The Journal of International Advanced Otology

J Int Adv Otol 2023; 19(2): 140-148 • DOI: 10.5152/iao.2023.22697

Original Article

Wideband Tympanometry and Absorbance for Diagnosing Middle Ear Fluids in Otitis Media with Effusion

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Cite this article as: Şentürk M, Ardıç FN, Tümkaya F, Kara CO. Wideband tympanometry and absorbance for diagnosing middle ear fluids in otitis media with effusion. *J Int Adv Otol*. 2023;19(2):140-148.

BACKGROUND: Surgical tympanostomy tube insertion is a standard procedure in Otitis media with effusion after proper follow-up. During the surgery, the presence of serous or mucoid fluids, atelectatic tympanic membrane, or empty ear may be observed, despite all patients having the same diagnosis. A better method based on a non-invasive approach can help avoid unnecessary surgery. This study aimed to compare surgically confirmed otitis media with effusion with wideband tympanometry and absorbance tests.

METHODS: A total of 122 children diagnosed with otitis media with effusion were included. Eighty healthy children were included as controls. Ears were divided into 4 groups: serous, mucoid, atelectasis, and empty. Resonance frequency, 226 Hz and 1000 Hz compliance, wideband peak pressure, and absorbance data were used for comparison.

RESULTS: The most practical tests were the average of 500, 1000, and 2000 Hz absorbance according to positive likelihood ratio (4.8) and model 2 according to negative likelihood ratio (0.11). It was better than the standard 226 Hz and 1000 Hz compliance tests. Although some statistically significant parameters were observed between serous fluid and empty ear, they were not sufficiently impactful for a differential diagnosis. No parameter could help us differentiate between serous and mucous fluids.

CONCLUSION: According to negative likelihood ratio (0.11), a person with normal middle ear is 9 times more likely to have negative test with the use of resonance frequency, wideband tympanometry, and average absorbance together. To differentiate serous fluid from the empty ear, using only 226 Hz or 1000 Hz compliance for surgical indication can potentially cause wrong decisions according to negative likelihood ratios.

KEYWORDS: Absorbance, compliance, otitis media with effusion, wideband tympanometry

INTRODUCTION

Otitis media with effusion (OME) is one of the most frequent problems associated with pediatric age. It is diagnosed with an ear examination in 15%-40% of children aged between 1 and 5 years.[1] Maw and Bawden (1994)[2] followed up with 222 children and found that 22% of them had a spontaneous resolution of OME within a year. After a long follow-up period, they observed that 95% of OME took 10 years to heal spontaneously if left untreated.[2] Nearly 50% of the children with OME had a minimum of 20 dB of hearing loss.[3] Hearing is an essential requirement for efficient education and good quality of daily life. Therefore, proper diagnosis and treatment of OME are important issues within the pediatric population.

The detection of fluid in the middle ear, the waiting time for spontaneous resolution, and treatment options have been discussed, and international committees have published standardized consensus statements on this subject.[4,5] After a proper diagnosis, in general, 3 months of follow-up is recommended before surgical tympanostomy tube insertion. However, different children have different prognoses and clinical pictures. One of the factors that affect the prognosis is the characteristics of the middle ear fluid. It is often believed that serous effusions lead to a better outcome than mucoid fluids.[6,7] Additionally, it has been shown that the duration of the disease may be a factor affecting fluid viscosity.[8] Therefore, waiting time before ventilation tube insertion may be effective for the OME prognosis.

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Received: January 31, 2022 • **Accepted:** August 1, 2022 • **Publication Date:** March 24, 2023
Available online at www.advancedotology.org

Determination of the time of initiation of the disease is often difficult because the patients are typically diagnosed and treated by general practitioners at the onset of the disease. So, otolaryngologists mostly see the normal tympanic membrane of a recurring disease. It is also impossible to estimate the characteristics of the middle ear fluid before myringotomy. In some cases, after the 3-month wait, a highly thickened fluid or the initiation of adhesion can be observed. This is not apparent before the surgery, making the 3-month waiting time unnecessary and should not have been included in the treatment plan. Another problem is encountering an empty middle ear during surgery, despite a proper diagnosis and follow-up. If the status of the middle ear or fluid type can be estimated using a non-invasive method, we can prescribe either an earlier surgery or a longer follow-up without intervention for these patients.

Ear examination, pneumatic otoscopy, 226-Hz tympanometry, and multifrequency tympanometry were proposed for the diagnosis of OME.[9] Myringotomy is accepted as the gold standard; however, it is an invasive technique. Harris et al[9] compared 226-Hz, 678-Hz, and 1000-Hz tympanometry in children with middle ear effusion as confirmed with myringotomy. They found that a multifrequency tympanogram was better than a conventional tympanogram, particularly in identifying the abnormal middle ear status. When they considered only type A and B tympanograms on 226-Hz tympanometry, the sensitivity and specificity were 80% and 100%, respectively. The sensitivities for 678-Hz and 1000-Hz tympanometries were 95% and 100%, respectively, while the specificity in both tests was 54%.[9] As an alternative, wideband immitancemetry is an encouraging technique for the diagnosis of middle ear diseases.[10] Beers et al (2010)[11] reported that a 1250-Hz reflectance was better in distinguishing middle ear effusion than 226-Hz tympanometry. However, none of the studies in the literature focused on the differential diagnosis of fluid characteristics.

Hence, this study aimed to preoperatively and noninvasively compare and differentiate the surgically confirmed types of middle ear effusions using wideband tympanometry (WBT) and absorbance tests.

