H.Ü. Sağlık Bilimleri Fakültesi Dergisi
Cilt:8, Sayı:1, 2021
doi: 10.21020/husbfd.858576

Original Research

Examination of Wideband Tympanometry (WBT) Parameters in Individuals with Healthy Middle Ear

Murat Şahin[1], Songül Aksoy [2]

Sub. Date: 12 January 2021 **Acceptance Date:** 19 March 2021 **Early View Date:** 23 April 2021
Pub.Date: 30 April 2021

Abstract

Objective: The aim of this study is to collect the WBT data of healthy middle ears and to examine the age-related changes in WBT results.
Material and Methods: 60 individuals with normal hearing aged 20–49 years were included in the study. Three age groups comprising 20 individuals were formed for each decade. WBT measurements were performed.
Results: There is no statistically significant difference between the groups in terms of WBT values (p>0.05). The WBT results are not age-dependent within the age range of 20–49 years. There is no statistically significant difference between pressurized and nonpressurized absorbance values (p>0.05).
Conclusion: We concluded that there was no difference between pressurized and nonpressurized absorbance values in individuals with a healthy middle ear and the WBT results did not change with age in the 20–49 age range due to the lack of statistical significance. As it provides lot of information with a single measurement, Wideband tympanometry can be safely used in the clinic as a part of an audiological test set. Studies can be conducted to determine the specificity and sensitivity of WBT in adult and pediatric patient groups.

Keywords: *Wideband typmanometry, Absorbance, Middle ear*

[1]**Murat Şahin.** Hacettepe University, Faculty of Health Science, Department of Audiology, Ankara/Turkey, Tel. no: 03123051667,e-mail: muratsahin2013@gmail.com ORCID: 0000-0002-0172-3580.
[2]**Songül Aksoy (Corresponding Author).** Hacettepe University, Faculty of Health Science, Department of Audiology, Ankara/Turkey, Tel.no:03123051667, e-mail: songulaksoy@hotmail.com ORCID: 0000-0003-4584-5528.

*This study is MSc thesis of Murat ŞAHİN and was presented as an oral presentation in Lisbon, 2019.

doi: 10.21020/husbfd.858576

Introduction

Wideband tympanometry (WBT) and Wideband Absorbance (WBA) measurement are practical, low-cost and noninvasive measurement methods that play a significant role in providing objective information about the state of the middle ear for audiological evaluation (Hunter & Shahnaz, 2013) and used to evaluate different middle ear pathologies such as middle-ear dysfunction in infants (Hunter, Feeney, Miller, Jeng, & Bohning, 2010) and otosclerosis (Shahnaz et al., 2009).

Wideband tympanometry uses a click stimulus covering the frequency range of 226 - 8000 Hz. The result of the measurement is a graph called "3-D Tympanogram". In this graph, the X axis presents the pressure values, whereas the Y and Z axis present the absorbance amount of the middle ear and frequency values, respectively. In WBT, the sound reflected from the middle ear is called reflectance and the sound absorbed by the middle ear is called absorbance. The range of these inversely proportional parameters is between 0 and 1. The point where the absorbance reaches its peak, the reflectance ratio becomes minimum (Hunter & Shahnaz, 2013; www.interacoustics.com).

Absorbance Graph

The absorbance graph shows the absorbance amount in the range of 226–8000 Hz. The absorbance graph can be created in two ways: Pressurized and nonpressurized. The pressurized absorbance graph shows the amount of absorption at peak pressure on the 3D tympanogram. The nonpressurized absorbance graph shows the amount of absorption at 0 daPa on the 3D tympanogram. The absorbance graph can also be obtained using Wideband Absorbance (WBA) measurement. In the Wideband absorbance measurement the 3D tympanogram is not plotted because the pressure of the external ear canal is not changed (www.interacoustics.com).

Averaged Wideband Tympanogram (A-WBT)

The plotted 3D tympanogram is a two-dimensional graph that shows the absorbance values in the range of 375–2000 Hz (www.interacoustics.com).

Unlike the conventional tympanometry, the resonant frequency (RF), which is an important parameter for the stiffness of the middle ear (Shanks & Shohet, 2009) can be determined by Wideband tympanometry (www.interacoustics.com).

Studies have shown that ethnicity cause anatomical and physiological differences, thus affects the immitancemetry and WBT results (Shahnaz & Bork, 2006; Shahnaz & Davies, 2006). Therefore, it will be useful to determine the normative data of each clinic to correctly distinguish between normal and pathological conditions.

H.Ü. Sağlık Bilimleri Fakültesi Dergisi
Cilt:8, Sayı:1, 2021
doi: 10.21020/husbfd.858576

In this study, we aimed to collect the data of healthy middle ears with the Titan Wideband Tympanometer, which is recently used in clinics, and to investigate age-dependent changes in WBT findings.

