The Effect of Otitis Media in Childhood on the Development of Middle Ear Admittance on Reaching Adulthood

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Objectives: To determine the long-term change in static admittance values of subjects with a positive or negative history of otitis media (OM) and ventilation tube (VT) insertion; and to investigate the association between static admittance values and tympanic membrane abnormalities.

Design: Prospective follow-up study.

Subjects: A total of 358 subjects with or without a history of OM (OM+ or OM−) and VT insertion (VT+ or VT−) derived from a birth cohort that had been observed from preschool to adulthood.

Main Outcome Measures: Otomicroscopic and tympanometric data obtained at subject ages 8 and 18 years.

Results: Static admittance values generally increased with age. At age 8 years, static admittance values were highest in OM+VT+ ears and lowest in OM− ears. At age 18 years, the difference between OM+VT+ and OM+VT− ears was larger, while the difference in static admittance values between OM+VT− and OM− ears had disappeared. In the group of VT+ subjects, the proportion of extreme static admittance values increased from 16% to 35% between ages 8 and 18 years. Correlation coefficients of individual static admittance values at 8 and 18 years were high in all groups and ranged from 0.61 to 0.85. We could not demonstrate an intermediate role of tympanic membrane abnormalities in the relation between VTs and static admittance at young adult age, except for atrophy.

Conclusions: The static admittance value at age 8 years was a strong predictor for the value at age 18 years. A VT+ status was associated with a larger increase in static admittance than can be explained on the basis of age alone.


Auscustic Middle Ear Admittance, as assessed by tympanicometry, is a measure of the ease with which acoustic energy flows into the middle ear. Usually, this is assessed with a probe tone of 226 Hz; at this frequency the admittance is dominated by stiffness of the middle ear system.1 Although incorrect, the term compliance has been used interchangeably with admittance. An obvious example of a condition leading to values above the reference range of admittance is discontinuity of the ossicles; an example of a condition associated with values below the reference range is otitis media (OM) with effusion. Tympanic membrane abnormalities also seem to affect admittance. While atrophy is associated with increased admittance values,2 tympanosclerosis tends to be associated with decreased middle-ear admittance values.3 Gaiehde et al3 compared static admittance values of ears with and without a history of ventilation tubes (VT+ and VT−). More tympanic membrane abnormalities were observed in VT+ ears, but the static admittance values were normal. The reason might be that tympanosclerosis and atrophy in VT+ ears have opposite effects on static admittance values.

It is not yet known how static admittance develops over time in subjects who had OM as children, whether it was treated with VTs or left untreated. Tympanic membrane abnormalities seem to be dynamic in that atrophy tends to increase over time.4,8 Tympanosclerosis, however, tends to be a more stable condition after the extrusion of VTs.8,9 The objective of this study is to report on the dynamics of static admittance and to evaluate the association between static admittance values and tympanic membrane abnormalities. A birth cohort that had been observed with repeated otomicroscopy and tympanometry from the age of 2 years was an ideal study population for a follow-up examination at age 18 years.

Four questions are addressed in this study: (1) Are the observed differences in static admittance values related to OM and/or VT status in childhood? (2) How do static admittance values at age 8 years correlate...
with those at age 18 years? (3) Are the higher static admittance values found for OM+ ears associated with tympanic membrane abnormalities? (4) Are changes in static admittance values between ages 8 and 18 years associated with changes in tympanic membrane abnormalities over that same period?

**METHODS**

**SUBJECTS**

This study is based on data derived from 358 individuals (716 ears) who were selected from a birth cohort that had been observed from the age of 2 years. At that age a detailed history regarding OM (and its treatment) in the first 2 years of life was recorded. Between the ages of 2 and 4 years, a tympanogram was made every 3 months. At age 8 years, otomicroscopy was performed, and the occurrence and treatment of OM between ages 4 and 8 years were documented. Parental information was checked in the medical records of these individuals. Graphically illustrates details about this cohort.

