Continuous Long-term Measurements of the Middle Ear Pressure in Subjects with Symptoms of Patulous Eustachian Tube

BO TIDEHOLM, BJÖRN CARLBORG and MARIANNE BRATTMO

From the Department of Oto-rhino-laryngology, Division of Audiology, Malmö University Hospital, Sweden

Direct middle ear (ME) pressure measurements during 24 h and tubal function tests were performed on 11 subjects with the clinical diagnosis patulous Eustachian tube (PET). The pressure was recorded from the ME via a perforation in the tympanic membrane. The method used has previously been reported in a study on subjects with normal ME function and no symptoms of PET: a normal group. Results from tubal function tests correlated well with the clinical diagnosis of PET and the sniff test was positive in most subjects. Continuous ME pressure measurements during normal everyday and night-time activities showed no indications of pressure changes induced by sniffing. Subjects with the clinical diagnosis PET did not have a static state of an open ET. The ME pressure varied during the day and night, indicating that the function of the ET changed over time from a closed to an open state. Subjects with PET had a long-term pressure pattern significantly different from that of a normal group, a difference seen in the erect as well as in the recumbent position during the night, whereas the normal group had a slight positive mean pressure. The difference was statistically significant. Many subjects demonstrated frequent slow rate negative pressure trends during normal day-time and night-time activities. Long-term continuous pressure measurements seem to add valuable information to that of conventional tubal function tests. Key words: closing failure, direct measurement, tubal function.

INTRODUCTION
A characteristic feature of a patulous Eustachian tube (PET) is a closing failure, i.e. a weakness or instability of the Eustachian tube (ET) to withstand physiological pressure variations in the nasopharynx (1, 2). The diagnosis of a PET is generally based on history, symptoms and breathing correlated movements of the tympanic membrane verified at otomicroscopy. Objective recordings of tympanic membrane movements are frequently used to confirm the diagnosis (2–4).

The term patulous Eustachian tube may lead one to expect a chronic condition of a rigid open tube. It is an established clinical observation that symptoms of PET may vary in intensity, duration and may change depending on activity or body position. Magnusson and Falk suggest three different categories of closing failure of the ET: relative, intermittent and constant (1, 2). A constantly wide-open ET is considered a condition to which patients often are habituated and unaware of. Symptoms of an intermittently wide-open ET are often considered to be more pronounced (1, 2).

The clinical diagnosis of PET can be overlooked and misinterpreted since the symptoms may paradoxically simulate those occurring in ET obstruction. Most patients with current PET can generate a negative pressure in the ME by sniffing (2). This behaviour is adopted by some patients to suppress annoying symptoms of a PET (5). It has been suggested that habitual sniffing can be an essential factor in the pathogenesis of tympanic membrane retractions, chronic adhesive ME pathology and retraction type cholesteatoma (1, 6, 7).

Tympanometry and microflow methods have been used for indirect measurement of the ME pressure in several investigations (3, 4, 8, 9). Such indirect studies have not measured the pressure continuously, and the subjects have been restrained to the instrumental set-up and location. The conditions have not been those of normal everyday activities. Direct measurement of the ME pressure during tubal function tests have thoroughly revealed the capacity of the ET to equilibrate pressure differences between the ME and nasopharynx (9–12). Tubal function tests are provocation tests reflecting a condition at the specific moment of investigation. A study of a condition that might vary with time, activity and body position is likely to benefit from using a method allowing continuous long term recordings during normal every day and night conditions. Our group recently developed such a method for ambulatory direct ME pressure measurement using an equipment that is conveniently portable (13).

The aims of this study were to:
1. evaluate the long-term ME pressure in subjects with clinical symptoms of PET and relate this to results from tubal function tests;
2. compare results from subjects with clinical symptoms of PET to results from subjects with no symptoms of PET and no history of ME disease;
3. evaluate whether the clinical diagnosis PET is associated with a stable condition of an open ET
and if the ME pressure is influenced by recumbent position during the night;
4. determine whether subjects with PET are prone to have frequent, rapid, negative pressure reductions, indicating a sniffing behaviour.

