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Original Article

Transformation of audiological characteristics of neonatal otitis media with effusion in 7-month-olds

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Abstract: This study sought to characterize the audiological features of neonatal otitis media (OME) in 1- to 7-month-old subjects. Evaluation of 184 ears which failed universal newborn hearing screening (UNHS) were referred to the distortion product optoacoustic emissions (DPOAE) test and had flattened non-peak type of 1-KHz tympanogram at 1-3 months age. Auditory brainstem response (ABR) tests were also performed. The DPOAE, tympanometry, and ABR tests were repeated at 5-7 months of age. Tests from 1-3 to 5-7 months of age produced the following results: For the 1-KHz tympanogram, a complete recovery to a normal type A was observed for 73 ears (39.7%), 21 ears (11.4%) improved to a type C, 36 ears (19.6%) were observed to be fluctuating non-peak, and 54 ears (29.3%) remained flattened non-peak type. For the DPOAE test, 90 ears (48.9%) eventually passed the test, and 94 ears (51.1%) were referred. For the ABR test, the average threshold improved to 28.12 ± 14.59 dB nHL from 44.84 ± 10.67 dB nHL. In addition, the thresholds of 126 ears (68.5%) were 30 dB nHL or less. We conclude that OME in infants can greatly improve before 7 months of age with the development of the anatomical structure of the middle ear.

Keywords: Newborn hearing screening, middle ear, neonate, otitis media with effusion, tympanometry, auditory brainstem response

Introduction

As universal newborn hearing screening (UNHS) has been clinically applied worldwide, infants with hearing loss are being identified at earlier ages than ever before. The initial goal of the early hearing detection and intervention (EHDI) programs is to classify correctly an infant's hearing status, so that appropriate intervention can take place if needed. Investigations from around the world have found that cumulative incidences of OME are approximately 35% to 85% for 1- to 6-month-old infants and 50% to 96% for 1-year-old children, respectively [1]. In China, statistics from several hospitals have demonstrated that 5% to 10% of children fail their first hearing screening; however, only 2-3% of children are eventually diagnosed with congenital hearing loss [2, 3]. Therefore, the number of the referred results for the initial hearing screening is dozens of times greater than the number of children who are eventually diagnosed with sensorineural hearing loss. A proportion of the remaining children fail their hearing screenings due to otitis media effusion. Boudewyns [4] reported that as large as 55.3% infants that were referred to the UNHS was attributed to otitis media with effusion (OME). In OME, the long-term persistence of liquid in the middle ear cavity can result in hearing loss and can be correlated with impaired speech acquisition and even behavioral and/or balance problems [5, 6]; therefore, the early diagnosis of OME is highly important.

The auditory neural system of infants is still maturing, and reduced auditory input may adversely influence the structural and functional development of this system. However, inappropriate medical therapy, particularly the overuse of medicines and surgical treatments, should also be avoided. Thus, it is extremely important to adopt effective measurements to investigate the transformation of infants' audiological characteristics over time. Adequate evidence has confirmed that conventional tympanometry at a frequency of 226 Hz is insufficiently sensitive for detecting middle ear pathology in infants; a series of previous studies reported that 1-KHz tympanometry should be used

