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The Usefulness of Wideband Absorbance in the Diagnosis of Otosclerosis

Abstract

Objective

To compare wideband absorbance (WBA) patterns between ears with otosclerosis and normal hearing ears and to investigate if WBA findings could be useful in the diagnosis of otosclerosis.

Design

WBA was obtained at 107 frequency samples ranging from 0.226 to 8 kHz (24 per octave). A T-test was performed to compare between WBA in ears with otosclerosis and in normal hearing ears. The ability of WBA to discriminate between the patients with otosclerosis from the normal hearing participants was tested with a receiver operating characteristics (ROC) curve analysis.

Study sample

Thirty-five patients with otosclerosis and thirty-five normal hearing volunteers.

Results

In frequency range 0.432-1.059 kHz, mean WBA in otosclerosis was significantly lower than mean WBA in normal hearing ears and in frequency range 4.238-8 kHz mean WBA in otosclerosis was significantly higher than mean WBA in normal hearing ears. The ROC analysis revealed that ears with otosclerosis and normal hearing ears could be distinguished based on mean WBA in frequency range >0.5≤1 kHz (AUC=0.673) and based on mean WBA in frequency range >4≤8 kHz (AUC=0.769).

Conclusion

Our findings suggest that WBA in ears with otosclerosis differ from WBA findings in normal hearing ears.

Keywords: Otosclerosis; Wideband absorbance; Energy absorbance; Wideband reflectance.

Introduction

Otosclerosis is a middle ear disorder characterized by bone sclerosis and the immobilization of the stapes. It is the most common cause of conductive hearing loss in Caucasion adults (Chen et al., 2002). Preoperatively, the diagnosis is presumed based on a normal otoscopy finding, conductive hearing loss in pure tone audiometry, type A standard tympanogram and absent cochleostapedial reflex (Probst, 2007). However, the same findings can be found in some cases of ossicular chain discontinuity (OCD) which cannot be differentiated from otosclerosis based on a standard diagnostic procedure and the diagnosis is definitely confirmed during the surgery (Fujino et al., 2007). According to previous studies, Wideband Acoustic Immittance (WAI) measures seem to have potential as an uninvasive acoustic test which could improve the diagnosis of otosclerosis (Shahnaz et al., 2009). These measures are used to assess middle ear transfer function with wideband stimuli that cover broad frequency range (Feeney et al., 2017). The results of WAI measures are usually expressed in terms of wideband reflectance (WBR) or wideband absorbance (WBA) (Aithal, Kei & Driscoll, 2014). WBR represents an estimate of the ratio of energy reflected from the tympanic membrane to the incident energy presented in the ear canal. WBA was introduced later and represents the part of the incident energy that is absorbed by middle ear. WBA and WBR both range from 0 to 1 and are related by equation $WBA=1-WBR$. The pattern of WBA change across frequency range is similar to a traditional single frequency pattern, which makes it more familiar to a clinician and contributes to the simplicity of interpretation (Liu et al., 2008). In order to simplify the comparison of different studies, in further text only WBA will be used, i.e. the results of the studies in which WBR was originally used will be transferred to WBA according to the formula above.

The area of normal WBA values across frequency range for adults and children has been reported (Keefe et al., 1993; Liu et al., 2008; Rosowski et al., 2012). Also, the characteristics of WBA patterns distinctive of different middle ear disorders have been described suggesting that WBA can provide important information about middle ear function and improve differential diagnosis in conductive hearing loss (Feeney, Grant & Marryott, 2003; Feeney, Grant & Mills, 2009; Nakajima et al., 2012; Keefe et al., 2012; Sanford & Brockett, 2014; Hunter at al., 2017).