METHODS

Patient Groups

A total of 202 children were enrolled in this study. Among them, 122 children (244 ears) diagnosed with OME, followed up for 3 months, and treated surgically were included in the study. Eighty (160 ears) sex- and age-matched children were included in the control group. All the children's parents were informed about the procedure, and written consent was obtained. Ethical approval for the study was given by the University Ethics Committee (60116787-020/15202). This study was supported by the University Research Fund (2016TIPF013).

All the patients were diagnosed via ear examination, pneumatic otoscopy, and type B tympanogram (no peak in compliance curve) using 226-Hz tympanometry. First examinations and follow-ups were conducted by different experienced otolaryngologists from our department. The patients were operated on by 2 experienced otolaryngologists, and WBTs were performed by the same audiologist. The patients were followed up for 3 months while they were taking the appropriate medications. After 3 months, surgical ventilation tube insertion was offered, if no change in ear examination and 226-Hz tympanometry results were observed. Preoperative pure tone audiometry (if applicable) and WBT were performed on the same day, before surgery. Patients with chronic ear diseases, ototoxic drug use, and/or neurological diseases were excluded. Patients were divided into groups according to the observation during surgery. After paracentesis of the tympanic membrane, fluid aspiration was performed. If the fluid was watery and easily aspirated, it was considered serous. If the fluid was sticky, slimy, and elongating through the ear canal during aspiration, it was considered mucoid. The surgeons observed each other numerous times until reaching a clear conclusion about the fluid definitions. If the patient's tympanic membrane was thinner, retracted toward the middle ear cavity, sat on the medial wall without being attached to the middle ear mucosa, and had no fluid with aspiration, the patient was placed in the atelectatic group. If there was fluid behind the retracted membrane, they were classified according to the nature of the fluid. If there was no fluid behind the normal tympanic membrane in the middle ear at the time of surgery, the patient was considered to have an empty ear. Therefore, there were 4 groups: 1, serous fluid; 2, mucoid fluid; 3, atelectatic tympanic membrane; and 0, empty middle ear.

The control group (group 4) comprised volunteers who were admitted to the otolaryngology department with complaints that were not ear-related (e.g., lymphadenopathy and epistaxis), relatives of patients, employees, or other such persons. They all had normal tympanic membranes, pneumatic otoscopy results, and normal compliance in 226-Hz tympanometry.

Parameters

The participants were instructed not to speak, cough, yawn, or gulp during the WBT procedure. The ears were tested in random order. After the probe was inserted, the correct position was automatically checked. If the result was not by the expected curve, it was checked multiple times until the audiologist was confident with the result. Wideband tympanometry measurements were performed using Titan clinical tympanometry (Titan Suite software, Interacoustics, Denmark).

Wideband measurements were performed using narrow band clicks for every 100 Hz at frequencies ranging between 226 and 8000 Hz, while the pressure changed from +200 to −400 daPa. The parameters included the following:

1. Resonance frequency (RF; Hz).
2. Wideband peak pressure (WPP; also known as WBT; an average of 375–2000 Hz tympanograms; daPa).
3. Equivalent ear canal volume (ECV; mL).
4. The compliance at 226 Hz and 1000 Hz (compensated admittance [Ytm]; 226C, 1000C; mL, mmho)
5. Absorbance values (Abs) (%) of 250 Hz, 500 Hz, 1000 Hz, 2000 Hz, 4000 Hz, and 8000 Hz were noted for comparison. All of the values were extracted from the database as a Mathematical Input File (M file). We also calculated the average Abs at different frequencies.

In the surgery room, the characteristics of the middle ear fluid and tympanic membrane were noted immediately after the surgery.

Statistical Evaluation

We performed a power analysis. The calculated suggested sample size was 140 (a minimum of 28 ears for each group) to determine the WBT difference between groups, with a power of 80% or more at a 95% confidence level according to the data obtained from another study.[12]

Statistical Package for Social Sciences (SPSS) version 24.0 (IBM Corp., Armonk, NY, USA) was used for statistical analysis. Continuous parameters were plotted as mean ± standard deviation and median, minimum, and maximum values. Categorical variables were plotted as numbers and percentages. Kruskal–Wallis variance analysis and post hoc Mann–Whitney *U* test with Bonferroni correction were performed to compare independent groups. The diagnostic performance of variables was tested using receiver operating characteristic (ROC) curve analyses. Sensitivity, specificity, and area under the curve were calculated. Cut-off points were obtained using the Youden index method. Statistical significance was set at $P < .05$. Furthermore, we tested some models for the differential diagnoses of normal and empty ears from serous otitis. Logistic regression analysis and ROC curve analyses were used for these models.

We used positive and negative likelihood ratios (LR+, LR−) to classify the diagnostic power according to the following criteria: informative (LR+ ≥ 10 or LR− ≤ 0.1), suggestive (LR+ ≥ 3 and <10 or LR− ≤ 0.3 and > 0.1), or uninformative (LR+ < 3 or LR− > 0.3).[13]

RESULTS

In total, 122 patients (49 females, 73 males) with OME and 80 age- and sex-matched controls (33 females, 47 males) were included. The mean ages of the control and patient groups were 4.74 ± 0.6 and 5.24 ± 3.3 years, respectively. There was no difference between the groups according to age or sex ($P = .207$, $P = .987$, respectively).

After WBT measurements, the patients underwent ventilation tube insertion. Serous fluid was observed in 57 ears (group 1), mucous fluid in 103 ears (group 2), atelectasis in 42 ears (group 3), and no fluid in 41 ears (group 0). One perforated eardrum was observed. A total of 160 normal ears in the control group (group 4) underwent only the WBT test. A total of 244 study ears and 160 control ears were included.

All of the parameters are summarized in Table 1.

