Multifrequency Tympanometry and Evoked Otoacoustic Emissions in Neonates during the First 24 Hours of Life

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Abstract
Multifrequency, complex-component tympanograms and transient evoked otoacoustic emissions (EOAEs) were recorded in 55 neonates less than 24 hours of age. The purpose of the investigation was to determine the normal middle ear immittance characteristics of neonates less than 24 hours old (the approximate discharge age of well-babies) and to assess whether an association exists between transient EOAE response and middle ear status in neonatal ears. The tympanometric patterns recorded in the 55 neonates were, in general, not typical of those observed in older children and adults. Complex patterns were recorded at low probe frequencies indicating differences in the contribution of mass, stiffness, and resistance elements to admittance in the neonatal middle ear. Results from EOAE screening indicated a pass rate or partial pass rate of 82 percent. Although no clear association emerged between admittance characteristics and EOAE results, some interesting tendencies were noted.

Key Words: Evoked otoacoustic emissions (EOAEs), multifrequency tympanometry, newborn hearing screening

There is growing interest in determining whether universal hearing screening can be cost-effectively implemented in the hospital nursery prior to discharge, which is typically within the first 25 hours of life (HCIA, 1994). Evoked otoacoustic emissions (EOAEs) have been recognized by several studies as a potentially quick, objective, and cost-effective technique for screening newborn infants (Bonfils et al, 1988; Stevens et al, 1990; Kennedy et al, 1991; Uziel and Piron, 1991; White et al, 1993).

The detection of EOAEs is dependent upon the status of the auditory system peripheral to the cochlea. EOAEs rely on normal middle ear function for both the transmission of the stimulus to the cochlea and for the reverse transmission of the emission to the external auditory meatus. Therefore, it is important to assess the status of the middle ear when using EOAEs as a technique to screen for sensory hearing loss. Some results have indicated that EOAE screening has low specificity when the procedure is performed during the first postnatal day (e.g., Hogan and Callaghan, 1990; Salomon et al, 1992), although more recent reports have shown a pass rate of over 91 percent (Maxon et al, 1995). It is possible that some EOAE failures are due to fluid or other material temporarily remaining in the neonatal middle ear.

Evaluation of the neonatal middle ear using acoustic immittance measures has not been widely performed. There is some indication that the routine application of tympanometry using a standard 226-Hz probe to the neonatal population is problematic because the recordings obtained using low-frequency probe tones often result in double-peaked susceptance, conductance, and admittance tympanograms. In normal adults and older children, single-peaked patterns are typically recorded at this low frequency. The use of tympanometry using a low
probe frequency is further complicated by the fact that both normal and notched tympanograms have been recorded in neonates with confirmed middle ear effusion (Paradise et al, 1976; Marchant et al, 1986). These findings demonstrate the questionable validity of standard tympanometry employing low-frequency probe tones for the detection of middle ear effusion in neonates. The explanation for the differences between adult and neonatal tympanograms is not clear.

Multifrequency measures have been used to more completely describe the tympanometric differences seen in the neonate in comparison to the older child. This technique allows the assessment of the relative contribution of mass, stiffness, and resistive elements to acoustic admittance of sound by employing multiple probe tone frequencies (Hunter and Margolis, 1992). It has been demonstrated that multifrequency tympanometric patterns recorded in young infants do not follow the same patterns as in older children and adults (Himelfarb et al, 1979; Holte et al, 1991; Hirsch et al, 1992). From these studies, some generalizations can be made regarding the resistive and reactive elements of the neonatal ear, assuming that the differences between neonatal tympanograms and those of older children and adults can be attributed to the characteristics of the middle ear. First, impedance of the neonatal middle ear is dominated more by mass and/or resistive elements at low frequencies than is the middle ear impedance of older infants and adults (Himelfarb et al, 1979; Holte et al, 1991). Consequently, there is a downward shift to around 350 to 450 Hz in the resonant frequency of the neonatal middle ear. Second, there is a growing contribution of stiffness elements and a decrease in the contribution of mass elements to overall impedance during early infancy (Himelfarb et al, 1979; Holte et al, 1991). This is demonstrated by an increase in negative reactance values and admittance phase angles during the first few months of life. Third, multifrequency tympanometric measures suggest that significant maturational changes take place by 2 to 4 months of age, at which time the frequency-dependent mechanics of the infant middle ear become more like those of adults (Holte et al, 1991). Finally, research suggests that tympanometry using higher probe tone frequencies (e.g., 800 Hz) may be a better predictor of middle ear effusion than tympanometry using standard 226-Hz probe tones (Hirsch et al, 1992).

At the present time, there is little information available on tympanometric patterns recorded during the first 24 hours of life. To completely assess the condition of the neonatal middle ear, multicomponent tympanometric recordings are needed. This information takes on particular significance in light of the current interest in screening cochlear function in neonates using EOAEs.

