Predictive Accuracy of Wideband Absorbance at Ambient and Tympanometric Peak Pressure Conditions in Identifying Children with Surgically Confirmed Otitis Media with Effusion

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Abstract

Background Wideband absorbance (WBA) measured at ambient pressure (WBA_A) does not directly account for middle ear pressure effects. On the other hand, WBA measured at tympanometric peak pressure (TPP) (WBA_{TPP}) may compensate for the middle ear pressure effects. To date, there are no studies that have compared WBA_A and WBA_{TPP} in ears with surgically confirmed otitis media with effusion (OME).

Purpose The purpose of this study was to compare the predictive accuracy of WBA_A and WBA_{TPP} in ears with OME.

Research Design Prospective cross-sectional study.

Study Sample A total of 60 ears from 38 healthy children (mean age = 6.5 years, SD = 1.84 years) and 60 ears from 38 children (mean age = 5.5 years, SD = 3.3 years) with confirmed OME during myringotomy were included in this study.

Data Collection and Analysis Results were analyzed using descriptive statistics and analysis of variance. The predictive accuracy of WBA_A and WBA_{TPP} was determined using receiver operating characteristics (ROC) analyses.

Results Both WBA_A and WBA_{TPP} were reduced in ears with OME compared with that in healthy ears. The area under the ROC (AROC) curve was 0.92 for WBA_A at 1.5 kHz, whereas that for WBA_{TPP} at 1.25 kHz was 0.91. In comparison, the AROC for 226-Hz tympanometry based on the static acoustic admittance (Y_{tm}) measure was 0.93.

Conclusions Both WBA_A and WBA_{TPP} showed high and similar test performance, but neither test performed significantly better than 226-Hz tympanometry for detection of surgically confirmed OME.

Key words

- ambient pressure
- glue ear
- otitis media with effusion
- test performance
- tympanometric peak pressure
- wideband absorbance

Introduction

Otitis media with effusion (OME) is defined as the presence of fluid in the middle ear without signs or symptoms of acute ear infection (Stool et al[50]; Shekelle et al[49]). OME in children can lead to reduced hearing sensitivity and deficits in speech and language development (Wallace et al[56]; Friel-Patti and Finitzo[11]; Roberts and Wallace[39]). Normal hearing is a

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prerequisite for normal speech and language development, but a hearing loss of >15 dB HL can be handicapping for children (Northern and Downs[34]). Presence of OME can cause a conductive hearing loss of varying degrees which can be transient or of long duration. Hearing loss caused by OME can vary from 0- to 50-dB HL averaged across the speech frequencies (Bess[7]; Fria et al[10]; Hunter et al[20]). Because a large portion of conversational speech does not exceed 50-dB SPL, even a minimal conductive loss could compromise a childs ability to understand speech.

Binaural hearing (Hall et al[15]; Yonovitz et al[59]; Aithal et al[5]), auditory processing (Keogh et al[29]; Graydon et al[12]), academic success (Aithal et al[4]), and speech and language development (Winiger et al[58]) have been shown to be compromised in children with long-lasting OME. Numerous studies have reported delays in speech and language development for children with early onset of OME compared with typically developing children (Klausen et al[30]; Winiger et al[58]). However, studies addressing the long-term effects of OME on language development have reported contradictory findings. For instance, Teele et al[52] and Shaffer et al[48] found significant positive correlations between long-standing OME in the first three years of life and articulation and language-related skills. Unsurprisingly, Paradise et al[38] found no relationship between early onset of OME and later language comprehension and production abilities.

Because early onset OME has the potential to impact on children's speech and language and education, it is important to regularly review young children with hearing loss to monitor their hearing sensitivity, speech and language development, and academic progress. Nevertheless, measuring hearing status and middle ear function can be challenging in this population as they are not always co-operative for testing.

Tympanometry using a 226-Hz probe tone is the standard test for assessment of middle ear function in children and adults. The sensitivity of tympanometry in identifying OME, when compared with myringotomy, is reported to be 80–90% and specificity from 74% to 100% (Finitzo et al[9]; Nozza et al[35,36]; Watters et al[57]; Palmu et al[37]; Takata et al[51]; Harris et al[17]). Tympanometric width, or sharpness of the tympanogram shape, has been demonstrated to be the best single criterion for detecting OME with a sensitivity of 81% and specificity of 82% (Nozza et al[35,36]). Nevertheless, the diagnostic use of tympanograms for identification of OME is limited, especially with tympanograms demonstrating negative middle ear pressure (e.g., <−150 daPa). Studies have found that identification of OME based on negative tympanometric peak pressure (TPP) findings do not adequately separate normal ears from ears with OME (Lildholdt[31]; Shanks and Shelton[47]; Nozza et al[36]).

In the last decade, research has shown that wideband acoustic immittance (WAI) is a sensitive test of middle ear function. Of the various measures of WAI, wideband absorbance (WBA) is gaining popularity for use in research and clinical settings. The additional WAI measures include resonance frequency, equivalent ear canal volume, TPP, admittance magnitude, and phase angle. WBA is defined as the ratio of energy absorbed by the middle ear to incident acoustic energy supplied by the probe receiver (Ellison et al[8]). Most earlier studies focused on measuring WAI at ambient pressure. WBA at ambient pressure (WBA_A) is shown to be effective in identifying middle ear dysfunction and conductive disorders in infants (Sanford et al[43]; Hunter et al[19]; Aithal et al[3]; Aithal et al[2]), children (Keefe and Simmons[27]; Keefe et al[26]), and adults (Margolis et al[32]; Shahnaz and Bork[44]; Shahnaz et al[45]). In particular, studies have shown WBA_A to be useful in identifying OME in infants and children (Margolis et al[33]; Jeng et al[22]; Hunter, Tubaugh, et al[21]; Beers et al[6]; Ellison et al[8]; Terzi et al[53]).

Myringotomy is considered as the gold standard to determine the presence or absence of OME. As myringotomy is an invasive procedure, which requires general anesthesia in children, it is not performed on asymptomatic children for ethical considerations. The lack of effusion may be confirmed by pneumatic otoscopy and hence could be used as a reference standard instead of myringotomy (Rosenfeld et al[40]). Ellison et al[8] investigated the use of WBA_A with 44 children with OME confirmed by myringotomy and 44 children without a history of middle ear disorders based on surgery and normal pneumatic otoscopic findings. They found that WBA_A was reduced in ears with OME compared with ears from the control group. The test performance of WBA_A in identifying OME was high with area under the receiver operating characteristic (AROC) curve of 0.93. Terzi et al[53] assessed 34 typically developing children, 44 children diagnosed with OME during myringotomy, and 28 children with OME but no signs of effusion during myringotomy. Terzi et al[53] reported that WBA_A was significantly lower in the OME group. In evaluating the test performance of the WBA_A test, they found that WBA in the frequency region 0.375–2 kHz had the highest AROC of 0.984, followed by that at 1 and 1.5 kHz of 0.973 and 0.967, respectively. In another study, Beers et al[6] compared WBA_A in 78 children who passed a battery of tests with that of 25 children with OME confirmed by video otomicroscopy and pneumatic otoscopy. They reported that WBA_A >0.8 kHz had high test performance in distinguishing normal middle ear status from OME. They found that WBA_A at 1.25 kHz had the highest AROC of 0.97.

Surprisingly, there is limited research regarding comparison of test performance of WBA with conventional 226-Hz tympanometry. Studies have suggested that WBA_A is significantly better than 226-Hz tympanometry in distinguishing ears with OME from normal middle ears (Beers et al[6]; Terzi et al[53]) and predicting conductive hearing loss in young children due to OME (Keefe et al[26]). Keefe et al[26] noted that both WBA_A and tympanometric WBA showed better test performance compared with 226-Hz tympanometry in children.