When we compared the groups using variance analysis, there was a statistically significant difference in all the parameters between the groups (Table 1). We then compared the groups with each other using the Mann–Whitney *U* test. A statistically significant difference was observed in most parameters between the groups (Table 2). The most prominent differences were found between the control group and the patients.

We compared 250 Hz, 500 Hz, 1000 Hz, 2000 Hz, 4000 Hz, 8000 Hz, and average Abs (%). Median values, error bars, and extreme values of absorbance were plotted in Figure 1. We first performed a variance analysis. We found that there was a significant difference between the groups at all frequencies (Table 1). Then we compared groups one by one with the other groups separately. The mean absorbance levels are plotted in Figure 2. Tympanic peak pressure was also valuable in distinguishing controls from patients. The mean tympanic peak pressure is in Figure 3.

When we compared the groups independently, absorbance measures were significantly higher in the control group than in the patient groups at all frequencies. However, this was not true between the patient groups. All the groups were compared with each other, and the results are shown in Table 2.

Comparing Non-fluid Ears with Effusions

We investigated whether these parameters could be used to separate non-fluid ears from middle ear effusions.

We reunited groups and compared 0+4 with 1+2+3. Every parameter was used as a single test method. We performed a ROC analysis

Table 1. Parameters Measured by Wideband Tympanometry were plotted according to groups.

	0, Empty Ear (n = 41)	1, Serous (n = 57)	2, Mucoid (n = 103)	3, Atelectasis (n = 42)	4, Control (n = 160)	*P*
Age	5.02 ± 3.25	4.69 ± 2.22	5.11 ± 3.34	6.6 ±3.99	4.74 ± 0.6	.207
EECV (mL)	0.81 ±0.39	0.79 ±0.25	0.86 ±0.3	0.93 ±0.46	0.91 ±0.22	<.001
RF (Hz)	1158.32 ± 521.67	759.44± 469.76	736.37 ± 649.4	920.28 ± 546.61	990.64 ± 475.26	.<001
WPP (daPa)	−91.23 ± 134.81	−88.23 ± 162.35	−93.6 ± 171.33	−94.04 ± 160.77	−52.43 ± 79.53	<.01
C 226 Hz Tymp (mL)	0.71 ± 1.26	0.48 ± 0.36	0.4 ± 0.36	0.53 ±0.32	0.47 ± 0.29	<.05
C 1000 Hz Tymp (mmho)	1.61 ± 1.21	1.34 ± 1.50	1.68 ± 3.09	2.87 ±3.7	2.63 ± 8.27	<.05
250 Hz Abs (%)	10.64 ± 4.42	9.79 ± 5.25	10.38± 5.45	11.71 ±10.42	14.87 ± 3.87)	<.001
500 Hz Abs (%)	18.06 ± 10.46	14.79 ± 10.31	14.1 ± 7.63	20 ± 16.26	27.27 ± 13.43	<.001
1000 Hz Abs (%)	46.45 ± 24.83	33.75 ± 22.37	30.76 ± 15.68	48 ± 26.43	61.83 ± 19.89	<.001
2000 Hz Abs (%)	45.16 ± 29.65	39.16 ± 32.86	36.66 ± 28.36	45.71 ± 25.81	66.58 ± 19.47	<.001
4000 Hz Abs (%)	57.74 ± 30.18	41.87 ± 29.65	36.02 ± 26.54	55.14 ± 32.39	68.98 ± 26.08	<.001
8000 Hz Abs (%)	28.38 ± 22.22	29.79 ± 24.45	30.25 ± 22.21	26 ± 16.83	38.41 ± 18.97	<.001
Avg Abs	34.40 ± 14.19	28.19 ± 12.6	26.75 ± 8.78	34.42 ± 14.43	46.32 ± 10.04	<.001

Abs, absorbance; Avg, average; C, compliance; EECV, equivalant ear canal volume; RF, resonance frequency; WPP, wideband tympanometry peak pressure, Tymp, tympanometry.

Table 2. All Groups Were Compared with Each Other. Two Independent Groups Were Compared with the Mann–Whitney *U* Test. The Significant Parameters Were Shown in the Square at the Intersection of the 2 Groups.

	0, Empty	1, Serous	2, Mucoid	3, Atelectasis
1- Serous	RF $P < .01$ C1000 $P < .05$ A1000 $P < .05$ A4000 $P < .05$ Abs $P < .05$			
2- Mucoid	RF $P < .001$ C226 $P < .05$ C1000 $P < .01$ A500 $P < .05$ A1000 $P < .01$ A4000 $P < .01$ Abs $P < .01$	None		
3- Atelectasis	None	Vol $P < .05$ C1000 $P < .05$ A1000 $P < .05$ Abs $P < .05$	C226 $P < .05$ C1000 $P < .01$ A500 $P < .05$ A1000 $P < .01$ A4000 $P < .01$ Abs $P < .01$	
4- Control	Vol $P < .01$ WPP $P < .01$ C1000 $P < .01$ A250 $P < .01$ A500 $P < .01$ A1000 $P < .01$ A2000 $P < .01$ A4000 $P < .05$ A8000 $P < .01$ Abs $P < .001$	RF $P < .01$ Vol $P < .01$ WPP $P < .05$ C1000 $P < .001$ A250 $P < .001$ A500 $P < .001$ A1000 $P < .001$ A2000 $P < .001$ A4000 $P < .001$ A8000 $P < .01$ Abs $P < .001$	RF $P < .001$ Vol $P < .05$ WPP $P < .01$ C1000 $P < .001$ A250 $P < .001$ A500 $P < .001$ A1000 $P < .001$ A2000 $P < .001$ A4000 $P < .001$ A8000 $P < .001$ Abs $P < .001$	WPP $P < .05$ A250 $P < .01$ A500 $P < .001$ A1000 $P < .01$ A2000 $P < .001$ A4000 $P < .05$ A8000 $P < .01$ Abs $P < .001$