Material and Methods

The Noninvasive Clinical Research Ethics Committee was approved the study protocol. The participants were informed about the scope and procedures of the study. All patients were provided written informed consent before participating the study.

Participants

Overall, 86 adults were assessed in the study. In pure tone audiometry, pure tone threshold was unilaterally above 25 dB HL at 4 kHz in three participants; bilaterally at 6 kHz in six; unilaterally at 8 kHz in one and bilaterally in five, at 6 and 8 kHz in four participants. Six participants had unilateral and one participant had bilateral negative middle ear pressure. A total of 26 participants who did not meet the inclusion criteria were excluded from the study; finally, 60 participants aged 20–49 years were included (120 ears). The tests were for approximately 40 min long. The participants were divided into three groups. Table 1 shows the age and gender distribution of each group.

Table 1. Demographic Data of the Subjects.

				N
Group I	Mean ± SD	23.00 ± 2.89	Female	10 (% 50)
	Age	20-29	Male	10 (% 50)
Group II	Mean ± SD	33.43 ± 2.97	Female	9 (% 45)
	Age	30-39	Male	11 (% 55)
Group III	Mean ± SD	43.63 ± 2.87	Female	8 (% 40)
	Age	40-49	Male	12 (% 60)
Group I + II + III	Mean ± SD	32.31 ± 8.74	Female	27 (% 45)
	Age	20-49	Male	33 (% 55)

The participants whose otoscopic examination findings were normal; who did not have external and middle ear surgery; who had bilaterally 25 dB HL and lower thresholds for the range of 250–8000 Hz; whose air-bone gap was <10 dB HL at 500, 1000, 2000, and 4000 Hz;

and who had ≥3dB emission bilaterally in at least three of the frequency bands of 1000, 1500, 2000, and 4000 Hz in TEOE measurement were included in the study.

Tests and Methods

Pure tone audiometry, OAE, immittancemetry, and WBT measurements were performed in all participants.

Pure tone audiometry

After ENT examination, air conduction hearing thresholds at 250, 500, 1000, 2000, 4000, 6000, and 8000 Hz and bone conduction hearing thresholds at 500, 1000, 2000, and 4000 Hz were determined.

Pure tone audiometry was performed using GSI Audiostar Pro clinical audiometer, TDH 50P supra-aural headphone, and B71 bone vibrator. The airway and bone-conducting pure tone thresholds were determined following the Hughson-Westlake procedure.

OAE measurements

The bilateral TEOAE measurements were performed using the Autodynamics Echoport ILO292 OAE measuring system and recorded with EZ-Screen Software.

WBT measurements

The bilateral WBT measurements of the participants were performed with the Interacoustics Titan Wideband Tympanometer. The measurements were done by using the click stimulus that covers the frequency range of 226–8000 Hz and is given 21.5 Hz rate. WBT results were recorded as Mathematical Input File (M file) in a target folder specified in the protocol created in the Wideband Tympanometer, then copied to the custom Microsoft Office Excel file created by Interacoustics, and the graphics were plotted.

Statistical Method

The statistical analyses were performed using a Windows-based SPSS 20.00 package program. The gender distribution of the groups was compared using Pearson Chi-square test. The normality of the results was determined using Shapiro–Wilk’s test. One-way analysis of variance (ANOVA) was used for the between-group analyses of the normally distributed results, where Kruskal–Wallis test was used for the between-group analyses of the non-normally distributed results.

Results

Pearson Chi-square test revealed no statistically significant difference between the groups in terms of gender distribution.

doi: 10.21020/husbfd.858576

Pressurized and nonpressurized absorbance values and percentage ratios of all participants for the range of 226–8000 Hz (107 frequency points in total) are shown in Figures 1 and 2.

