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Validation of sonotubometry in healthy adults

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Abstract

Background: Frequent active opening of the eustachian tube (ET) allows ventilation of the middle ear and equilibration of pressure changes. Active opening is accomplished by the contraction of the paratubal muscles during swallowing. Because a disturbance of the ventilatory function of the ET may contribute to the development of otitis media with effusion, it is important to investigate ET function. Sonotubometry can be used to detect whether the ET can open or not during swallowing acts.

Methods: We developed a sonotubometer to test ET ventilatory function in 36 healthy adults. The width of the test signal frequency was between 5500 and 8500 Hz (centre frequency of 7000 Hz) and the loudness was 95 dB. To test reproducibility, testing took place in two sessions of 10 swallowing acts each.

Results: Opening of the ET could be registered in 91.6 per cent of the subjects in at least one of the two measurements. The first and the second measurements were highly correlated, with a Spearman's coefficient of 0.907.

Conclusion: We confirmed that there is generally a good ventilatory ET function in otologically healthy adults, although, in a few cases, ET opening was not registered. Furthermore, we confirmed that our sonometric test equipment had acceptable reproducibility. Sonotubometry is a promising method for assessing ventilatory ET function. Research is ongoing to test the discriminative power of sonotubometry in children with various otological conditions.

Key words: Eustachian Tube; Sound; Ventilation; Physiology; Sonotubometry

Introduction

The most important functions of the eustachian tube (ET) are ventilation, protection and clearance of the middle ear.^{1,2} Gases are exchanged continuously between the tympanic cavity and the middle-ear mucosa via diffusion. Regular, active opening of the ET allows ventilation of the middle ear and equilibration of pressure changes. Active opening is accomplished by the contraction of the paratubal muscles. These muscles contract during swallowing, yawning or movement of the mandible. However, the ET does not open during each swallow.

Because disturbance of any of the ET functions may contribute to the development of otitis media with effusion,^{3–11} it is important to investigate ET function. Investigations of ET function have mainly measured its ventilatory aspect. In addition to manometric function tests^{12–16} and indirect tubal function tests (e.g. tympanometry, pure tone audiometry and otoscopy), sonotubometry^{17–27} can be used to detect whether the ET can open or not. The latter function test has some advantages compared with

the former tests.²⁸ Sonotubometry takes place under physiological circumstances, can be performed on ears with an intact tympanic membrane (in contrast to manometric tests) and is easily tolerated by the subject. Sonotubometry is based on the principle that sound that is applied to the nasopharyngeal ostium of the ET is conducted through the ET to the middle ear. During active opening of the ET, more sound will be recorded in the external auditory canal. Several investigators have studied sonotubometry to determine its usefulness in assessing ET ventilatory function.^{17–27}

However, thus far, this test has still not been applied in clinical practice, partly because there is currently no consensus on test equipment and test properties in the literature, and partly because the test's reproducibility and clinical value are yet to be demonstrated. It is therefore argued that sonotubometry needs further improvement. Although various reports have been published on sonotubometry in adults, it appears to be difficult to obtain reliable, positive test results in more than 60 per cent of healthy ears.

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Moreover, the question of the test's reproducibility remains.

The aim of this study was to improve the performance of sonotubometry in adults.

Methods and materials

The equipment used in the present investigation is schematically illustrated in Figure 1.

A test signal was produced by a computer using Cool Edit Pro 2.0 software (Syntrillium Software Corporation, USA) and delivered to the nasopharyngeal ostium of the ET using an Ear Tone 3A insert phone (Auditory Systems, Indianapolis, USA) fixed into one of the nostrils of the subject with a foam ear tip (this tip adjusted itself to the shape of the nostril to prevent leakage of sound). A probe microphone (Etymotic Research-7c, Illinois, USA) was placed in the ipsilateral external auditory canal and also fixed with a foam ear tip to prevent loss of test sound and interference by background noises. The microphone was connected to the computer and the sound recorded using the Cool Edit Pro 2.0 software.

Earlier studies on sonotubometry¹⁷⁻²⁷ were considered carefully in order to choose the optimal test properties. We started with a high frequency test sound, following the work of Virtanen, who showed that only frequencies higher than 5000 Hz were appropriate.¹⁷ A pure tone test signal was used with a frequency of 7000 Hz and an initial loudness of 75 dB. Using these settings, we could register tubal openings in 60 per cent of a population of healthy adults. However, this result was disappointing compared with earlier publications, so our equipment or test properties needed improvement. Thus, loudness was increased to 95 dB (as the test signal might have been too low to be detected by the probe microphone in the external ear canal).

