Original Article

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Multifrequency tympanometry in infants

Timpanometria em lactentes utilizando sonda multifrequencial

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Summary

Introduction: The use of conventional tympanometry is not sufficiently sensitive to detect all cases of middle ear changes, and this hinders accurate diagnosis.
Objective: To characterize acoustic immittance measures of infants from 0 to 3 months of age using multifrequency tympanometry in a prospective study.
Method: 54 infants from 0 to 3 months of age were evaluated. The inclusion criteria included absence of respiratory infections during the evaluation, presence of transient evoked otoacoustic emissions, and absence of risk indicators for hearing loss. The subjects were evaluated by an audiologic interview, a visual inspection of the ear canal, and measures of acoustic immittance at the frequencies of 226 Hz, 678 Hz, and 1,000 Hz. Tympanometric records of the occlusion effect, tympanometric curve type, tympanometric peak pressure, equivalent ear canal volume, and peak compensated static acoustic admittance were collected.
Results: The results indicated the presence of an occlusion effect (2.88% at 226 Hz, 4.81% at 678 Hz and 3.85% at 1,000 Hz), predominance of a tympanometric curve with a single peak (65.35% at 226 Hz, 81.82% at 678 Hz, and 77.00% at 1,000 Hz), and tympanometric peak pressure ranging from -155 to 180 daPa. Further, the equivalent ear canal volume increased with the frequency of the probe (0.64 mL at 226 Hz, 1.63 mho at 678 Hz, and 2.59 mmho at 1,000 Hz) and the peak compensated static acoustic admittance values increased with an increase in frequency (0.51 mL at 226 Hz, 0.55 mmho at 678 Hz and 1.20 mmho at 1,000 Hz). 93.06% of the tympanograms were classified as normal at 226 Hz, 81.82% at 678 Hz, and 77.00 % at 1,000 Hz, respectively.
Conclusion: Taken together, these results demonstrated that utilizing these evaluations made it possible to characterize the acoustic immittance measures of infants.
Keywords: hearing, infant, middle ear, acoustic impedance tests.

Resumo

Introdução: O uso de uma única frequência na timpanometria não é sensível na detecção de todos os casos de alteração na orelha média, dificultando o diagnóstico preciso.
Objetivo: Caracterização das medidas de imitância acústica de lactentes utilizando três tipos de sonda. Estudo prospectivo.
Método: Foram avaliados 54 lactentes, com idade entre zero e três meses. Os critérios de inclusão foram ausência de infecções de vias aéreas, presença de emissões otoacústicas evocadas transientes, ausência de indicadores de risco para perda auditiva. Foi realizada entrevista audiológica, inspeção visual do meato acústico externo e medidas de imitância acústica nas frequências de 226Hz, 678Hz e 1000Hz. Foram coletados os registros timpanométricos de efeito de oclusão, curva e pressão de pico timpanométrico, volume equivalente do meato acústico externo e pico compensado da admitância acústica estática.
Resultados: Os resultados indicaram presença de efeito de oclusão (2,88% em 226Hz, 4,81% em 678Hz e 3,85% em 1000Hz); predomínio de curva em pico único (65,35% em 226Hz, 81,82% em 678Hz e 77,00% em 1000Hz); pressão de pico variando de -150 a 180daPa; aumento do volume equivalente do meato acústico externo com aumento da frequência da sonda (0,64ml em 226Hz, 1,63mmho em 678Hz e 2,59mmho em 1000Hz); aumento do pico compensado da admitância acústica estática (0,51ml em 226Hz, 0,55mmho em 678Hz e 1,20mmho em 1000Hz). Foram classificados como normais 93,06% dos timpanogramas com 226Hz, 80,81% em 678Hz e 82,00% em 1000Hz.
Conclusão: Por meio destas avaliações e resultados foi possível caracterizar as medidas de imitância acústica dos lactentes.
Palavras-chave: audição, lactente, orelha média, testes de impedância acústica.