MATERIALS AND METHODS

A total of 11 subjects were selected from the out-patient clinic with the following inclusion criteria of PET:

1. symptoms of autophonia and a sensation of hearing their own breathing. The symptoms were present since at least 6 months;
2. otomicroscopic verification of tympanic membrane movements during forced nasal breathing and/or characteristic breathing correlated fluctuations seen at tympanometry;
3. no current ear disease, but childhood chronic SOM and recurrent AOM was accepted.

The age of the subjects ranged from 17 to 72 years, with a mean of 40 years.

The tympanic membrane was anaesthetized, using a small drop of 90% phenol. A small perforation was made in the drum. The method for ME pressure measurement was developed by our group and previously described in detail (13). A commercial ear protector (Comfit®) with tubing was tightly fitted deep into the external ear canal. The tubing was coupled to a piezo-electric pressure transducer (Sen-Sym®). The transducer was connected to an instrument amplifier and via a low pass filter to an 8 bit AD-converter. The resolution was 3.9 daPa. When performing conventional tubal function tests, a set-up with sufficiently high temporal resolution was used. The sampling rate was set at 18.2 Hz giving a sampling interval of 0.055 s. This has been found adequate for detailed analyses of rapid pressure changes at tubal function tests. For continuous long-term pressure measurements the equipment included a crystal-driven clock and a digital memory. The sampling rate was 1.25 Hz and the sampling interval was 0.8 s. This was previously found adequate for detecting pressure changes exceeding 3.9 daPa during 0.8 s. Thus, significant rapid pressure changes could be detected and low rate pressure trends analysed in detail. The requirements of temperature and baseline stability were well met. The apparatus measuring 120 × 60 × 35 mm was conveniently worn in a specially designed chest harness. The capacity of the memory was sufficient for 27 h of continuous pressure recording. The connection of the tubing was checked regularly and signs of leakage were objectively tested before and after each experiment by introducing a standard pressures change into the ME.

Each subject was initially subjected to tubal function tests and thereafter 24 h of ambulatory continuous pressure measurement.

Tubal function tests were performed according to a test protocol similar to that described by Elner et al. (9, 13). The tests included, Valsalva’s manoeuvre, Toynbee, powerful sniff provocation, opening pressure of the ET and pressure equilibration, respectively. The opening pressure of the ET was determined by introducing into the ME a positive pressure at an even rate. The opening level was defined as the level at which a rapid pressure change > 10 daPa towards ambient pressure was recorded in the ME. Normal equilibration was defined as the ability to fully equilibrate a positive and a negative ME pressure of 200 daPa, respectively, with 4 deglutitions (9, 13). The continuous measurements occurred ambulatory and off clinic during 24 h, with no restrictions on normal everyday and night-time activities. Each subject received a personal investigation protocol. The subjects were instructed to enter the exact time and activity of any event considered relevant to the ME pressure (i.e. body position, wilful pressure equilibrations, sneezing, physical exercise and estimated time of sleep).

Otomicroscopy was performed 3 weeks after the measurement to evaluate healing of the iatrogenic perforation of the tympanic membrane.

The investigation was approved by the Research Committee on Ethics, University of Lund, Sweden (LU 185–93).

Analysis

The entire 24-h pressure recording was examined in detail for each subject. Special analyses was focused on pressure sequences related to notations made by the subject, i.e. body position, wilful pressure equilibration, sneezing and physical exercise, time of going to bed and estimated time of sleep.

Pressure equilibration during the 24 h measurements was defined as a rapid pressure change > 10 daPa towards ambient pressure, resulting in a new transiently stable pressure.

Every negative pressure change of a magnitude ≥ 30 daPa and a rate ≥ 15 daPa/s resulting in a negative ME pressure for more than 0.8 s was analysed as a possible sniff induced event. The magnitude of the pressure change was set according to results of sniff induced pressure levels obtained in tubal function tests in previous as well as this present study (12, 13). The rate and duration criteria were set to be compatible with the capacity performance of the method for long-term pressure measurements.
The mean pressure for each hour of the long-term measurement was calculated using the area under the graph. Each hour was split into 1,200 equal portions and a mean value was calculated from this. The mean pressure was related to the time of going to bed (zero time). The significance of pressure changes before and after going to bed was calculated using Wilcoxon signed rank tests. The results were compared with our previously reported results from a group of subjects with no symptoms of PET (hereafter called the normal group) (12). Differences were calculated using Mann-Whitney test. A value of $p < 0.05$ was considered significant.