A250, 250 Hz absorbance level; A500, 500 Hz absorbance level; A1000, 1000 Hz absorbance level; A2000, 2000 Hz absorbance level; A4000, 4000 Hz absorbance level; A8000, 8000 Hz absorbance level; Abs; average absorbance; C226, 226 Hz tympanometry compliance; C1000, 1000 Hz tympanometry compliance; RF, resonance frequency; Vol, equivalent ear canal volume; WPP, wideband tympanometry peak pressure.

and attempted to determine the cut-off points (Table 3). Absorbance measurements showed a relatively better performance. According to the aforementioned criteria, RF, 226 Hz compliance, and absorbance measures except for 4000 Hz and 8000 Hz were in the suggestive group. The only tests that fulfilled both the positive and negative likelihood criteria were the average Abs and average low tones Abs (Table 3). The best test was the average absorbance to distinguish effusion from non-fluid ears (Figure 4).

Additionally, we tested the 2 models. The first model used RF + compliance 1000 Hz + average absorbance together according to the cut-off points in Table 3. The area under the curve was 0.737, which was weaker than the average absorbance alone. The second model was RF + WPP + average absorbance. The area under the curve was 0.823 (Table 3). The negative likelihood ratio of the second model was very close to the informative level.

We divided the patients into 3 groups (control, atelectasis+empty, serous+mucoid) as they had close curves seen in Figure 2 and tried to find a cut-off point between them. We tested average Abs and calculated some cut-off points (Figure 5).

Comparing Different Effusion Types

We investigated whether we could identify a diagnostic factor between the patients. There were some significantly different parameters observed between the groups in our study (Table 2). These parameters were used to differentiate the serous fluid from an empty ear. We tested RF, 1000C, 1000 Abs, or average Abs; however, only RF was in the suggestive range (Table 4). There was no significant difference in parameters between the serous and mucoid fluids. We also tested RF + compliance 1000 Hz + average absorbance to differentiate empty ear from serous otitis. The area under the curve was 0.837 (Table 4). It was classified as suggestive according to the diagnostic power.

DISCUSSION

We attempted to investigate whether WBT could better estimate the middle ear status in patients with OME to help us to choose between early intervention or a longer follow-up period. We tested patients and controls with WBT and recorded the parameters RF, ECV, 226C, 1000C, WPP, and Abs of frequencies from 250 Hz to 8000 Hz. We found that nearly all of the parameters were statistically significant between the patients and controls (Table 2). The most valuable tests were the average 500, 1000, and 2000 Hz absorbance according to positive likelihood ratio (4.8) and model 2 according to negative likelihood ratio (0.11). When we considered the differences between patient groups, the situation is not the same.

Although serous fluid and empty ear had some statistically significant parameters, when we evaluated these parameters with a separate test method, they were not sufficiently powerful for a differential diagnosis. However, RF and model 1 provided a better diagnosis.

No parameter could help in differentiating between serous and mucous fluids. We could not find any significant difference between the atelectasis and empty ear groups, also. But when we looked at Figure 2, some convergence of curves was seen. So, we redistributed patients again into 3 groups (control, atelectasis+empty, serous+mucoid). We calculated cut-off limits between them for the average absorbance test (Figure 5). According to the results, between 29 and 42 average absorbance, there is a gray zone. In this zone, ears may have no fluid but seem like OME. It is also some atelectasis may be possible. But there was no clear conclusion about differential diagnosis between empty+atelectasis and serous+mucoid ears. If average absorbance is in the gray zone, it is recommended to be suspicious about atelectasis or empty ears.

The interesting question is why do the empty and atelectatic ears have similar curves in WBT? Sadé[14] showed inflammatory changes and destruction of the collagenous layer in atelectatic ears, long ago. Poorer mastoid aeration had been blamed.[15] Inflammatory changes disrupted mucosal gas exchange, and abnormal eustachian tube function was also reported in atelectatic ears.[16] It was measured by laser vibrometry that the atelectatic segment vibrated more than the normal tympanic membrane because it was more flexible.[17] In an experimental model, it is also reported that tympanometry could not show the middle ear pressure correctly in the atelectatic ear.[18] All reported findings were logical and in accordance with the clinical findings. But what about the empty ear? There are very few reports about the empty ear regarding mostly intraoperative findings. Ovesen et al found that 30% of 393 ears diagnosed as OME with otomicroscopy had empty ears in myringotomy.[19] They reported that 14 of 51 patients had B type, and 24 of 51 patients had C type tympanometric curves.[19] There have been