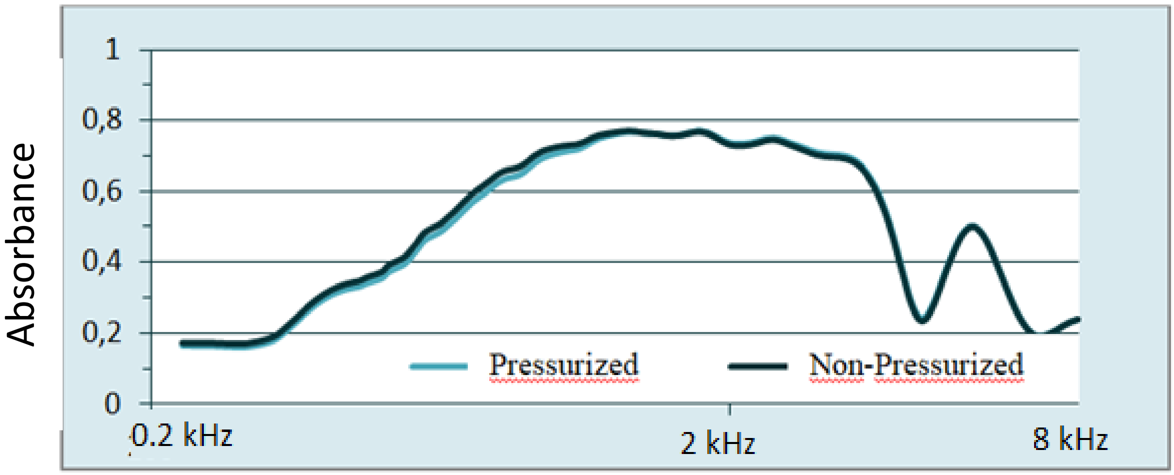

Figure 1. Pressurized and Nonpressurized Absorbance Graphs of 120 Ears

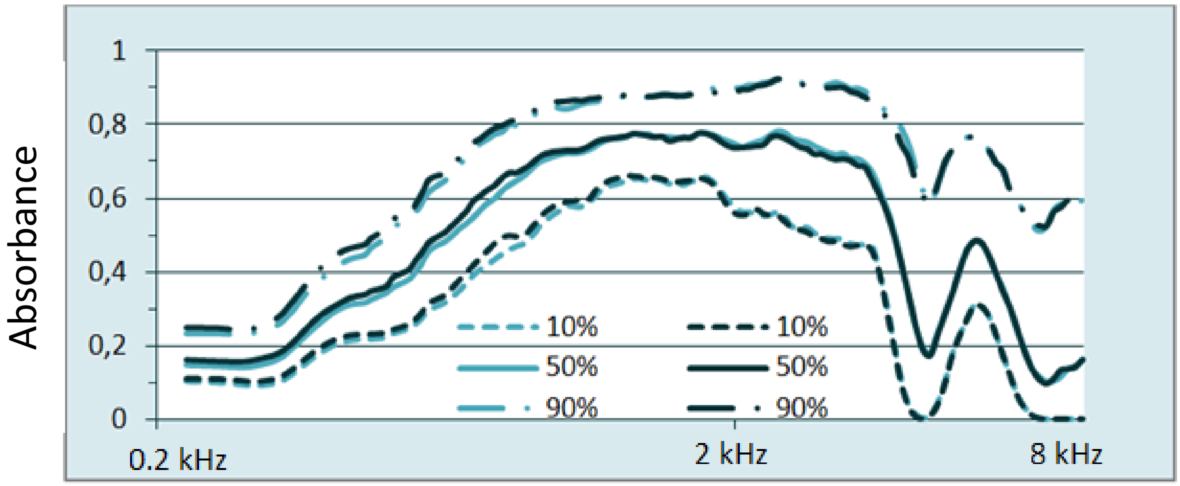

Figure 2. Percentiles of Pressurized and Nonpressurized Absorbance Graphs of 120 Ears

The lowest nonpressurized absorbance value was 0.16 at 280 Hz, whereas the highest nonpressurized absorbance value was 0.77 at 1781 Hz (Figure 2). The lowest pressurized absorbance value was 0.01 at 280 Hz, whereas the highest pressurized absorbance value was 0.77 at 1334 Hz (Figure 2).

Pressurized absorbance values were higher than nonpressurized absorbance values in the range of 226–1373 and 7336–8000 Hz, respectively, and lower than nonpressurized absorbance values in 1414–7127 Hz range. The biggest difference between the pressurized and nonpressurized absorbance values was at 727 and 749 Hz. Kruskal–Wallis test revealed

doi: 10.21020/husbfd.858576

no statistically significant difference between pressurized and nonpressurized absorption values in any of the frequencies (107 frequency points; $p > .05$; Figure 2).

Both pressurized and nonpressurized absorbance values increased from approximately 300 up to 1200 Hz. Absorbance values, which started to decline from approximately 3000 Hz, began to increase again from approximately 4200 up to 5200 Hz. This change in absorbance values created an explicit notch in absorbance graphs around 4200 Hz (Figure 2).

Table 2. The Absorbance Values of 120 Ears at 226, 500, 1000, 2000, 4000, and 8000 Hz.

Frequency (Hz)	Mean	Min	Max
226	0.16 ± 0.06	0.03	0.46
500	0.35 ± 0.11	0.08	0.77
1000	0.71 ± 0.11	0.21	0.93
2000	0.73 ± 0.14	0.13	0.98
4000	0.37 ± 0.24	0.00	0.90
8000	0.23 ± 0.25	0.00	0.94

***** The general descriptive statistics of absorbance values obtained from all subjects at 226, 500, 1000, 2000, 4000 and 8000Hz.