The aforementioned studies have measured WBA_A. WBA can also be measured under tympanometric pressurized conditions, known as wideband tympanometry (WBT). WBT provides additional information of middle ear function compared with WBA_A measurements, by measuring absorbance at TPP (WBA_{TPP}). Earlier studies have suggested that WBA_{TPP} may be more sensitive to middle ear disorders in children and adults (Margolis et al[32]; Keefe and Simmons[27]; Sanford and Feeney[42]). More recently, Keefe et al[23] evaluated normal and surgically confirmed otosclerotic ears and using a multivariate predictor with three reflectance variables and reported that tympanometric reflectance was more accurate than ambient reflectance (AROC 0.95 versus AROC 0.88) in classifying ears as normal or otosclerotic ears. However, other studies have shown similar test performance for WBA_A and WBA_{TPP} for identifying middle ear dysfunction and conductive hearing loss (Sanford et al[43]; Keefe et al[26]).

Margolis et al[32] suggested that it may be potentially advantageous to assess middle ear function using both WBA_A and WBA_{TPP} procedure. The researchers reported a single case study of a ten-year-old child with a conductive loss of 35-dB HL and TPP of −250 daPa. They found the absorbance to be abnormal even when the ear canal was pressurized to match the TPP and suggested that pathologic middle ear changes might have occurred in addition to the presence of negative pressure in the middle ear (Margolis et al[32]).

By measuring absorbance at TPP, WBT provides additional information of middle ear function compared with WBA_A measurements. More importantly, WBT produces an optimal WBA_{TPP} response by compensating for the effect of the difference in pressure between the ear canal and the middle ear. WBT generates a three-dimensional plot of absorbance as function of both ear canal pressure and frequency. From this plot, WBA at any applied pressure, including TPP, can be derived. WBA_A evaluates middle ear function without adjusting for middle ear pressure effects. But WBA_{TPP} evaluates middle ear function after compensating for the difference in pressure between the outer ear and the middle ear. Hence, measuring WBA at TPP will reduce the middle ear pressure effects and measure changes in absorbance due to the middle ear pathology per se.

Although many researchers have studied WBA_A in ears with OME based on otoscopy and audiological findings, surgical confirmation of OME is important and significant as otoscopic measures are often subjective and less reliable. To date, there are only two studies that have investigated WBA_A in ears with surgically confirmed OME (Ellison et al[8]; Terzi et al[53]). However, neither of these studies have studied WBA_{TPP}. The purpose of the present study was to compare the predictive accuracy of WBA_A and WBA_{TPP} in ears with OME confirmed by myringotomy.

Materials and Methods

Participants

The study was approved by Townsville Hospital and Health Service Ethics Board. Written consent was obtained from parents or carers. The participants were divided into two groups.

Control Group

The control group consisted of 60 healthy ears (35 right and 25 left) from 38 children (25 males and 13 females) who presented to the audiology clinic with no history of ear or hearing difficulties. Mean age at the time of testing was 6.5 years (standard deviation [SD] = 1.84, range 4.11–11.4 years). Inclusion criteria for the control group were as follows: (a) no significant history of middle ear infection at the time of testing, (b) normal otoscopic findings, (c) normal tympanogram with peak Ytm between 0.3 and 1.4 mmhos and TPP between −100 and 100 daPa, (d) air conduction (AC) thresholds <20-dB HL between 0.25 and 8 kHz, (e) air-bone gap of <l5 dB at frequencies between 0.25 and 4 kHz, and (f) a pass in transient evoked otoacoustic emissions (TEOAEs) as determined by signal to noise ratio of ≥3 dB at 2, 3, and 4 kHz (Kei et al[28]).

OME Group

Children with OME as determined by an ear nose and throat (ENT) specialist and who were scheduled for myringotomy with or without grommet insertion were enrolled in the OME group. Initial diagnosis of OME was made based on otomicroscopy by the ENT specialist. Subject data were only included in the OME group if the ENT specialist confirmed the presence of effusion during myringotomy. This group consisted of 60 ears (30 right and 30 left) from 38 children (25 males and 13 females). The ENT specialist subjectively rated middle ear fluid as thick or thin during surgery. Thick fluid was noted in 37 ears and thin fluid in 23 ears. Mean age at the time of diagnosis was 5.5 years (SD = 3.3 years, range 1.1–14.3 years). There was no significant difference between the mean age of two groups [$t_{(74)} = -1.64$, $p = 0.11$].

Test Procedure

All testing was performed by a clinical audiologist in a sound-treated room with ambient noise <35-dB A. Testing was scheduled at least one hour before the surgery. Although both ears were tested, only the ear with surgically confirmed OME was included in the study. Tympanometry, TEOAEs, pure-tone audiometry, WBA_A, and WBA_{TPP} were performed in no particular order.

Tympanometry

Tympanometry was performed using a GSI Tymp Star 2 middle ear analyzer (Grason-Stadler; Eden Prairie, MN). Tympanograms were obtained by presenting a 226-Hz probe tone at 85-dB SPL to the ear while the ear canal pressure was varied from +200 to −400 daPa. Quantitative tympanometric measures of peak compensated static acoustic admittance measured between the peak and 200 daPa (Y_{tm} in mmho) and TPP in daPa were used to classify tympanograms as normal, flat, or negative middle ear pressure. Tympanograms with static admittance between 0.3 and 1.4 mmho and middle ear pressure of between −100 and 100 daPa were classified as normal. Tympanograms with static admittance <0.3 mmho with no identifiable peak were classified as flat tympanograms, and tympanograms with middle ear pressure <−100 daPa as negative middle ear pressure (Nozza et al[35,36]; Valente et al[54]).

TEOAEs Test

A Biologic Scout Version.3.45 (Natus; San Carlos, CA) was used to measure TEOAEs. The signal consisted of wideband clicks of 80-p.s duration, at a target amplitude of 80-dB peak-equivalent sound pressure level. The pass criteria included reproducibility of ≥70% and a difference between the amplitude of the emission and the associated noise floor of ≥3 dB at 2,3, and 4 kHz (Kei et al[28]; Vander Werff et al[55]).

Audiometry

AC and bone conduction (BC) audiometry were performed using an Interacoustic AC 40 audiometer (Interacoustics; Assens, Denmark). Thresholds were determined using the Hughson-Westlake Method. Conditioned play audiometry was used for children aged between 2.5 and 5 years. AC thresholds were measured at 0.25, 0.5, 1, 2, 4, and 8 kHz and BC thresholds were measured at 0.25, 0.5,1, 2, and 4 kHz. Air-bone gap data were obtained at all BC test frequencies.

Visual reinforcement audiometry was performed for children younger than 2.5 years using an Interacoustic AC 40 audiometer with a free field setup. Visual reinforcement audiometry thresholds were determined for warble tones at 0.5, 1, 2, and 4 kHz presented through a loudspeaker kept at 1-m distance at an angle of 45° from the child's ears.

Wideband Absorbance Measurements and Analysis

Both WBA_A and WBA_{TPP} were measured using a prototype system developed by Interacoutics (Keefe et al[25]; Sanford et al[43]; Aithal et al[3]). The Reflwin computerized system consisted of a Windowsbased computer, a 24-bit resolution sound card, a pressure pump and controller system containing an acoustic immittance instrument (AT235), and custom software (version 3.2.1) (Interacoustics, Assens, Denmark) for stimulus generation and data acquisition. Calibration was performed every day before data collection (Keefe and Simmons[27]; Sanford and Feeney[42]). Calibration was performed at ambient pressure to determine the source reflectance and incident sound pressure associated with the probe and its transducers based on acoustic measurements in four rigid-walled cylindrical calibration tubes that were open at one end and closed at the other with a steel rod. The infant calibration tubes had lengths of 232.11 and 53.19 mm, each with a diameter of 4.8 mm (small-tube) and the adult calibration tubes had lengths of 290.50 and 81 mm, each with a diameter of 7.9 mm (large-tube). A root mean squared reflectance error of <0.009 was required for successful calibration and any calibration that did not meet the criteria was repeated after the probe reinsertion. Reflectance is the ratio of reflected energy at the probe termination in the ear canal to incident acoustic energy supplied by the probe receiver (Ellison et al[8]). Absorbance is defined as 1–reflectance. Responses in the age group equal to or older than 0.5 years were analyzed with respect to large-tube calibration and newborns through 0.4 years were analyzed with respect to small-tube calibration. However, in the present study, only adult calibration values were used as the youngest child tested was only 1.1 year old.

