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OTOLOGY

Clinical benefit of wideband-tympanometry: a pediatric audiology clinical study

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Abstract

Purpose Wideband-tympanometry (WBT) could give more informative data about the tympanic condition than the conventional tympanometry. In the actual literature, the clinical profit of wideband-tympanometry in pediatric audiological settings is not well evaluated. The aim of this study was to analyze the additional clinical benefit.

Methods 150 children (281 ears) with normal hearing, at the age from 11 days up to 14;10 years, checked with pure tone audiometry or auditory brainstem responses (ABR) participated in this retrospective study. We divided in four age ranges (≤ 6 month; > 6 month ≤ 3 years; > 3 years ≤ 11 years; > 11 years). All children were evaluated with ENT examination including ear microscopy, conventional 226-Hz or 1000-Hz tympanometry and WBT. Ear canal volumes were determined.

Results Compared with literature data, our patients aged ≤ 3 years showed smaller mean ear canal volumes (≤ 4 ml). We found a good statistical correlation between the WBT-results and 1000-Hz tympanometry but a rare correlation between WBT-results and ear microscopic findings. In the patients with pathologic ear microscopic results in all groups of age, a significant reduction of WBT-absorbance in 1000 Hz and 2000 Hz was found.

Conclusions This study confirms that WBT collects additive data to detect the correct middle ear status. In pediatric audiology, WBT is an additional useful method to value middle ear problems and to analyze the character of infantile hearing loss. Standard guidelines for the interpretation of the pediatric population are needed. Hence, it will be necessary to determine these findings in a larger number of infantile ears.

Keywords Tympanometry · Wideband-tympanometry · Otitis media with effusion · OME · Pediatric audiology · Hearing loss in childhood

Introduction

Otitis media with effusion (OME) is one of the most common diseases in early childhood. Up to 80% of children from newborn to sub-teenage are affected by this [1]. This is the reason why a solid tympanometry is necessary in every pediatric audiological clinical examination as recommended by the BIAP society [2]. The composition and viscosity of the tympanic effusion (mucosal, serous-mucosal, or serous) allows conclusions to be drawn about the characteristics of the sound conduction component as well as the spontaneous healing rate or the necessity of surgical restoration. In the case of prolonged tympanic effusion with conductive hearing loss, a speech delay could be developed [3]. Tympanometry is more effective in combination with a detailed anamnesis [4]. Therefore, tympanometry (impedance measurement) is an important part of the pediatric audiological examination. The impedance describes the resistance to an acoustic signal, compliance of the eardrum and gives information about the oscillation ability of eardrum, middle ear and ossicles. With the measurement of the acoustic admittance (inverse of impedance), the compliance is described [5]. Conventional tympanometry uses 226 Hz or 1000 Hz as probe stimuli. A higher probe frequency gives

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more information about the middle ear status, especially in newborns and infants [6] due to the lower volume of the ear canal. The ear canal rises up from 14 mm up to 35 mm [7]. In newborns, the ear canal is cartilaginous, from the fourth month of age it begins to ossify and the system changes from mass oriented to stiffness oriented [8]. Many studies show that the 1000 Hz tympanometry is more sensitive in the age from 4 to 6 months than the 226 Hz probe tone tympanometry [6, 9–11]. Limberger et al. [12] supposed that the ear canal volume could be the decisive factor to determine the right compliance. For the ear canal volume up to 0.61 ml, the 1000-Hz tympanogram showed the rather correct results. Only high-frequency signals were used to appoint the acoustic emittance to evaluate the middle ear status. However, the literature also shows that high-frequency tympanometry still could not give the right findings [13, 14].

