Wideband Reflectance Measurements in Newborns: Relationship to Otoscopic Findings

Jacob Pitaro, MD[a,b]; Laila Al Masaoudi, MD[a,b]; Hamid Motallebzadeh, PhD[a,d]; W Robert J Funnell, PhD[a,b,d]; Sam J Daniel, MD[a.b.c,*]

[a] McGill Auditory Sciences Laboratory, McGill University, The Montréal Children's Hospital, 1001 Boul. Décarie, Montréal, QC H4A 3J1, Canada

[b] Department of Otolaryngology-Head and Neck Surgery, McGill University, The Montréal Children's Hospital, 1001 Boul. Décarie, Montréal, QC H4A 3J1, Canada

[c] Department of Pediatric Surgery, McGill University, The Montréal Children's Hospital, 1001 Boul. Décarie, Montréal, QC H4A 3J1Canada

[d] Department of BioMedical Engineering, McGill University, 3775, rue University, Montréal, QC H3A 2B4, Canada

International Journal of Pediatric Otorhinolaryngology 86: 156-160 (2016)
http://dx.doi.org/10.1016/j.ijporl.2016.04.036

Abstract

Objectives: Newborn hearing screening includes testing with otoacoustic emissions and the auditory brainstem response. Unfortunately, both tests are affected by the presence of material in the ear canal and middle ear such as vernix, meconium, and amniotic fluid. The objective of this study was to determine to what extent occlusion of the ear canal as seen on otoscopy affects wideband energy reflectance measurements in newborns. A secondary objective was to obtain additional normative wideband reflectance data in newborns.

Methods: Newborns from a well-baby nursery were enrolled. Wideband energy reflectance measurements and otoscopy were done immediately after the hearing screening. Occlusion of the ear canal as seen on otoscopy was described on a scale of 0 to 100%.

Results: A total of 156 babies were enrolled (mean age = 25 hours). A statistically significant difference in the reflectance at ambient pressure was found between the 0-70% and 80-100% occlusion groups. There was no significant difference in reflectance between the right and the left ears. The median reflectance pattern generally followed that of previous studies but in certain frequency regions the present reflectance values were higher.

Conclusion: A significant increase in reflectance occurs when 70% to 80% of the ear-canal diameter is occluded. Taking otoscopy findings into account may improve the interpretation of reflectance measurements. However, further studies are required to better establish the relationship between canal occlusion and reflectance.

Keywords: Newborn; Hearing screening; Wideband reflectance; Otoscopic findings

This paper was presented and won the third-place award in the basic-science category at the American Society of Pediatric Otolaryngology Annual Meeting; 2015 April 24–26, Boston, Massachusetts.

* Corresponding author: sam.j.daniel@mcgill.ca

1. Introduction

Universal newborn hearing screening (UNHS) has become a standard procedure in many countries around the world and is based on automated testing with otoacoustic emissions (OAE) and the auditory brainstem response (ABR) [1,2]. A major problem is that both tests are affected by obstruction of the newborn's ear canal and/or middle ear by materials such as vernix, meconium and amniotic fluid which can lead to false positive results and may cause parental anxiety, a negative attitude toward the baby, prolongation of diagnostic time, increased costs to the system, and decreased confidence in UNHS programs [2–9]. For all of these reasons it is recommended that an improved and more reliable technology be developed for evaluating middle-ear status at the time of newborn hearing screening [1,2]. Tympanometry, using a 226-Hz probe tone provides an effective measure of middle-ear status in adults and older children [10]. However, since the newborn ear canal and middle ear undergo developmental changes during the first few months of life, 226-Hz tympanometry produces different tympanograms in this age group and is not recommended under 7 months of age [11,12]. With a higher probe-tone frequency more consistent tympanograms are produced that can predict middle-ear status in newborns more accurately [13,14]. However, even with a high probe-tone frequency, variable results are found in newborns [15]. Energy reflectance (ER) is defined as the ratio of the energy reflected back to the probe location to the incident energy delivered by the probe. Assuming that the energy absorbed in the canal is negligible (a better approximation for adults than for infants), then the ER equals the ratio of the energy reflected from the middle ear to the incident energy, uninfluenced by the location of the probe within the canal [16]. 'Wideband' measurements for both ER and admittance are performed over a wide range of frequencies at the same time [17]. This is in contrast to conventional measurements at a single frequency at a time. Wideband measurements have the advantage of being very fast (seconds), much faster than measurements with pure tones at multiple frequencies. Both ER and admittance can be measured under either pressurized (tympanometric) or non-pressurized (ambient) conditions. Wideband measurements may be able to serve as a complementary tool in newborn hearing screening. However, wideband measurements have not been described in relation to otoscopic findings and it is unknown how the results are affected by occlusion of the ear canal and middle ear by different amounts of materials present immediately after birth.