Introduction

Hearing is the main source for speech and language skill acquisition in children with normal hearing ability. Hearing loss can cause delay in these skills, making the communication process more difficult. In infants, it is recommended that a complete hearing evaluation be performed with electrophysiological and electroacoustic measurements as well as behavioral methods.

Acoustic immittance measurements are valuable tools for assessing middle ear changes, since detection is quick and objective. Characterized by the mechanical analysis of the auditory system in response to acoustic stimulation, acoustic immittance measures the acoustic energy transfer that occurs when sound pressure is applied to the tympanic membrane, which causes its movement. This type of assessment evaluates the ease or opposition to this sound energy flow within the auditory system.

Multifrequency tympanometry emerged as a promising new method for the evaluation of middle ear conditions because it is fast, straightforward, noninvasive, objective, and more sensitive than conventional tympanometry (performed at a frequency of 226 Hz). Multifrequency tympanometry was developed because episodes of acute otitis media were not always detected by conventional tympanometry (1).

Middle ear pathologies that are identified by conventional tympanometry are also identifiable by multifrequency tympanometry. However, conventional tympanometry may fail to detect middle ear pathologies that are correctly identified by multifrequency tympanometry, which is able to identify small changes in the middle ear acoustic mechanism. Some authors recommend the combination of conventional and multifrequency tympanometry in neonates, children, and adults (2-5).

The tympanic-ossicular system behaves differently in children up to 2 years of age, as mass is the dominating physical feature and can be evaluated more efficiently at high frequencies (probe tones 678 Hz and 1,000 Hz). After this age, there is a change in behavior, reaching the adult stage, which is dominated by stiffness and is better evaluated by a frequency of 226 Hz (6).

Conventional tympanometry in infants has been used in various studies (7-10), although the literature shows that the use of a single frequency is not sensitive enough to detect all cases of middle ear pathology, which hinders accurate diagnosis (11-14).

Acoustic immittance methods using high frequencies help to clarify the false-positive screening results that occur due to pathology in the middle ear or the presence of secretion. Accurate middle ear evaluations in the neonatal period result in appropriate medical and audiological referrals and can improve the efficacy of newborn hearing screening programs (15). Evidence suggests that the use of a single frequency probe is not sensitive enough to detect all cases of middle ear alterations, making accurate diagnosis difficult. Therefore, the purpose of this study was to characterize acoustic immittance measurements in infants between 0 and 3 months of age using 3 probe types.

Method

This study was approved by the Ethics Committee (protocol no. 52/2009, Faculty of Dentistry of Bauru, São Paulo University, USP).

The inclusion criteria for the participants in this study included the following: infants were 0 to 3 months of age, complaints and/or infections of the upper airway were absent during the study, the ear canal was without obstacles to the examination, transient evoked otoacoustic emissions were present, and there were no risk indicators for hearing loss, as defined by the Joint Committee on Infant Hearing (16).

Parents received a Term of Free and Informed Consent form that contained information about the study in clear and simple language. Assessments were initiated once parental consent was obtained. This study included 54 infants: 27 (50%) girls and 27 (50%) boys. The age ranged from 8 to 115 days, with an average age of 31.8 days. In 4 infants, it was not possible to assess both ears. Therefore, in total, 104 ears were evaluated, 51 (49.1%) right and 53 (50.9%) left.

The assessment consisted of an audiologic interview, visual inspection of the ear canal, and acoustic immittance measurements. The audiologic interview was conducted with parents through leading questions, in accessible language, with the purpose of obtaining information regarding infant hearing, presence of upper respiratory infection, and risk indicators for hearing loss.

Visual inspection of the ear canal was performed by an audiologist who checked for the presence of any impediment to the evaluation of the acoustic immittance measurements. In the instances in which an impediment to the evaluations (for example, cerumen) was present, the infant was referred to an otorhinolaryngologist for evaluation.

To obtain the acoustic immittance measurements, TympStar GSI version 2, Middle Ear Analyzer (Grason-Stadler) with probe tones of 226 Hz, 678 Hz, and 1,000 Hz, were used. The acoustic immittance was applied using these 3 frequencies, with the pressure ranging from + 200 to -400 daPa and a pressure change rate of 600/200 daPa per second. The intensity of probe tone was 85 dB SPL to 226 and 678 Hz, and 75 dB SPL at 1,000 Hz, following the specifications of the equipment manual (17).