Coletti's multi-frequency tympanometry from Coletti [15] allowed recording of the resonance frequency of the middle ear. This was the first time that a model of the middle ear was described, especially for infants [16]. With the new, so called wideband-tympanometry (WBT) it is possible to measure the energy absorbance for the spectrum from 226 Hz up to 8000 Hz. Hence, the middle ear status could be analyzed for the whole frequency band. This characteristic data adopt the value between 0 and 1 (0 and 100%). Zero implies the whole energy is reflected at the ear drum, 1 represents the maximum of energy is absorbed by the middle ear. Liu et al. and Merchant et al. [17, 18] determined normative data for adults (Liu 92 ears) and Sanford et al. [19, 20] for children (375 ears ≤ 2nd day of life who passed DPOAE and each 20 for 4-, 12-, 24-week-old infants). With the three-dimensional analysis (frequency, pressure and absorbance) enhanced information about the ear drum and middle ear system can be recorded, consequently, there are clinical data available for differential diagnosis [21]. Many authors describe studies, analysis and comparisons of WBT with other objective tests (DPOAE). Guan et al. analyzed the frequent occurrence of absorbance influence to the absorbance in a chinchilla model. They found a significantly reduced effect on the course of the absorbance in relation to the frequency [22]. Sanford and Brockett support this, by examining negative pressure and ventilation disturbances of the Eustachian Tube on 30 children with OME [23]. The comparison between WBT and classic tympanometry is described too. It can be concluded that WBT gives more information about middle ear pathologies than the classical tympanometry [19, 24, 25]. All these studies describe energy absorbance (EA), mainly in adults.

This study examines the correlation between WBT and further clinical diagnostics, like ear microscopy, classic tympanometry and pure tone audiogram, ear canal volume in children in different age ranges. The aim of this study was to get meaningful data to detect the pathological middle ear status in newborns, infants and children with WBT. The essential consideration to use the right type of tympanometry could be omitted, because WBT should give significant results in every age range, from newborn up to adult.

Materials and methods

Subjects

150 children (281 ears), 87 male and 63 female, without hearing impairment checked with pure tone audiometry (PTA) or auditory brainstem response (ABR), at the age from 11 days up to 14;10 years (mean: 44.9 months) were retrospectively analyzed in the study. The subject population was analyzed in four age groups:

- Group 1: ≤ 6 months.
- Group 2: > 6 months and ≤ 3 years.
- Group 3: > 3 years and ≤ 11 years.
- Group 4: > 11 years and ≤ 15 years.

Tympanometric testing

The wideband-tympanometry assessment was performed with the Titan Tympanometer 3.2, Suite Version 3.2.1.5 including Software OtoAccess 1.3 (Interacoustics A/S, Middelfart, Denmark).

The Titan tympanometer uses a wideband stimulus (226–8000 Hz) with a repetition rate of 21.5 Hz. Like conventional tympanometry the pressure is modified from − 600 daPa to + 300 daPa during the measurement with a pressure variation speed of 300 daPa per second. Stimulus presentation level was set to 96 peSPL (peak equivalent sound pressure level) for the age younger than 6 months and 100 peSPL above 6 months. A 3D-diagram presents the dependence absorbance on pressure and frequency. In addition to this the resonant frequency and specifications such as compliance, gradient, pressure and ear canal volume are determined. The absorption factor for the WBT is calculated using the mean of the frequency range between 800 Hz up to 2000 Hz for the younger children (≤ 6 months) and between 375 and 2000 Hz for the older children (> 6 months). All these data are relevant to identify the OME/tympanic effusion. Standard values to match the absorbance are deposited [17, 20]. This absorbance rate peak level is measured to detect pathological.

The 'classical' tympanometry at certain stimulus frequencies (226 Hz or 1000 Hz) were measured with the MAICO MI 34 system (MAICO Diagnostics GmbH, Berlin, Germany). The pressure range was + 200 to − 400 daPa with a test level 85 dB SPL in 2 cm^3 independent of age. A 2D-diagram presents the dependence

absorbance on pressure with a compliance range 0.2–3.0 ml. The ear canal volume was also measured in a range of 0.1–6.0 ml.

ENT examination

All patients underwent ear microscopic inspection of the ear canal. Children with severe ear canal stenosis or ear canal atresia and no visible ear drum were excluded from the study. Ear-wax plugs were removed. Further medical examination was done additional to the otitis media and otitis media with effusion. The microscopic results were classified into "inconspicuous" and "conspicuous" (OME and Otitis media). In the analysis, only otitis media and otitis media with effusion were matched to the WBT result as indicative.