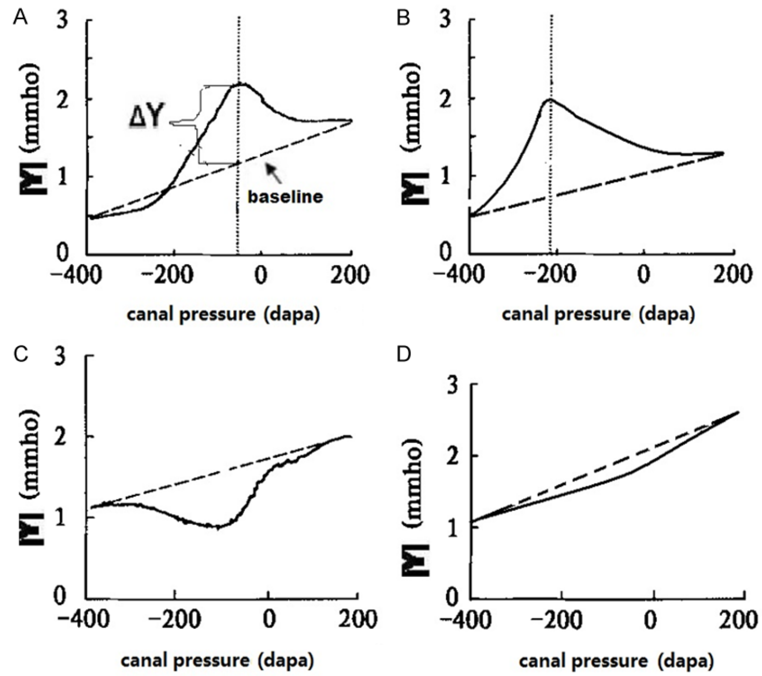

Figure 1. The types of 1000 Hz tympanogram. A. Normal tympanogram type A: a curve with a peak of admittance between -150 daPa and a volume ΔY > 0.2 mmho; B. Type C: the admittance peak shifted to negative pressures and is less than -150 daPa; C and D. Two subtypes of the non-peak type of tympanogram. Subtype c is non-peak but fluctuating; subtype d is non-peak and flattened.

instead as a better assessment tool to identify neonatal OME [7-10]. Further, the latest diagnostic guidelines for OME in infants under 6 months, which have been adopted by Great Britain and the United States, emphasize obtaining a 1-KHz tympanogram as a better approach than obtaining a 226-Hz tympanogram [11-13]. Furthermore, it was asserted that a 1-KHz tympanogram can be used to confirm the diagnosis of OME [14]. However, transformation of audiological characteristics of neonatal OME in 7-month-olds with large sample and combined examination of 1-KHz Tympanometry, distortion product otoacoustic emission (DPOAE), and auditory brain-stem response (ABR) tests has not been adequately demonstrated. In this study, a large sample of 184 ears were evaluated and we found that OME can improve to various extents due to growth after 3 months of age. Accordingly, the results of DPOAE and ABR assessments exhibited marked progress over time. On the other hand, 29.3% of ears didn't show resolution over the course of the study. Our study strongly highlights the significance of analyzing the transformation of audiological characteristics of neonatal OME and therefore provides potential guidance for clinical intervention.

Materials and methods

Subjects

A total of 116 infants (78 males, 38 females), 184 ears (99 left, 85 right) of 1-7 months of age were retrospective analyzed from the Children's Audiology Center of Ningbo between January 2013 and June 2015. Informed consent was obtained from parents before the measurements. Objectives with vernix occlusion of external ear canal were excluded by otoscopy test. The inclusion criteria were a 'refer' result for DPOAE at the first post-natal screening, and a 'refer' result for DPOAE, a flattened non-peak type of 1-KHz tympanogram, ABR thresholds > 30 dB nHL, < 70 dB nHL at the first diagnosis when they were 1-3 months old. At the second diagnosis, DPOAE, 1-KHz tympanometry, and ABR tests were executed at 5-7 months old. The average ages for the first and the second diagnosis were 67.8 ± 27.7 days and 177 ± 42.8 days, respectively. The examination was performed after infants fell asleep naturally and in some cases a 10% chloral hydrate enema (0.5 ml/kg) was administered if they did not naturally fall asleep.

Methods

Tympanometry: A 1-KHz tympanogram was obtained using GSI TympStar (Grason-Stadler Co., USA). The starting and ending pressures were +200 daPa and -400 daPa, respectively, and the rate of change was 200 daPa/s. Importantly, calibration was strictly performed each day prior to clinical examination and every ear was examined at least two times to avoid artifact. The following approach proposed by Sanford [15] was used to determine the type of tympanogram. Initially, the baseline was established by connecting the positive tail at +200

Table 1. The transformation of tympanograms from 1-3 months (mos) to 5-7 months

Age	Type A	Type C	Type NP	
			Subtype c	Subtype d
1-3 mos	0	0	0	184 (100%)
5-7 mos	73 (39.7%)	21 (11.4%)	36 (19.6%)	54 (29.3%)

Table 2. The transformation of DPOAE test results from 1-3 months (mos) to 5-7 mos