RESULTS

The 24-h continuous ME pressure demonstrated a similar general pattern in all subjects with PET. It was characterized by several pressure changes of low rate interrupted by few rapid changes. The pattern also included significant ($> 20$ daPa) negative pressure trends of low rate often several ones, with a duration exceeding 1 h. This occurred in 9/11 subjects and the mean time of negative pressure was $4.9 \pm 3.2$ h. Significant positive pressure trends with a duration exceeding 1 h was seen in only 3/11 subjects, and the mean time of positive pressure was $2.5 \pm 1.0$ h. For each subject the mean pressure of the 24 h recording differed $\pm 20$ daPa from ambient pressure during $\pm 1$ h. In only 1/11 subjects did the pressure fluctuate around zero during most part of the recording. The subjects' notation protocols were analysed for any correlation between specific events and pressure changes. Body position did influence the ME pressure in many subjects, but not in a uniform way. In 5/11 subjects the pressure increased in the recumbent position during the night, but in 3 subjects a substantial pressure decrease was seen during several hours. None of the subjects with PET demonstrated repeated negative pressure changes of a magnitude $\geq 30$ daPa and a rate $\geq 15$ daPa/s, resulting in a negative ME pressure for more than 0.8 s, i.e. our definition of possible sniffing.

Analyses of the mean pressure for each hour, consisting of 1,200 pressure values, was performed for each subject. The mean pressures in erect position 2 h before and in the recumbent position 2 h after going to bed were $-13.2$ daPa and $-13.0$ daPa, respectively. The difference was not significant.

The mean pressure during the first 2 h after going to bed was significantly lower in subjects with PET ($-13.0$ daPa) compared with that of a normal group ($+16.1$ daPa) ($p = 0.023$). There was no significant pressure difference in the erect position between the groups (Figs 1 and 2). Thus, the PET group did not demonstrate a significant rise in mean pressure in the recumbent position as previously reported for the normal group. The mean and median pressure levels for the recumbent position differed in the PET group, due to the inter-individual pressure differences (Fig. 2). In the normal group there was no significant difference.

Results from the tubal function tests in subjects with PET are summarized in Table I. All 11 subjects with PET were able to perform Valsalva's manoeuvre resulting in a direct ME pressure rise (range 200–500 daPa). All subjects with PET could with less than 4
Table I. Results from the tubal function tests. The pressure is indicated in daPa. Positive (Pos) means that the
provocation altered the ME pressure. Negative (Neg) means that the provocation did not alter the ME pressure. Positive equilibration was defined as the ability to fully equilibrate a positive and a negative ME pressure of 200
daPa respectively, with less than four deglutitions.

<table>
<thead>
<tr>
<th>Sub</th>
<th>Valsalva</th>
<th>Toynbee</th>
<th>Sniff</th>
<th>Equilibration test +200 daPa</th>
<th>−200 daPa</th>
<th>Opening pressure (daPa)</th>
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<tr>
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<td>Pos</td>
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<td>Neg</td>
<td>Pos</td>
<td>Pos</td>
<td>60</td>
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</tbody>
</table>

deglutitions equilibrate a pressure of +200 daPa introduced into the ear. In fact, for 9/11 subjects the ET opened before the ME pressure reached +200 daPa. The opening pressure level of the ET, ranged from 0 to +300 daPa.

All but one subject could equilibrate a pressure of −200 daPa with less than four deglutitions. Four subjects opened the ET before even reaching −200 daPa. All subjects could change the ME pressure with Toynbee’s manoeuvre (range −160 to −50 daPa). Nine subjects could reduce the ME pressure with a powerful sniff. The range of the pressure change was −30 to −270 daPa.

At the end of the 24-h of investigation, most subjects reported a mild discomfort from the ear canal. One of the subjects removed the equipment after 11 h due to discomfort.

The long-term pressure measurements did not induce any side-effects, such as infection in the ME or the ear canal. The tympanic membrane perforations healed within 3 weeks in 9/11 subjects. Two subjects choose to have a grommet inserted after the recordings were completed.