Statistic

Statistical analyses were performed with the Software SPSS Version 22 (IBM, Armonk, NY, USA). Correlation analysis for the age, ear canal volume and resonance frequency was calculated by Pearson-correlation. Statistical significance was tested by the analysis of variance (ANOVA). p values < 0.05 were considered statistically significant.

Cohen's kappa coefficient measure (κ) was calculated to test inter-rater reliability for qualitative items. The reliability between WBT and otoscopic finding, conventional tympanometry and conductive hearing loss was analyzed.

Results

Ear canal volume

At total, 281 ears were analyzed in this study. Ear canal volume depending on age at testing as scatter plot and correlation analysis are shown in Fig. 1a. The median of the ear canal volume (Fig. 1b) for age group 1 (n = 100) and 2 (n = 48) was 0.4 ml, for age groups 3 (n = 120) 0.7 ml and age group 4 (n = 9) 1.0 ml. Children with an ear canal volume less or equal to 0.6 ml showed a higher correlation between WBT and 1000 Hz tympanometry ($\kappa = 0.65$) than 226 Hz ($\kappa = 0.54$). WBT showed a significant relation to 1000 Hz tympanometry ($\kappa = 0.70$) independently of the ear canal volume. A significant correlation between age at testing and ear canal volume ($r = 0.521$; $p < 0.01$; $n = 277$) can be found.

Absorbance

In Fig. 2, mean frequency-dependent absorbance of WBT for inconspicuous and conspicuous tympanum and the age groups are shown and normative data ranges are presented [17, 20]. Pictured are the norm data (upper and lower limit in grey area) and the curves for abnormal (red) and regular (green) ear microscopic findings. For age group 1, the measured curves are nearly as expected. The green line is completely in the norm range, by trend to the lower limit. The red curve marking OME and otitis media around 2500 Hz up to 6000 Hz is located inside the norm range. For age group 2, the area of the norm range is very different to group one,

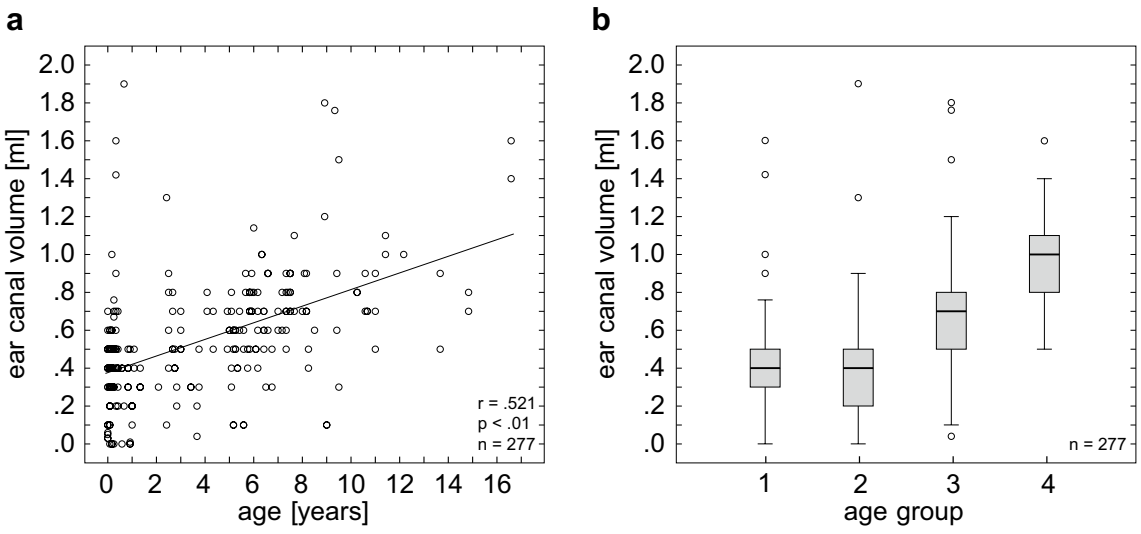

Fig. 1 Ear canal volume depending on age at testing. **a** Scatter plot and correlation analysis. **b** Box plots contains median, first and third quartiles, minimum and maximum values depending on age groups. Circles indicate outliers