Three hundred tympanograms were collected: 101 (33.67%) with a 226 Hz probe tone, 99 (33.00%) with a 678 Hz probe tone, and 100 (33.33%) with a 1,000 Hz probe tone. This distribution was not equal because some ears showed an occlusion effect.

Occlusion effect, tympanometric curve, tympanometric peak pressure, equivalent ear canal volume, and peak compensated static acoustic admittance were collected and analyzed.

When tympanometric data was not obtained, the occlusion effect was recorded. In the event of occlusion with a 226 Hz probe tone, the olive was removed from infant's ear and repositioned, and the exam was restarted. In the event of occlusion with the remaining frequencies (678 Hz and 1,000 Hz), a new attempt was made to obtain the tympanogram after re-administering the test at 226 Hz.

Tympanogram shapes were classified as either a single-peaked tympanogram (SP) with maximum peak admittance, a double-peaked tympanogram (DP) with 2-peak admittance, an asymmetric tympanogram (A) with a gradual decline of the admittance ranging from +200 to -200 daPa, an inverted peaked tympanogram (IP) with an inverted peak admittance in relation to +200 to -200 daPa, or a flat tympanogram (F) with no peak admittance.

Tympanometric Peak Pressure (TPP) is the maximum admittance pressure peak expressed in daPa. Equivalent ear canal volume (Ecv) is the acoustic admittance measurement that is registered at +200 daPa. Peak compensated static acoustic admittance (Ymt) refers to the maximum admittance peak, where the pressures of the external and middle ear are equal. Values were measured in mL at 226 Hz and in mmho at 678 Hz and 1,000 Hz.

SP or DP tympanograms were classified as normal at 226 Hz, based on previous studies (19, 28).

For 1,000 Hz and 678 Hz frequencies, tympanograms were classified using the Sutton Protocol (18), which is recommended for tympanometric analysis of infants up to 4 months of age. Following this protocol, tympanograms with Ymt>0 and TPP>-200 daPa were classified as normal. Tympanograms with Ymt≤0 or TPP<-200 daPa were classified as abnormal.

After the classification as either normal or abnormal, the results of tympanograms that were classified as normal were analyzed, and the tympanograms with different probe types were compared. Descriptive analyses were performed on the results of the normal tympanograms through tables and charts, in addition to the other analyses performed using statistical tests.

A non-parametric test was used to compare TPP, Ecv, and Ymt in tympanograms with the 3 different frequencies that were tested, as the results from this sample were not normally distributed. Both the Chi-square Test and the Friedman Test were performed, adopting p=.05 as the significance level.

Individual comparisons were made between TPP, Ecv, and Ymt with respect to the evaluated frequencies. To perform these comparisons, the Friedman Test was performed only for subjects that had normal tympanograms in all of the tested frequencies. Thus, this analysis included data from 68 participants.

RESULTS

An occlusion effect was present with all 3 frequencies (226 Hz, 678 Hz, and 1,000 Hz). Table 1 indicates the occlusion effect occurrence in the total sample of ears (N=104).

Three hundred total tympanograms were collected: 101 at 226 Hz, 99 at 678 Hz, and 100 at 1,000 Hz. Figure 1 represents the tympanometric occurrence curve by probe tone.

Percentage values of the tympanometric curve and occlusion effect were compared across the 3 frequencies, accounting for gender and age, as shown in Table 2.

TPP, Ecv, and Ymt results were analyzed according to the frequency, considering only normal tympanograms. Table 3 describes the TPP values that were found in the evaluated ears.

The TPP Chi-square analysis indicated significant differences between the tested frequencies (p<.001). In the individual frequency comparisons using the Friedman Test, the mean values obtained with a 1,000 Hz probe were found to be higher than the mean values obtained with a 678 Hz probe, the latter being well above the values at 226 Hz. This difference was statistically significant.