The first objective of this study was to determine whether a correlation exists between wideband ER measurements and different levels of occlusion of the ear canal. A second objective was to provide additional normative data for wideband measurements in newborns.

2. Materials and methods

The study was approved by the Institutional Review Board (IRB) of the McGill University Health Centre. Infants were recruited from the well-baby nursery at the Royal Victoria Hospital, Montréal, Canada. An IRB-approved consent form was used to obtain parent's written consent. The measurements and otoscopy took place immediately following the hearing screening. If the baby had a "refer" result on OAE, the research measurements were done after a subsequent ABR test. Testing was done with the baby in the crib or in the parent's arms. The more conveniently positioned ear was tested first. Whenever possible, an attempt was made to test both ears. A wideband tympanometry research system (WB Tymp 3.2, Interacoustics Inc.), based on a Titan probe and a modified AT235 instrument, was used to measure ER. Calibration was performed daily before a new set of data was obtained. The wideband signal was introduced through the probe into the subject's sealed ear canal. Ambient measurements were obtained by recording the acoustic response to clicks. If a leaky insertion occurred, a warning appeared on the screen. If the baby was crying or moving, or if the canal was too narrow to insert the measuring probe, the baby was excluded from the study. In one-month-old babies the equivalent air volume (estimated from the acoustical admittance) may be slightly negative at low frequencies [17]. However, large negative volumes are not expected to occur and may represent a probe leak. As was described by Keefe et al. [17], cases with equivalent volumes below −1.15 cm^3 were excluded from the study.

The wideband system provided the results as energy absorbance (= 1 − ER) as a function of frequency, with 60 data points between 0.24 and 8 kHz. The absorbance measurements were transformed into reflectance for analysis. The median reflectance of each occlusion group (increments of 10%) was plotted to identify trends and grouping of the reflectance results in relation to the occlusion grade of the ear canal.

After the reflectance measurements, otoscopy was performed using a manual otoscope (Welch Allyn Inc.) by a trained and highly experienced otolaryngologist or by a medical doctor who was guided, trained and supervised by the otolaryngologist. The otoscopy was performed only once so the baby would not be disturbed and to avoid the parents' withdrawal from the study. Therefore, an inter-rater reliability assessment was not possible. The occlusion of the ear canal was described on a scale of 0% to 100% with increments of 10%. A clear canal with no visible debris was denoted by 0%, while complete occlusion was denoted by 100%. The otoscopic field was visually divided into half and then into smaller subdivisions. Occlusion was recorded as the sum of the areas of the subdivisions (Figure 1). A statistical analysis with a linear mixed model was used to examine whether differences exist in ER between right and left ears, and among the occlusion groups. The statistical software SPSS 18 was used for analysis.

3. Results

A total of 156 babies were included. There were 80 females and 76 males with a mean age of 25 hours (range 12-54). In 10 babies the measurement was done only in the right ear, and in 10 other babies it was done only in the left ear, so measurements were done in 292 ears. Three ears were excluded because the equivalent volume was too negative, so 289 ears are included in the results that follow. Table 1 summarizes the demographic characteristics. On otoscopy, most of the ear canals were found to contain some amount of material and it was difficult to identify and evaluate the status of the TM. To explore whether there is a correlation between the ear-canal occlusion and the ER results, the median for each occlusion group was plotted for the right and left ear. As seen in Figures 2 and 3, the largest separation between occlusion groups occurred between the 0 to 70% groups and the 80 to 100% groups. This separation is more pronounced below approximately 400 Hz and between 840 Hz and 6 kHz in the right ear, and below 400 Hz and between 1.6 and 3.2 kHz in the left ear. For the investigation of whether a difference in reflectance exists between the right and left ears, between the two main occlusion groups (0–70% and 80–100%) and among different frequencies, the 60 frequency data points were divided into 6 groups of 10.