Measurements were obtained by recording acoustic response to clicks presented at 55 dB SPL at a rate of one click per 46 msec. Responses from a total of 32 clicks were averaged for each measurement and reflectance was calculated for each response. The response consisted of 16 data points at 1/3 octave frequencies from 226 to 8000 Hz. WBA_A was always measured before WBA_{TPP}. WBT testing was performed using Reflwin software in combination with the modified acoustic immittance instrument (AT 235). A slow pump speed of 75 daPa/sec was used and the pressure was swept from +200 to −300 daPa, respectively. Visual inspection of the absorbance curve was performed to determine adequate probe fit. Absorbance more than 0.29 in the low frequency band (0.25–0.5 kHz) was indicative of a probe leak (Groon et al[14]). When probe leakage was suspected, the probe was reinserted, and the test was repeated.

Data were exported to an Excel spreadsheet using a MATLAB software (R2014b) (The MathWorks Inc, Natick, MA). The data were then transferred into the IBM SPSS (version 23) (IBM Corporation, Armonk, NY) for further analysis. Mean WBA_A and WBA_{TPP} were determined for 16 one-third octave frequencies from 0.25 to 8 kHz and were also obtained for frequencies between 0.3 and 2 kHz, 1 and 2 kHz, and 2 and 8 kHz. WBA_A was measured at ambient pressure in the ear canal whereas WBA_{TPP} was measured at TPP. TPP was measured by calculating the pressure at which the maximum of low-frequency averaged absorbance (0.376–2 kHz) occurred. It was automatically calculated by the program. For tympanograms with no peaks, the program identified the maximum-averaged absorbance point and measured the TPP. In this case, the TPP does not necessarily indicate the difference in pressure between the ear canal and middle ear cavity.

Statistical analysis was performed using the IBM SPSS software version 23. A mixed model analysis of variance (ANOVA) was used to analyze data for ears with and without OME. The Greenhouse and Geisser[13] (G-G) approach was used to compensate for the violation of compound symmetry and sphericity. Data were analyzed using ear status (control versus OME) as between group factor and frequencies as within group factor. Post hoc analyses were performed using multiple pair wise comparison tests with Bonferroni adjustments to determine the frequencies at which significant differences existed between control and OME groups. A p value of <0.05 was considered statistically significant for all analyses.

Measures of Test Performance

The test performance of WBA_A and WBA_{TPP} to detect OME was determined using ROC analyses. AROC was determined for each of the 16 one-third octave frequencies as well as 0.3–2, 1–2, and 2–8-kHz frequency bands for WBA_A and WBA_{TPP} using SPSS software (version 23).

Results

There was no significant difference in age between the two groups of participants [$t_{(74)} = -1.64$. $p = 0.11$] (►**Table 1**). An ANOVA was fitted to the WBA_A and WBA_{TPP} data from the control and OME groups to test the significance of difference between right and left ears, and male and females, and their interactions. To analyze the ears and gender, only one ear was selected for the study and in case of children passing both ears, only one ear was selected at random. This was performed to avoid the potential influence of pooling the data across ear for analysis. This resulted 38 ears (24 right and 14 left) for WBA_A and 21 ears (12 right and 9 left) for WBA_{TPP} in

Table 1 Participant Details

	Control Group	OME Group
No. children	38	38
Male	25	25
Female	13	13
Total no. of ears	60	60
Right ear	35	30
Left ear	25	30
Age (years)		
Mean	6.5	5.5
SD	1.84	3.3
Range	4.11–11.4	1.1–14.3

control group. Similarly, 38 ears (22 right and 16 left) were selected for WBA_A and 32 ears (19 right and 13 left) for WBA_{TPP} in the OME group. Less ears were selected for WBA_{TPP} condition as data were not available for all children for the TPP conditions.

For the control group, results of an ANOVA fitted to the data obtained from WBA_A showed no significant difference between ears, $F_{(1,\ 34)} = 1.01$, $p > 0.05$; gender, $F_{(1,\ 34)} = 0.06$, $p > 0.05$ and ear X gender interaction, $F_{(1,\ 34)} = 0.06$, $p > 0.05$. Likewise, no significant difference between ears, $F_{(1,\ 17)} = 2.47$, $p > 0.05$; gender, $F_{(1,\ 17)} = 0.04$, $p > 0.05$; and ear X gender interaction, $F_{(1,17)} = 0.01$, $p > 0.05$ were observed for the WBA_{TPP} measure.

For the OME group, results of an ANOVA fitted to the data obtained from WBA_A showed no significant difference between ears, $F_{(1,\ 34)} = 1.24$, $p > 0.05$; gender, $F_{(1,\ 34)} = 0.17$, $p > 0.05$; and ear X gender interaction, $F_{(1,\ 34)} = 1.15$, $p > 0.05$. Likewise, no significant difference between ear, $F_{(1,\ 28)} = 0.73$, $p > 0.05$; gender, $F_{(1,\ 28)} = 1.06$, $p > 0.05$; and ear X gender interaction, $F_{(1,\ 28)} = 0.05$, $p > 0.05$ were observed for the WBA_{TPP} measure. Subsequently, ears were pooled for both groups for further analysis.

The tympanometric data were analyzed based on quantitative analyses. All the 60 ears from 38 children in the control group had normal tympanogram with Y_{tm} between 0.3 and 1.4 mmhos (mean = 0.57 mmho, SD = 0.23 mmho, range = 0.3–1.1 mmho) and TPP of within 6100 daPa (mean = −10 daPa, SD = 35.58 daPa, range = −100 to 30). In the OME group, a total of 52 ears had flat tympanograms and six ears had negative middle ear pressure with a mean TPP of −200 daPa (SD = 95 daPa, range = −105 to −335 daPa) and normal Y_{tm}. Two ears had normal tympanograms with a mean TPP of −17 daPa (range = − 45 to 10 daPa) and normal Y_{tm}.

Complete TEOAE data sets were available for the control group but not for the OME group. All 60 ears of children in the control group passed the TEOAE test. In the OME group, four ears passed and 36 ears failed the TEOAE test. TEOAE data were not available for 20 ears mainly because of lack of cooperation from the child and insufficient time as tests were performed one hour before the surgery.

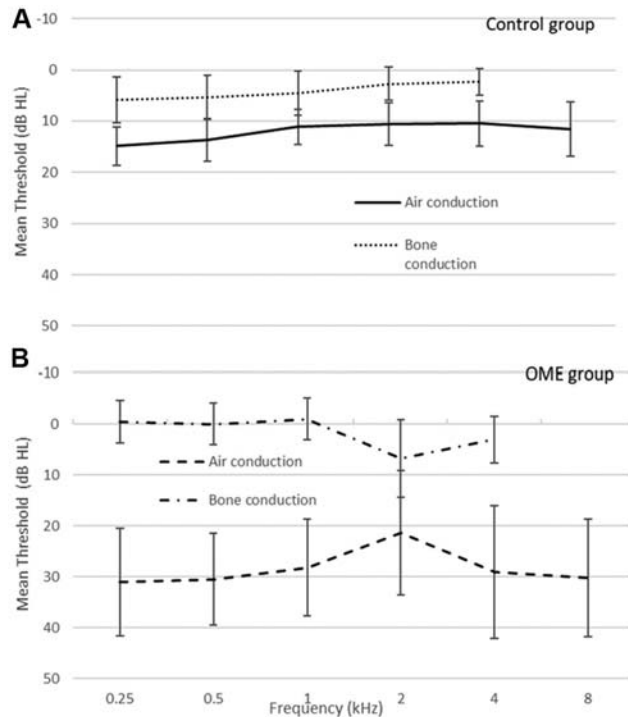

Fig. 1 Mean AC and BC thresholds of participants in (**A**) control and (**B**) OME group. Error bar denotes ±1 SD.

Initially, 93 ears from 58 children were suspected to have OME based on otoscopic and audiometric findings. Of these, 33 ears from 20 children were found not to have fluid during surgery. Effusion was noted in 60 ears from 38 children during surgery and only results from ears with confirmed OME were used for further analysis and to test the predictive accuracy of WBA.

►**Figure 1** shows the mean AC and BC thresholds of ears in the control and OME group. AC and BC thresholds were available for all 60 ears of 38 children in the control group and 30 ears of 19 children in the OME group. The OME group demonstrated a mild conductive hearing loss throughout the frequency range with better AC thresholds, but worse BC thresholds at 2 kHz than that at other frequencies.