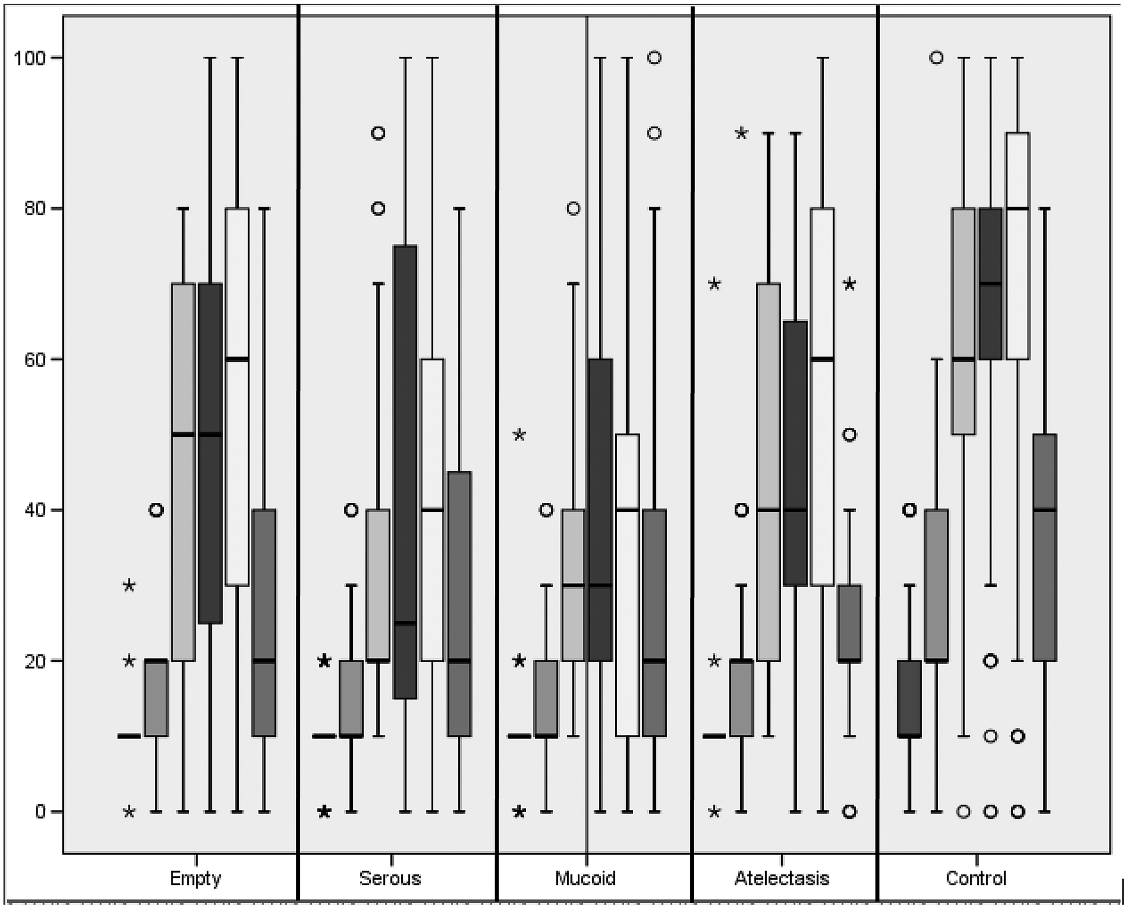

Figure 1. Frequency-specific absorbance values of all groups were plotted in the same graphic. Over every group label, frequencies 250-, 500-, 1000-, 2000-, 4000-, and 8000-Hz error bars were shown. Median, error bars, and extreme cases of all the groups were plotted also.

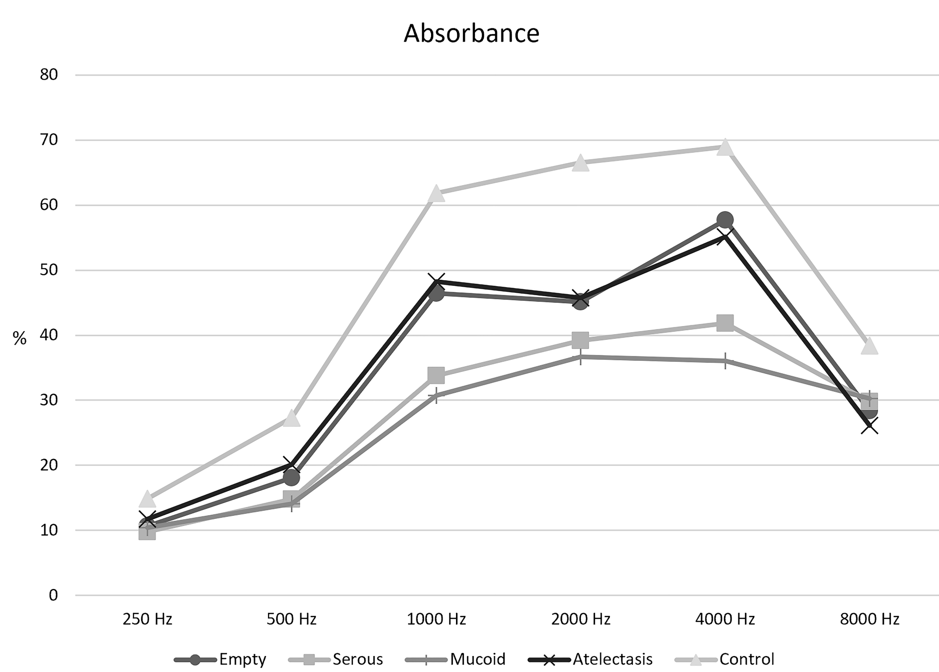

Figure 2. The mean absorbance measurements of different patient groups are shown. It is noteworthy that the empty and atelectatic groups have very similar curves.