Data regarding WBA in otosclerosis are still insufficient. According to previous research, ears with otosclerosis seem to have lower WBA in low frequency range in comparison to normal hearing ears (Shahnaz et al., 2009). However, some studies reported only a few cases of WBA findings in ears with otosclerosis. For example, Feeney et al. (2003) reported reduced WBA at frequencies below 1 kHz in two otosclerotic ears and Allen et al. (2005) described similar findings in one subject with bilateral otosclerosis. Shahnaz et al. (2009) compared differences between WBA in twenty-eight otosclerotic and sixty-two normal hearing ears. In this study WBA in otosclerosis was statistically lower between 0.4 and 1 kHz than WBA in normal hearing ears and WBA in all ears with otosclerosis fell outside the 10^{th} or 90^{th} percentile of WBA in normal hearing ears at least at one frequency. However, the pattern of WBA was not consistent among the ears with otosclerosis making results difficult to interpret and limiting its implication in clinical practice. In this study, the control group and the tested group were not comparable according to age (the average age of the control group was significantly lower than the average age of the tested group) and gender which could influence the results according to some studies (Feeney et al., 2014; Mazlan et al., 2015). Also, in this study, WBA values at frequencies between 6 kHz and 8 kHz were not included since the measurements of WBA were obtained at frequencies up to 6 kHz.

In our study, we aimed at investigating if WBA values at ambient pressure in frequency range between 0.226 and 8 kHz could be used to differentiate between ears with otosclerosis and normal hearing ears and to determine the frequency range at which possible differences between the ears with otosclerosis and normal hearing ears are the most evident.

Materials and Methods

Participants

A prospective longitudinal study was conducted between June 2017 and May 2018 in Clinical Hospital Center Sisters of Charity in Zagreb. After obtaining ethical approval from the Hospital Ethical Committee thirty-five patients with otosclerosis and thirty-five normal hearing volunteers were included in the study. The experimental group consisted of thirty-five patients with otosclerosis without previous ear surgery on the affected ear. Otosclerosis was diagnosed based on normal otoscopy finding, mixed or conductive hearing loss, type A tympanogram and absent cochleostapedial reflex. Patients were admitted to Clinical Hospital Center Sisters of Charity in Zagreb to be operated. Of these thirty-five patients, twenty-three had bilateral otosclerosis. In all patients, only the measurements on operated ear were included. The control group was formed afterwards. This group consisted of thirty-five normal hearing volunteers, whose age and sex were comparable with those of the tested group without the history of hearing problems, middle ear disease or previous ear surgery. The participants of both groups were all Caucasians. All participants of the control group had normal hearing (defined as pure-tone audiometric thresholds of 25 dB or better for all tested frequencies (Shahnaz et al., 2009) and no air-bone gap at any frequency), normal otoscopy finding, type A tympanogram and present cochleostapedial reflex on both ears. In each normal hearing subject only one ear was included which was decided by the toss of a coin (Rosenkranz, 2011).

Procedure

In all patients with otosclerosis, otoscopy and pure-tone audiometry were repeated the day before the surgery, followed by standard 226 Hz tympanometry, cochleostapedial reflex and WBA. Otosclerosis was confirmed during the surgery when stapedotomy was performed and

four weeks after the operation pure tone audiometry showed improvement in hearing in all patients. For the control group otoscopy, pure-tone audiometry, standard 226 Hz tympanometry, cochleostapedial reflex and WBA were performed in the same order as in the tested group.

Interacoustics audiometer (AC40) with headphones was used for pure tone audiometry. Air conduction was tested at frequencies 0.125 kHz, 0.250 kHz, 0.5 kHz, 1 kHz, 2 kHz, 3 kHz, 4 kHz, 6 kHz and 8 kHz. A subset of these frequencies up to 4 kHz was used to test bone conduction. Standard one frequency tympanometry, cochleostapedial reflex and WBA measurements were conducted using a Titan test platform (Interacoustics, Denmark), version 3.1 with IMP440 impedance system that operates in 0.226-8 kHz range, 100 dB sound pressure stimulus was applied. Cochleostapedial reflex was tested for both ipsilateral and contralateral stimulation at frequencies 0.5 kHz, 1 kHz ,2 kHz and 4 kHz. Numerical data for WBA were extracted as an Excel file in which WBA at ambient pressure was obtained at 107 frequency samples (24 per octave) ranging from 0.226 kHz to 8 kHz.