►**Figure 2(A)** illustrates mean WBA_A and shaded area (interquartile range [IQR], range between 25^{th} and 75^{th} percentiles) from 0.25 to 8 kHz for the control and OME groups. Errors bar shows mean ±1 standard error of mean (SEM). Mean WBA_A for both groups showed a single-peaked pattern at 3 kHz. Mean WBA_A of the control group increased gradually from 0.09 at 0.25 kHz to reach a maximum of 0.86 at 3 kHz, and then decreased rapidly with frequency to 0.14 at 8 kHz. In comparison, mean WBA_A of the OME group varied between 0.08 and 0.28 from 0.25 to 1.5 kHz, increased gradually until it reached a maximum of 0.42 at 3 kHz, and then decreased rapidly with frequency to 0.17 at 8 kHz. Mean WBA_A of the OME group was below the 25^{th} percentile of mean WBA_A of the control group at all frequencies between 0.4 and 6 kHz. In comparison, mean WBA_A of the control group was above the 75^{th} percentile of the OME group at all frequencies.

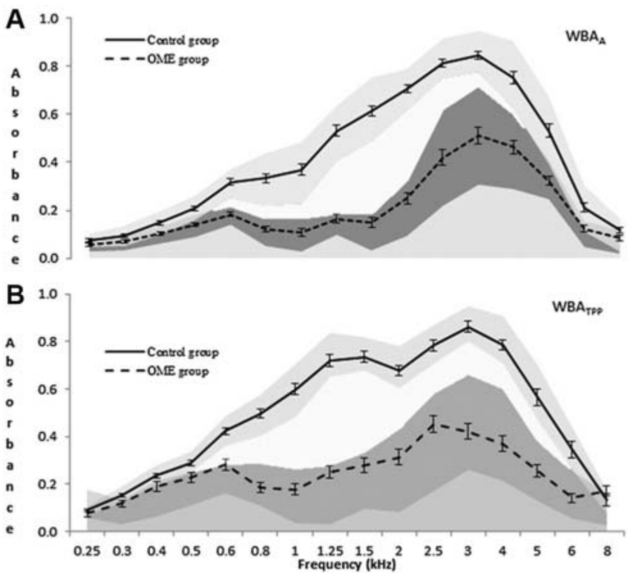

Fig. 2 (A) Mean WBA_A and IQR from 0.25 to 8 kHz for the control and OME group. (B) Mean WBA_{TPP} and IQR from 0.25 to 8 kHz for the control and OME group. Vertical bars denote mean ±1 SEM. Shaded areas denote IQR (control group—light gray shading; OME group—dark gray shading).

An ANOVA was performed with WBA_A as the dependent variable and ear condition (control versus OME group) and frequency as independent variables. The results showed a significant main effect for ear condition [$F_{(1, 118)} = 293.01$, $p < 0.001$, partial eta square = 0.71, observed power = 1]. The main effect of frequency [$F_{(4, 468)} = 280.68$, $p < 0.001$, partial eta square = 0.70, observed power = 1] and interaction between ear condition and frequency [$F_{(4, 468)} = 45.15$, $p < 0.001$, partial eta square = 0.28, observed power = 1] were also significant.

A series of t-tests applied to the WBA_A data showed that mean WBA_A of the OME group was significantly lower than that of the control group at frequencies between 0.25 and 6 kHz and frequency bands of 0.3–2, 1–2, and 2–8 kHz (►**Table 2**).

The results of an ANOVA with WBA_{TPP} as the dependent variable showed a significant main effect for ear condition [$F_{(1, 55)} = 77.43$, $p < 0.001$, partial eta square = 0.59, observed power = 1]. The main effect of frequency [$F_{(4, 259)} = 8.48$, $p < 0.001$, partial eta square = 0.59, observed power = 1] and interaction between ear conditions and frequency [$F_{(4; 259)} = 20.95$, $p < 0.001$, partial eta square = 0.28, observed power = 1] were also significant.

►**Figure 2(B)** illustrates the mean WBA_{TPP} and IQR from 0.25 to 8 kHz for the control and OME groups. Mean WBA_{TPP} for the control group showed two large peaks with the first peak occurring at 1.25–1.5 kHz and the second peak at 3 kHz. Mean WBA_{TPP} was reduced <1.25 and >3 kHz. In comparison, mean WBA_{TPP} of the OME group showed a large peak occurring at 2.5 kHz. Mean WBA_{TPP} of OME group was lower than that of the 25^{th} percentile of the control group at all frequencies between 0.4 and 6 kHz. On the other hand, mean

Table 2 Mean, SEM, Significance of Difference and Magnitude of Effect in WBA_A between the Control and Otitis Media with Effusion (OME) Group

Frequency (kHz)	Control Group, n = 60 Ears Mean ± SEM	OME Group, n = 60 Ears Mean ± SEM	t-Value	Eta Square	Observed Power
0.25	0.08 ± 0.01	0.06 ± 0.01	2.16*	0.04	0.57
0.3	0.09 ± 0.01	0.07 ± 0.01	2.28*	0.04	0.62
0.4	0.15 ± 0.01	0.10 ± 0.01	3.77*	0.11	0.96
0.5	0.21 ± 0.01	0.14 ± 0.01	5.02*	0.18	0.99
0.6	0.32 ± 0.01	0.18 ± 0.01	8.13*	0.36	1.00
0.8	0.33 ± 0.02	0.12 ± 0.02	8.81*	0.40	1.00
1	0.37 ± 0.02	0.11 ± 0.02	8.91*	0.40	1.00
1.25	0.53 ± 0.02	0.17 ± 0.02	11.87*	0.54	1.00
1.5	0.61 ± 0.02	0.15 ± 0.02	15.24*	0.66	1.00
2	0.70 ± 0.02	0.25 ± 0.02	16.07*	0.69	1.00
2.5	0.81 ± 0.02	0.42 ± 0.02	11.04*	0.51	1.00
3	0.85 ± 0.02	0.51 ± 0.02	8.52*	0.38	1.00
4	0.75 ± 0.03	0.46 ± 0.03	7.77*	0.34	1.00
5	0.53 ± 0.03	0.32 ± 0.03	6.04*	0.24	1.00
6	0.21 ± 0.02	0.12 ± 0.02	3.96*	0.12	0.98
8	0.12 ± 0.01	0.09 ± 0.01	1.89	0.03	0.47
0.3–2	0.37 ± 0.01	0.14 ± 0.01	13.56*	0.61	1.00
1–2	0.55 ± 0.02	0.17 ± 0.02	15.28*	0.66	1.00
2–8	0.57 ± 0.01	0.31 ± 0.01	13.81*	0.62	1.00

*Significant difference with $p < 0.05$.

Table 3 Mean, SEM, Significance of Difference and Magnitude of Effect inWBA$_{TPP}$ between the Control and OME Group

Frequency (kHz)	Control Group, n = 60 Ears Mean ± SEM	OME Group, n = 60 Ears Mean ± SEM	t-Value	Eta Square	Observed Power
0.25	0.09 ± 0.01	0.08 ± 0.02	21.98	0.07	0.49
0.3	0.15 ± 0.01	0.12 ± 0.02	1.57	0.05	0.34
0.4	0.24 ± 0.01	0.19 ± 0.02	1.61	0.05	0.35
0.5	0.29 ± 0.01	0.23 ± 0.02	1.53	0.04	0.32
0.6	0.42 ± 0.01	0.28 ± 0.02	3.22*	0.17	0.89
0.8	0.49 ± 0.02	0.18 ± 0.02	5.05*	0.33	1.00
1	0.60 ± 0.02	0.18 ± 0.02	7.56*	0.53	1.00
1.25	0.72 ± 0.03	0.25 ± 0.03	9.28*	0.63	1.00
1.5	0.74 ± 0.02	0.28 ± 0.03	7.88*	0.55	1.00
2	0.68 ± 0.02	0.31 ± 0.03	6.85*	0.48	1.00
2.5	0.78 ± 0.02	0.45 ± 0.04	6.52*	0.45	1.00
3	0.86 ± 0.02	0.42 ± 0.03	6.88*	0.48	1.00
4	0.78 ± 0.03	0.37 ± 0.03	5.62*	0.38	1.00
5	0.56 ± 0.03	0.26 ± 0.03	4.97*	0.33	1.00
6	0.35 ± 0.02	0.14 ± 0.02	4.02*	0.24	0.98
8	0.14 ± 0.03	0.17 ± 0.02	0.28	0.00	0.06
0.3–2	0.62 ± 0.02	0.29 ± 0.02	6.80*	0.48	1.00
1–2	0.68 ± 0.02	0.23 ± 0.03	8.91*	0.61	1.00
2–8	0.60 ± 0.02	0.30 ± 0.02	8.12*	0.56	1.00

*Significant difference with $p < 0.05$.