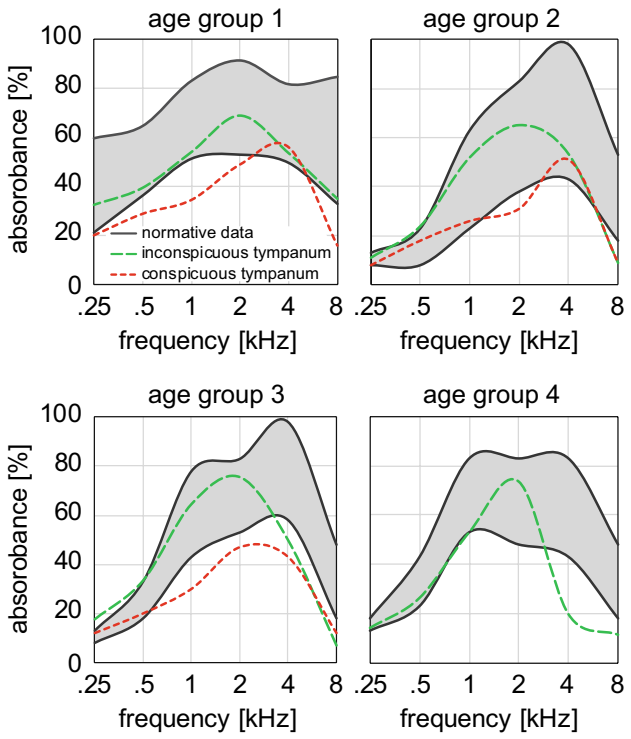

Fig. 2 WBT absorption rates depending on frequency for analyzed age groups. Normative data (grey area) are age-specific [17, 20]. Dashed lines represent absorption rates of inconspicuous and conspicuous tympanum at microscopic ear canal inspection

also the measured curves. Analyzing the green line, around 2000 Hz, the curve is pathologic outside the norm zone.

Age group 3 shows an additional aberration of the unobtrusive curve underneath 500 Hz and above 3000 Hz. The look to the frequencies above 750 Hz situated in the pathologic area shows that also the red curve differs to the expectation. Age group 4 with nine participants is too small to get statistical significant results. We only found inconspicuous reports. For these ears with normal microscopic findings, the mean curve around 2000 Hz in the normal range and for ≥ 3000 Hz underneath the lower limit.

Comparison of reports of microscopy of the ear drum

The accordance between tympanometry types and reports of a microscopy of the ear drum were analyzed. In the style of literature [7], the ear canal volume was split at 0.6 ml to screen the test type. The view of the category up to 0.6 ml shows a higher agreement between WBT and 1000 Hz (72%) than to 226 Hz (61%). Like the expectation for smaller counted ear canal, the compliance between WBT and 1000 Hz is approved. Even though that for the ear canal volume > 0.6 ml, there is a higher agreement to the 226-Hz tympanometry, it is incidental a better agreement with the 1000-Hz tympanometry, too.

Table 1 Consistency of the results of tympanic ear microscopy and the results of the tympanometry examination

	Ear canal volume	
	≤ 0.6 ml	> 0.6 ml
WBT and 226 Hz	113 (61%)	60 (67%)
WBT and 1000 Hz	132 (72%)	77 (86%)
WBT, 226 Hz and 1000 Hz	106 (57%)	53 (59%)
Number of ears	183/281	90/281

In the style of literature, the ear canal volume was split at 0.6 ml to screen the test type

The conducted measurements depending on ear canal volume (≤ 0.6 ml or > 0.6 ml) and used probe frequencies (226 Hz, 1000 Hz or both) are shown in Table 1.

Dependencies between resonant frequency and absorbance with age and pathological ear microscopic results were found (Table 2). In patients with pathologic ear microscopic results in all groups of age, a significant reduction of WBT-absorbance in 1000 Hz and 2000 Hz was found. Group 4 did not show pathological findings in otoscopy, so there was no comparison possible.

The results from the microscopic finding of an OME/tympanic effusion and abnormal WBT-results (revealed only a small agreement ($\kappa = 0.20$)) [125 peculiar results in WBT without pathological findings in otoscopy (44%)]. Abnormal WBT-results included also dysfunction of the Eustachian tube without OME.