The use of a pure tone signal was also considered a reason for the false negative test responses. In a unilateral closed tube, e.g. the external ear canal, a pure tone sound can cause a standing wave pattern. A standing wave pattern consists of nodes and anti-nodes. Measurement in the centre of a node can generate false negative results. So, to prevent the formation of standing wave patterns, the test signal was changed from a pure tone signal to a band signal

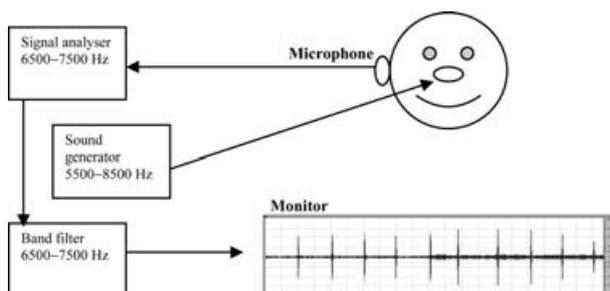


FIG. 1

Diagram of equipment used.

between 5500 and 8500 Hz, with a centre frequency of 7000 Hz.

We thus chose to use a sound with a bandwidth between 5500 and 8500 Hz and a fixed loudness of 95 dB. The sound level in the external ear canal was continuously measured and these data stored. Off-line, the recordings were band pass filtered with a central frequency of 7000 Hz, with a minimum of 6500 Hz and a maximum of 7500 Hz. Filtering was applied to minimize ambient noise and sounds due

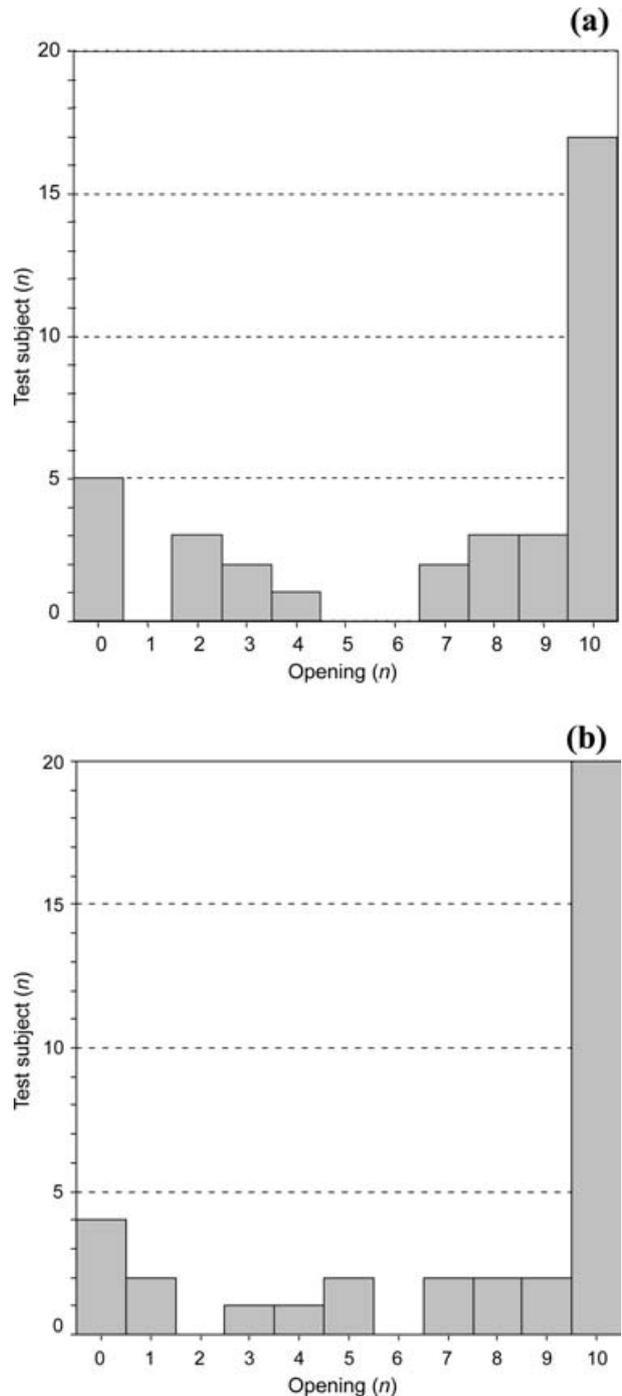


FIG. 2

Eustachian tube openings in the (a) first and (b) second test measurements ($n = 36$ subjects).

to swallowing. Discrimination between a positive and a negative response was done by visual evaluation. Furthermore, a measured peak was only counted as a positive response if it occurred simultaneously with a swallowing act.

To evaluate the patency of the ET, subjects were instructed to swallow water 10 times, in a sitting position, at 10-second intervals. After 10 swallows, the microphone and the sound source were removed and, after a short 5-minute break, replaced for the second measurement. The second measurement was performed in an identical fashion to the first measurement in order to test its reproducibility.