WBA$_{TPP}$ of the control group was above the 75th percentile of the OME group at all frequencies except 8 kHz.

Mean WBA$_{TPP}$ of the OME group was significantly lower than that of the control group at frequencies between 0.6 and 6 kHz and frequency bands of 0.3–2, 1–2, and 2–8 kHz as indicated by the t-test results (see ►**Table 3**).

►**Figure 3** shows the comparison of mean absorbance at WBA$_A$ and WBA$_{TPP}$ for the control and OME groups. Error bar shows mean ±1 SEM. An ANOVA was applied to assess the difference in absorbance across the two WBA measures for each group. The results showed a significant difference between the two measures, with WBA$_{TPP}$ showing significantly higher absorbance between 0.3 and 1.5 kHz, and 6 kHz for the control group and between 0.25 and 1.5 kHz, and 6 kHz for the OME group.

►**Table 4** summarizes the AROC, 95% confidence intervals (CIs), cutoff value, sensitivity, and specificity of WBA$_A$ and WBA$_{TPP}$ for each of the one-third octave frequency between 0.25 and 8 kHz and frequency bands of 0.3–2, 1–2, and 2–8 kHz. The diagnostic accuracy of WBA$_A$ was higher than 0.7 in the frequency between 0.6 and 4 kHz and frequency bands of 0.3–2, 1–2, and 2–8 kHz. The AROC was highest at 1.5 kHz (0.92) followed by 1.25 kHz (0.90). The sensitivity of WBA$_A$ reached the highest values of 0.92 and 0.88 at 1.5 and 1.25 kHz, respectively. In comparison, the specificity of WBA$_A$ remained high across the entire frequency range.

The diagnostic accuracy of WBA$_{TPP}$ was higher than 0.7 in the frequency between 0.3 and 5 kHz and frequency bands of

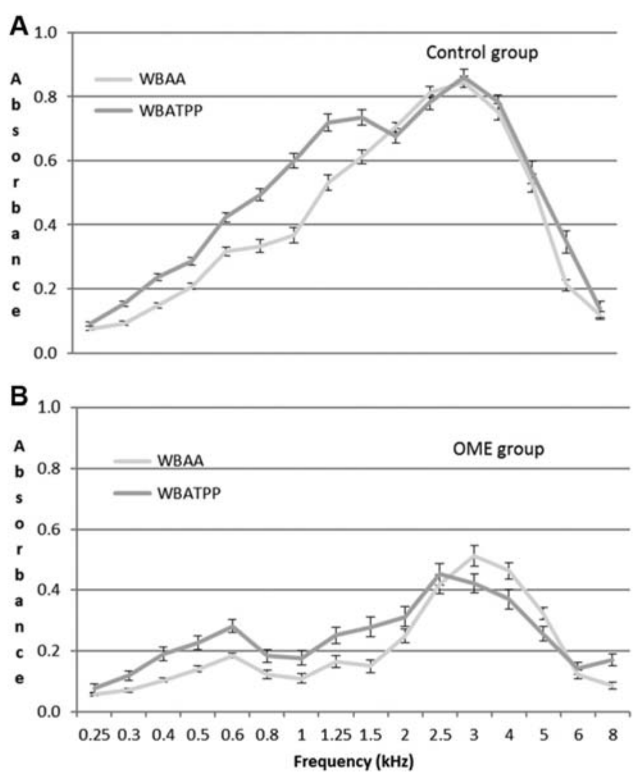

Fig. 3 Comparison of mean WBA$_A$ and WBA$_{TPP}$ conditions for (**A**) control and (**B**) OME group. Error bar denotes ±1 SEM. Significant difference with $p < 0.05$ noted at 0.3–1.5 and 6 kHz for control group and 0.25–1.5 and 6 kHz for OME group.

Table 4 The Area Under the Receiver Operating Curve (AROC) and Corresponding CIs, Sensitivity, and Specificity for WBA_A and WBA_{TPP}

Frequency (kHz)	WBA_A					WBA_{TPP}				
	AROC	95% CI	Cutoff WBA_A	Sensitivity	Specificity	AROC	95% CI	Cutoff WBA_{TPP}	Sensitivity	Specificity
0.25	0.45	0.35–0.55	0.01	0.00	0.90	0.58	0.45–0.70	0.05	0.21	0.94
0.30	0.49	0.39–0.60	0.02	0.07	0.92	0.79*	0.69–0.89	0.10	0.64	0.94
0.40	0.56	0.46–0.66	0.06	0.18	0.93	0.79*	0.70–0.89	0.17	0.66	0.94
0.50	0.64	0.54–0.74	0.10	0.35	0.93	0.74*	0.64–0.85	0.20	0.55	0.94
0.60	0.71*	0.61–0.80	0.19	0.50	0.92	0.86*	0.78–0.94	0.32	0.79	0.94
0.80	0.79*	0.71–0.88	0.15	0.67	0.92	0.90*	0.82–0.97	0.33	0.82	0.97
1.00	0.80*	0.72–0.88	0.11	0.68	0.92	0.90*	0.82–0.97	0.36	0.86	0.94
1.25	0.90*	0.84–0.96	0.28	0.88	0.92	0.91*	0.83–0.98	0.54	0.88	0.94
1.50	0.92*	0.86–0.97	0.39	0.92	0.92	0.82*	0.73–0.91	0.53	0.73	0.90
2.00	0.87*	0.80–0.94	0.57	0.73	1.00	0.84*	0.76–0.92	0.50	0.75	0.94
2.50	0.85*	0.78–0.92	0.63	0.78	0.92	0.81*	0.71–0.90	0.60	0.71	0.90
3.00	0.79*	0.71–0.88	0.68	0.72	0.88	0.78*	0.68–0.88	0.61	0.66	0.90
4.00	0.72*	0.62–0.81	0.49	0.53	0.90	0.78*	0.68–0.88	0.55	0.66	0.90
5.00	0.55	0.45–0.65	0.23	0.18	0.92	0.75*	0.65–0.86	0.27	0.57	0.94
6.00	0.58	0.48–0.69	0.05	0.25	0.92	0.66*	0.55–0.78	0.15	0.39	0.94
8.00	0.52	0.41–0.62	0.00	0.03	1.00	0.62	0.50–0.74	0.02	0.34	0.90
0.3–2	0.91*	0.85–0.97	0.24	0.95	0.87	0.86*	0.77–0.94	0.48	0.82	0.92
1–2	0.92*	0.86–0.97	0.38	0.92	0.92	0.88*	0.81–0.96	0.51	0.86	0.90
2–8	0.90*	0.84–0.96	0.44	0.90	0.90	0.88*	0.81–0.96	0.44	0.83	0.93

*Significant difference with $p < 0.05$.

Table 5 Summary of AROC, SEM, and 95% CI for WBA_A, WBA_{TPP}, and 226-Hz Tympanogram (Y_{tm})

	AROC	SEM	95% CI
WBA_A (1.5 kHz)	0.92	0.03	0.86–0.97
WBA_{TPP} (1.2 kHz)	0.91	0.04	0.83–0.98
Y_{tm} (226 Hz)	0.93	0.03	0.88–0.99

0.3–2, 1–2, and 2–8 kHz. The AROC was highest at 1.25 kHz (0.91), followed by 1 and 0.8 kHz (0.90). The sensitivity of WBA_{TPP} reached the highest values of 0.88 and 0.86 at 1.25 and 1 kHz, respectively, whereas the specificity of WBA_{TPP} remained high across the entire frequency range. Statistical significance of the difference in AROC between WBA_A and WBA_{TPP} was determined as suggested by Hanley and McNeil.[16] AROC for WBA_{TPP} was significantly higher than WBA_A at 0.3, 0.4, 0.6, and 5 kHz.