The mean absorbance curves of the pathological otoscopic findings in group 1 from 2500 Hz up to 6000 Hz, in group 2 underneath 1500 Hz and above 2500 Hz and in group 3 underneath 500 Hz contravene the preset age-adapted standard ranges. It can be seen that many more conspicuous results of WBT are compared to the otoscopy finding (Table 3).

Discussion

This study showed that the WBT provides useful data to detect middle ear pathologies. WBT is also an efficient test method for age-independent clinical daily screening. Reliable diagnoses of middle ear pathologies are detectable, if WBT is combined with findings of anamnesis and ear microscopy and other tests in the pediatric population like pure tone audiometry or ABR.

Table 2 The absorption rates and resonant frequency dependence on age and pathological ear microscopy result were found

Age group	Frequency [Hz]	Ear microscopy report	Average [%]	SD [%]	Min [%]	Max [%]	ANOVA *p* value
Group 1	250	Inconspicuous	33	17	3	78	< 0.01
		Conspicuous	20	10	3	38	
	500	Inconspicuous	40	17	3	78	0.03
		Conspicuous	29	16	3	63	
	1000	Inconspicuous	54	23	3	98	< 0.01
		Conspicuous	35	19	3	78	
	2000	Inconspicuous	69	26	3	98	< 0.01
		Conspicuous	49	24	13	93	
	4000	Inconspicuous	54	28	3	98	0.72
		Conspicuous	56	32	3	98	
	8000	Inconspicuous	35	29	3	98	0.01
		Conspicuous	16	25	3	83	
Group 2	*250*	Inconspicuous	11	5	3	23	0.06
		Conspicuous	8	5	3	18	
	500	Inconspicuous	24	11	8	53	0.16
		Conspicuous	18	19	3	68	
	1000	Inconspicuous	52	23	3	83	< 0.01
		Conspicuous	26	24	3	73	
	2000	Inconspicuous	65	24	3	98	< 0.01
		Conspicuous	31	24	3	83	
	4000	Inconspicuous	53	27	13	98	0.83
		Conspicuous	51	30	8	93	
	8000	Inconspicuous	9	13	3	53	0.96
		Conspicuous	9	12	3	48	
Group 3	250	Inconspicuous	18	8	3	43	< 0.01
		Conspicuous	12	11	3	53	
	500	Inconspicuous	33	13	8	73	< 0.01
		Conspicuous	20	11	3	48	
	1000	Inconspicuous	65	18	8	93	< 0.01
		Conspicuous	30	20	3	83	
	2000	Inconspicuous	76	17	13	98	< .0.01
		Conspicuous	47	24	8	83	
	4000	Inconspicuous	50	27	3	98	0.34
		Conspicuous	43	38	3	93	
	8000	Inconspicuous	7	10	3	68	0.06
		Conspicuous	12	20	3	73	

Group 4 did not show pathological finding in otoscopy

Table 3 The correlation check between WBT and ear microscopy finding shows only a moderate agreement ($\kappa = 0.198$)

	WBT	
	Inconspicuous	Conspicuous
Otoscopy report		
Inconspicuous	106	125
Conspicuous	3	45

Ear canal volume

The ear canal volume rises up with age (ear canal length from approx. 14 mm up to 35 mm) reported by Keefe et al. [7]. This study showed only a low correlation between age and ear canal volume ($r = 0.49$). The median of the ear canal volume in our participants was comparable small with 0.4 ml in group 1 up to 6 months and group 2 6 months up to 3 years. The medians of both groups did not agree with the literature which defines age for small ear canal volume only up to 6 months, so the decision for the right test type is