In A-WBTs obtained from all individuals, the peak pressure was −4 daPa, whereas the absorption value at peak pressure was 0.60 (Figure 3 and 4).

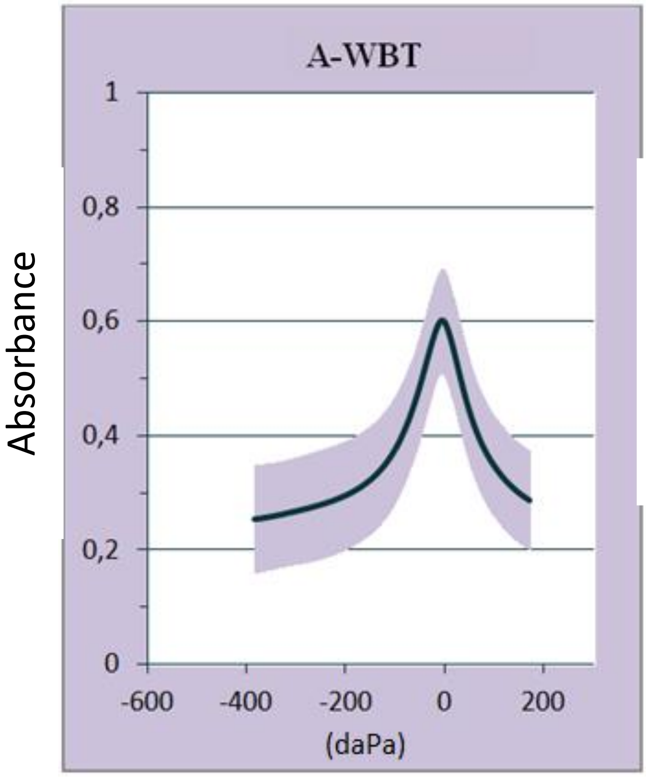

Figure 3. The Mean Averaged Wideband Tympanogram (A-WBT) of 120 Ears

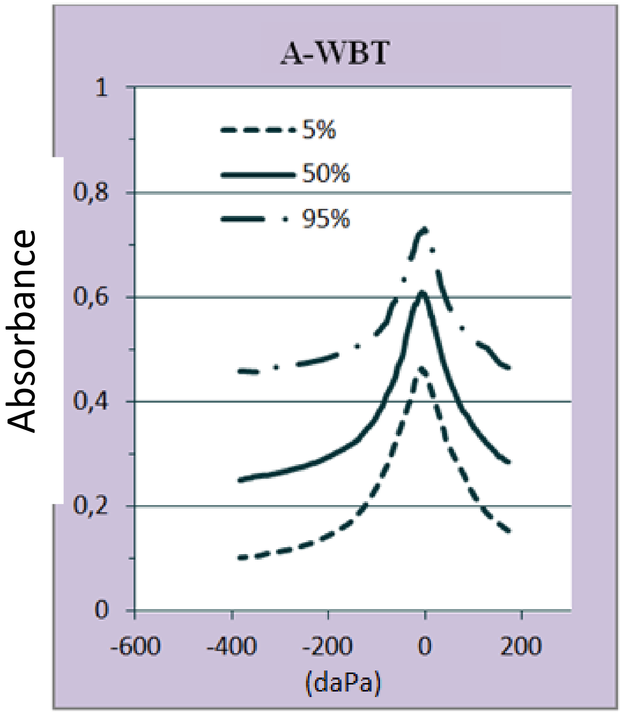

Figure 4. The Percentiles of Averaged Wideband Tympanogram (A-WBT) from 120 Ears

H.Ü. Sağlık Bilimleri Fakültesi Dergisi
Cilt:8, Sayı:1, 2021
doi: 10.21020/husbfd.858576

Nonpressurized absorbance graph of each group was similar to Figure 2. Comparison of the nonpressurized absorbance values of the groups revealed that the absorbance values of Group III were the highest in the range of 226–943 Hz, and the absorbance values of Group II were the lowest in the range of 226–1633 Hz. The lowest absorbance value in the range of 4237–7336 Hz belonged to Group III, and the highest absorbance value in the range of 1681–8000 Hz belongs to Group II. The biggest absorbance value difference was between Group II and III at 594 and 4621 Hz. Kruskal–Wallis test showed no statistically significant difference between groups in terms of absorbance values in any of the frequencies (107 frequency points) (Figure 5, Table 3).