►**Table 5** shows a summary of AROC and corresponding SEM and 95% CI for WBA_A at 1.5-kHz and WBA_{TPP} at 1.2-kHz and 226-Hz Ytm tympanogram. These frequencies were selected because of the optimal performance of WBA at these frequencies. Comparison of AROC among these measures revealed no significant differences among the WBA_A, WBA_{TPP}, and 226-Hz tympanometry.

►**Figure 4** shows a comparison of the mean WBA_A and WBA_{TPP} for the control group with that of the three tympanogram types of the OME group. Mean WBA_A of the control group showed a single peak at 3 kHz, whereas mean WBA_{TPP} showed two prominent peaks at 1.5 and 3.5 kHz. For ears with OME with normal tympanogram, both mean WBA_A and WBA_{TPP} showed a single peak. For ears with OME with flat tympanograms, both mean WBA_A and WBA_{TPP} showed the lowest absorbance. For ears with OME with negative middle ear pressure, both WBA_A and WBA_{TPP} showed absorbance in between OME with normal and flat tympanograms.

►**Figure 5** shows a comparison of mean WBA_A for both the control and OME group of the present study with that obtained by Keefe et al[26] and Terzi et al.[53] The results of the present study resembled closely with those of the study by Keefe et al.[26] Terzi et al[53] showed improved absorbance for their control group ~1–2 kHz and OME group ~1.5–3 kHz.

Subjective rating of the OME fluid as thick or thin by operating ENT surgeon was analyzed in this study. ►**Figure 6** compares WBA_A and WBA_{TPP} for the OME group with thick and thin fluid with that of the control group. Mean WBA_A obtained for both thick and thin fluid conditions were similar. However, mean WBA_{TPP} obtained for the thin fluid was higher than that for thick fluid across 0.25–8 kHz.

Discussion

The results of the study showed no significant ear, gender, or gender by ear interaction effects on WBA_A and WBA_{TPP}. These

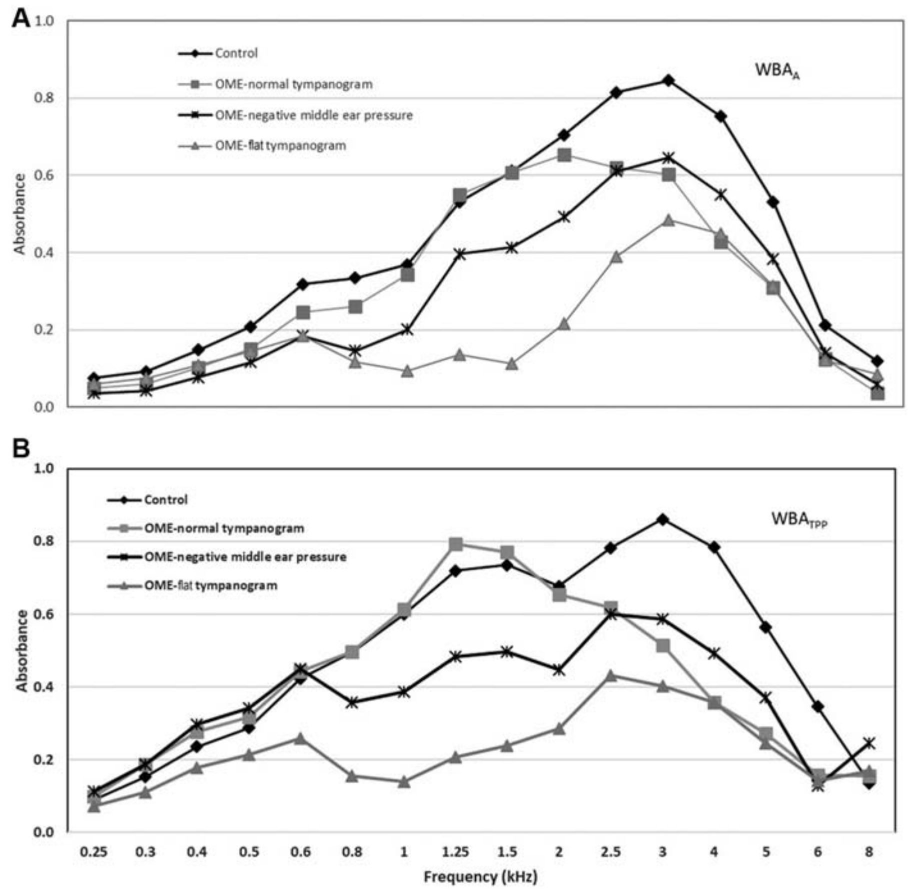

Fig. 4 Comparison of (A) WBA$_A$ and (B) WBA$_{TPP}$ for control group and OME group with different types of tympanograms.

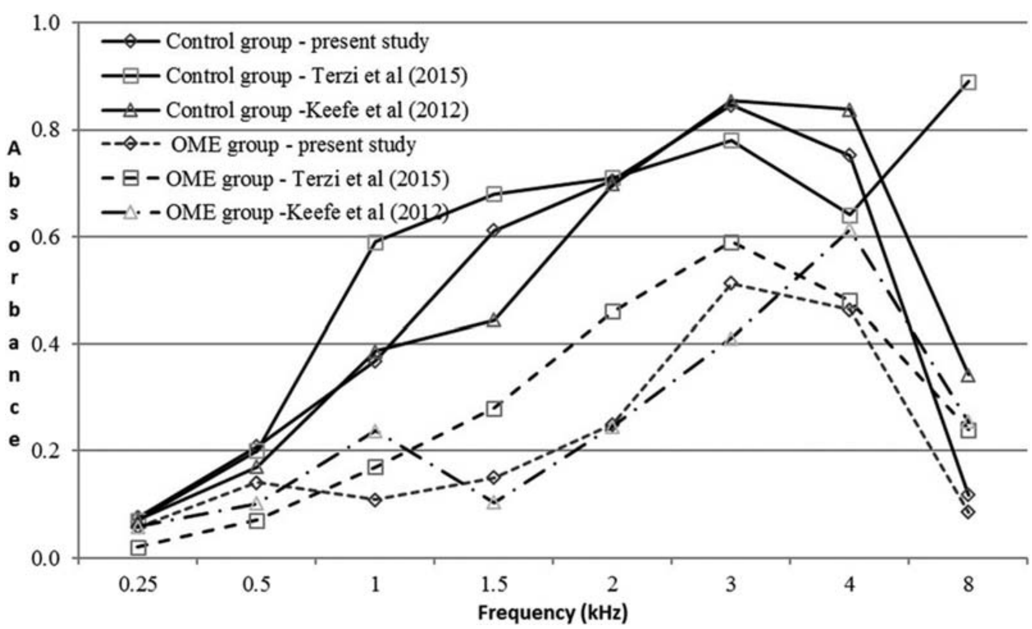

Fig. 5 Comparison of mean WBA$_A$ with control and OME group of the present study with WBA$_A$ of the studies by Keefe et al[26] and Terzi et al.[53]

findings are consistent with the previous studies (Hunter, Bagger-Sjoback, et al[18]; Beers et al[6]), which reported no significant differences in WBA$_A$ across ears and genders. On the other hand, the effect of gender on WBA$_A$ is inconclusive. For example, Shahnaz et al[46] reported that WBA$_A$ varies differently between females and males across frequencies. The males had lower absorbance at 4 and 5 kHz than females. Although the source of these ear and gender differences is not known, it may be partly due to the methodological differences, including age range of