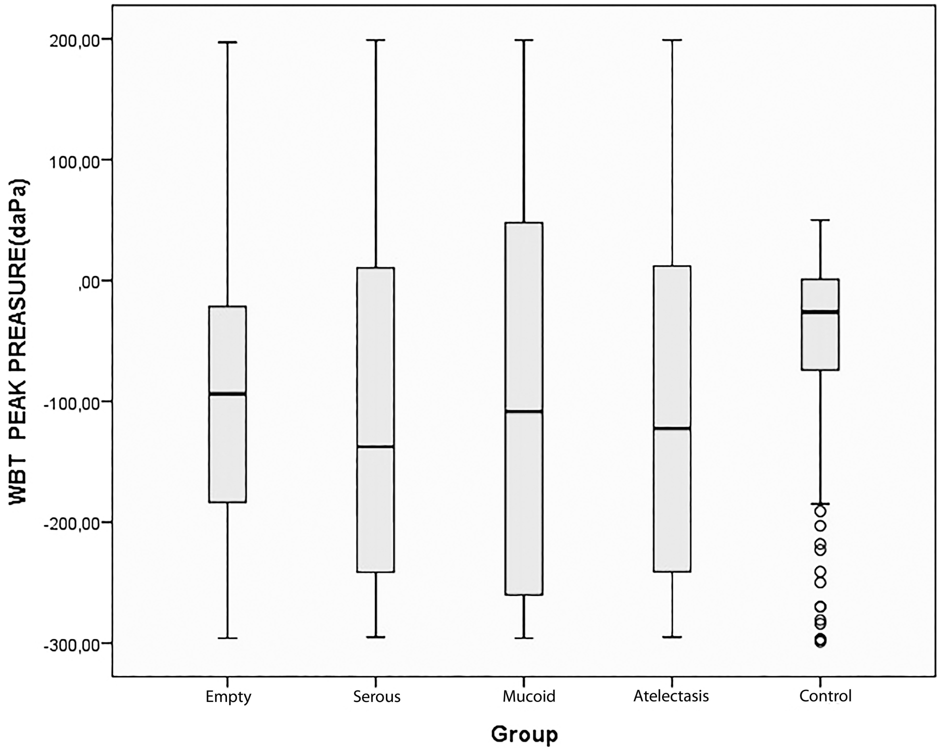

Figure 3. Tympanic peak pressure of the groups.

Table 3. We Divided the Whole Group Into 2 parts; Normal Middle Ear and Patients. We Compared Groups 0+4 with Groups 1+2+3. The Predictive Values of Each Parameter to Separate Patients From Normals Were Determined by ROC Analysis. Cut-off Points Were Observed According to the Youden Index Method. (Model 2 Was the Most Valuable Method According to Negative Likelihood Ratio)

Test	AUC	*P*	Cut off	Sensitivity	Specificity	LR+	LR-	Class
RF (Hz)	0.670	<.01	454	0.353	0.922	4.53	0.70	Suggestive
WBT Peak Pressure (daPa)	0.588	<.01	−67.5	0.617	0.685	1.96	0.56	Uninformative
C 226 Hz Tymp (mL)	0.606	<.05	0.25	0.406	0.905	4.27	0.66	Suggestive
C 1000 Hz Tymp (mmho)	0.699	<.05	1.15	0.593	0.775	2.64	0.53	Uninformative
250 Hz Abs (%)	0.631	<.01	15	0.925	0.256	1.24	0.29	Suggestive
500 Hz Abs (%)	0.753	<.01	15	0.615	0.852	4.16	0.45	Suggestive
1000 Hz Abs (%)	0.777	<.01	45	0.770	0.762	3.24	0.30	Suggestive
2000 Hz Abs (%)	0.725	<.01	45	0.609	0.815	3.29	0.48	Suggestive
4000 Hz Abs (%)	0.738	<.01	65	0.789	0.64	2.19	0.33	Uninformative
8000 Hz Abs (%)	0.626	<.01	35	0.689	0.524	1.45	0.59	Uninformative
Ave Abs	0.831	<.01	37.5	0.795	0.815	4.30	0.25	Suggestive
Ave 250-500-1000 Hz Abs	0.789	<.01	25	0.775	0.778	3.49	0.29	Suggestive
Ave 500-1000-2000 Hz Abs	0.782	<.01	35	0.634	0.868	4.80	0.42	Suggestive
Ave 4000-8000 Hz Abs	0.735	<.01	42.5	0.696	0.720	2.49	0.42	Uninformative
Model 1 (RF+C 1000 HZ+ Ave Abs)	0.737	<.01		0.879	0.528	1.86	0.23	Suggestive
Model 2 (RF+ WBT Peak+ Ave Abs)	0.823	<.01		0.936	0.586	2.26	0.11	Suggestive

Abs, absorbance; AUC, area under curve; Ave, average; C, compliance; RF, resonance frequency; ROC, receiver operating characteristic ; Tymp, tympanometry; WBT, wideband tympanometry.

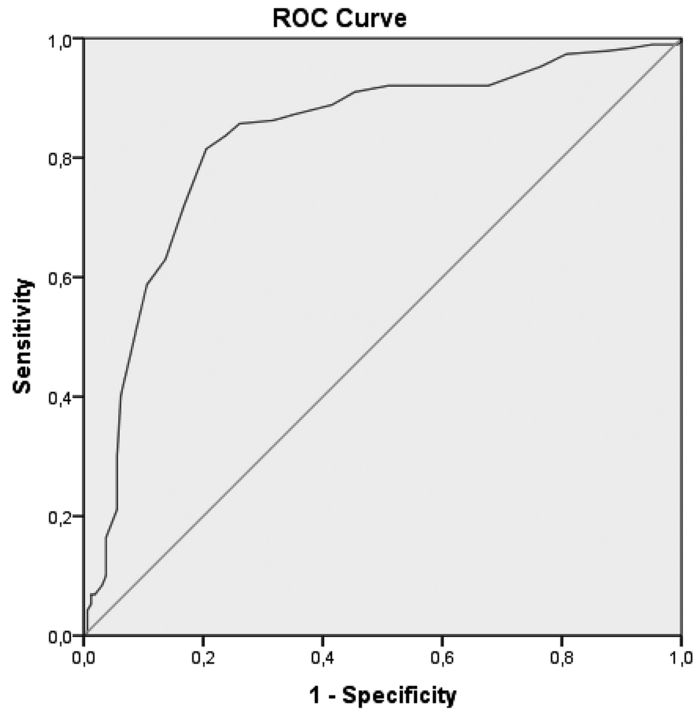

Figure 4. Receiver operating characteristic curve analysis of average absorbance parameter to distinguish patients from controls (area under the curve: 0.831, *P* < .01).

no reports about empty ear histologic or physiologic characteristics in our knowledge. It may be speculated that empty+atelectasis and serous+mucoid ears are 2 different clinical courses of OME and an empty ear may be a preatelectatic ear that cannot be seen by otomicroscopy.