Statistical analysis

To compare WBA between the ears with otosclerosis and normal hearing ears, a t-test was performed for each of 107 frequency samples obtained at ambient pressure. Also, the 10^{th} and 90^{th} percentile of WBA values in normal hearing ears were calculated and compared with WBA values in ears with otosclerosis. In order to summarize the results, we averaged the WBA over octave bands grouping frequencies in five ranges ($\geq 0.226 \leq 0.5$ kHz, $>0.5 \leq 1$ kHz, $>1 \leq 2$ kHz, $>2 \leq 4$ kHz, $>4 \leq 8$ kHz). For each of these ranges we performed a t-test to compare the average WBA between the ears with otosclerosis and normal hearing ears. The ability of WBA to discriminate between patients with otosclerosis from normal hearing participants was tested with a receiver operating characteristics (ROC) curve analysis. The

ROC is a probability curve used to assess the accuracy of a diagnostic test and the area under the curve (AUC) represents the measure of diagnostic accuracy i.e. AUC tells us how much the test under study is capable of distinguishing between the two groups. Higher AUC is connected with better distinguishing between the two groups while AUC of 0.5 indicates that the test does not have the abillity to distinguish between the two groups (Hosmer & Lemeshow, 2000).

Peak frequency (PF) and median frequency (MF) were calculated for each participant of both otosclerotic and the control group. PF was defined as a frequency at which WBA reached the maximum value. MF was defined as a frequency at which 50% of cumulative WBA is achieved at frequencies below it and 50% is achieved at frequencies above it, e.g. MF is a value at which the area under the WBA plot is divided into two equal parts.

Data were presented as mean ± SD and analyzed using Student's t-test. For the comparison of categorical data, Chi Square test was used. All the tests were two-sided and $P<0.05$ was considered statistically significant. The ROC curve analysis was expressed as an area under the curve (AUC) with 95% confidence intervals and used to determine the efficacy of WBA to discriminate between ears with otosclerosis and normal hearing ears.

Results

Demographic data are given in Table 1. In the group of patients with otosclerosis there were 27 (77%) female and 8 (23%) male patients while the control group consisted of 25 (71%) females and 10 males (29%). There was no significant difference in age (49.6 ± 9.46, 46.23 ±9.47, Student's t-test, P=0.141) and sex (P=0.784, Chi-Square Test) between the groups. Pure tone audiometry in ears with otosclerosis revealed the greatest air-bone gap at frequencies 0.25 and 0.5 kHz (Table 2).

When comparing WBA between the ears with otosclerosis and normal hearing ears at each of 107 frequency samples (24 per octave ranging from 0.226 kHz to 8 kHz), statistically significant difference was found in frequency ranges 0.432 -1.059 kHz and 4.238-8 kHz (Figure 1). WBA in ears with otosclerosis was lower than WBA in normal hearing ears at all tested frequencies ranging from 0.432 kHz to 1.059 kHz. In frequency range 4.238-8 kHz WBA in ears with otosclerosis was higher in comparison to WBA in normal hearing ears at all tested frequencies (Figure 1). The values of WBA in the 10^{th} -90^{th} percentile range in normal hearing ears and WBA for each of the ears with otosclerosis are shown in Figure 2. Most of the ears with otosclerosis (34 of 35) had WBA outside the 10^{th}-90^{th} percentile range of WBA values in normal hearing ears in some frequency range but there was one ear with otosclerosis that had WBA between the 10^{th} and 90^{th} percentile of normal hearing ears at all tested frequencies. In order to summarize the results, we averaged WBA over octave bands grouping frequencies in five ranges (≥0.226≤0.5 kHz, >0.5≤1 kHz,>1≤2 kHz, >2≤4 kHz, >4≤8 kHz). For each of these ranges we compared mean WBA between the otosclerotic and the control group. Statistically significant difference was observed in ranges >0.5≤1 kHz and >4≤8 kHz (Table 3). We evaluated the ability of WBA in ranges >0.5≤1 kHz and >4≤8 kHz to discriminate between the patients with otosclerosis from normal hearing participants by