To select the subjects for the present study, a cumulative OM score was calculated for each individual. Details on calculating this score have been reported previously. In short, the OM score is based on the documented number of episodes of either OM with effusion (OME) or acute OM (AOM), diagnosed by tympanometry, or OM with effusion (OME). The OM score forms the OM score. The subjects in the highest and lowest third of the OM score (n=528) form the groups with either a positive (OM+) or a negative (OM−) history of OM. Of these 528 subjects, 358 (183 OM+ and 175 OM−) agreed to participate in the present follow-up study at age 18 years. The OM+ group was then divided into subjects who had been treated with VTs (OM+VT+, n=51) and those whose OM was managed nonsurgically (OM+VT−, n=132). In terms of numbers of ears, 102 were OM+VT+, 264 were OM+VT−, and 350 were OM−.

To compare middle-ear admittance values at ages 8 and 18 years, ears with OME, AOM, otosclerosis, or VTs at the time of either examination were excluded from the analyses. As a result, this part of the study included 54 OM+VT+ ears of 31 subjects, 224 OM+VT− ears of 119 subjects, and 342 OM− ears of 172 subjects.

Approval for the study was obtained from the ethics committee of the University Medical Center Nijmegen. All participants signed informed consent forms.

**OUTCOME MEASURES**

The first author (B. de B.) performed otomicroscopy and tympanometry in all subjects at age 18 years. At that time, tympanic membrane abnormalities were documented according to the same classification that the third author (A.S.) had used to evaluate these subjects when they were between 7 and 8 years old. Pars tensa pathologic features such as tympanosclerosis, atrophy, atelectasis, retraction pocket, perforation, and pars flaccida retraction were recorded. At age 18 years, tympanometry was performed with a Tym87 Middle Ear Analyzer (Danplex, Copenhagen, Denmark), whereas at age 8 years, it was performed with a GSI-27 Middle Ear Analyzer (Grason Stadler Inc, Madison, Wis). With both tympanometers, a 226-Hz probe tone and a pump speed of 200 decapascals (daPa/s) were applied. The measure of interest for this study was static admittance expressed in cubic centimeters. The static admittance value is defined as the peak admittance value (when pressure on both sides of the tympanic membrane is equal) minus the admittance value of the ear canal at +200 daPa (at the start of tympanometry when the tympanic membrane is stiffened).

To account for the interdependence of the 2 ears in 1 subject, either the mean of both ears was calculated, or both ears were included in a fixed-effect regression model. The contribution of tympanic membrane abnormalities to the variation in static admittance value was analyzed by comparing multiple regression models with and without explanatory variables. All analyses were performed using SAS statistical software (version 6.12; SAS, Cary, NC).

**RESULTS**

Distributions of static admittance values for the study groups at ages 8 and 18 years are listed in Table 1. At age 8 years, the median static admittance values were 0.7 cm² in OM+VT+ ears, 0.5 cm² in OM+VT− ears, and 0.6 cm² in OM− ears. There were small but statistically significant differences in 90% ranges (from the 5th to the 95th percen-

**Table 1. Distribution of Static Admittance Values**

<table>
<thead>
<tr>
<th>Subject Age at Measurement, y</th>
<th>Subjects, No.</th>
<th>5th Percentile</th>
<th>Median</th>
<th>95th Percentile</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OM+VT+</td>
<td>31</td>
<td>0.4</td>
<td>0.7</td>
<td>1.9</td>
</tr>
<tr>
<td>OM+VT−</td>
<td>119</td>
<td>0.2</td>
<td>0.5</td>
<td>1.8</td>
</tr>
<tr>
<td>OM−</td>
<td>172</td>
<td>0.3</td>
<td>0.6</td>
<td>1.3</td>
</tr>
<tr>
<td>18</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OM+VT+</td>
<td>49</td>
<td>0.5</td>
<td>1.2</td>
<td>2.8</td>
</tr>
<tr>
<td>OM+VT−</td>
<td>131</td>
<td>0.2</td>
<td>0.7</td>
<td>2.0</td>
</tr>
<tr>
<td>OM−</td>
<td>174</td>
<td>0.4</td>
<td>0.7</td>
<td>1.7</td>
</tr>
</tbody>
</table>

Abbreviations: OM, otitis media; VT, ventilation tube; +, positive history; −, negative history.

The mean of both ears of each subject was used. All static admittance values are reported in cubic centimeters.
tile) between the OM/H11001 VT+ and OM/H11001 VT− groups and between the OM/H11001 VT− and OM− groups (Wilcoxon, P<.05).