In the Ecv data, as described in Table 4, the Chi-square analysis indicated a significant difference between the results ($p<.001$).

The Friedman test revealed a significant difference in the individual comparison between the Ecv values; mean values at 1,000 Hz were greater than those at both 678 Hz and 226 Hz.

Table 5 presents the Ymt measurements that were obtained for the frequencies that were evaluated, and the associated descriptive statistical analysis.

The Chi-square analysis revealed a significant difference between the results ($p<.001$). The individual comparisons between frequencies, performed using the Friedman Test, showed significant differences between the mean values; the mean values at 1,000 Hz were greater than those at both 678 Hz and 226 Hz.

The tympanogram analysis demonstrated that 93.06% (94) of ears evaluated with a 226 Hz probe tone were normal. With a 678 Hz probe, 80.81% (80) of ears were classified as normal, and with a 1,000 Hz probe, the percentage of ears that were classified as normal was 82.00% (82).

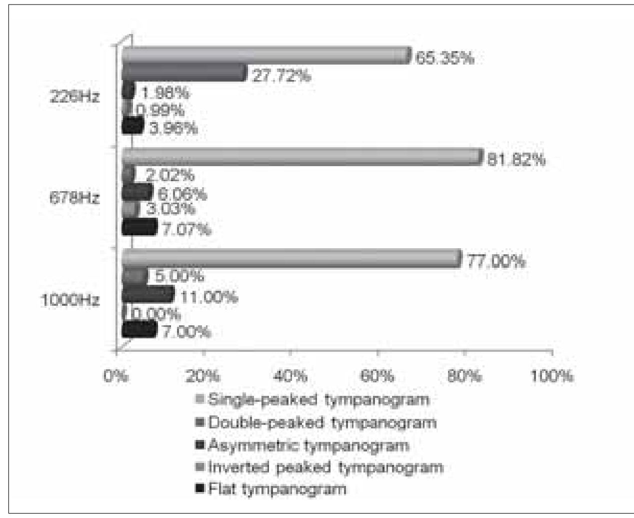

Figure 1. Tympanograms shape occurrence for frequency tested.

Table 1. Occlusion effect occurrence by frequency.

	Occlusion effect	
	N	%
226Hz	3	2,88
678Hz	5	4,81
1000Hz	4	3,85
Total	12	11,54%

Table 2. Occlusion effect and tympanometric curve, accounting for gender and age.

Tympanometric findings	Gender		Age			
	Male	Female	8 to 29 days old	30 to 59 days old	60 to 89 days old	90 to 115 days old
	N = 156(%)	N = 156(%)	N = 255(%)	N = 18(%)	N=15(%)	N = 24(%)
SP	66.67	76.28	70.20	61.11	86.67	79.17
DP	12.82	9.62	10.98	16.67		12.50
A	7.69	6.41	7.06	11.11		4.17
IP	0.64	1.92	0.78	5.56		4.17
F	5.13	5.13	5.49	5.56	6.67	0
OC	7.05	0.64	4.31	0	6.67	0

Legend: N – Number of ears evaluated; SP – Single-peaked tympanogram; DP – Two-peak tympanogram; A – Asymmetric tympanogram; IP – Inverted-peaked tympanogram; F – Flat tympanogram; OC – Occlusion effect.

Table 3. Tympanometric peak pressure values.

Frequency	Nº of ears	Mean (daPa)	Standard deviation (daPa)	Minimum (daPa)	Maximum (daPa)	Quartile 1º	Quartile 3º
226 Hz	94	27.93	39.10	-65	115	6.25	53.75
678 Hz	81	24.75	55.35	-150	145	0	57.50
1,000 Hz	82	36.49	59.76	-115	180	6.25	60.00

Table 4. Equivalent ear canal volume values.

Frequency	Nº of ears	Mean	Standard deviation	Minimum	Maximum	Quartile 1º	Quartile 3º
226 Hz	94	0.64	0.24	0.20	1.60	0.50	0.70
678 Hz	81	1.63	0.74	0.60	4.80	1.20	1.80
1,000 Hz	82	2.59	0.92	1.00	5.80	2.00	2.90

Table 5. Peak compensated static acoustic admittance values.

