorbance patterns identified in the tympanic membrane perforation and middle ear effusion groups were also consistent with the literature. Previous studies have demonstrated that low-frequency sound transmission decreases with increasing tympanic membrane perforation size (20,28,29). In our study, absorbance at

0.25 and 0.5 kHz was lower in the perforation group than in normal ear values but remained higher than at other frequencies. Similarly, the reduction in absorbance observed at frequencies below 1 kHz in the middle ear effusion group aligns with the findings of Feeney et al. (19) and Voss et al. (20), who demonstrated that middle ear fluid increases energy reflectance at low frequencies.

Interestingly, although ossicular chain discontinuity has been associated with a notch-like reduction in energy reflectance between 0.4 and 0.8 kHz (7,30), no such pattern was observed in this study. This discrepancy may be due to differences in the extent or type of ossicular chain damage among the study populations, warranting further investigation.

In otosclerosis, the reduced absorbance observed at low frequencies (0.25 and 0.5 kHz) aligns with previous findings by Nakajima et al. (31) and Feeney et al. (19), who reported elevated reflectance values at similar frequencies. This reflects the stiffness-dominated mechanics of otosclerotic ears, reinforcing the utility of WBT for detecting such changes.

Clinical Implications

The observed frequency-specific correlations between ABG and absorbance highlight the diagnostic potential of WBT absorbance measurements. Combining ABG and WBT in clinical practice may enhance the diagnostic accuracy of middle ear pathologies and provide additional insights into their severity. For instance, middle ear effusion and otosclerosis exhibit distinct absorbance trends that can guide preoperative evaluation and surgical planning.

Moreover, the universal reduction in absorbance at 4 kHz across all pathologies suggests that this frequency may serve as a general indicator of the severity of conductive hearing loss. While traditional audiometry remains the standard for evaluating hearing thresholds, WBT absorbance offers complementary information by characterizing the biomechanical properties of the middle ear.

Limitations and Future Directions of this Study

A limitation of this study was the lack of stratification by pathological severity or specific anatomical characteristics, such as the size or location of tympanic membrane perforations or the extent of ossicular damage. Future research should consider these factors to provide more detailed insights into the relationship between ABG and absorbance.

Additionally, the sample size in some pathology groups, particularly ossicular chain discontinuity, was relatively small, which may have limited statistical power. Larger studies with broader pathological representations are needed to validate these findings. Future research could also explore the application of WBT absorbance in mixed or sensorineural hearing loss to assess its diagnostic potential.

CONCLUSIONS

The observed frequency-specific correlations between ABG and absorbance highlight the diagnostic potential of WBT absorbance measurements. Combining ABG and WBT in clinical practice may enhance the diagnostic accuracy of middle ear pathologies and provide additional insights into their severity. For instance, middle ear effusion and otosclerosis exhibit distinct absorbance trends that can guide preoperative evaluation and surgical planning.

Moreover, the universal reduction in absorbance at 4 kHz across all pathologies suggests that this frequency may serve as a general indicator of the severity of conductive hearing loss. While traditional audiometry remains the standard for evaluating hearing thresholds, WBT absorbance offers complementary information by characterizing the biomechanical properties of the middle ear.

Ethics

Ethics Committee Approval: This study was approved by Ankara University Clinical Research Ethics Committee (decision no: 09-710-19, date: 13.05.2019).

Informed Consent: Written informed consent was obtained from all participants.

Footnotes

Author Contributions: Surgical and Medical Practices - M.A.; Concept - M.A.; E.O.; S.T. Y.; Design - M.A.; E.O.; S.T. Y.; Data Collection and/or Processing - M.A.; E.O.; S.T. Y.; Analysis and/or Interpretation - M.A.; E.O.; S.T. Y.; Literature Search - M.A.; Writing - M.A.

Conflict of Interest: The authors have no conflict of interest to declare.

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