DISCUSSION

The present study concerns an analysis of the ME pressure in an unselected group of otherwise ear healthy subjects with the clinical diagnosis of PET. The diagnosis was verified according to established clinical criteria including breathing correlated eardrum fluctuations verified at otomicroscopy and/ or tympanometric monitoring (2–4). The symptoms of PET had in all subjects persisted for more than 6 months, but it was beyond the scope of this investigation to correlate the results to a subjective evaluation of the severity of the perceived symptoms. The clinical diagnosis was found to be in accordance with results from the tubal function tests, demonstrating a positive Toynbee test in 100% and a positive sniff test in 82% of the subjects. Corresponding figures for a normal group was 50% and 10%, respectively (12). Also, the opening pressure of the ET was significantly lower in the PET group compared with a normal group (Table II). Thus, in subjects with the clinical diagnosis of PET the ET demonstrated a weakness to withstand pressure variations in the nasopharynx (1, 2). The results are comparable with those reported by others for the condition PET (6, 8). However, when comparing different investigations one should be aware of the difference between studies defining a condition as PET on the basis of results from tubal function tests and a study defining a condition as PET on clinical criteria. From literature and our previous understanding of the clinical condition PET we formed our hypotheses that the ME pressure in erect position most of the time would fluctuate around the ambient pressure level (4, 14). We also expected to find, repetitive negative pressure reductions caused by sniffing. Further, we presumed that the ET in many subjects would not be open constantly, but close in the recumbent position. This would result in a pattern of increasing ME pressure during the night as previously reported for a normal group (12). Most of our hypotheses were proved wrong.

Results from our tubal function tests demonstrated a rather uniform picture among subjects with PET, but such provocation tests reflect the equilibrating capacity of the ET at the specific moment of investigation. A more complex pattern of pressure regulation than anticipated was revealed by the continuous
long term pressure recordings. The ET did not seem to function as a rigid open tube throughout the day. The ME pressure demonstrated a greater individual variation among subjects with PET than seen among subjects of a normal group. This was demonstrated by the difference in median and mean pressure levels in subjects with PET, a difference not seen in the normal group (12). During daytime in erect position all subjects with PET had a ME pressure periodically fluctuating around the ambient pressure level indicating a patulous ET. But in all subjects with PET the pressure differed from ambient pressure for more than 1 h and in most subjects for a considerably longer time. During this time frequent, slow rate, transient and mostly negative pressure trends occurred. Transient tubal closure is a prerequisite for this type of pressure changes to occur. On the other hand, the normal group of subjects had a ME pressure pattern more uniform with prolonged periods of slight negative pressure interrupted by transient tubal openings (12). These findings indicate a possibility for a more prolonged gas exchange between the ME and nasopharynx in subjects with PET compared to a normal group (12). A greater gas exchange is likely to induce a relatively higher O2 concentration in the ME due to differences in gas admixture between the nasopharynx and the ME cavity. Oxygen transportation from the ME initiated at the time of transient tubal closure might explain the frequent, slow rate, negative pressure trends noted in this study. Such a theory supported by experimental research seems to emphasise the significance of gas exchange over the mucosa for the pressure regulation of the ME (15, 16). The slow rate of the pressure changes indicate a distinctly different cause than sniffing, which produces rapid changes as demonstrated by tubal function tests. The slow rate negative pressure trends were more frequent and occurred in more subjects with PET than seen in subjects of the normal group (12). Several studies indicate that the ET function is affected by body position. Increased venous pressure in the mucus membranes and peritubal tissues may seal the ET in the recumbent position (9, 17). A positive ME pressure may arise spontaneously seemingly without contribution from the ET (16–18). A positive ME pressure has been reported in subjects with the ET obstructed by common cold. The subjects were resting in the recumbent position, but not sleeping (7). In our previous long-term study of a normal group, an increase in ME pressure was demonstrated in almost all subjects in the recumbent position during the night. In this study of PET there was no significant pressure difference between erect and recumbent position during the night. Subjects with PET demonstrated a negative pressure in the recumbent position during the night, whereas the normal group had a slight overpressure (12). This pressure difference was significant. This does not imply a lack of influence by body position or sleep on subjects with PET. But, the effect varied among subjects with PET in a way not typical for the normal group (12). In some subjects with PET the ME pressure increased in the recumbent position in a similar way as seen in normal subjects, but in others a substantial, long-lasting pressure decrease occurred. Our study cannot explicitly demonstrate the reason for the variable results in the recumbent position among subjects with PET. However, a plausible explanation similar to that described above for the erect position might be suggested. When a prolonged free gas exchange between the ME and nasopharynx temporarily is stopped by ET closure, oxygen resorption is initiated by the ME mucosa. This would lead to a low rate pressure reduction in the ME. On the other hand, among subjects with less free gas exchange, and a prolonged period of tubal closure, the ME gas composition would be more like that of normal subjects. This would be likely to result in a pressure pattern similar to that of normal subjects, i.e. a rise in ME pressure in the recumbent position. Thus, the study clearly demonstrated that the ET in many PET subjects was closed for several hours, which further supports that the clinical diagnosis PET was not associated with a static state of an open ET. This study does not give separate information regarding results in the awake and sleeping state in recumbent position respectively. But, the results adds some objective support as to why symptoms of PET may