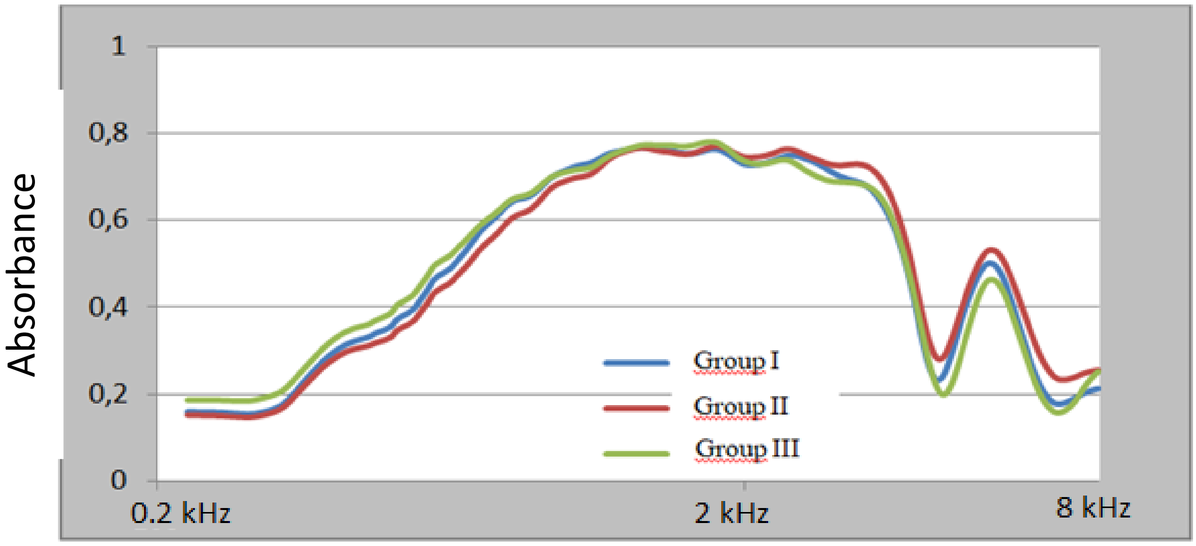

Figure 5. Absorbance Graphs of Three Age Groups

Table 3. Comparison of Nonpressurized Absorbance Values

	Group I			Group II			Group III				
Frequeny (Hz)	Mean ± SD	Min	Max	Mean ± SD	Min	Max	Mean ± SD	Min	Max	N	*p*
226	0.15 ± 0.05	0.03	0.31	0.14 ± 0.04	0.07	0.27	0.18 ± 0.07	0.09	0.46	40	0.145
500	0.35 ± 0.13	0.08	0.77	0.32 ± 0.08	0.17	0.52	0.39 ± 0.11	0.20	0.61	40	0.089
1000	0.72 ± 0.13	0.21	0.90	0.68 ± 0.10	0.43	0.93	0.72 ± 0.09	0.55	0.86	40	0.120
2000	0.72 ± 0.18	0.13	0.98	0.74 ± 0.13	0.52	0.98	0.74 ± 0.10	0.47	0.90	40	0.966
4000	0.33 ± 0.21	0.00	0.76	0.40 ± 0.26	0.02	0.87	0.36 ± 0.25	0.00	0.90	40	0.509
8000	0.22 ± 0.22	0.00	0.77	0.24 ± 0.27	0.00	0.94	0.23 ± 0.27	0.00	0.88	40	0.822

H.Ü. Sağlık Bilimleri Fakültesi Dergisi
Cilt:8, Sayı:1, 2021
doi: 10.21020/husbfd.858576

Figure 6 shows the averaged Wideband tympanograms (A-WBT) of each group. In averaged Wideband Tympanograms, averaged peak pressure of Groups I, II, and III were −5, −3, and −3 daPa, respectively, whereas the averaged absorbance values at peak pressure were 0.60, 0.58, and 0.61, respectively. ANOVA revealed no significant difference between the averaged peak pressures of the groups (p >.05). Kruskal–Wallis test showed no statistically significant difference between the averaged absorbance values of the groups (p >.05).