At age 18 years, the median static admittance values were 1.2 cm3 in OM/H11001 VT+ ears, 0.7 cm3 in OM/H11001 VT− ears, and 0.7 cm3 in OM− ears. Apparently, the difference in static admittance values between OM/H11001 VT+ and OM/H11001 VT− ears had become larger, while the difference in static admittance values between OM/H11001 VT− and OM− ears had disappeared by the time the subjects had reached age 18 years.

In general, static admittance values increased with age. Extreme values can be separated from normal values by using an age-specific reference, namely, the 95th percentile static admittance value of the OM− ears. The extreme values at age 8 years were defined as values above 1.3 cm3. Accordingly, 9% of the OM+ VT− ears and 16% of the OM+ VT+ ears had extreme static admittance values. At age 18 years, 11% of the OM+ VT− ears and 35% of the OM+ VT+ ears had an extreme static admittance value above the 95th percentile of the reference group, ie, a value above 1.7 cm3.

**Figures 2, 3, and 4** are scatterplots of the (log-transformed) individual static admittance values at ages 8 and 18 years for the OM−, OM+ VT−, and OM+ VT+ ears, respectively. The diagrams show that static admittance values at ages 8 and 18 years were very well correlated for all study groups. The correlation coefficient for OM+ VT+ ears was 0.61. For the OM+ VT− and OM− groups, the correlation coefficients were even higher: 0.83 and 0.85 respectively.

Tympanic membrane abnormalities are strongly associated with OM, and some abnormalities seem to be the direct result of previous VT insertions. We therefore investigated the contribution of tympanic membrane abnormalities to static admittance values at age 18 years in the whole OM+ study group (OM+ VT+ and OM+ VT− combined) using multiple linear regression models. Tympanosclerosis, atrophy, atelectasis, retraction, and retraction of the pars flaccida were all included in this model as covariates. They were used to test the hypothesis that tympanic membrane abnormalities of whatever nature explain the effect of previous VT insertion on static admittance at age 18 years. Comparison of 2 models (not shown), 1 with and 1 without these tympanic membrane abnormalities, by no means supported this hypothesis. The effect of previous VT insertion remained unchanged after introducing tym-
Table 2. Effect of Tympanic Membrane Abnormalities on Change in Static Admittance Values

<table>
<thead>
<tr>
<th>Subject Age at Measurement, y</th>
<th>Change in Admittance From Age 8 to 18 y, cm²</th>
<th>P Value (t Test)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Age 8</td>
<td>18</td>
</tr>
<tr>
<td>Tymanosclerosis</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>+</td>
<td>−</td>
</tr>
<tr>
<td></td>
<td>−</td>
<td>+</td>
</tr>
<tr>
<td>Atrophy</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>+</td>
<td>−</td>
</tr>
<tr>
<td></td>
<td>−</td>
<td>+</td>
</tr>
<tr>
<td>Atelectasis</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>+</td>
<td>−</td>
</tr>
<tr>
<td></td>
<td>−</td>
<td>+</td>
</tr>
<tr>
<td>Retraction Pocket</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>+</td>
<td>−</td>
</tr>
<tr>
<td></td>
<td>−</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>−</td>
<td>−</td>
</tr>
<tr>
<td>Retraction Pars Flaccida</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>+</td>
<td>−</td>
</tr>
<tr>
<td></td>
<td>−</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>−</td>
<td>−</td>
</tr>
</tbody>
</table>

Abbreviations: NA, not applicable; +, abnormality present; −, abnormality absent; ?, unknown. All static admittance values are reported in cubic centimeters.

Panasonic membrane abnormalities into this model. Of the latter, only atrophy contributed significantly to the model. Table 2 lists, for each tympanic membrane abnormality separately, the change in static admittance value (the value at age 18 years minus the value at age 8 years) related to the change in status of each abnormality. Static admittance values tended to increase from ages 8 to 18 years when atrophy, atelectasis, retrac tion pocket, or retraction of the pars flaccida persisted or appeared in this period. Likewise, an increase in static admittance value was noted when abnormalities were absent or resolved in this period, although this increase was smaller. In contrast to expectation, persistent or newly developed tympanosclerosis was not associated with a smaller (or negative) increase in static admittance between ages 8 and 18 years. As expected, newly developed atrophy coincided with a significantly higher increase in static admittance \((P=.05)\) compared with ears free of atrophy at both ages. The same result was found for newly developed retraction pockets \((P<.05)\).