The test population consisted of 36 adults, 12 men and 24 women. Their ages varied from 18 to 55 years, with a mean age of 33 years. Only otologically healthy subjects were included; individuals with a history of middle-ear surgery, recurrent otitis media or complaints of tubal dysfunction were excluded.

Results

Figure 2 shows the results of the sonotubometric measurements. At least one opening of the ET was registered in 31 of the 36 ears in the first measurement and in 32 of the 36 ears in the second measurement. Combining the results of the two measurements per subject, ET opening could be registered in at least one of the measurements in 33 of the 36 tested ears (91.6 per cent). In the other three cases, not a single ET opening was detected. The number of ET openings varied from zero to 10 out of 10 swallowing acts. Figure 3 shows the reproducibility of the test. In 23 of the 36 ears (64 per cent), there was no difference in number of openings between the first and the second measurements. The difference in the number of openings in the

first test compared with those in the second test was one in eight subjects (22 per cent) and two or more in five subjects (14 per cent), with a maximum difference of five. The first and second measurements were highly correlated, with a Spearman's correlation coefficient of 0.91 ($p < 0.001$).

Discussion

The purpose of this study was (a) to develop a sonotubometer, and (b) to test whether sonotubometry was a valid and reproducible method of measuring ET ventilatory function. A non-invasive, physiological method of testing ET ventilatory function is not currently available in ENT practice. Previous studies investigated the role of sonotubometry in the assessment of ET function, but, despite promising results, insufficient confirmation existed to introduce sonotubometry as a routine tubal test in ENT practice.²⁸

- **Sonotubometry is based on the principle that sound applied to the nasopharyngeal ostium of the eustachian tube (ET) is conducted through the ET to the middle ear; during active opening of the ET, more sound will be recorded in the external auditory canal**
- **This report describes a sonotubometer developed to test ET ventilatory function in 36 healthy adults. The width of the test signal frequency was between 5500 and 8500 Hz (centre frequency of 7000 Hz) and loudness was 95 dB**
- **Sonotubometry is a promising method of assessing ventilatory ET function. Research is ongoing to test the discriminative power of sonotubometry in children with otological conditions**

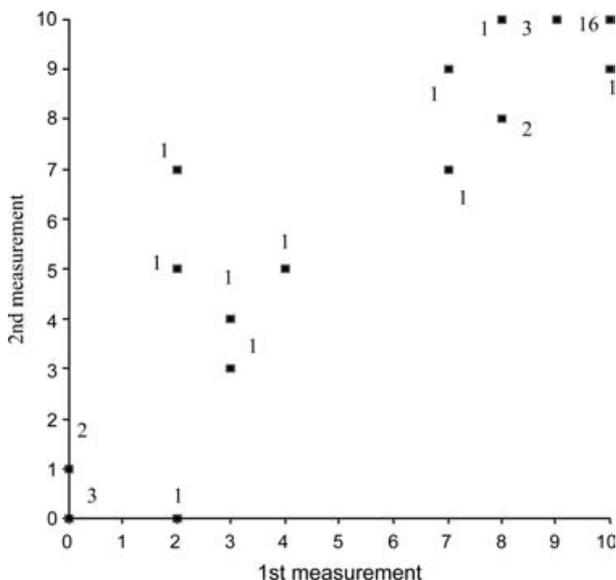


FIG. 3

Reproducibility of eustachian tube opening assessment, comparing the first and second test measurement results. One square represents one or more test persons.

Earlier studies¹⁷⁻²⁷ were considered thoroughly when developing the test equipment used in this study. As described in the methods, we initially used a high frequency test sound, following the work of Virtanen.¹⁷ Later, the loudness used was increased to 95 dB. To prevent the formation of standing wave patterns, the test signal was changed from a pure tone signal to a band signal of between 5500 and 8500 Hz with a centre frequency of 7000 Hz. With these properties, the testing was performed under the same conditions as the first measurements. Thirty-six healthy adults were tested, and ET openings could be registered in 33 subjects (91.6 per cent). This response is similar to the highest positive response found in earlier studies.^{17,21} It indicates that, in a otologically healthy adult population, there is generally good ET ventilatory function; however, in some cases, no ET openings were registered during 20 swallowing acts. These subjects had no complaints of ET dysfunction, and otoscopy did not show any ET disturbances. Thus, a much lower incidence of ET opening during swallowing acts is probably needed to

ensure sufficient ET function. Also, ET dysfunction may not always lead to middle-ear problems.

Furthermore, we confirmed that our sonotubometry test method had acceptable reproducibility (i.e. negligible test–retest variability).

As there is currently no physiological ET function test applicable to ears with an intact tympanic membrane and usable in daily ENT practice, these results are promising. Additional research is needed to evaluate the role of sonotubometry as a tubal function test. Such studies in children with various otological conditions are needed to substantiate the benefits of sonotubometry for routine ENT consultations.

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