the ROC curve analysis. The two groups could be distinguished based on WBA in frequency range >0.5≤1 kHz (AUC=0.673, 95% CI 0.550 to 0.780, P=0.007) and based on WBA in frequency range >4≤8 kHz (AUC=0.769, 95% CI 0.653–0.861, P<0.001) (Figure 3). In frequency range >0.5≤1 kHz with cut-off point of ≤ 0.46, sensitivity of 45.7% and specificity of 85.7% were found while in frequency range >4≤8 kHz, with a cut-off point of >0.27, sensitivity of 65.71% and specificity of 88.57% were achieved.

In the otosclerotic group PF ranged between 0.707 and 6.727 kHz (average 2.340 kHz) and in the control group it was between 0.707 and 3.267 kHz (average 1.969 kHz). MF was found between 1.414 and 2.828 kHz (average 1.819 kHz) in otosclerosis and between 0.944 and 2 kHz (average 1.533 kHz) in the control group (Table 4).

Discussion

WBA is expected to improve a differential diagnosis of middle ear disorders, but its possibilities have not yet been completely investigated (Feeney et al., 2013). Previous studies suggested possibile usefulness of WBA in the diagnosis of otosclerosis. However, WBA measurements provide us with a huge amount of data and it is still not clear which of these data are the most important in differentiating otosclerotic from normal hearing ears (Shahnaz et al., 2009; Keefe et al., 2017). In our study a significant difference between WBA in normal hearing ears and WBA in ears with otosclerosis was found in frequency range >0.5≤1 kHz with lower WBA in ears with otosclerosis and in frequency range >4≤8 kHz with higher WBA in ears with otosclerosis (Table 3). Lower WBA in otosclerosis at frequencies below 1 kHz is comparable to the results of previous studies. Shahnaz et al. (2009) reported WBA in otosclerosis to be significantly lower between 0.4 and 1 kHz. This was also observed by Nakajima et al. (2012) in a study with 14 otosclerotic ears. Keefe at al. (2017) described otosclerotic ears to have lower mean WBA at frequencies below 1 kHz but this difference was not statistically significant. In their study, a statistically significant difference was found at 4 kHz. Reduced WBA at low frequencies in otosclerosis could be explained by increased stiffness of the middle ear conduction system caused by the immobilization of the stapes. Stiffness mostly affects low frequencies whereas higher frequencies are more affected by mass. This influence can also be seen in pure tone audiometry with hearing loss caused by otosclerosis, which is usually the most evident at lower frequencies (Allen et al., 2005; Voss et al., 2012; Tabuchi et al.,2005).

However, in our study the difference between WBA in otosclerosis and WBA in normal hearing ears was more obvious at high frequencies with mean WBA higher in ears with otosclerosis than in normal hearing ears (Table 3). The ability of WBA to discriminate

