Developmental Changes in Static Admittance and Tympanometric Width in Infants and Toddlers

Jackson Roush*
Kristin Bryant†
Martha Mundy‡
Susan Zeisel§
Joanne Roberts'

Abstract
Longitudinal measures of peak-compensated static acoustic admittance and tympanometric width are reported for infants and toddlers from 6 months to 30 months of age, based on over 1600 assessments of 88 children during a 24-month period. The subjects were all African-American children in full-time day care. Significant age effects were observed, with younger children displaying lower static admittance values and wider tympanograms. The results of this investigation underscore the importance of age- and population-specific norms when using acoustic immittance measures to evaluate middle ear status in children.

Key Words: Immittance, impedance, middle ear, tympanometry

Aural acoustic immittance measures are used routinely in the audiologic assessment of middle ear function. A battery of immittance measures often includes peak-compensated static acoustic admittance (static admittance) and calculation of tympanometric gradient or width. Static admittance is an estimate of the acoustic immittance at the lateral surface of the tympanic membrane. It is calculated by subtracting the admittance obtained with the ear canal pressurized from the admittance measured at the peak value. Although static admittance has considerable variability in normal subjects, low static admittance measured with a low-frequency probe tone is often associated with middle ear effusion. Measures of static admittance can also enhance the classification of tympanometric shape, since most classification procedures are based on the height of the admittance peak (Margolis and Heller, 1987).

Methods of calculating the shape of a tympanogram have varied substantially, but several investigators have noted that measures of tympanometric gradient or width are potentially more sensitive to middle ear effusion than static admittance or tympanometric peak pressure (Brooks, 1968; Paradise et al, 1976; Haughton, 1977; Fiellau-Nikolajsen, 1983; Nozza et al, 1994).

Most commercially available immittance instruments now report tympanometric width according to the pressure interval defined by a 50 percent reduction in peak admittance, expressed in dekaPascals (daPa) (see Fig. 1). Support for this method, first proposed by Liden et al (1970), comes from the work of Koebell and Margolis (1986) and deJonge (1986), who compared various methods of calculating tympanometric gradient.

In an effort to collect normative data using contemporary instrumentation and standardized recording measures, Margolis and Heller (1987) reported static admittance, tympanometric width, equivalent ear canal volume, and...
Figure 1 Calculation of tympanometric width in daPa.

tympanometric peak pressure in adults and preschool subjects. The children in their study ranged in age from 2.8 years to 5.8 years, with a mean age of 4.7 years. The resulting data were subsequently reported in ASHA's Guidelines for Screening for Hearing Impairment and Middle Ear Disorders (ASHA, 1990) as “interim norms,” which appear in an appendix to the revised guidelines.

The present study was undertaken to acquire normative data for static admittance and tympanometric width in children under 3 years of age. In particular, we were interested in determining if there are developmental changes that need to be considered when applying these measures to the evaluation of middle ear function in young children.

METHOD

Subjects

The 88 subjects in this investigation were part of an ongoing prospective study designed to explore the relationship between otitis media in early childhood and the development of language and learning (Roberts et al, 1995). There were 40 males and 48 females. All subjects were low- and middle-income African-American children attending full-time day care in one of nine child care centers in the central Piedmont region of North Carolina. Their average age at entry to day care was 5.2 months (SD = 3.0 months).

Otoscopic Examination

The children were seen biweekly for pneumatic otoscopy performed by an experienced pediatric nurse practitioner (PNP). Their ears were examined an average of 9.2 times between the ages of 6 and 30 months. During the 24-month observation period, the children experienced bilateral otitis media with effusion (OME) in 51 percent of the cases, unilateral OME in 12 percent of the cases, and no OME in 37 percent of the cases. Diagnosis of OME was based on otoscopic observation; tympanometry was used to corroborate the OME diagnosis. When otoscopic examination was not successful, tympanometry was used as the primary diagnostic tool. OME was classified as purulent (acute) when the fluid in the middle ear was opaque and yellowish/white. OME was classified as serous when the fluid in the middle ear was clear or straw-colored in appearance. Fluid was presumed to be present when the tympanic membrane was immobile and/or fluid levels were observed in the middle ear.

Agreement between judgment of mobility on pneumatic otoscopy and tympanometry was evaluated throughout the investigation. Interobserver agreement between the PNP and the pediatrician was 90 percent (kappa = .65) for mobility and 91 percent (kappa = .68) for diagnosis. Interobserver agreement between the PNP and a pediatric otolaryngologist, whose otoscopy skills have been validated against myringotomy, was 89 percent (kappa = .64) for mobility and 89 percent (kappa = .64) for diagnosis, based on 76 ear observations.