Age	Pass	Refer
1-3 mos	0	184 (100%)
5-7 mos	90 (48.9%)	94 (51.1%)

daPa with the negative tail at -400 daPa. Subsequently, analysis could be conducted using the peak admittance value and the corresponding pressure above the baseline. The criterion for a normal tympanogram type A was a normal curve with a single peak of admittance between -150 and 100 daPa and a volume ΔY (the admittance value between the peak and the baseline) > 0.2 mmho. When there were two peaks, the peak with greater admittance was used for analysis. When the admittance peak shifted to negative pressures and was less than -150 daPa, the tympanogram was considered to be type C. The non-peak type of tympanogram (a flat curve with ΔY of less than 0.2 mmho or with no positive admittance peak) could be subdivided into two subtypes based on the fluctuation of the curve. Subtype c is non-peak but fluctuating and subtype d is non-peak and flattened (**Figure 1**).

DPOAE: DPOAE was performed using an oto-acoustic emission (OAE) system (Maico, Germany). The intensities of the two initial pure tone signals were L1=65 dB SPL and L2=55 dB SPL, with a frequency ratio f2/f1=1.2. The f2 frequencies were 1.5-KHz, 2-KHz, 3-KHz, 4-KHz, 5-KHz and 6-KHz. The amplitudes of distortion products at each analyzing frequency were obtained. The pass criteria included a signal-to-noise ratio (SNR) of at least 7 dB and an absolute DPOAE signal level of at least -5 dB SPL, for at least 3 out of the 6 tested frequencies. Any ear not passing the DPOAE test was classified as a refer.

ABR: The equipment used to assess ABR was the Smart EP ABR system from Intelligent Hearing Systems (USA). ABR assessments were conducted in a sound-proof room. The recording, reference, and ground electrodes were placed on the high forehead, the ipsilateral mastoid and the low forehead, respectively. Other recording parameters were an inter-electrode impedance ≤ 3 kΩ, EAR-3A insert earphones, 25 cm of soft tubing, an alternating click stimulus, a stimulation rate of 19.3/s, 1024 average sweeps, a time window of 12 ms, 100K amplification, filtering bandwidth of 100-1500 Hz; and a noise floor < 25 dB (A). The intensity was initially 80 dB nHL and decreased in steps of 20 dB nHL; as the intensity approached the threshold, the step size was reduced to 5 dB nHL. A repeatable and consistent wave V at the lowest intensity was regarded as the threshold.

Statistical analysis

The statistical software package SPSS 19.0 was used. Alterations in every parameter between 1-3 and 5-7 months of age were analyzed, using paired-sample t tests or non-parametric tests depending on whether it accorded with normal distribution, with $p < 0.05$ used as significance for statistical significance.

Results

The transformation of the 1-KHz tympanogram

The results of the 1-KHz tympanogram of all 184 ears were flattened non-peak type when they were 1-3 months old. As shown in **Table 1**, when subjects were 5-7 months of age, tympanograms for 73 ears (39.7%) out of the 184 assessed ears had changed to type A, indicating the complete resolution of the middle ear effusion. There were 21 ears (11.4%) with improvement in their tympanograms (to type C); 90 ears (48.9%) continued to exhibit non-peak tympanograms, however, 36 ears (19.6%) expressed subtype c (non-peak but fluctuating), the remaining 54 ears (29.3%) still had the subtype d tympanogram (non-peak and flattened) (**Table 1**).

DPOAE

DPOAE results indicate that among the 184 ears of 1- to 3-month-old infants that initially produced a ‘refer’ result, 90 ears (48.9%) passed the DPOAE test when subjects were

Table 3. Transformations of ABR thresholds based on tympanogram, DPOAE, and ABR findings alone from 1-3 months (mos) to 5-7 mos