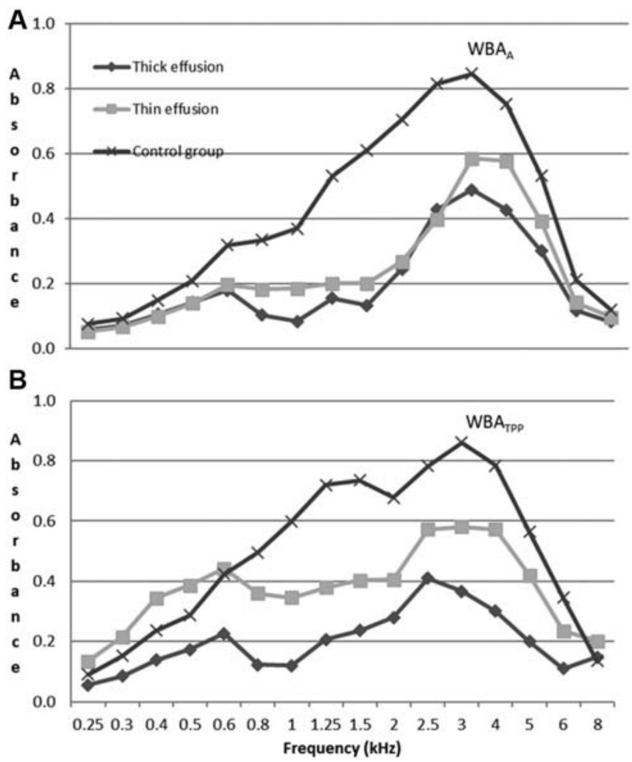

Fig. 6 Comparison of (**A**) WBA$_A$ and (**B**) WBA$_{TPP}$ for control and OME group with thick and thin effusion as determined by ENT surgeon during surgery.

participants, equipment, calibration, and selection criteria used in the respective studies.

In the present study, results showed a significant group effect for ear conditions (control versus OME group) for both WBA$_A$ and WBA$_{TPP}$ This study also noted a significant main effect for frequency and frequency by ear conditions for both WBA$_A$ and WBA$_{TPP}$ tests, suggesting that the absorbance pattern across frequency was different for each group. Mean WBA$_A$ of the control group increased gradually from 0.25 kHz to reach a maximum at 3 kHz. In comparison, mean WBA$_A$ of the OME group was relatively stable with only 10% variation and increasing gradually to reach a maximum at 3 kHz. Mean WBA$_A$ of the OME group was lower than the 25th percentile of WBA$_A$ of control group at all frequencies between 0.4 and 6 kHz. In comparison, mean WBA$_A$ of the control group was above the 75th percentile of the OME group at all frequencies (►**Figure 2A**).

Mean WBA$_{TPP}$ for the control group showed two large peaks with the first peak occurring at 1.25–1.5 kHz and the second peak at 3 kHz. In comparison, mean WBA$_{TPP}$ of the OME group showed a large peak at 2.5 kHz. Mean WBA$_{TPP}$ of the OME group was lower than that of the 25th percentile of the control group at all frequencies between 0.4 and 6 kHz. On the other hand, mean WBA$_{TPP}$ of the control group was above the 75th percentile of the OME group at all frequencies except 8 kHz (►**Figure 2B**).

In the control group, both mean WBA$_A$ and WBA$_{TPP}$ were the highest between 1 and 4 kHz and reduced <1 kHz and >4 kHz (►**Figure 3A**). These findings were consistent with the results of several studies that have reported absorbance to vary across frequencies in children (Beers et al[6]; Ellison et al[8]). The frequency region between 1 and 4 kHz is the most sensitive frequency region for middle ear assessments as energy is transmitted most efficiently through the middle ear. Hence, any change in middle ear transmission due to middle ear dysfunction can easily be detected in this region. Studies by Keefe et al,[26] Ellison et al[8] and Sanford and Brockett[41] demonstrated that absorbance at frequencies between 1 and 4 kHz provided good discriminability of middle ear function in children.

The main aim of the present study was to compare the predictive accuracy of WBA$_A$ and WBA$_{TPP}$ to detect OME in children. The present study showed that both WBA$_A$ and WBA$_{TPP}$ identified OME with high accuracy. The frequency region between 1 and 2.5 kHz had the highest accuracy (AROC $\geq$0.80) for WBA$_A$, whereas the frequency region between 0.6 and 2.5 kHz had the highest accuracy for WBA$_{TPP}$. Optimal test performance for WBA$_A$ was achieved at 1.5 kHz with an AROC of 0.92 and sensitivity and specificity of 0.92. In comparison, optimal test performance for WBA$_{TPP}$ was obtained at 1.25 kHz with an AROC of 0.91, sensitivity of 0.88, and specificity of 0.94. Overall, WBA$_{TPP}$ showed predictive accuracy across a wider frequency region (0.3–6 kHz) with better sensitivity than WBA$_A$ (0.6–4 kHz). The AROC for WBA$_{TPP}$ was significantly greater than that for WBA$_A$ at 0.3, 0.4, and 0.6 kHz. These results suggest that WBA$_{TPP}$ can provide additional and diagnostically useful information across a wider frequency region than WBA$_A$.

In comparison, several studies have investigated the predictive accuracy of WBA$_A$ in identifying OME in children (Ellison et al[8]; Keefe et al[26]; Terzi et al[53]). Terzi et al[53] compared WBA$_A$ in healthy children and children diagnosed with OME during myringotomy. They reported that WBA$_A$ had high diagnostic values at 1 and 1.5 kHz with an AROC of 0.973 and 0.967, respectively. Ellison et al[8] reported an AROC of 0.93 for a univariate measure of WBA$_A$ determined across frequencies 0.25–8 kHz. Beers et al[6] compared WBA$_A$ in children with normal middle ear status and children with OME confirmed through pneumatic otoscopy and video otomicroscopy. They reported high diagnostic accuracy with AROC between 0.95 and 0.97 at 1–4 kHz. The highest accuracy of 0.97 was observed at 1.2 and 1.6 kHz. However, the present study showed an AROC of 0.90 at 1.25 kHz and 0.92 at 1.5 kHz for WBA$_A$, 0.90 at 0.8 kHz and 1 kHz, and 0.91 at 1.25 kHz for WBA$_{TPP}$. Although the present study demonstrated that both WBA$_A$ and WBA$_{TPP}$ could predict OME in children with high accuracy, they were slightly lower when compared with that of the above studies. The discrepancies could be due to the use of different subject samples and methods.

The present study also evaluated the diagnostic accuracy of 226-Hz tympanometry against surgical findings as the gold standard. The results showed high predictive accuracy with an AROC of 0.93 (95% CI: 0.88–0.99). These results are comparable with the optimal test performance of WBA$_A$ at 1.5 kHz (AROC 0.92; 95% CI: 0.86–0.97) and WBA$_{TPP}$ at 1.25 kHz (AROC 0.91; 95% CI: 0.83–0.98). However, these results are not consistent with those obtained by Beers et al[6] who noted that the AROC of

WBA_A at 1.25 kHz (AROC 0.97; 95% CI: 0.94–0.99) was greater than that of 226-Hz tympanometry using Y_{tm} (AROC 0.81; 95% CI: 0.75–0.87). Similarly, Keefe et al[26] reported that both WBA_A and tympanometric WBA tests were better predictors of conductive hearing loss (AROC values ≥0.97) than 226-Hz tympanometry using tympanometric width as the dependent variable (AROC ranging from 0.68 to 0.93). Furthermore, they found no significant difference in AROC between WBA_A and tympanometric WBA. Terzi et al[53] also reported WBA_A to be more accurate than 226-Hz tympanometry using qualitative measures of classifying tympanograms.

The main reason for the difference between the present study and the aforementioned studies could be due to the fact that dry ears were not included in the present study, whereas the studies by Keefe et al[26] and Beers et al[6] might have included dry ears as there was no surgical confirmation of middle ear effusions. Another reason could be due to ceiling effect where all three tests are equally effective in identifying ears with definite effusion, whereas they may perform differently when there is a varying degree of difficulties in separating ears with OME from normal ears.

Ellison et al[8] investigated the test performance of WBA_A to detect OME and reported an AROC of 0.93 (95% CI: 0.87–0.97). They also measured admittance magnitude (AROC: 0.93; 95% CI: 0.87–0.97), phase angle (AROC: 0.90; 95% CI: 0.82–0.95), and combined predictor of all three measures (AROC: 0.94; 95% CI: 0.88–0.98) and noted no significant differences between them. However, Ellison et al[8] used pneumatic otoscopy results as the reference standard and concluded that WBA_A measures are at least as effective in predicting the presence of fluid in OME cases as those methods currently recommended by clinical guidelines which includes pneumatic otoscopy and 226-Hz tympanometry.