There was no significant difference in reflectance between the right and left ears. Table 2 shows a comparison of the mean reflectances of the two main occlusion groups for the six groups of frequencies, and the corresponding *p* values in both ears. As shown, there was a significant difference in reflectance ($p<0.001$) between the two main occlusion groups in both ears for every group of frequencies.

4. Discussion

The present study has shown that occlusion of the newborn ear canal by transient materials affects the wideband ER measurements. In addition, the study has provided further baseline data of wideband reflectance from a large population of newborns. Previous studies have reported reflectance values in newborns but, to the best of our knowledge, this is the first study that has correlated otoscopic findings to reflectance measurements. Statistical analysis has shown that there is a significant difference in ER between low and high levels of occlusion. It was found that the largest difference in ER between neighbouring occlusion groups occurred between the 70 and 80% occlusion groups in some frequency regions.

Figure 4 shows a comparison of the median ER in newborns between the present study and previous studies. Our results agree with previous findings that have shown a high reflectance below approximately 1 kHz and around 4 kHz, and a low reflectance between 1 and 4 kHz and at frequencies higher than 4 kHz. However, the reflectance values in the present study are higher than those in previous studies. There may be different explanations for these differences. The study by Aithal et al. [18] included only ears with normal middle-ear function as determined by a battery of tests. Their inclusion criteria may explain their finding a lower reflectance than in the present study, since a normal middle ear implies a lower ER. The plot taken from the study by Hunter et al. [2] represents babies who passed the hearing screening based only on OAE. The present study included ER measurements that were taken from babies who passed the hearing screening, either on the first or second attempt with OAE, or on the third attempt with ABR. Although all of the babies but one passed the hearing screening, some of them may have had somewhat abnormal middle-ear status, which might explain the higher reflectance found in the present study. The babies included in the results here may better represent a typical population of newborns to be screened. Another factor is the age of the participants. Keefe et al. [17] included babies from the intensive care unit. Hearing screening for babies in the intensive care unit is often delayed and so the test might have been performed when the ear canal and middle ear were already cleared of debris, resulting in reduced overall ER values. In the study published by Aithal et al. [18], the mean age of the babies was 46 hours while Hunter et al. [2] presented data from babies with a mean age of 29 hours. In the present study, the mean age was 25 hours. It has been shown that ER decreases with increasing newborn age, so the findings of higher ER in the present study might be explained in part by the age differences [2,17].

The present study included only babies in the well-baby nursery. The only risk factor present in the group was a family history of hearing loss, but not in first-degree relatives. Aithal et al. [18] included healthy babies and did not mention any risk factors. In the study by Hunter et al. [2] "risk factors were rare, because all babies were considered well babies". In contrast, the subject population in the study by Keefe et al. [17] included a subgroup of babies with risk factors for hearing loss, such as cleft palate, dysmorphic features, ventilator support and positive family history, as well as babies from the intensive care unit who as a group tend to require ventilator support. The latter study showed that in patients with cleft lip or palate the ER was higher at all frequencies than in the group without risk factors. Interestingly, as can be seen in Figure 4, their mean ER was lower than in the other studies even though a mixed population was included.

Another difference among the studies is the usage of different instruments. Keefe et al. [17] used a custom-made system. Hunter et al. [2] used the HearID R4 system (Mimosa Acoustics, Inc.). Aithal et al. [18] used the same instrument that was used in the present study. Different calibration procedures might also have contributed to the different results.