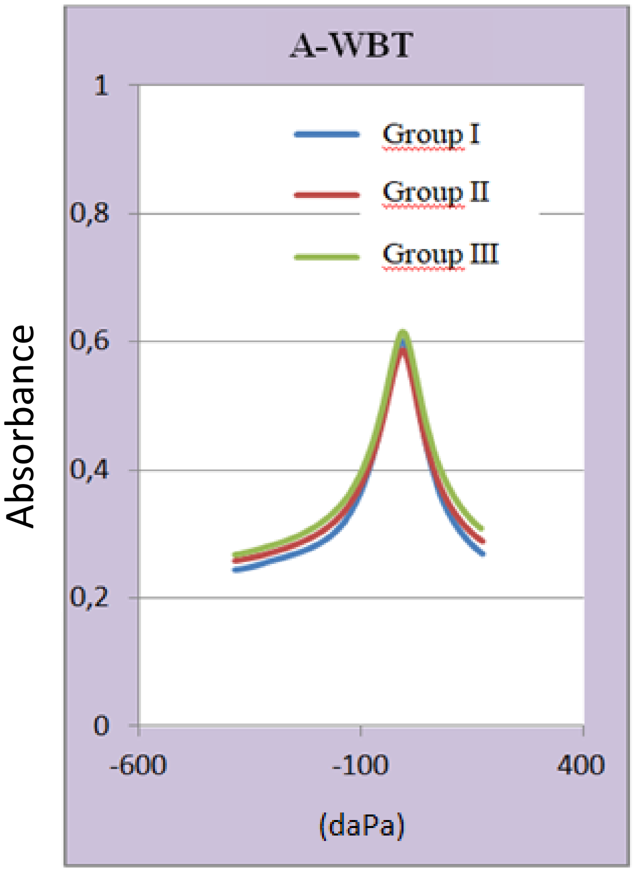

Figure 6. Averaged Wideband Tympanograms of Three Age Groups

RF values of Groups I, II, and III were 931.66 ± 237.22 Hz, 927.95 ± 185.51 Hz, and 864.91±228.18 Hz, respectively, with not a statistically significant difference between the groups according to the Kruskal–Wallis test (p >.05).

Discussion

We determined the WBT findings of adults with a healthy middle ear along with investigating the differences between the groups' WBT findings. Pressurized and non-pressurized absorbance results obtained by Wideband tympanometry were recorded at 107 frequency points within the 226–8000 Hz range.

(Kenny, 2011) who defines WBA measurement as "Static Mode" and measurement as "Dynamic Mode," has compared Caucasian and Chinese participants and found that both ethnic groups have lower absorbance values with Static Mode at low frequencies. (Karuppannan and Barman, 2020) reported that pressurized absorbance values were observed to be higher than WBA values, with the difference seen mostly at low and mid-frequencies up to 2000 Hz.

(Liu et al., 2008) claimed that the reason for obtaining lower absorbance values at low frequencies in Static Mode compared to Dynamic Mode was the decrease in the ear membrane elasticity because of the positive pressure generated by the compressed air within the ear canal due to the probe insertion.

For positive pressure generated by the probe insertion to cause a decrease in membrane elasticity, the middle ear must have 0 daPa or negative pressure. In the case of a membrane with a natural position or a stretched position toward the middle due to the negative pressure within the middle ear, the permeability will be decreased as the positive pressure caused by the probe insertion will increase the membrane stretching toward the middle ear. On the other hand, if the membrane was stretched toward the outer ear because of positive middle ear pressure, then the positive pressure generated by probe insertion will push the membrane toward its natural position, thus cause an increase in permeability. The pressure increase stated by (Liu et al., 2008) is expected to reduce permeability only in negative middle ear pressure cases.

Pressurized absorbance is the absorbance value when the pressure difference between the two sides of the membrane is 0 daPa, in other words, when the membrane is neutral. Nonpressurized absorbance is the absorbance value when the external ear pressure is 0 daPa. The fact that we could not find a statistically significant difference between the pressurized and nonpressurized absorbance values obtained from all individuals leads us to think that the positive or negative pressures occurring within the normal limits in the healthy middle ears do not affect absorbance.

We only analyzed the nonpressurized absorbance values, as the pressurized and nonpressurized absorbance values were the same.

(S. Voss, Moonshiram, & Horton, 2008) as well as (Rosowski et al., 2012) reported that the increase in elasticity leads to a decrease in reflectance (increase in absorbance) at low frequencies. (Feeney, Grant, & Marryott, 2003; Karuppannan and Barman, 2020) reported that negative middle ear pressure, which causes to decrease in elasticity, increases reflectance at low frequencies. In otosclerosis, which is another pathology that decreases elasticity, absorption decreases at low frequencies (Allen, Jeng, & Levitt, 2005; Nakajima et al., 2012; Śliwa et al., 2020). (S. E. Voss, Merchant, & Horton, 2012) monitored the reflectance changes by varying the membrane elasticity via applying positive and negative pressure to the outer ears of the cadaver and found that at high frequencies the reflectance does not change under positive pressure, but decreases under negative pressure. In ossicular chain dislocation, absorbance increases at low frequencies due to increased elasticity of the membrane, whereas decreases at high frequencies (Feeney et al., 2003). (Feeney & Sanford, 2004) found that the young group had lower absorbance values than the elderly group at low frequencies, whereas the absorbance values of the young group were higher than of the elderly group.