Frequency	N	Mean	Standard deviation	Minimum	Maximum	Quartile 1º	Quartile 3º
226 Hz	94	0.51	0.32	0.10	1.60	0.30	0.70
678 Hz	81	0.55	0.47	0.10	2.30	0.20	0.80
1,000 Hz	82	1.20	1.13	0.10	5.90	0.40	1.50

DISCUSSION

In this study, the right and left ears were grouped together to facilitate a better analysis of the results and sample characterization, since no differences were found between ears in other studies.

In the literature, the absence of tympanometric records (due to the occlusion effect) was associated with several factors: presence of cerumen in the ear canal, incorrect placement of the probe in the infant ear (17), or differences between the tympanic-ossicular system in adults and infants. These differences occurred because the infant system is mostly influenced by mass, while in adults, effects of stiffness are predominant (13, 22, 23). This condition can be indicated in the middle ear as occlusion.

In order to record accurate data without occlusion, visual inspection of the ear canal was performed to ensure that there was no cerumen present. In the event of occlusion, the probe was repositioned and the ear was reevaluated.

Despite the care taken, the occlusion effect was present at all 3 frequencies. This finding was inconsistent with the literature, in which there were no other known reports of this effect with a 226 Hz probe tone (19-21). Another inconsistency was the higher incidence of this effect at the higher frequencies in other studies, for example, 49% at 678 Hz and 51% at 1,000 Hz (19), 29% in 1,000 Hz (20), and 97% at 678 Hz and 2% at 1,000 Hz (21).

The occlusion effect occurred in infants that were younger than 4 months old (19). A higher occurrence of this effect in infants up to 2 months old was observed, while being absent in infants who were 3 months old.

In tympanometry assessments that were performed with a 226 Hz probe tone, the occurrence of single-peaked tympanograms was predominant in some studies (19, 21, 24, 25), while other studies indicated a preponderance of double-peaked tympanograms (26, 28).

Although there was no evidence of middle ear changes in the infants of this study, there was a low occurrence of flat tympanograms, which indicate the possible presence of fluid in the middle ear.

There is disagreement in the literature regarding tympanogram results with a 678 Hz probe tone. Some studies reported a higher incidence of single-peaked tympanograms (19, 21), followed by flat tympanograms (21). However, a different study indicated a higher incidence of asymmetric tympanograms (28). At 1,000 Hz, there was a consistently higher incidence of single-peaked tympanograms reported in the literature (19, 21, 24, 26, 28-30).

The differences between tympanometric curves that were reported by previous studies may be due to normal variations in the subject population and also by the differences in the infants' ages.

In the literature, single-peaked and double-peaked tympanograms are considered normal, while asymmetric, inverted, and flat tympanograms are considered abnormal (18, 19, 25, 28, 31).

After analyzing the results, the mean TPP at 226 Hz was observed to be lower than the mean TPP at 1,000 Hz, in accordance with other studies (8, 12, 19, 20, 25, 26, 28). However, the values found in the current study were higher than those reported in the literature. The analysis of TPP at 678 Hz has been reported by only a single study (19), in which the reported mean TPP was lower than the mean TPP found in the current study.

Although there were statistically significant differences between the frequencies with respect to TPP, none of the differences were clinically significant. That is, the results for all 3 frequencies were within the normal range (18).

TPP values that are lower than -100 daPa in infants represent a tube dysfunction or may be a precursor of secretory otitis media (33, 34), but this does not prevent the registration of Transient Evoked Otoacoustic Emissions (TEOAEs) (35).

Ecv is a useful measurement for determining compensated static acoustic admittance and identifying the causes of flat tympanogram occurrence (40). The mean Ecv with a 226 Hz probe tone in the current study was close to the results that were described in the literature (19, 28, 20, 26), but higher than the results reported in another study (32). For this probe tone, the normal range is between 0.3 and 1.0 mL (35-37).