Finally, in this study we used four types of rubber probe tips that were supplied by the company (Interacoustics Inc.). Two of the probe tips had a tube shape while the other two had a cone shape. Merchant et al. [19] used rubber and foam tips during their methodological development. They reported that the rubber tip had a tendency to fall out and that it was difficult to achieve a proper seal. Eventually they used the foam tips during their study. Vander Werff et al. [20] also reported that the rubber tip easily slipped out of the canal and that it was difficult to get a tight seal, which resulted in a high degree of variability when the probe was reinserted. In the latter study they also compared ER measurements between the rubber tip and the foam tip. Test-retest differences with the rubber tip were greater than with the foam tips. It is unknown whether different tip shapes influenced the measurements in the present study since no test-retest measurements were performed.

Hunter et al. [2] reported on results at two test sites, and found a difference that occurred below 1 kHz. Their assumption was that the difference might have been due to different techniques of probe insertion, depth in the canal and seal confirmation. Such differences in using the probe may also have contributed to the differences in ER among the different studies. The orientation of the probe in relation to the axis of the canal may also influence the measurements. For example, if the probe faces the canal wall the results may be different than if it faces the TM.

We found no significant difference in ER between the right and left ears, consistent with the findings of Hunter et al. [2] and Aithal et al. [18] In contrast, Keefe et al. [17] found that below 1414 Hz the left ear had a higher ER than the right ear, while above 1414 Hz they found a lower ER in the left ear than in the right ear.

Hunter et al. [2] have shown that ER at 2-kHz best discriminates between the babies who passed or were referred on OAE. Interestingly, from the present study it seems that the largest difference in ER that occurred between the two main occlusion groups was in the region around 2 kHz. This finding may suggest that in the neighbourhood of 2 kHz the middle ear is more sensitive to factors affecting sound transmission.

Even though the newborn ear canal is narrow, it was possible to perform otoscopy in most of the babies. Most ear canals were found to contain some amount of material and it was difficult to differentiate between the canal wall and the TM. When the TM was identified, it could be seen that there was less angulation between it and the superior canal wall than in adults. Earlier studies have documented similar otoscopic results [21].

In some of our ambient measurements the absorbance values were negative. Sanford et al. [22] reported on a similar finding in tympanometric measurements. They considered negative absorbance as a measurement error. All negative absorbances in their study were set to zero. In the present we used reflectance and so when negative absorbance occurred the reflectance was set to 1.

The differences among the studies mentioned above make clear the importance of consistency, including such factors as inclusion criteria and age. The present results also introduce canal occlusion as a factor that affects the results and that may be independently measurable.

There are several limitations to the present study. First, testing had to be performed only once and rapidly, so that the baby would not to be disturbed and to avoid the parents' withdrawal from the study; therefore no inter-rater comparison could be conducted. Future studies could use a documentation system, such as video otoscopy with a recording capability, so a more accurate and quantitative occlusion assessment would be possible, as well as an inter-rater comparison. This would also permit an estimate of the actual patent area in absolute terms, which may be more directly related to reflectance than the ratio of occlusion to the canal size.

Another limitation is the fact that the ear-canal is a 3-dimensional structure, while our grading of the occlusion was based on a 2-dimensional view. It may be that the effect of an obstruction is determined more by the narrowness of the narrowest part of the remaining lumen than by the length of the obstruction, but this remains to be investigated. In addition, further data are required to draw conclusions about the relationship between otoscopy and reflectance measurements in a 'referred' population. Since, reflectance measurements are affected by conductive factors and not by sensorineural factors as are OAE and ABR; reflectance could help in deciding whether OAE and ABR results are poor because of conducting factors.

The present study did not include tympanometry. This would be a valuable addition in future studies designed to investigate occlusion or to establish normative data for ER.

5. Conclusions

The present study is the first to describe a correlation between otoscopic findings and ambient wideband ER. It has been shown how different occlusion levels of the ear canal after birth affect the ER. Wideband measurements are currently being studied as a possible future complementary tool in newborn hearing screening, and the current study also provides additional normative data in a newborn population who passed the hearing screening.

Funding source: Canadian Institutes of Health Research, Montréal Children's Hospital Research Institute, McGill University Health Centre Research Institute: these organizations played no role in the research apart from funding.