<table>
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<th>Positive Valsalva</th>
<th>Positive Toynbee</th>
<th>Positive Sniff</th>
<th>Equilibration test</th>
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<tr>
<td></td>
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<td>Opens before +200 daPa</td>
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<td>Normal group 10/10</td>
<td>5/10</td>
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Table II. Results from the tubal function tests in 11 patients with PET and 10 subjects from a normal group in a previous study (12)
diminish in the recumbent position in some subjects with PET. The negative pressure trend seen in some subjects with a PET might possibly support the theory that chronic ME retraction type pathology may develop as a reaction to certain types of ET closing failures (1, 6, 8).

Habitual sniffing is reported to occur among many subjects with tympanic membrane retraction pockets and retraction cholesteatoma (1). A sniffing behaviour is also reported to ameliorate annoying symptoms of autophonia among some patients with PET (5). In our study most subjects had a positive sniff test at tubal function tests, but during normal everyday and night-time activities there were no indications of repeated sniffing induced pressure changes. The slow rate pressure trends seen in this study and described above were distinctly different to the rapid rate of sniffing induced pressure changes seen at the tubal function tests. It might be argued that the lower sampling rate (1.25 Hz) and sampling interval (0.8 s) used for our 24 h recordings did not allow a detailed analyses of the entire course of a pressure change as rapid as that of sniffing. But, the method is adequate for detecting any change resulting in a ME pressure exceeding \(-3.9\) daPa for more than 0.8 s. Thus, it is quite unlikely that our results can be explained by methodological shortcomings. This study cannot give an explicit explanation as to why two subjects had a negative sniff test when the inclusion criteria involved breathing correlated eardrum movements. A possible explanation might be that a forcefully induced sniff in some subjects with PET would lock the ET due to a Bernoulli effect. Judging from our small material, sniffing is not a typical or frequent behaviour among otherwise ear healthy subjects with clinical PET. This study was not designed to address any correlation between chronic ME disease and sniffing or closing failure of the ET. To address with our method, the issue of sniffing for curtailing symptoms of PET a special study focused particularly on this problem would seem to be required.

CONCLUSION

The clinical diagnosis of PET was found to be in accordance with results from the tubal function tests. Most subjects had a positive sniff test, but during normal every day and night activities there were no indications of repeated sniffing induced pressure changes as defined in this study. The clinical diagnosis of PET does not necessarily imply a static state of an open ET. The ME pressure varied during day and night, indicating that the function of the ET changed over time between a closed and an open state. Subjects with PET had a long-term pressure pattern significantly different from that of a normal group. A difference seen in the erect as well as in the recumbent position during the night. A negative mean pressure level was demonstrated in the recumbent position after going to bed, whereas a normal group had a slight, positive mean pressure (12). During day and night frequent slow rate negative pressure trends occurred in many subjects. This might be due to gas resorption from a ME exposed to free gas exchange with the nasopharynx prior to a transient tubal closure. Long-term continuous pressure measurement during normal everyday and night-time activities seem to add valuable information to that of conventional tubal function tests. An extended study is needed before an improved classification of ET closing failure can be suggested, and better information and treatment offered to patients suffering from symptoms of PET.

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REFERENCES


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Address for correspondence:
Bo Tideholm, MD
Department of Oto-rhino-laryngology
University Hospital
SE-205 02 Malmö
Sweden
Fax: + 46 40 337066
E-mail bo.tideholm@oron.mas.lu.se