Age	Threshold avg (184 ears) ($\overline{X}$ ± s) dB nHL	Transformations of the ABR threshold in dB nHL based on findings from various tests ($\overline{X}$ ± s)						
		Tympanogram			DPOAE		ABR	
		73 ears	21 ears	90 ears	89 ears	95 ears	126 ears	58 ears
1-3 mos	44.84 ± 10.67	Type NP 42.92 ± 10.47	Type NP 42.86 ± 8.00	Type NP 46.83 ± 11.10	Refer 42.25 ± 10.34	Refer 47.26 ± 10.46	(> 30 dB nHL) 43.29 ± 10.55	(> 30 dB nHL) 48.19 ± 10.25
5-7 mos	28.12 ± 14.59	Type A 19.25 ± 6.11	Type C 19.29 ± 7.95	Type NP 37.39 ± 14.95	Pass 18.15 ± 5.46	Refer 37.48 ± 14.29	(≤ 30 dB nHL) 19.64 ± 5.80	(> 30 dB nHL) 46.55 ± 10.27

Table 4. The distribution of tympanogram according to the ABR test at 5-7 months

ABR threshold (ears)	Type A	Type C	Type NP	
			Subtype c	Subtype d
≤ 30 dB nHL (126 ears)	18.72 ± 5.31 dB nHL (71 ears)	17.28 ± 5.32 dB nHL (19 ears)	22.64 ± 5.89 dB nHL (36 ears)	_ (0 ear)
> 30 dB nHL (58 ears)	37.47 ± 3.55 dB nHL (2 ears)	37.52 ± 3.49 dB nHL (2 ears)	_ (0 ear)	47.22 ± 10.26 dB nHL (54 ears)

5-7 months of age, and the remaining 94 ears (51.1%) produced a 'refer' result (**Table 2**).

ABR testing

For infants between 1 and 3 months of age, the average hearing threshold among 184 ears was 44.84 ± 10.67 dB nHL. This threshold significantly reduced to 28.12 ± 14.59 dB nHL ($p=0.00$, $p < 0.05$) when these subjects reached 5-7 months of age. Among the tested ears, 126 ears had thresholds of 30 dB nHL or less, which decreased from 43.29 ± 0.55 dB nHL to 19.64 ± 5.80 dB nHL ($p=0.00$, $p < 0.05$), whereas 58 ears had thresholds of 46.55 ± 10.27 dB nHL and didn't have significant difference ($p=0.187$, $p > 0.05$).

With respect to tympanogram types, the hearing threshold became normal for 5- to 7-month-old infants when a type A or a type C tympanogram was obtained. As indicated (**Table 3**), the ABR threshold of type A tympanogram of 73 ears was 19.25 ± 6.11 dB nHL, the type C tympanogram of 21 ears was 19.29 ± 7.95 dB nHL. On the other hand, the hearing threshold decreased from 46.83 ± 11.10 dB nHL to 37.39 ± 14.95 dB nHL on average ($p=0.00$, $p < 0.05$), even if a type NP tympanogram was obtained. Among 126 ears that had ABR thresholds of 30 dB nHL or less, 71 ears had type A tympanogram, 19 ears had type C tympanogram, the remaining 36 ears had non-peak curve, but all of the 36 ears belonged to subtype c. For the 58 ears of ABR thresholds higher than 30 dB nHL, 54 ears had non-peak and flattened tympanogram which belonged to subtype d, 2 ears had type A tympanogram and 2 ears had type C tympanogram (**Table 4**).

When infants were 5-7 months old, their hearing thresholds changed to 18.15 ± 5.46 dB nHL with a passing result obtained for DPOAE. Even if a refer result was obtained, the average hearing threshold was markedly reduced from 47.26 ± 10.46 dB nHL to 37.48 ± 14.29 dB nHL ($p=0.00$, $p < 0.05$).