Conflict of interest: None

Acknowledgments

The authors wish to thank the staff at the Department of Audiology at the Royal Victoria Hospital, Montréal, Canada.

We also wish to thank Elice Mok, Ph.D., and Xun Zhang Ph.D., for their help with data analysis.

References

[1] G. Village, Year 2007 position statement: Principles and guidelines for early hearing detection and intervention programs., Pediatrics. 120 (2007) 898–921.

[2] L.L. Hunter, M.P. Feeney, J. a Lapsley Miller, P.S. Jeng, S. Bohning, Wideband reflectance in newborns: normative regions and relationship to hearing-screening results., Ear Hear. 31 (2010) 599–610.

[3] M.S. McLellan, C.H. Webb, Ear studies in the newborn infant, J. Pediatr. 58 (1961) 523–527.

[4] T.J. Balkany, S.A. Berman, M.A. Simmons, B.W. Jafek, Middle ear effusions in neonates., Laryngoscope. 88 (1978) 398–405.

[5] K.J. Doyle, P. Rodgers, S. Fujikawa, E. Newman, External and middle ear effects on infant hearing screening test results, Otolaryngol. -- Head Neck Surg. 122 (2000) 477–481.

[6] M. Magnuson, L. Hergils, The parents' view on hearing screening in newborns. Feelings, thoughts and opinions on otoacoustic emissions screening., Scand. Audiol. 28 (1999) 47–56.

[7] Z. Poulakis, M. Barker, M. Wake, Six month impact of false positives in an Australian infant hearing screening programme., Arch. Dis. Child. 88 (2003) 20–24.

[8] C.R. Kennedy, Controlled trial of universal neonatal screening for early identification of permanent childhood hearing impairment: coverage, positive predictive value, effect on mothers and incremental yield. Wessex Universal Neonatal Screening Trial Group., Acta Paediatr. Suppl. 88 (1999) 73–75.

[9] A.R. Kemper, S.M. Downs, A cost-effectiveness analysis of newborn hearing screening strategies., Arch. Pediatr. Adolesc. Med. 154 (2000) 484–488.

[10] J. Jerger, Clinical experience with impedance audiometry., Arch. Otolaryngol. 92 (1970) 311–24.

[11] J.L. Paradise, C.G. Smith, C.D. Bluestone, Tympanometric detection of middle ear effusion in infants and young children., Pediatrics. 58 (1976) 198–210.

[12] S.E. Meyer, C. a Jardine, W. Deverson, Developmental changes in tympanometry: a case study., Br. J. Audiol. 31 (1997) 189–195.

[13] J. Kei, J. Allison-Levick, J. Dockray, R. Harrys, C. Kirkegard, J. Wong, et al., High-frequency (1000 Hz) tympanometry in normal neonates., J. Am. Acad. Audiol. 14 (2003) 20–8.

[14] J. Alaerts, H. Luts, J. Wouters, Evaluation of middle ear function in young children: clinical guidelines for the use of 226- and 1,000-Hz tympanometry., Otol. Neurotol. 28 (2007) 727–732.

[15] M. Baldwin, Choice of probe tone and classification of trace patterns in tympanometry undertaken in early infancy., Int. J. Audiol. 45 (2006) 417–427.

[16] M.R. Stinson, E.A. Shaw, B.W. Lawton, Estimation of acoustical energy reflectance at the eardrum from measurements of pressure distribution in the human ear canal., J. Acoust. Soc. Am. 72 (1982) 766–73.

[17] D.H. Keefe, R.C. Folsom, M.P. Gorga, B.R. Vohr, J.C. Bulen, and S.J. Norton, Identification of Neonatal Hearing Impairment: Ear-Canal Measurements of Acoustic Admittance and Reflectance in Neonates, Ear Hear. 21 (2000) 443–461.

[18] S. Aithal, J. Kei, C. Driscoll, A. Khan, Normative wideband reflectance measures in healthy neonates, Int. J. Pediatr. Otorhinolaryngol. 77 (2013) 29–35.