In general, screening techniques using EOAEs in neonates have high sensitivity (Clarkson et al, 1994); however, when EOAE measurement is performed during the first 24 hours of life, there is often a high false-positive rate requiring follow-up testing, which diminishes the cost effectiveness of EOAEs as a screening device (Kok et al, 1992). There have been several explanations for the limited specificity of EOAE testing during the first days of life. These include reduced oxygen tension in the neonatal ear during the first 24 hours of life (Salomon et al, 1992), debris (vernix caseosa) obstructing the external ear canal (Chang et al, 1993), and middle ear fluid, a factor that has been shown to attenuate the EOAE response (Maxon et al, 1993). The neonatal middle ear may contain residual amniotic fluid (Kok et al, 1992) or mesenchyme, the postnatal remnants of loose, spongy developmental tissue known to exist in the neonatal temporal bone (Takahara et al, 1986). Some investigators have argued that the condition of the neonatal middle ear is not related to the poor response rate (Salomon et al, 1992); however, these studies employed low-frequency probe tone tympanometry and thus may not have been based on accurate assessment of the middle ear in newborns.

The purpose of this investigation, therefore, was twofold. The first aim was to study middle ear function in neonates during the first postpartum day using multifrequency, complex-component tympanometric measures. The second aim was to determine if a predictable relationship exists between the acoustic admittance characteristics of the middle ear and the EOAE results.

**METHOD**

**Subjects**

Subjects were 55 healthy, full-term neonates less than 24 hours of age from the newborn nursery at the University of North Carolina Hospitals, Chapel Hill.
Tympanometric Measurements

Multifrequency tympanograms were recorded unilaterally in each subject (n = 55). Only the more accessible ear was used for testing. Complex acoustic admittance tympanograms were recorded using probe tone frequencies of 226, 678, and 1000 Hz. Tympanograms were recorded twice at each frequency to confirm their reliability. All measurements were performed using a commercially available acoustic immittance instrument (Virtual 310). Ear canal pressure was varied in the positive-to-negative direction (+/-), as recommended by Holte et al (1991). Susceptance (B) and conductance (G) tympanograms were obtained for analysis and classification. Whenever possible, tympanometric shapes were classified according to the Vanhuyse et al (1975) model. That is, each was labeled by the number of extrema in the B and G tympanograms. Because the neonates often demonstrated unusual tympanometric patterns, the category "other" was added. In addition, tympanograms that showed no mobility were labeled "flat." An approximation of the resonant frequency of the middle ear was determined by observing the probe frequency at which the susceptance "notch" dipped below the positive tail of the B tympanogram.

EOAE Recording

EOAE testing was conducted unilaterally prior to the tympanometric measurements. A computer-based analyzer (Otodynamic Analyzer, ILO88) was used to record click-evoked EOAEs from the test ear. Babies were tested in open bassinets in a quiet, but not sound-insulated, room. Every effort was made to optimize probe placement and recording conditions by (a) selecting the most appropriate probe tip size; (b) reseating the probe if necessary to obtain the best apparent fit; (c) positioning the probe cord so that it was not affected by infant movement; (d) adjusting test parameters (stimulus gain, noise rejection level) as necessary; and (e) suspending recording during periods of excessive noise. However, no attempt was made to swab or otherwise clean the ear apart from any happenstance debris removal that occurred as a consequence of repositioning the probe. A pass in EOAE screening was defined as an emission response with ≥50 percent reproducibility in two frequency bands or ≥80 percent reproducibility in one frequency band. Absent or weak responses (<50% reproducibility) were defined as a fail. Neonates who failed the EOAE screening or received a partial pass were tested at least twice to confirm the results.

RESULTS

Tympanograms were successfully recorded at 226, 678, and 1000 Hz in each subject. Their classification, according to a modified Vanhuyse et al (1975) model, is displayed in Table 1. With the exception of two infants, single or multipeaked 226-Hz tympanograms were recorded in all of the neonates. It should be noted that in the two exceptions, estimates of ear canal volume suggested that the flat tympanograms were most likely due to debris obstructing the external auditory canal rather than to middle ear admittance characteristics. At 678 Hz, 34 flat tympanograms were recorded. The remaining 678-Hz tympanograms were evenly divided between the 1B1G pattern and the classification "other." The majority of the tympanograms recorded at 1000 Hz could not be classified according to the Vanhuyse et al (1975) model. Most were labeled as "other" or "flat." The remaining tympanograms recorded at 1000 Hz were divided among the three Vanhuyse patterns. Figure 1 shows an example of the most commonly recorded tympanometric pattern recorded at each test frequency. An estimate of middle ear resonance was made from the 226-Hz tympanograms, which showed that 57 percent of the neonates had a middle ear resonant frequency below 226 Hz and 43 percent had resonance above this frequency.

Screening using EOAEs was completed immediately prior to the immittance testing. The results indicated a pass rate of 71 percent, a partial pass rate of 11 percent, and a fail rate of 18 percent. Table 2 displays a breakdown of the tympanometric patterns of the infants according to the outcome of the EOAE screening. As the results demonstrate, no clear association emerged between tympanometric pattern and EOAE result.