Discussion

A series of studies have shown that OME in infancy and early childhood can greatly affect life [16, 17]. The first phenomenon associated with OME is hearing loss, which directly influences the extraction of verbal information and subsequently impacts speech development. In infants, pneumatic otoscopy and surgical findings are seldom available, and otoscopic observations are suspect [18]. However, throughout the world, the use of 1-KHz probe tone tympanometry for diagnosing abnormalities of the middle ear has been widely accepted and recommended, thus, this method was applied in the current study. Besides, it was reported that OME can only cause mild to moderate hearing loss, those ABR thresholds higher than 70 dB nHL were excluded from this study to distinguish the sensorineural hearing loss. For 184 ears diagnosed with OME, tympanometry, DPOAE and ABR results were collected when subjects were 1-3 and 5-7 months of age, and these findings were compared and analyzed. At 5-7 months of age, 126 ears (68.5%) had ABR thresholds of 30 dB nHL or less, which markedly decreased from 43.29 ± 0.55 dB nHL to 19.64 ± 5.80 dB nHL ($p=0.00$, $p < 0.05$). For the tympanometry, all 184 ears had non-peak and flattened tympanogram at 1-3 months of age, but when they reached 5-7 months of age, the non-peak type divided to subtype c and d. The ABR threshold of the subtype C (36 ears, 22.64 ± 5.89 dB nHL) was significantly lower than the subtype d (54 ears, 47.22 ± 10.26 dB nHL), but was still statistically higher than the threshold of type A (73 ears, 19.25 ± 6.11 dB nHL) and C (21 ears, 19.29 ± 7.95 dB nHL). Besides, the average ABR threshold with Type A and Type C has no significant difference ($p < 0.0001$, $p < 0.05$). Accordingly, the transformation pathway of neonatal OME can be assumed to be non-peak and flattened → non-peak but fluctuating → type C, type A. For the DPOAE test, the number of referrals (94 ears) was higher than the number of abnormality of ABR test (> 30 dB nHL, 58 ears), which reflects the fact that OAE measurements are especially sensitive to OME, because both the eliciting stimulus and its evoked cochlear response must travel through the middle ear. From these results, we found that OME improved to various extents after 3 months of growth, and 68.5% of the included subjects reached the normal hearing threshold. These results suggest an initial presence of OME which causes increased ABR thresholds, absent DPOAE, flat tympanograms, and a clearing of fluid over 1-3 months old and 5-7 months old in some infants results in improvement in hearing threshold and tympanic membrane mobility, but still may exhibit residual Eustachian dysfunction causing negative pressure. Consequently, we suggest that changes in the audiological characteristics of infants with OME can be explained by the anatomical growth of the middle ear and mastoid prior to 7 months of age. As this growth occurs, the distance from the tympanic membrane to the stapes footplate lengthens, and the gas cavity of the middle ear then increases in size, eventually enlarging the volume of the middle ear. This has been demonstrated in both humans [19] and animals [20]. Moreover, an increase in mastoid gasification strengthens the compliance of the tympanic membrane and enhances low-frequency conduction. Additionally, as amniotic fluid cells and mesenchymal cells gradually disappear, the density of the stapes decreases accordingly, and the connection between the ossicular chain and the tightness of the joint at the attachment of the stapes footplate to the oval window also change [21]. Besides, the development and maturation of ciliated mucosal epithelium helps clearing mesenchyme and other materials from the middle ear. The ear also benefits from the improvement of the function of Eustachian tube that allows improving aeration of the middle ear.

At 5-7 months of age, there were 54 ears (29.3%) that still had non-peak and flattened tympanograms and their ABR thresholds had no significant improvement. We found that some of them had upper respiratory tract infections between the first and second test that could delay recovery from OME. Nasal congestion was also observed in some of these objectives which presumes the dysfunction of Eustachian tube. For such children, additional longitudinal tracking and follow-up are required to establish follow-up programs and guidance for clinical intervention for infants and young children with OME.

Disclosure of conflict of interest

None.

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References

[1] Neff MJ; AAP; AAFP; AAO-HNS. AAP, AAFP, AAO-HNS release guideline on diagnosis and management of otitis media with effusion. Am Fam Physician 2004; 69: 2929-2931.

[2] Hu S, Li J, Zheng J, Lan L, Song J, Li N, Jiang L, Han Y, Ding H, Wu Z. The analysis of hearing screening results with 16 654 subjuects. Journal of Audiology and Speech Pathology 2010; 18: 426-428.

[3] Liu MN, Wang M, Wang F, Gao XT, Huang Z. Hearing screening of 15 247 newborns. Chinese Journal of Child Health Care 2007; 15: 296-297.

[4] Boudewyns A, Declau F, Van den Ende J, Van Kerschaver E, Dirckx S, Hofkens-Van den

Brandt A, Van de Heyning P. Otitis media with effusion: an underestimated cause of hearing loss in infants. Otol. Neurotol 2011; 32: 799-804.