between ears with otosclerosis and normal hearing ears was tested with the ROC analysis with AUC as a measure of diagnostic accuracy. In frequency range >0.5≤1 kHz, AUC of 0.673 was found (95% CI 0.550 to 0.780, P=0.007). With a cut-off point of ≤ 0.46, sensitivity of 45.7% and specificity of 85.7% were found. AUC different than 0.5 in the ROC curve analysis suggests possible usefulness of WBA in this frequency range, however, it must be taken into consideration that sensitivity for otosclerotic ears was very low. According to our resullts, higher AUC was found in frequency range >4≤8 kHz (AUC=0.769, 95% CI 0.653–0.861, P<0.001). In this frequency range, with a cut-off point of >0.27, sensitivity of 65.71% and specificity of 88.57% were achieved (Figure 3). In comparison to our findings, Shahnaz et al. found the largest AUC when looking at WBA values of single frequency at 0.315 and 0.5 kHz. In their study AUC was 0.85 at 0.315 kHz and 0.86 at 0.5 kHz. In Shahnaz study most of the otosclerotic ears (71%) exceeded the 10^{th} percentile below 1 kHz, 10% exceeded the 10^{th} percentile above 1.5 kHz, and 18% exceeded the 90^{th} percentile mainly at frequencies above 1 kHz. Niemczyk at al. (2018) analyzed the shape of WBA plot in otosclerosis and showed that WBA in otosclerotic ears can change across frequency range in five different patterns. One of the types described by Niemczyk (type two) is characterized by a high peak of WBA reaching high values shifted towards a high frequency range. The 18% of ears that exceeded the 90^{th} percentile at frequencies above 1 kHz in Shahnaz study and type two described by Niemczyk suggests possible elevation of WBA in otosclerosis at higher frequencies. Also, Zhang & Gan (2013) used finite model of human ear to investigate WBA findings in normal middle ear and in some middle ear disorders. In a model simulating otosclerosis they found WBA to be lower at frequencies below 2.8 kHz while at frequencies above 3 kHz they found a small increase of WBA in comparison to a model of normal ear. In our study the elevation of WBA at high frequencies seems to be more expressed than described in previous studies since previous reports mostly

emphasized decreased WBA in ears with otosclerosis at low frequencies while our results suggest more obvious difference between normal hearing and ears with otosclerosis at frequencies higher than 4 kHz (Table 3). The tendency of ears with otosclerosis to have lower WBA at low frequencies and higher WBA at higher frequencies in comparison to normal hearing ears, found in our study, is also evident from MF. MF represents the frequency at which 50% of cumulative WBA is achieved at frequencies below it and 50% is achieved at frequencies above it. The average MF was higher in otosclerosis showing that higher proportion of WBA is absorbed at higher frequencies in otosclerosis than in the control group (Table 4). When comparing our results to the results of previous studies we must take into consideration that in some previous reports (Shahnaz et al., 2009; Keefe et al., 2017) the control groups were significantly younger than otosclerotic groups. Feeney and Sanford (2004) described that WBA at high frequencies is decreasing with age. This suggests that difference in age between the control and the tested group could influence the results and that older mean age in the tested group could cause more pronounced reduction of WBA at high frequencies in comparison to the control group. Also, in Shahnaz study values of WBA in freqency range 6-8 kHz were not taken into consideration since WBA was measured only at frequencies up to 6 kHz.

To facilitate the usage of WBA findings in clinical practice, a simple and practical representation of results would be of interest. Some previous studies aimed to identify consistent patterns of WBA that would be a distinct feature of different middle ear disorders suggesting that pictorial representation of the results by a graph showing dependence of WBA on frequency could be useful in distinguishing normal hearing ears and ears with different middle ear pathologies (Feeney et al., 2003; Sanford et al., 2014). Accordingly, the need for determining WBA finding in normal hearing ears to be used as normative values has been recognized. Several studies have reported ranges of normal WBA values for

children and adults (Keefe et al., 1993; Liu et al., 2008; Rosowski et al., 2012). However, statistically significant differences of normal values of WBA depending on sex, age and race have been described suggesting a need for further research in determining normative values of WBA (Feeney et al., 2014; Shahnaz & Bork, 2006; Mazlan et al., 2015; Feeney et al., 2013). Possible utility of age-specific and ethnicity-specific norms has also been suggested (Shahnaz et al., 2013). According to our results, at frequencies 0.226-1 kHz, mean WBA in normal hearing ears was gradually increasing. At frequencies between 1 kHz and 2.6 kHz WBA was the highest (with values ranging between 0.75 and 0.85). Afterwards, mean WBA started to decrease reaching a minimum value of approximately 0.14 at frequencies around 6 kHz. In frequency range 6-8 kHz WBA slightly increased to approximately 0.17 at 8 kHz point (Figure 1). This pattern is comparable to previous reports. Kefee at al. (1993) reported findings on ten adult subjects. In their study, the highest WBA (0.65) was found at 3.2 kHz and the lowest (0.27) was found at 8 kHz. Rosowski et al. (2012) described the results of 29 subjects (58 ears) and found the highest mean WBA (0.6 - 0.7) at frequencies between 1 and 4 kHz. The maximum WBA between 2 and 4 kHz, where the 10^{th} to 90^{th} percentile ranged from 0.5 to 0.9 was found by Liu et al. (2008). According to our results and previous reports, WBA in normal hearing ears seems to be the highest around midfrequency range at which human ear is the most sensitive to sound (Allen et al., 2005).