With a 678 Hz probe tone, the mean Ecv approached the values that were found in the literature (19). At 1,000 Hz, the literature reported great variability, with results both higher (25) and lower (20, 38) than those found in the current study. Most of the studies in the literature reported a mean of about 1.5 mmho (12, 19, 26, 32).

Grason-Stadler (39) reported that the Ecv values obtained at a frequency of 678 Hz were 3 times larger than the Ecv values obtained at 226 Hz, and that at 1,000 Hz this difference can be up to 4.4 times larger. Considering these findings, it can be concluded that although the findings from the present study are not close to those found in the literature, they are still within the normal range. Consistent with this statement, a significant difference between the results of the 3 frequencies was found, with the mean Ecv value at 1,000 Hz greater than the mean values at 678 Hz and 226 Hz.

By measuring the Ymt, it is possible to identify changes in the middle ear, such as the presence of secretions, fixation of the ossicular chain, otosclerosis, and disjunction chains, among others (34).

As observed in the Ecv values, there was a gradual increase in Ymt at high frequencies, with a significant difference between the values obtained at 1,000 Hz and the other 2 frequencies. The literature also reports higher mean Ymt values at 1,000 Hz compared to 226 Hz (19, 20, 26, 28).

As with the analysis of other variables, only a single study (19) that used the 678 Hz frequency was found, which indicated values close to those described here.

At 1,000 Hz, several studies presented Ymt values close to those found in the current study (12, 15, 25), the more recent of which (41) found mean Ymt values equal to 1.06 mmho when evaluating neonates.

The analysis of tympanograms using the protocol described by Sutton (18) resulted in 93% of ears having normal tympanograms at 226 Hz, 81% of ears having normal tympanograms at 678 Hz, and 82% of ears having normal tympanograms at 1,000 Hz; these results were similar to those reported by other studies (19, 21, 28, 29, 42, 43).

Ears with tympanograms that were classified as abnormal showed positive results in the transient evoked otoacoustic emission analysis; this was not expected. According to the literature, the presence of mild middle ear dysfunction, a delay in the neonatal middle ear maturation, the probe tone frequency being too low for some newborns, inadequate sealing of the probe, or the presence of motion artifacts are possible explanations for this finding (25).

Another justification provided by the literature is that high-frequency tympanometry seems to provide more detailed information about the state of the mechanics and acoustics of the ear, especially for changes related to the mass factor (44, 45), as well as the possibility of middle ear pathology at the initial or final stage. Thus, neither of these conditions should have interfered in the outcome of the transient evoked otoacoustic emissions (43).

Previous studies (13, 44) that evaluated the sensitivity and specificity of tympanometry indicated that the sensitivity of conventional tympanometry was greater than that of high-frequency tympanometry, but that the specificity of high-frequency tympanometry was greater than that of conventional tympanometry.

Considering the current analysis and comparisons, we can infer that these results are in accordance with the findings in the literature and can serve as normative data. However, it is evident that it is necessary to further define normative values at different ages to adapt clinical practice to the use of high frequencies with young children.

Conclusion

Through the described assessments, it was possible to characterize the acoustic impedance measurements in infants, as described below:

- There was a low incidence of the occlusion effect, which was observed at the frequencies of 226 Hz, 678 Hz, and 1,000 Hz;
- Single-peaked tympanograms were predominant in the 3 tested frequencies (65.35% at 226 Hz, 81.82% at 678 Hz, and 77.00% at 1,000 Hz)
- The tympanometric pressure peaks presented a mean of 27 daPa at 226 Hz, 24 daPa at 678 Hz, and 36 daPa at 1,000 Hz;
- The equivalent ear canal volumes showed values of 0.64 mL at 226 Hz, 1.63 mmho at 678 Hz, and 2.59 mmho at 1,000 Hz;
- The compensated static acoustic admittance peaks showed values of 0.51 mL at 226 Hz, 0.55 mmho at 678 Hz, and 1.20 mmho at 1,000 Hz.

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