Data from ear examinations used in the present analysis were limited to those in which the diagnosis was normal based on otoscopic examination and for which immittance measures were judged to be accurate and complete. In general, the otoscopic examiner was blind to the tympanometric results; however, in some cases, practical considerations required tympanometry to precede otoscopy. Thus, the examiner was sometimes aware of the tympanometric findings prior to otoscopy.

Instrumentation

Acoustic immittance data were obtained using an automatic tympanometer (Micro Audiometrics Earscan), which was calibrated according to ANSI standards. This device uses a 226-Hz probe tone at 85 dB SPL with a positive to negative air pressure sweep, at a rate of 150 daPa/sec. Acoustic admittance magnitude was measured in acoustic mmhos (1 acoustic mmho = $\text{Im}^3 \times 10^{-9}/\text{Pa/sec}$) over an ear canal pressure range of $+200$ to $-300$ daPa. The static value was obtained by subtracting the admittance at $+200$ daPa from the peak value.

Tympanometric width was calculated automatically by the tympanometer according to the
pressure interval corresponding to a 50 percent reduction in static admittance (see Fig. 1). The instrument did not attempt to calculate tympanometric width unless the static admittance value was greater than or equal to 0.3 mmhos. Daily calibration measurements were made in the hard-walled calibration cavity supplied by the manufacturer.

RESULTS

Tympanograms displayed peak pressure that was similar for all ages ranging from -174 daPa to +18 daPa, with a mean value of -64 daPa (SD = 75 daPa). The means, standard deviations, and 90 percent ranges for static admittance and tympanometric width are shown in Tables 1 and 2. For static admittance, the mean for all ages combined was 0.45 mmhos (SD = 0.19), with a 90 percent range of 0.2 mmhos to 0.7 mmhos. Tympanometric width for all ages combined was 148 daPa (SD = 40), with a 90 percent range of 102 daPa to 204 daPa.

Age and gender effects were studied using general linear mixed models (Laird and Ware, 1982; McLean et al., 1991). These methods can be viewed as a generalization of repeated measures analysis of variance in which systematic individual effects on the repeated assessments are represented in the analysis model by random effects. Accordingly, these methods take into account the fact that multiple assessments on the same individual are likely to be correlated. Specifically, the static admittance and tympanometric width were analyzed with a model that included age as a continuous variable, gender and age × gender as fixed effects, and the individual as a random effect. Results indicated that age differences were reliably detected for both static admittance (F = 27.7) and tympanometric width (F = 44.0). There were no significant gender differences.

DISCUSSION

Direct comparison of these data to previous studies is complicated by technical and procedural differences. Many of the earlier studies of acoustic immittance were based on measurements performed using tympanograms expressed in “arbitrary compliance units” and thus are not amenable to comparison. For contemporary instruments, the most important variables are (1) the method of compensating for ear canal volume; (2) the method of calculating tympanometric width from the peak-compensated static admittance value; (3) pump speed; and (4) probe-tone frequency. Regarding correction for ear canal volume, Margolis and Shanks (1991) note that compensation at +200 daPa is slightly less accurate than “maximum/minimum” calculations or compensation at extreme negative values (e.g., -400 daPa); however, this method has been used successfully in several studies (e.g., Shanks and Wilson, 1986; Margolis and Heller, 1987). Regarding calculation of tympanometric width, Margolis and Heller (1987) note that tympanometric gradient based on the pressure interval corresponding to a 50 percent reduction in static admittance, expressed in daPa, appears to have several advantages over other methods. Advantages include (1) relative invariance to pump speed; (2) a wide range of values between normal and abnormal values, thus facilitating identification of diseased ears; and (3) low correlation with static admittance, thus

---

1The Earscan, like most tympanometric screening instruments, does not compute tympanometric width on tympanograms having a static admittance less than 0.3 mmhos due to the loss of accuracy that occurs when calculations must be made at or near the “noise floor.”
supplementing rather than duplicating other immittance measures. Pump speed is likely to have a significant effect only on peak admittance, with faster pump speeds (e.g., 400 daPa/sec) producing higher values of peak Y than slower speeds. Regarding probe tone, a low-frequency probe (e.g., 226) has been generally considered well suited for detecting middle ear effusion in all but neonatal populations, although some have challenged this assumption (Keefe et al., 1993).