In our study, there was no statistically significant difference between groups in terms of absorbance values at neither low (226–943 Hz range) nor high (4237–7336 Hz) frequencies. In the study by (Feeney & Sanford, 2004) the younger group comprised individuals aged 18–28 years and the elderly group aged 60–85 years. In our study, we think that the absorbance values of the groups were similar because the age difference between the groups was not huge enough. It will be appropriate to use the absorbance values obtained in this study as normal values in our clinic for evaluating individuals aged between 20 and 49 years.

Obtaining, analyzing, and interpreting all the absorbance values (at 107 frequencies) found in the absorbance graph is not practical and advantageous. Therefore, for clinical convenience, it is important to know the normative data of healthy ears at certain frequencies. (Shahnaz et al., 2009) reported that reflectance measurement at 500 Hz is more accurate in detecting otosclerosis than Ytm measurements.

Our absorbance values at 500 Hz were close to value found by (Shaw, 2009), at 1000 Hz was close to the value found by (Hougaard et al., 2020), at 2000 Hz was close to the value found by (Shahnaz & Bork, 2006). The average absorbance value we found at 4 kHz was lower than those reported in the literature. To the best of our knowledge, there is no study explaining this phenomenon. (Shahnaz, 2015) focused on calibration error, test–retest reliability, device variability, and ethnicity characteristics as possible reasons of this

H.Ü. Sağlık Bilimleri Fakültesi Dergisi
Cilt:8, Sayı:1, 2021
doi: 10.21020/husbfd.858576

difference. (Kenny, 2011) reported two different results for the measurements made with two different Wideband tympanometers.

The difference found by (Kenny, 2011) with two different Wideband Tympanometer at any frequency was not as significant as our results at 4 kHz. Because the device was properly calibrated and regularly checked along with obtaining similar test and retest results, we suggest that the ethnicity characteristics may explain the difference between the measurements. It is necessary to perform studies with larger number of participants from different ethnic groups to determine the effect of the ethnicity characteristics on absorbance.

A-WBT, a recent method, is a two-dimensional graph of the averaged absorbance values within the 375–2000 Hz range. (Liu et al., 2008) reported that the peak of averaged tympanogram measured with the pressure change rate of −400 daPa/s was in the negative field compared to averaged tympanogram measured with the pressure change rate of −75 daPa/s. In the same study, the peak of averaged tympanograms measured at a pressure change rate of 400 daPa/s was in the positive field compared to averaged tympanograms measured with the pressure change rate of 75 daPa/s. On the averaged tympanograms, the speed of pressure change affects the location of the peak in pressure when compared to the direction of change. (Hougaard et al., 2020) reported that the mean wideband averaged tympanogram peaks around − 5 daPa in normal hearing adults.

In our study, the average A-WBT peak point was −4 daPa. There was no statistically significant difference between the groups in A-WBT peak values. There were no statistically significant differences between groups in averaged absorbance values at the peak point. Averaged absorbance values at the peak did not change with age in the range of 20–49 years.

Various RF values were reported in the literature for healthy ears. For example, (Lutman, 1984) found that 871 Hz was the average RF value of 67 ears, whereas (Valvik, Johnsen, & Laukli, 1994) found the average RF value as 1049 ± 261 Hz in a larger group. (Wiley, Cruickshanks, Nondahl, & Tweed, 1999) and (Uchida et al., 2000) reported that the RF does not vary with age. In our study, the average RF value of 120 ears was (912 Hz) close to the value reported by (Valvik et al., 1994). There was no statistically significant difference between groups in terms of RF values. Our finding that the RF values do not change with age is coherent with the findings of (Wiley et al., 1999) and (Uchida et al., 2000). Obtained average RF value can be accepted as the standard value for healthy middle ears in the range of 20–49 years.

H.Ü. Sağlık Bilimleri Fakültesi Dergisi
Cilt:8, Sayı:1, 2021
doi: 10.21020/husbfd.858576

Conclusion

We obtained the normative data and WBT results of individuals with a healthy middle ear. Besides, individuals were divided into three groups in the age range of 20–29, 30–39, and 40–49 years, and then WBT results of the groups were compared. Results and future recommendations:

1. There was no difference between pressurized and nonpressurized absorbance values in individuals with a healthy middle ear.
2. We concluded that the WBT results did not change with age in the 20–49 age range due to the lack of statistical significance.
3. Studies that evaluate the WBT results in different middle ear pathologies and compare these results with other audiological results can be conducted.
4. It is appropriate to accept the average absorbance value (0.60) of all individuals as the normal value for this age range for future studies to be conducted at our clinic.
5. As it provides lot of information with a single measurement, Wideband tympanometry can be safely used in the clinic as a part of an audiological test set.
6. Normative A-WBT data of newborns with healthy external and middle ear can be determined.
7. Studies can be conducted to determine the specificity and sensitivity of WBT in adult and pediatric patient groups.