The pattern of WBA in otosclerosis is described to be similar to the one found in normal ears (Shahnaz et al., 2009; Keefe et al., 2017). This was also shown in our study. According to our results, in both normal hearing ears and the ears with otosclerosis, the highest values of WBA were reached in frequency range 1-2.6 kHz (Figure 1) showing that in this frequency range the most of the energy presented in the ear canal was absorbed by middle ear. Also, previously reported inconsistency of WBA pattern in otosclerosis is evident from our results (Figure 2). According to our findings, 34 of 35 ears with otosclerosis (97%) fell outside the

10^{th}-90^{th} percentile range of WBA in normal hearing ears in certain frequency range but there was one ear with otosclerosis that had WBA between the 10^{th} and 90^{th} percentile of normal hearing ears at all tested frequencies. Most of the ears with otosclerosis (24 of 35, i.e. 69%) exceeded the 90^{th} percentile of WBA in normal hearing ears at frequencies higher than 4 kHz. WBA in 16 (67%) otosclerotic ears was below the 10^{th} percentile of WBA in normal hearing ears at frequencies below 1 kHz. Obviously, some of the otosclerotic ears exceeded both the 10^{th} percentile at lower frequencies and the 90^{th} percentile at higher frequencies. Also, 11 (31%) otosclerotic ears had WBA lower than WBA at the 10^{th} percentile of normal hearing ears at frequencies between 1 kHz and 4 kHz (Figure 2). Inconsistency of WBA pattern in otosclerosis is also confirmed by the fact that one ear with otosclerosis fell outside the observed percentiles only by having WBA below the 10^{th} percentile of WBA in normal hearing ears at frequencies higher than 4 kHz and one ear with otosclerosis that had WBA higher than the 90^{th} percentile of WBA in normal hearing ears only at frequencies lower than 1 kHz. Also, the maximum of WBA was reached at various frequencies (expressed in term of PF) for both otosclerotic and normal hearing ears. However, PF in the otosclerotic group was obtained at much wider range including frequencies from 0.707 kHz up to 6.727 kHz (Table 4).

The overlap between WBA values in ears with otosclerosis and in normal hearing ears in wide range of frequencies, found in the previous reports and our study, as well as variability of WBA findings in ears with otosclerosis complicate the interpretation of the results (Shahnaz et al., 2009; Niemczyk et al., 2018) and suggest a need for further research in order to determine ranges of WBA values that could be found in otosclerosis.

Although this is one of the studies with the biggest number of both otosclerotic and normal hearing ears, there are still some limitations and our findings should be taken cautiously.

First, as already mentioned, there is a lot of deviation of WBA measurements in both groups. Second, while a decrease of WBA in low frequencies can be explained by increased stiffness of the middle ear that is expected to be found in otosclerosis, we are not able to provide an explanation for mechanisam of increased WBA in otosclerotic ears in high frequency range. However, a recent study (Wang et al., 2019) reported similar results which support our findings. Further investigation should perhaps be focused on defining ranges of WBA values of both normal and otosclerotic ears in various sex, age and ethnic groups. Also, studies are warranted to provide a precise explanation of mehanicism of WBA increase at high frequencies.