This prospective follow-up study is unique in that it observed subjects with and without OM from preschool age to adulthood and thereby documented long-term changes in middle-ear mobility, specifically static admittance values, in relation to OM and its treatment. The difference in static admittance values between OM+VT+ and OM+VT− ears was not as distinct at age 8 years as it was at age 18 years. The highest values for static admittance at both ages were observed in the OM+VT+ group. At age 18 years, the difference in static admittance values between the OM+VT− and OM− ears had disappeared. This suggests that treatment with VTs accelerates the increase of static admittance values. While there was hardly any change in the proportion of ears that had extreme static admittance values between ages 8 and 18 years in the OM+VT− group, a dramatic increase of this proportion was observed in the OM+VT+ group. Specifically, 1 of 3 OM+VT+ ears had a static admittance value above the 95th percentile of the reference group (OM−) at age 18 years.

This study demonstrates remarkably high correlations in all study groups between static admittance values measured at ages 8 and 18 years. Despite a fairly large variation in static admittance values, the individual position in the distribution appears to be stable over the teenage years, making the value at age 8 years a good predictor of the value at age 18 years.

The static admittance values of ears in the OM− group, the otologically normal values, were in the same range as those used in the literature as reference values. For instance, Haapaniemi16 studied otologically normal school-aged children and found a 90% range of 0.2 to 1.0 cm² and a median of 0.5 cm² for 7-year-olds. This is comparable to the 90% range of static admittance values that we found in our nonotitis group at age 8 years: 0.3 to 1.3 cm²; median, 0.6 cm². At age 18 years, the 90% range of static admittance values in this group was 0.4 cm² to 1.7 cm², with a median of 0.7 cm². The data are in accordance with the values mentioned in studies by Wiley15 and Margolis and Goycoolea20 for 20- to 30-year-old subjects, a 90% range of 0.4 to 1.7 cm², with a median and mean, respectively, of 0.8 cm². Wiley et al14 showed that static admittance values increased with age, a finding also reported for static admittance values at school age.18 The present study also found a marked increase in median static admittance values from ages 8 to 18 years. It is not likely that this increase is due to a difference in the instruments used at both examinations because well-calibrated equipment was used in accordance with strict measurement procedures. Interestingly, De Chiscinis and Nozza22 showed that the static admittance data obtained with commercially available tympanometers were consistent, independent of the device used.

In the OM+VT+ group, we found a considerably higher median static admittance value than in the OM+VT− group. Abundant studies have demonstrated the close relation between tympanic membrane abnormalities and a history of VT insertion.5,6,8,10,24 Yet we could not demonstrate an intermediate role of tympanic membrane abnormalities in the relation between VTs and static admittance value. Only for atrophy could we find a statistically significant positive correlation with static admittance value. Consequently, tympanic membrane abnormalities do not explain the effect of VTs on static admittance value at age 18 years. Furthermore, changes in tympanic membrane abnormalities did not appear to be related to changes in the static admittance values over time. Only newly developed atrophy or retraction pocket
of the pars tensa increased static admittance value significantly in the period from ages 8 to 18 years. It should be emphasized that the number of subjects in the OM + VT + group was rather small. Therefore, it is hard to draw conclusions about various combinations of tympanic membrane abnormalities. The association between atrophy and static admittance value is in line with the data in the literature. For instance, in a follow-up study on VT insertion in 165 ears, Daly et al. found an association of high static admittance value with atrophy. However, 40% of the ears with high static admittance values did not show atrophy in that study. Apparently, other factors as yet unknown contribute to the pronounced difference in static admittance value between OM + VT + and OM + VT− ears. Changes in middle-ear structures resulting in an increased mobility might play a role. Our observations allow us to speculate on factors that mediate an increased mobility of the middle-ear system. Sheer stress from the weight of the VTs on the tympanic membrane could negatively affect the quality of the tympanic membrane permanently. Atrophy of the lenticular process of the incus is frequently seen during surgery on ears with a history of OM. This could result in laxity of the incudostapedial joint and consequently in an increased static admittance value.

The clinical importance of increased static admittance depends on its relation to hearing acuity. To our knowledge, there are no studies showing that increased static admittance results in or plays a mediating role in hearing loss, and consequently in an increased static admittance value.

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