The study by Margolis and Heller (1987), whose 50 pediatric subjects (92 ears) ranged in age from 2.8 years to 5.8 years and whose results are reported as “interim norms” in an appendix to the 1990 ASHA guidelines, was procedurally similar to the present investigation and therefore amenable to comparison. Using a screening instrument that measured acoustic admittance magnitude in acoustic mmhos over an ear canal pressure range of +200 to −300 daPa with a 226-Hz probe tone, Margolis and Heller reported normative data for both static admittance and tympanometric width. Using a 200 daPa/sec pump speed, they reported a mean static admittance value of .50 mmhos (90% range = .22–.81) and a mean tympanometric width of 100 daPa (90% range = 59–151 daPa). Although data were not reported for specific age groups, significant age effects were observed.

There is no obvious explanation for the lower static admittance and wider tympanograms observed in younger children, although the differences may be related to changes in the anatomy and physiology of the external and middle ear known to continue throughout childhood (Anson and Donaldson, 1981). It is also possible that younger subjects, known to exhibit a higher prevalence of middle ear effusion, may experience subtle and presumably temporary changes in the mechanical properties of the tympanic membrane, in the absence of otoscopic abnormalities. Although our measures were limited to single component (Y) tympanograms, these changes would most likely have their primary influence on the resistive components of middle ear impedance (Margolis and Shanks, 1985), the effects of which would be seen in a “broadening” and “flattening” of the admittance tympanogram. All of the subjects in the present investigation were in full-time day care, a factor often associated with higher prevalence of OME. Indeed, the prevalence of OME was very high in this sample. Although all ears were judged to be free of OME at the time these tympanograms were obtained, the recurrent OME history characterizing many of these subjects most likely had residual effects on middle ear function. This might account for the relatively wide tympanograms we observed even in our oldest subjects (mean = 144 daPa for the 24- to 30-month age group), compared to those of Margolis and Heller (1987). That is, the subjects in the present investigation most likely had a higher incidence of OME than the subjects studied by Margolis and Heller (1987).

Normative data for static admittance, tympanometric width, and other immittance variables has also been reported by Nozza et al. (1992), who studied subjects ranging in age from 3 to 16 years. The children were unselected with regard to OME history and thus were characteristic of the general population. Not surprisingly, means for peak admittance (0.78 mmho) and tympanometric width (104 daPa) differed from those of the present investigation. Nozza and colleagues have also reported immittance findings in children with recurrent OME histories who were tested just prior to undergoing surgery for myringotomy and tube placement (Nozza et al., 1994). In general, acoustic immittance measures revealed substantially lower peak admittance (0.28 mmho) and wider tympanograms (373 daPa), even when the children were free of middle ear effusion at the time of testing. These findings are consistent with those of the present investigation in demonstrating that middle ear status is likely to differ for children with and without OME histories, even when middle ear effusion is not present.

In summary, our findings suggest that infants and young toddlers with normal middle ear status, as judged otoscopically, are likely to exhibit lower static admittance values and wider tympanograms than those of older preschool-aged children drawn from the same population. The results of this study underscore the need for age- and population-specific norms, especially if the data are to be used in screening for middle ear dysfunction. The values reported here, however, should be applied only to the age groups included in our sample (6 months to 30 months), since younger infants are likely to show a variety of tympanometric findings that differ from older children and adults (e.g., Holte et al, 1991), and the mechanisms underlying these observations appear to be...
affected by the complex interaction of ear canal growth, resonance, and vibration (Keefe et al., 1993). Application of these norms also assumes that the acoustic immittance measures are obtained using instrumentation having similar technical specifications, that is, a low-frequency probe tone (e.g., 226 Hz), automatic compensation for ear canal volume by subtracting the admittance at +200 daPa from the peak value, and calculation of tympanometric width based on the pressure interval corresponding to a 50 percent reduction in static admittance. Finally, these norms will be most applicable to populations having a similar prevalence of OME, since children with a high rate of recurrence may exhibit residual changes in middle ear function, even during periods when OME has resolved.

The broad normative range of tympanometric widths observed for this age group and population may reduce the utility of this measure as a screening tool; however, further research is needed to determine the optimal immittance screening battery and cut-off values for each measure in the battery, for diseased as well as nondiseased ears.

Acknowledgments. This research was supported by grant MCJ-370599 and MCJ-370649, Maternal and Child Health Bureau, Health Resources and Services Administration, US Department of Health and Human Services. The authors are grateful to Dr. Margaret Burchinal for statistical consultation and Ms. Elizabeth Gunn for assistance with data analysis. Dr. Robert Margolis, Dr. Donald Schum, and two anonymous reviewers provided helpful comments on an earlier version of this manuscript. Portions of this paper were presented at the Annual Convention of the American Speech-Language-Hearing Association, Anaheim, CA, November, 1993.

REFERENCES