[5] Gravel JS, Wallace IF. Listening and language at 4 years of age: effects of early otitis media. J Speech Hear Res 1992; 35: 588-595.

[6] Rosenfeld RM, Culpepper L, Doyle KJ, Grundfast KM, Hoberman A, Kenna MA, Lieberthal AS, Mahoney M, Wahl RA, Woods CR Jr, Yawn B; American Academy of Pediatrics Subcommittee on Otitis Media with Effusion; American Academy of Family Physicians; American Academy of Otolaryngology--Head and Neck Surgery. Clinical practice guideline: otitis media with effusion. Otolaryngol Head Neck Surg 2004; 130: S95-118.

[7] Kei J, Allison-Levick J, Dockray J, Harrys R, Kirkegard C, Wong J, Maurer M, Hegarty J, Young J, Tudehope D. High-frequency (1000 Hz) tympanometry in normal neonates. J Am Acad Audiol 2003; 14: 20-28.

[8] Margolis RH, Bass-Ringdahl S, Hanks WD, Holte L, David A. Zapala DA. Tympanometry in newborn infants--1 kHz norms. J Am AcadAudiol 2003; 14: 383-392.

[9] Baldwin M. Choice of probe tone and classification of trace patterns in tympanometry undertaken in early infancy. Int J Audiol 2006; 45: 417-427.

[10] Swanepoel W, Werner S, Hugo R, Louw B, Owen R, Swanepoel A. High frequency immittance for neonates: a normative study. Acta Otolaryngol 2007; 127: 49-56.

[11] American Academy of Pediatrics, Joint Committee on Infant Hearing. Year 2007 position statement: principles and guidelines for early hearing detection and intervention programs. Pediatrics 2007; 120: 898-921.

[12] Stevens JC, Sutton GJ, Wood SA, Mason S. Guidelines for the early audiological assessment and management of babies referred from the newborn hearing screening programme. Academic Press 2007.

[13] American Academy of Audiology (2012). Audiologic guidelines for the assessment of hearing in infants and young children.

[14] Rosenfeld RM, Shin JJ, Schwartz SR, Coggins R, Gagnon L, Hackell JM, Hoelting D, Hunter LL, Kummer AW, Payne SC, Poe DS, Veling M, Vila PM, Walsh SA, Corrigan MD. Clinical practice guideline: otitis media with effusion executive summary. Otolaryngol Head Neck Surg. 2016; 154: 215-225.

[15] Sanford CA, Keefe DH, Liu YW, Fitzpatrick D, McCreery RW, Lewis DE, Gorga MP. Sound-conduction effects on distortion-product otoacoustic emision screening outcomes in newborn infants: test performance of wideband acoustic transfer functions and 1-kHz tympanometry. Ear Hear 2009; 30: 635-652.

[16] Paradise JL, Rockette HE, Colbom DK. Otitis media in 2253 Pittsburgh-area infants: prevalence and risk factors during the first two years of life. Pediatrics 1997; 99: 318-333.

[17] Williamson IG, Dunleavey J, Bain J, Robinson D. The natural history of otitis media with effusion--a three-year study of the incidence and prevalence of abnormal tympanograms in four South West Hampshire infant and first schools. J Laryngol Otol 1994; 108: 930-934.

[18] Eavey RD. Abnormalities of the neonatal ear: otoscopic observations, histologic observations, and a model for contamination of the middle ear by cellular contents of amniotic fluid. Laryngoscope 1993; 103: 1-31.

[19] Dahm MC, ShepherdRK, Clark GM. The postnatal growth of the temporal bone and its implications for cochlear implantation in children. Acta Otolaryngol Suppl 1993; 505: 1-39.

[20] Li Y, Liu HZ, Li J, Zhang Q, Gong S, He D. Morphology and ciliary motion of mucosa in the Eustachian tube of neonatal and adult gerbils. PLoS One 2014; 9: e99840.

[21] Isaacson, G. Endoscopic anatomy of the pediatric middle ear. Otolaryngol Head Neck Surg 2014; 150: 6-15.