[19] G.R. Merchant, N.J. Horton, S.E. Voss, Normative reflectance and transmittance measurements on healthy newborn and 1-month-old infants., Ear Hear. 31 (2010) 746–754.

[20] K.R. Vander Werff, B. a Prieve, L.M. Georgantas, Test-retest reliability of wideband reflectance measures in infants under screening and diagnostic test conditions., Ear Hear. 28 (2007) 669–681.

[21] M.S. McLELLAN, C.H. WEBB, Ear studies in the newborn infant: natural appearance and incidence of obscuring by vernix, cleansing of vernix, and description of drum and canal after cleansing., J. Pediatr. 51 (1957) 672–7.

[22] C. a Sanford, D.H. Keefe, Y.-W. Liu, D. Fitzpatrick, R.W. McCreery, D.E. Lewis, et al., Sound-conduction effects on distortion-product otoacoustic emission screening outcomes in newborn infants: test performance of wideband acoustic transfer functions and 1-kHz tympanometry., Ear Hear. 30 (2009) 635–652.

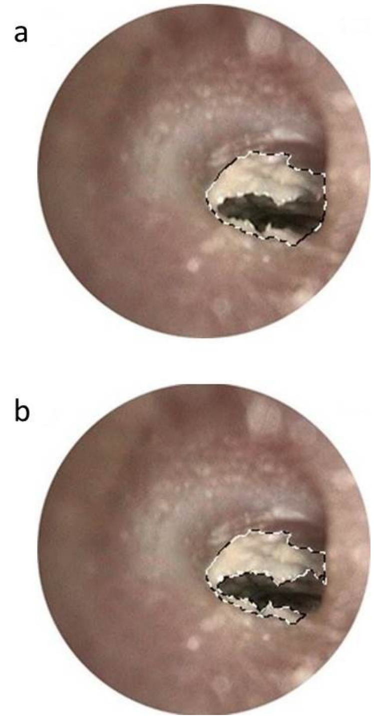

Figure 1: Example of ear-canal occlusion in a newborn. (a) The ear canal is outlined. (b) The occlusion is outlined. The estimated grade of occlusion in this case would be 60%.