DISCUSSION

The tympanometric configurations recorded in this group of newborn infants suggest that middle ear function is different in neonates than it is in older children and adults. Complex
Table 1  Tympanometric Patterns for the 55 Subjects Classified According to a Modified Vanhuyse et al (1975) Model

<table>
<thead>
<tr>
<th></th>
<th>226 Hz</th>
<th>678 Hz</th>
<th>1000 Hz</th>
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<tbody>
<tr>
<td>1B1G</td>
<td>10</td>
<td>10</td>
<td>4</td>
</tr>
<tr>
<td>3B1G</td>
<td>12</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>3B3G</td>
<td>31</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Other</td>
<td>0</td>
<td>10</td>
<td>29</td>
</tr>
<tr>
<td>Flat</td>
<td>2</td>
<td>34</td>
<td>16</td>
</tr>
</tbody>
</table>

tympanometric patterns were recorded at lower probe tone frequencies than are generally recorded in normal older children and adult ears, suggesting differences in the relative contributions of mass, stiffness, and resistance elements to impedance for the majority of the neonatal ears. Our results indicate that the reactive component of the neonatal middle ear reflects a relatively greater contribution of mass at lower probe tone frequencies in comparison to older children and adult ears. This is further demonstrated by the fact that over half of the infants had a middle ear resonant frequency estimated to be below 226 Hz. In contrast, the middle ear resonance of older children and adults is estimated to be around 1000 Hz (Lilly, 1984; Hunter and Margolis, 1992). Taken together, these findings demonstrate that the neonatal ear constitutes a different mechanical-acoustical system than the middle ear of older children and adults.

The validity of the 226-Hz tympanogram in assessing middle ear status in newborns remains questionable and controversial. It has been suggested by some investigators that tympanometric patterns recorded at 226 Hz represent not only middle ear admittance but also distention of the incompletely ossified ear canal walls. They speculated that movement of the ear canal walls may result in peaked tympanograms. Other reports (Holte et al, 1991) have brought into question the contribution of external canal wall movement to tympanometric shape recorded at 226 Hz. Keefe et al (1993) have determined that the measurement of the input impedance of an infant ear is

Table 2  Tympanometric Patterns Recorded at Each Test Frequency According to EOAE Response Classification: Pass, Partial Pass (P/Pass), Fail

<table>
<thead>
<tr>
<th></th>
<th>226 Hz</th>
<th></th>
<th>678 Hz</th>
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<th>1000 Hz</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Pass</td>
<td>P/Pass</td>
<td>Fail</td>
<td>Pass</td>
<td>P/Pass</td>
<td>Fail</td>
</tr>
<tr>
<td>1B1G</td>
<td>7</td>
<td>2</td>
<td>1</td>
<td>8</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>3B1G</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3B3G</td>
<td>27</td>
<td>0</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Other</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>10</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Flat</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>21</td>
<td>4</td>
<td>9</td>
</tr>
</tbody>
</table>

pressurizing the neonatal ear canal during tympanometry may cause distention of the incompletely ossified ear canal walls. They speculated that movement of the ear canal walls may result in peaked tympanograms. Other reports (Holte et al, 1991) have brought into question the contribution of external canal wall movement to tympanometric shape recorded at 226 Hz. Keefe et al (1993) have determined that the measurement of the input impedance of an infant ear is
tones, above 660 Hz, for the assessment of middle ear function in neonates.

Successful implementation of a universal screening program ideally involves testing prior to hospital discharge, which typically occurs within the first 24 hours of life. In the current study, 29 percent of the subjects screened during the first postnatal day received either a partial pass or fail and required follow-up testing. Although other investigators have reported a substantially higher pass rate (e.g., Maxon et al., 1995), others have reported similar outcomes (Kok et al., 1992; Salomon et al., 1992; Salamy et al., 1996).

No clear association emerged between EOAE results and middle ear admittance characteristics observed tympanometrically, possibly due in part to the relatively small number of ears tested. Although a clear association between EOAE results and tympanometric patterns is not apparent from these data, some possible tendencies emerged. For example, all babies who failed the emission screening had flat 678-Hz tympanograms, whereas several of the infants who had recordable EOAEs had peaked tympanograms at this frequency. This demonstrates that at 678 Hz, none of the infants who failed emissions showed any apparent admittance change with variation of air pressure, whereas a proportion of the babies with measurable EOAEs did exhibit such change.

Because multicomponent tympanometric measures have not been widely performed in neonates, a model for classifying the variety of tympanometric patterns recorded in this population has not been developed. The Vanhuyse et al. (1975) model has been used by some investigators to categorize multicomponent tympanograms in older children and adults, but it is not adequate for classifying and interpreting many neonatal tympanograms. In order to use tympanometry to assess the status of the middle ear in newborns, additional research is needed to develop a model for classifying and interpreting the patterns recorded in this population. Recording of acoustic reflexes might aid in the interpretation of neonatal tympanograms and help determine the clinical value of acoustic immittance measures in this population.

In summary, this study has demonstrated that the transmission characteristics of the neonatal middle and outer ears are likely to differ from those of older children and adults. Assessment of middle ear function in conjunction with otoacoustic emissions may lead to a better understanding of why some neonates with apparently normal cochlear function initially fail EOAE screening. Additional research is needed to further describe, classify, and interpret the immittance characteristics of the neonatal ear.

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REFERENCES