WBA_A and WBA_{TPP} with different tympanometric patterns (normal, negative middle ear pressure and flat) obtained with the OME group was analyzed. In total, 52 ears had flat tympanograms, six ears had negative middle ear pressure and two ears had normal tympanograms in the OME group. As illustrated in ►**Figure 4**, in general, for all the tympanogram types, both mean WBA_A and WBA_{TPP} were reduced from 0.25 to 0.5 kHz. Between 0.5 and 2.5 kHz, OME ears with normal tympanogram had the l argest mean WBA_A and WBA_{TPP} with values approaching the control group and slightly better than the control group at 1.25 and 1.5 kHz and decreasing steeply >2.5 kHz for mean WBA_{TPP}.

In comparison, ears with flat tympanograms in the OME group showed the lowest absorbance for both mean WBA_A and WBA_{TPP}. OME ears with negative middle ear pressure showed absorbance in between OME with normal and flat tympanograms. OME ears with negative middle ear pressure and normal tympanogram demonstrated improvement in mean WBA_{TPP} relative to mean WBA_A from 0.5 to 2.5 kHz and reduced absorbance >2.5 kHz. Despite the small number of ears with negative middle ear pressure, WBA_{TPP} provides useful data for ears with pre-exiting middle ear pathology and negative middle ear pressure. WBA_{TPP} measure compensates for the effect of the difference in pressure between the ear canal and the middle ear. For example, when child has a middle ear condition (fluid in the middle ear) plus Eustachian tube dysfunction (significant negative pressure), the WBA_{TPP} results will be significantly reduced when compared with control group even after compensating for the pressure differences. This may indicate presence of a pre-existing pathological condition (OME) in addition to Eustachian tube dysfunction as suggested by Margolis et al.[32]

Mean WBA_A of children in the control and OME groups was compared with the previously reported studies by Keefe et al[26] and Terzi et al.[53] ►**Figure 5** shows the comparison of mean WBA_A with control and OME groups of present study with other studies. Apart from slight differences in the WBA_A, the results of the present study were comparable with those reported by the earlier studies. Results of control and OME group in the present study resembled closely to Keefe et al[26] study, whereas results of the study by Terzi et al[53] showed improved absorbance for the control group ~1–2 kHz and OME group ~1.5–3 kHz. Mean WBA_A in healthy ears were highest between 2 and 4 kHz and reduced <2 and >4 kHz. Mean WBA_A was reduced in ears with OME across all frequencies when compared with healthy ears.

The present study also analyzed the absorbance result based on thickness of the middle ear fluid as determined by an experienced ENT surgeon. Although classification of middle ear fluid was subjective, it revealed interesting findings. Both thick and thin fluid demonstrated similar absorbance pattern for WBA_A with thin fluid showing slightly better absorbance between 0.8 and 2.5 kHz, and between 3 and 6 kHz. However, under WBA_{TPP} condition, thin fluid showed higher absorbance across the frequency range from 0.25 to 8 kHz, suggesting that WBA_{TPP} may have the ability to identify the thickness and/or viscosity of the middle ear fluid.

Several researchers have suggested that considering WBA over a frequency band is better than WBA at individual frequencies (Hunter et al[19]; Ellison et al[8]; Terzi et al[53]). For instance, Hunter et al[19] proposed area indices and they reported that absorbance in the frequency ranges ~2 kHz (e.g., 1–2, 1–4, 2–4 kHz) provided the best prediction of referring on distortion product otoacoustic emissions in neonates. Terzi et al[53] investigated the efficiency of WBA_A in identifying OME in children and reported that WBA averaged from 0.375 to 2 kHz had the highest diagnostic value of 0.984. Ellison et al[8] combined the multivariate information across frequencies into a univariate predictor and reported an AROC of 0.93 for WBA_A for diagnosing OME. The present study showed an AROC of 0.92 for averaged WBA_A between 1 and 2 kHz, 0.91 for averaged between 0.3–2 kHz and 0.90 for averaged between 2 and 8 kHz. These values agree with the above studies that have demonstrated high AROC for WBA_A averaged over a frequency band. Nevertheless, AROC averaged across 1–2 kHz for WBA_A was the same as AROC obtained at 1.5 kHz. However, AROC averaged across 1–2 kHz for WBA_{TPP} (0.88) was less than AROC at individual frequencies of 0.8, 1, and 1.25 kHz (►**Table 4**).

Implications of the Study

The high test performance of WBA_A and WBA_{TPP} against myringotomy suggests that both measures have high predictive accuracy for identification of OME in children. However,

WBA_{TPP} showed predictive accuracy across a wider frequency range (0.3–6 kHz) than WBA_A (0.6–4 kHz). In addition to this, WBA_{TPP} provides useful data for ears with both fluid and negative middle ear pressure conditions indicating that WBA_{TPP} can provide additional and diagnostically useful information such as reduced absorbance even after compensating for the pressure differences (Aithal et al[1]).

There was no significant difference in the predictive accuracy of WBA_A and WBA_{TPP} when compared with 226-Hz admittance tympanometry and neither test performed significantly better than the other in identifying ears with definite effusion as confirmed by surgery. However, in clinical situations, WBA and 226-Hz admittance tympanometry may perform differently when there are varying degrees of OME.

The result of the present study also suggests that apart from individual frequencies, WBA_A and WBA_{TPP} in the frequency band between 0.3 and 2 kHz, 1 and 2 kHz, and 2 and 8 kHz may identify the presence of OME in children. The cutoff values of 1–2 kHz averaged mean absorbance values of 0.38 and 0.51 for WBA_A and WBA_{TPP}, respectively, in the present study (►**Table 4**) may suggest the presence of OME in children. Cutoff values for other frequency bands are provided in the ►**Table 4**.

The result of the present study also suggests that WBA_{TPP} may have the ability to classify the middle ear fluid as thick or thin noninvasively and may become a useful clinical tool to predict the nature of the middle ear fluid preoperatively. However, a large-scale study with objective methods of classifying middle ear fluid along with other wideband immittance measures is needed to confirm this observation.

Limitations of the Study

The loose age criterion for inclusion of children in the OME group could have confounded the results in the present study. Because of small sample size under different age group, effect of age was not studied in this study. The 10th percentile cutoff WBA_A and WBA_{TPP} values were based on the normative values for the control group with an age range of 4.11–11.4 years and applied to the OME group where the age ranged from 1.1 to 14.3 years. Keefe et al[24] have shown that developments of the conductive system that strongly affect the acoustic responses of the ear are not complete at 24 months of age. Therefore, it is important to develop age-specific criteria for WBA_A and WBA_{TPP} for the determination of OME in younger children.

Another limitation of the study is that compensation was not done for the residual positive pressure during the probe insertion. This could have an impact on the results as the residual positive pressure due to probe insertion could potentially be different in both the control and OME group. Furthermore, WAI measures of admittance, phase angle, equivalent ear canal volume, and resonance frequency were not analyzed in this study. It is possible that these measurements may provide distinctive profiles that might be useful for discrimination of different middle ear pathologies as suggested by Sanford and Brockett[41] and may be useful in separating dry ears from ears with fluids in OME cases.

Conclusions

Both WBA_A and WBA_{TPP} demonstrated high test performance in predicting OME, but neither test performed significantly better than the other or 226-Hz admittance tympanometry. WBA_{TPP} showed predictive accuracy across a wider frequency region than WBA_A. The AROC for WBA_A was highest (0.92) at 1.5 kHz, whereas the AROC for WBA_{TPP} was highest (0.91) at 1.25 kHz.

Abbreviations

AC	air conduction
ANOVA	analysis of variance
AROC	area under ROC
BC	bone conduction
CI	confidence intervals
ENT	ear nose and throat
IQR	interquartile range
OME	otitis media with effusion
ROC	receiver operating characteristics
TEOAEs	transient evoked otoacoustic emissions
TPP	tympanometric peak pressure
WAI	wideband acoustic immittance
WBA	wideband absorbance
WBA_A	wideband absorbance measured at ambient pressure
WBA_{TPP}	wideband absorbance measured at tympanometric peak pressure
WBT	wideband tympanometry

Conflict of Interest
None declared.

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