Acknowledgement

The authors thank individuals for participation.

Conflict of Interest

The authors state no conflict of interest.

Funding information

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

H.Ü. Sağlık Bilimleri Fakültesi Dergisi
Cilt:8, Sayı:1, 2021
doi: 10.21020/husbfd.858576

References

Allen, J. B., Jeng, P. S., & Levitt, H. (2005). Evaluation of human middle ear function via an acoustic power assessment. *Journal of Rehabilitation Research & Development, 42*.

Feeney, M. P., Grant, I. L., & Marryott, L. P. (2003). Wideband energy reflectance measurements in adults with middle-ear disorders. *Journal of Speech, Language, and Hearing Research*.

Feeney, M. P., & Sanford, C. A. (2004). Age effects in the human middle ear: Wideband acoustical measures. *The Journal of the Acoustical Society of America, 116*(6), 3546-3558.

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, 1-7.

Hunter, L. L., Feeney, M. P., Miller, J. A. L., Jeng, P. S., & Bohning, S. (2010). Wideband reflectance in newborns: Normative regions and relationship to hearing screening results. *Ear and Hearing, 31*(5), 599.

Hunter, L. L., & Shahnaz, N. (2013). *Acoustic immittance measures: Basic and advanced practice*: Plural Publishing.

Karuppannan, A., & Barman, A. (2020). Evaluation of wideband absorbance tympanometry in adults with abnormal positive and negative middle ear pressure. Journal of Hearing Science, 10(4).

Kenny, S. P. V. N. (2011). Clinical application of the Interacoustics REFLWIN system wideband reflectance machine in the assessment of the eustachian tube (Doctoral dissertation, University of British Columbia).

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), 3708-3719.

Lutman, M. (1984). Phasor Admittance Measurements of the Middle Ear I. Theoretical Approach. *Scandinavian Audiology, 13*(4), 253-264.

Nakajima, H. H., Pisano, D. V., Roosli, C., Hamade, M. A., Merchant, G. R., Mahfoud, L., . . . Merchant, S. N. (2012). Comparison of ear-canal reflectance and umbo velocity in patients with conductive hearing loss: a preliminary study. *Ear and Hearing, 33*(1), 35.

Rosowski, J. J., Nakajima, H. H., Hamade, M. A., Mafoud, L., Merchant, G. R., Halpin, C. F., & Merchant, S. N. (2012). Ear-canal reflectance, umbo velocity and tympanometry in normal hearing adults. *Ear and Hearing, 33*(1), 19.

Shahnaz, N. (2015). 12th European Federation for Audiology Societies Congress, oral interview.

Shahnaz, N., & Bork, K. (2006). Wideband reflectance norms for Caucasian and Chinese young adults. *Ear and Hearing, 27*(6), 774-788.

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.

Shahnaz, N., & Davies, D. (2006). Standard and multifrequency tympanometric norms for Caucasian and Chinese young adults. *Ear and Hearing, 27*(1), 75-90.

Shanks, J., & Shohet, J. (2009). Tympanometry in clinical practice. *Handbook of clinical audiology, 6*, 157-188.

Shaw, J. (2009). Comparison of wideband energy reflectance and tympanometric measures obtained with Reflwin Interacoustics, Mimosa Acoustics and GSI Tympstar systems (Doctoral dissertation, University of British Columbia).

Śliwa, L., Kochanek, K., Jedrzejczak, W. W., Mrugała, K., & Skarżyński, H. (2020). Measurement of Wideband Absorbance as a Test for Otosclerosis. Journal of clinical medicine, 9(6), 1908.

Uchida, Y., Nomura, H., Itoh, A., Nakashima, T., Ando, F., Niino, N., & Shimokata, H. (2000). The effects of age on hearing and middle ear function. *Journal of epidemiology, 10*(1sup), 26-32.

Valvik, B.-R., Johnsen, M., & Laukli, E. (1994). Multifrequency Tympanometry: Preliminary Experiences with a Commercially Available Middle-Ear Analyzer: Original Paper. *Audiology, 33*(5), 245-252.

Voss, S., Moonshiram, D., & Horton, N. (2008). Effects of middle-ear pathologies on energy reflectance measurements. *Bull Am Aud Soc, 33*, 31.

doi: 10.21020/husbfd.858576

Voss, S. E., Merchant, G. R., & Horton, N. J. (2012). Effects of middle-ear disorders on power reflectance measured in cadaveric ear canals. *Ear and Hearing*, *33*(2), 195.

Wiley, T. L., Cruickshanks, K. J., Nondahl, D. M., & Tweed, T. S. (1999). Aging and middle ear resonance. *Journal of the American Academy of Audiology, 10*(4), 173-179.

www.interacoustics.com [Access date: April 5, 2014].