Merchant et al[20] tried to find a correlation between the effusion volume in the middle ear and Abs to estimate the HL in children. They found that Abs decreased while the volume of effusion increased and that the reduction was the highest, between 1 kHz and 5 kHz. They used the multivariate logistic regression approach to differentiate between different groups. They found that this approach could accurately distinguish the middle ear effusion volume difference. This approach was also moderately applicable in the comparison between normal and empty ears.[20] The weakest part of the study was the subjective estimation of effusion volume.

The value of immittance tests in OME has long been investigated. Initially, studies have mostly focused on the frequency parameter. Palmu et al[21] tested conventional tympanometry using myringotomy as the gold standard and reported a sensitivity of 70% and specificity of 98%. Harris et al (2005)[9] compared 226-Hz, 678-Hz, and 1000-Hz tympanometry in children with middle ear disease confirmed by myringotomy. They found that a multifrequency tympanogram was better than a conventional tympanogram, particularly in identifying abnormal middle ear status.[9] When they considered only type A and B tympanograms on 226-Hz tympanometry, they calculated the sensitivity and specificity as 80% and 100%, respectively. The

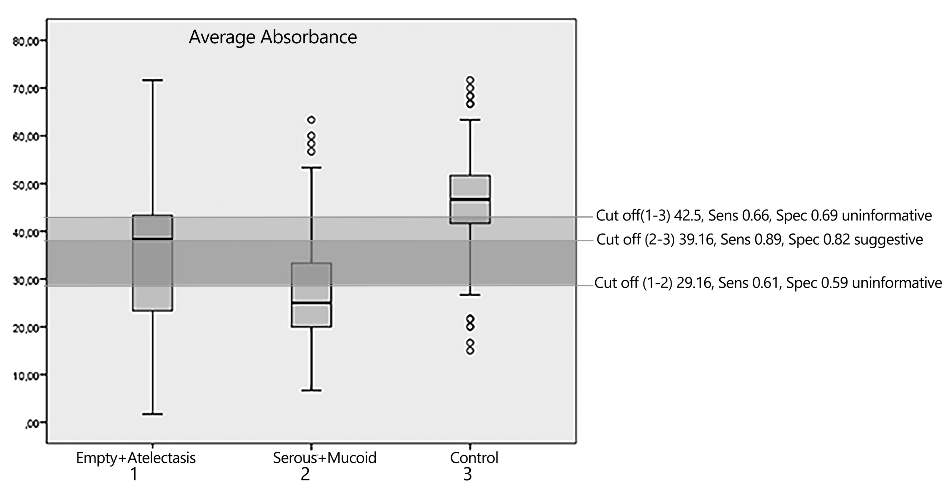

Figure 5. We divided patients into 3 groups according to the convergence of the absorbance curves in Figure 2 and tried to find cut-off points between them for the average absorbance test. (Sens = sensitivity, Spec = specificity).

Table 4. Differential Diagnosis Between the Empty Ear and Serous Fluid Tested by Possible Parameters According to Group Comparisons. The Best Result Was Achieved by Using RF, 1000 Hz Compliance, and Average Absorbance Together According to a Positive Likelihood Ratio.

Test	AUC	*P*	Cut off	Sensitivity	Specificity	LR+	LR−	Class
RF (Hz)	0.719	<.01	758.5	0.520	0.841	3.27	0.57	Suggestive
C 1000 Hz Tymp (mmho)	0.649	<.05	1.05	0.645	0.645	1.82	0.55	Uninformative
1000 Hz Abs (%)	0.647	<.05	45	0.813	0.516	1.68	0.36	Uninformative
Ave Abs	0.653	<.05	37.5	0.813	0.548	1.80	0.34	Uninformative
Model 1 (RF+C 1000 HZ+ Ave Abs)	0.837	<.01		0.789	0.765	3.36	0.28	Suggestive

Abs, absorbance; AUC, area under curve; Ave, average; C, compliance; RF, resonance frequency; Tymp, tympanometry.

sensitivities for 678 Hz and 1000 Hz tympanometries were 95% and 100%, respectively. The specificity was 54%, which was the same for both tests.[9] Age was also found to be an important factor in the frequency. Zhiqi et al[22] tested infants with 226-Hz and 1000-Hz tympanometry and used computed tomography as the gold standard. They concluded that the use of 1000-Hz tympanometry could better test infants under 6 months of age. They found a kappa value between 1000-Hz tympanometry and computed tomography scan as 0.961.[22] We tested all frequencies between 250 Hz and 8000 Hz using WBT. We analyzed 256 and 1000 compliance and WPP for their test performance. We found that the sensitivity and specificity of these tests were lower than those that have been reported in the literature (Table 2).