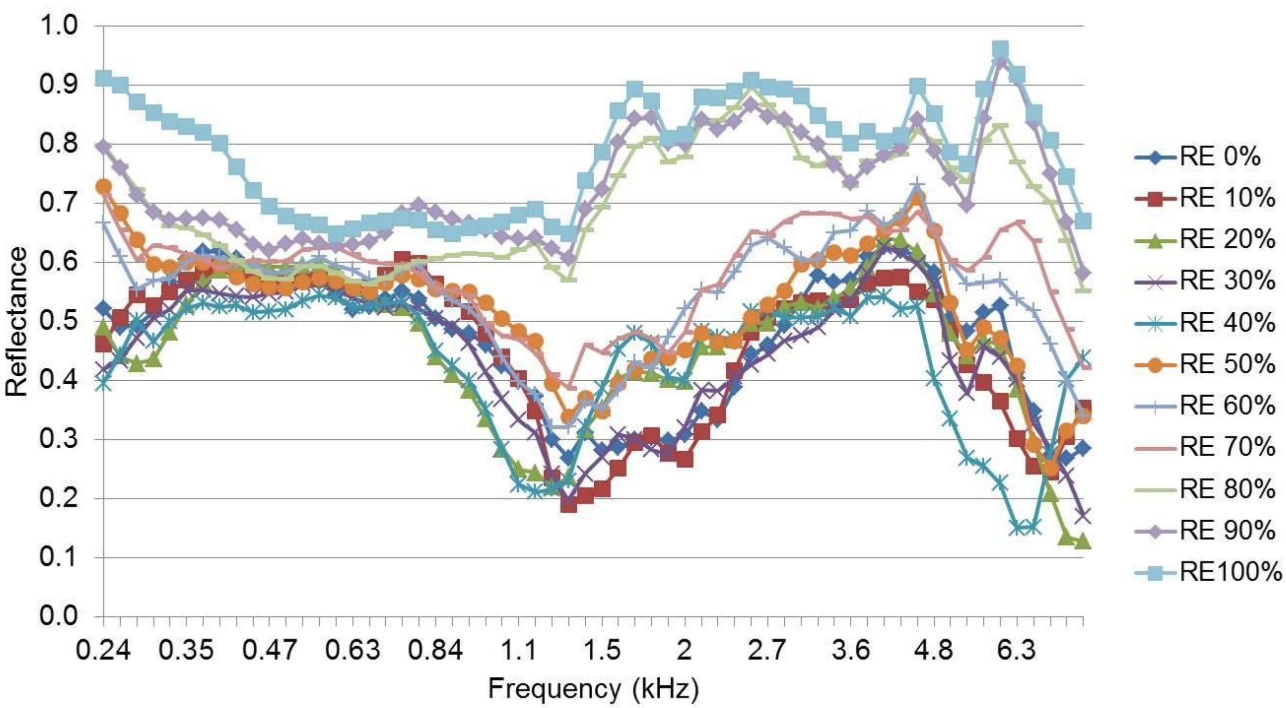

Figure 2: Median reflectance at each level of occlusion in the right ear

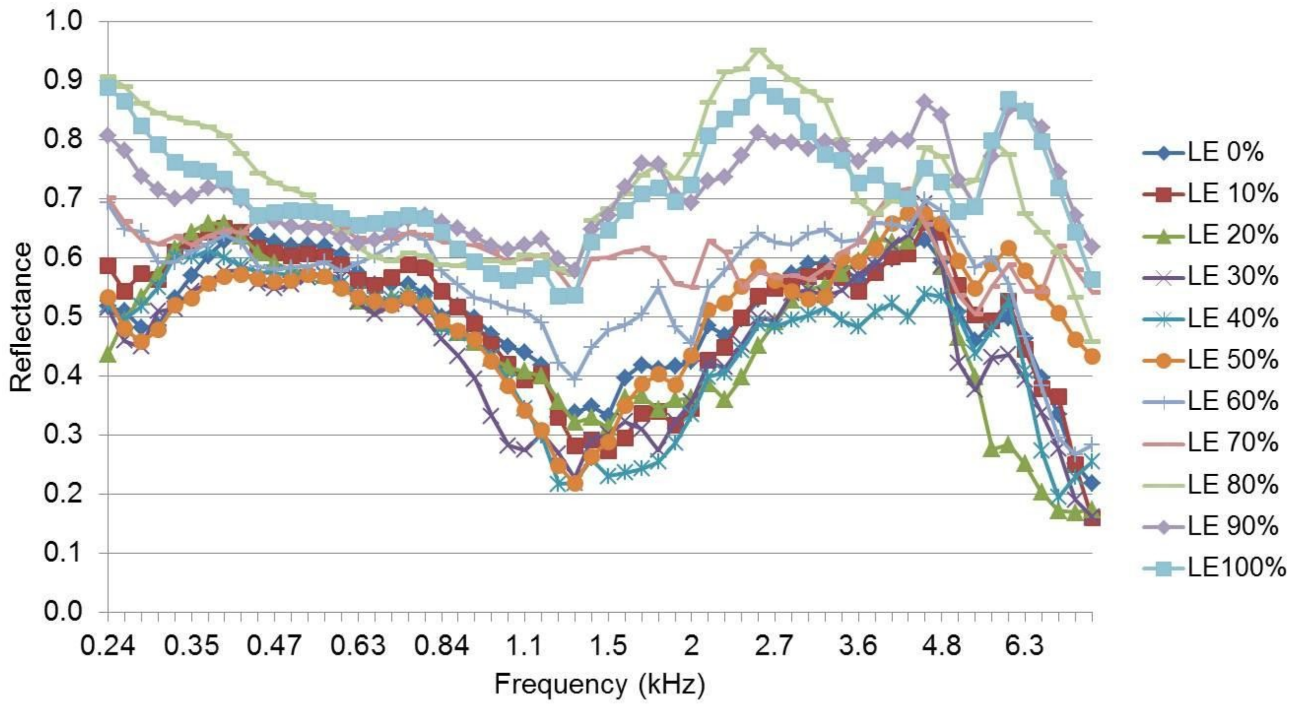

Figure 3:Median reflectance at each level of occlusion in the left ear

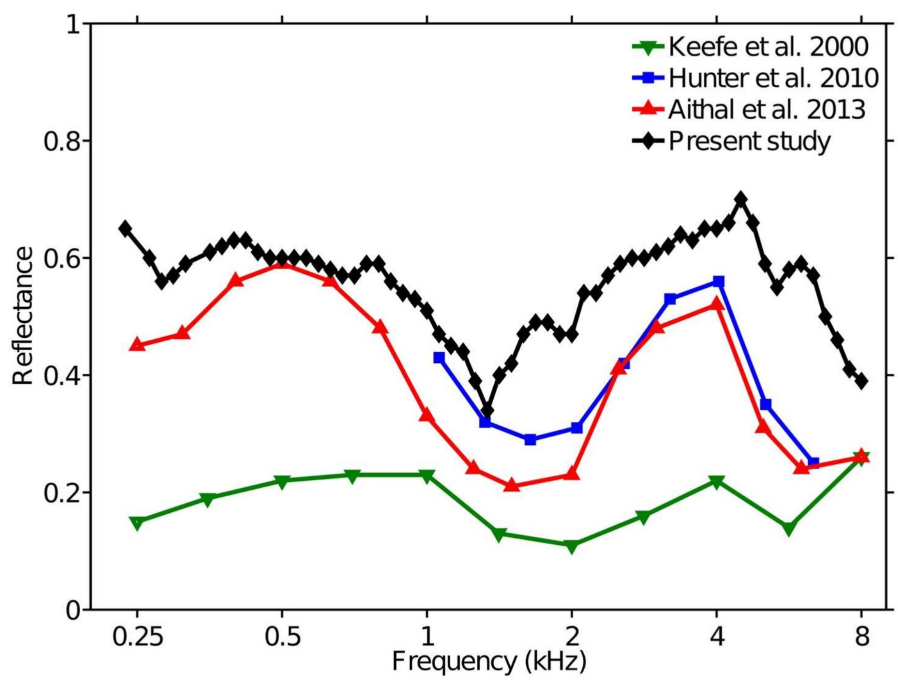

Figure 4: Comparison of median reflectance measured in different studies

Table 1: Demographic data

Babies	156
Gestational age	
Range (wks)	35-42
Mean (wks) ± SD (days)	39±10
Gender	
Females	80
Males	76
Birth type	
Vaginal	108
Cesarean Section	48
Ears	292
Right ear	146
Left ear	146
Age at screening (hrs)	
Range	12-54
Mean ±SD	25±8
Median	24
DPOAE	
Pass	155
Refer	1
Ear canal occlusion (%)	
Right ear Mean±SD	50±30
Left ear Mean±SD	50±30
Birth weight (g)	
Mean±SD	3406±472
Head circumference (cm)	
Mean±SD	34±2
Body length (cm)	
Mean±SD	51±3

Table 2: Comparison of the mean reflectances of the 2 main occlusion groups for the six groups of frequencies, and the corresponding p *values.*

		0-70% Occlusion			80-100% Occlusion			
			95% Confidence Interval			95% Confidence Interval		
	Freq. (kHz)	Mean	Lower	Upper	Mean	Lower	Upper	*p* value
1.	0.24-0.45	0.58	0.57	0.58	0.61	0.61	0.62	<0.0001
2.	0.47-0.79	0.56	0.56	0.57	0.58	0.58	0.59	<0.0001
3.	0.84-1.4	0.42	0.42	0.43	0.46	0.46	0.47	<0.0001
4.	1.5-2.5	0.46	0.45	0.47	0.52	0.51	0.53	<0.0001
5.	2.7-4.5	0.59	0.58	0.59	0.63	0.62	0.64	<0.0001
6.	4.8-8.0	0.45	0.44	0.46	0.51	0.50	0.52	<0.0001