imprecise. Rather the fine consideration of the ear canal volume as reported by Limberger et al. [12] assumed to identify the right compliance. Our data would set the boundaries at 3 years, an ear canal volume up to 0.6 ml. The correlation between WBT and classic tympanometry showed also a better agreement to the 1000-Hz tympanogram ($\kappa = 0.65$) and ($\kappa = 0.73$) independent of the ear canal volume. This suggests that independent of the age, the WBT gives meaningful results to detect middle ear pathologies. The ear canals in the younger age (group 1 and 2) are very tight and the examination is made difficult by the child's restlessness/defenses, so ear microscopic evaluation of the ear drum is very difficult. It assumes that WBT and 1000-Hz tympanometry, especially in childhood up to 3 years with tight ear canal gave more significant results than exclusive the otoscopy finding. Anyway, ear microscopy is indispensable to diagnose ear canal stenosis, ear canal atresia, foreign bodies and ear-wax plugs as reasons of infant hearing loss. Wide variation of the WBT-absorbance rate above the whole frequency area in age range up to 6 month owes the high physiological flexibility of the ear canal structure at that time of life.

Correlation to ear microscopic findings

The curve progression showed a higher correlation between WBT and 1000 Hz than with 226 Hz. The question is now can the WBT deliver the real result. Therefore, the accordance between ear microscopy finding and the WBT was analyzed. The absorbance for WBT (− 600 daPa up to + 300 daPa and 226 Hz up to 8000 Hz) was visual estimated and scaled in reports. Only a very low correlation ($\kappa = 0.2$) was found. In detail, 125 reports of the WBT were conspicuous contra in the ear microscopy finding inconspicuous. These microscopy findings were only listed when an OME was detected. In the WBT, every abnormal curve progression was described as abnormal, also defects at the Eustachian tube (15%). In addition, artifacts (18%) were described, mostly in group 1, this is the same reason as depicted in the capture above. At infants, the ear canal could be so narrow and not visible that we get a wrong negative result. Such as, in the WBT the result is OME although the otoscopy is without pathological findings. For interpreting the microscopy findings, the results of the WBT are very helpful. Either a second assessment is necessary or WBT supports and gives more detailed information.

Absorbance curve

Many authors explained the analysis of the absorbance of WBT. Sanford et al. compared the absorbance of WBT measurement with the 1000-Hz tympanogram and the distortion product otoacoustic emissions (DPOAE) [19, 26]. WBT and DPOAE results have a higher compliance than assumed and it is appropriate to be used in the newborn screening. A group of researchers analyzed the absorbance of normal hearing kids for different age groups up to 6 months and define age-specific norm data [26, 27]. Sanford and Brockett analyzed 30 kids with OME, negative pressure, and defects and the Eustachian tube [23]. All these pathologies reduced the absorbance curve. Only Pitaro et al. [28] described the absorbance with the otoscopy findings, but only for newborns. This study is based on all these studies to find a significant agreement between absorbance, age and meanly the otoscopic findings. In patients with conspicuous ear microscopic results in all age groups, a significant reduction of WBT-absorbance in 1000 Hz and 2000 Hz was found. Compared with the norm data of Sanford et al. and Liu et al., a high correlation was found. Eleven of 18 frequencies, for every age group, were significant, by means of a significant lower absorption rate than the norm for inconspicuous results. This confirmed the expectation that the absorbance curve for noticeable results converge to the lower border of the norm data [17, 20]. The middle curve progression of the normal otoscopic results was for every age group up to 3000 Hz in the norm range. The higher frequencies showed lower absorbance rates than the norm data. Like in the literature described, a reduction of the absorbance curve for microscopic results without pathological findings was expected. The combination of microscopic and WBT gave better results.

Conclusion

This study analyzed the correlation between WBT measurements in the daily clinical routine of pediatric patients in audiology. The WBT measurements were especially compared with ear microscopic findings. In the daily clinical routine, WBT is an effective measuring instrument irrespective of the age of the patient. It becomes apparent that these results are more precise in combination with ear microscopy than in in combination with classic tympanometry. The combination of WBT additional to anamnesis and ear microscopy could give a more precise indication for the following therapy. To get a true age-adapted assessment and norm data of the WBT, there are more studies with big data collective needed especially for the age group up to 3 years.

Compliance with ethical standards

Ethical approval All the procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. The local ethics committee Landesärztekammer Rheinland-Pfalz (approval number 2018–13391) approved this study.

Informed consent Due to the retrospective design, an informed consent was not necessary.

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