Sanford et al (2012)[13] performed a meta-analysis on the diagnostic accuracy of tympanogram tests on middle ear pathology. They evaluated 1000-Hz tympanometry, multifrequency tympanograms, and wideband acoustic transfer function. They stated that the wideband acoustic transfer function could be classified as diagnostic or informative according to the positive likelihood ratio. The wideband acoustic transfer function and 1000 Hz could be used for diagnostic suggestions according to the negative likelihood ratio.[13] Ellison et al[23] supported this conclusion. They tested children with middle ear effusion and concluded that the wideband transfer function was as accurate as the methods recommended in clinical guidelines.[23] The same criteria were used. We found that RF, 226 Hz compliance, and absorbance measures except 250 Hz and 8000 Hz were in the suggestive group. The only test that fulfilled the positive and negative likelihood criteria together was the average Abs (Table 3). We also tested 2 different models using regression analysis. If the cut-off values of RF, WPP, and average absorbance were used together, the negative likelihood was the lowest.

Beers et al (2010)[11] evaluated energy reflectance in 78 controls and 68 patients with OME. They found that frequencies over 800 Hz had a better performance in distinguishing control from middle ear effusion and that the best ROC curve performance was at 1250 Hz.[11] Our results were similar to this observation. We found the best performance at 1000 Hz absorbance according to the area under the curve. We did not record a frequency of 1250 Hz.

Keefe et al (2012)[24] investigated children with conductive hearing loss using wideband absorbance measurements and found that ambient absorbance and absorbance tympanometry were better than 226 Hz tympanometric width in predicting conductive hearing loss. On the contrary, Aithal et al[25] compared 226-Hz tympanometry with wideband Abs at Tympanic peak pressure (TPP) and ambient pressure. They determined that none of the Abs performed better than 226-Hz tympanometry in diagnosing surgically confirmed OME.[25] We did not compare the hearing threshold; however, we found that the average absorbance had a better negative likelihood ratio than conventional tympanometry for diagnosing OME. When we divided the whole group into 2 parts according to disease in the middle ear as group normal (0+4(Empty+Control)) and group OME (1+2+3(Atelectasis+Serous+Mucoid)), the average absorbance test (0.25) has better negative likelihood ratio than 226 Hz compliance (0.66). It means that a person without an ear disease has 4 times more likely to have a negative average absorbance test. While this ratio is only 1.5 for 226 Hz compliance.

Terzi et al (2015)[12] focused on differentiating OME from normal tissues using wideband absorbance tests. They reported that 0.375-2 kHz average absorbance was the best diagnostic parameter according to the ROC analysis (area under curve 0.9).[12] Different averages were used. The total average was the best, according to the ROC curve. However, the average of 500 Hz, 1000 Hz, and 2000 Hz was more accurate according to the positive likelihood ratio. Taiji and Kanzaki et al (2016)[26] compared 226-Hz tympanograms and wideband absorbance and claimed that 2000-4000 Hz absorbance measurements detected middle ear effusion better than did the tympanogram. They proposed an average of 1, 2, and 4 kHz absorbance with a cut-off of 40% as a diagnostic test.[26] Beers et al[11] tested the energy reflectance and found that 1250 Hz had the highest specificity and sensitivity for middle ear effusion. Callaham et al did the same grouping as in our study and found a significant difference in median Abs. They concluded that WBT had a potential for differential diagnosis between serous and mucoid effusions.[27] Different frequencies were tested. We also agreed on using the averages. Our cut-off value changed from 25% to 37.5%, according to which frequencies were included in the average.

One of the limitations of this study was that it did not consider the hearing thresholds or air-bone gap as an effective factor. Multiple test results can form a diagnostic algorithm for the differential diagnosis. The second limitation was the possibility of inter-individual differences in the definition of middle ear status during surgery. We attempted to mimic the error using group meetings. However, it did not consider the shape of the curves. They may provide additional power to multiple test models.

In conclusion, wideband absorbance measurements, particularly the average of all frequencies, are better tests for diagnosing middle ear pathology. Moreover, using RF, WPP, and average Abs together is a good choice. However, we could not find any parameter that could help in the noninvasive diagnosis of serous or mucoid fluids. To differentiate serous fluid from the empty middle ear, using RF, WBT, and average Abs together was found to be helpful. When these 3 tests were evaluated together, we calculated the negative likelihood ratio as 0.11 and which means that a person with a normal middle ear has 9 times more likely to have a negative test. While this ratio is only 1.5 for 226 Hz compliance (LR–: 0.66) and 3.3 for 1000 Hz compliance (LR–: 0.53). Using only 226 Hz or 1000 Hz compliance for surgical indication has a potential to cause wrong decisions according to negative likelihood ratios.

Ethics Committee Approval: Ethical committee approval was received from the Ethics Committee of Pamukkale University, (Approval No: 60116787-020/15202).

Informed Consent: Informed consent was obtained from each patient included in the study.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept – M.Ş., F.N.A., F.T, C.O.K.; Design – M.Ş., F.N.A., F.T., C.O.K.; Supervision – F.N.A.; Funding – F.N.A.; Materials – M.Ş., F.N.A., F.T., C.O.K.; Data Collection and/or Processing – M.Ş., F.N.A., F.T., C.O.K.; Analysis and/or Interpretation – M.Ş., F.N.A., F.T., C.O.K.; Literature Review – M.Ş., F.N.A., F.T., C.O.K.; Writing – M.Ş., F.N.A., F.T., C.O.K.; Critical Review – F.N.A.

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

Funding: This research was supported by Pamukkale University research fund, 2016TIPF013. The study was presented partially at the Ninth EAONO Instructional Workshop and Consensus on Auditory Implants, Copenhagen, 2018. The study was registered to clinicaltrials.gov (NCT04395261), retrospectively.

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