Conclusion

We found ears with otosclerosis to have lower WBA in frequency range 0.432 kHz–1.059 kHz and higher WBA in frequency range 4.238 kHz–8 kHz than normal hearing ears. The ROC analysis revealed that ears with otosclerosis and normal hearing ears could be distinguished based on mean WBA in frequency range >0.5≤1 kHz, although with relatively low AUC (AUC=0.673, 95% CI 0.550 to 0.780, P=0.007) and based on mean WBA at frequencies >4≤8 kHz (AUC=0.769, 95% CI 0.653–0.861, P<0.001). In comparison to the findings of previous studies, the importance of WBA values at high frequencies in discriminating between the ears with otosclerosis and normal hearing ears seems to be more expressed according to our results. Our results suggest that WBA findings could be useful in the diagnosis of otosclerosis, but further researches are needed.

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Authors declare no conflict of interest.

Data availability statement:

The data that support the findings of this study are available on request from the corresponding author (IK).

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Table 1. Demographic data

Characteristic	Controls (N=35)	Otosclerosis (N=35)	*P*- value
Age (years)[a]	46.23 ± 9.47	49.6 ± 9.46	0.141
Sex (N%) [b]			
males	10 (28.6%)	8 (22.9%)	0.784
females	25 (71.4%)	27 (77.1%)	
Ear (N%) [b]			
right	16 (45.7%)	18(51.4%)	0.811
left	19 (54.3%)	17(48.6%)	

[a] data presented as mean ± standard deviation, statistical comparison performed by Student t test

[b] groups compared by Chi Square test

Table 2. Pure tone audiometry results for ears with otosclerosis

	0.25 kHz	0.5 kHz	1 kHz	2 kHz	4 kHz	8 kHz
Air conduction (dB)	62.14 ± 12.26	61.57 ± 14.03	58.43 ± 15.42	57.29 ± 20.34	59.14 ± 22.8	65.29 ± 24.97
Air- bone gap (dB)	47.29 ± 10.1	36.86 ± 10.44	29.43 ± 12.29	16.86 ± 9.93	22.57 ± 12.97	

Data presented as mean ± standard deviation

Table 3.

Avarege energy absorbance grouped in five frequency ranges for normal hearing ears and ears with otosclerosis

Frequency range	Controls Average WBA ± SD	Otosclerosis Average WBA ± SD	P- value
≤0.5 kHz	0.252 ± 0.11	0.204 ± 0.106	0.072
>0.5≤1 kHz	0.617 ± 0.147	0.496 ± 0.189	0.004
>1≤2 kHz	0.774 ± 0.119	0.736 ± 0.16	0.255
>2≤4 kHz	0.636 ± 0.196	0.664 ± 0.147	0.493
>4≤8 kHz	0.187 ± 0.1	0.337 ± 0.171	<0.001

WBA: wideband absorbance, SD: standard deviation

P- value was calculated by Student t test

Table 4.

Comparison of peak and median frequency for the control group and otosclerosis

	Control group (average and range)	Otosclerosis (average and range)
PF	1969 (707 -3267) Hz	2340 (707-6727) Hz
MF	1533 (944-2000) Hz	1819 (1414-2828) Hz

PF: peak frequency (frequency at which WBA was the highest)

MF: median frequency (frequency at which 50% of cumulative WBA is achieved on frequencies below it and 50% is achieved on frequencies above it)

Figure 1.

Mean WBA of normal hearing (full line) and otosclerotic ears (broken line). Grey area represents frequency ranges in which differences between WBA in otosclerotic and in normal hearing ears were statistically significant.

Figure 2.

Full lines represent the 10^{th} and the 90^{th} percentile of mean WBA in normal hearing ears. Broken grey lines show WBA for each otosclerotic ear

Figure 3.

The Receiver operating characteristic (ROC) curves for energy absorbance in ranges >0.5≤1 kHz and >4≤8 kHz. Diagnostic efficacy for those values was assessed using the sensitivity and specificity at a cutoff point.