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Significance of a notch in the otoacoustic emission stimulus spectrum

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Abstract

Objective: To explain a clinical observation; a notch in the stimulus spectrum during transient evoked otoacoustic emission measurements in ears with secretory otitis media. Methods: The effects of tympanic under-pressure were investigated using a pressure chamber. A model of the ear canal was also studied. Results: Eardrum reflectance increased as a consequence of increased stiffness, causing a notch in the stimulus spectrum. In an adult, the notch could be clearly distinguished at an under-pressure of about -185 daPa. The sound frequency of the notch corresponded to a wavelength four times the ear canal length. The ear canal of infants was too short to cause a notch within the displayed frequency range. The notch was demonstrated using Otodynamics and Madsen equipment. Conclusion: Notched stimulus spectra can be caused by increased stiffness of the tympanic membrane, raising suspicion of low middle-ear pressure or secretory otitis media. The method is not applicable to infants.

Key words: Ear, middle; Otitis Media; Otoacoustic Emissions

Running head: Notched otoacoustic emission stimulus spectrum

Introduction

When measuring transient evoked otoacoustic emissions (TEOAEs) in children 3 years and older, the stimulus spectrum sometimes contains a notch, and at the same time the response is usually diminished or absent. The notch may occur at 2.5 kHz or higher. During a study which measured TEOAEs in four-year-old children, at the Malmö ENT clinic[1], we saw frequent examples of these notches in children with weak or absent TEOAEs. Examples of notched stimulus spectra from children and adults with secretory otitis media are shown in Figure 1.

The amount of acoustic reflectance from the eardrum depends on its stiffness. At a certain frequency (*f*), the sound from the probe loudspeaker will be reflected in reverse phase to the probe microphone (Fig. 2). Here, we assume that the two probe openings are close together, that the diameter of the ear canal is small compared with its length, and that the eardrum can be approximated with a flat surface, perpendicular to the external ear canal axis. A cancellation of the sound will then occur when the distance from the probe tip to the eardrum (*l*) is one-quarter wavelength. If the corresponding wavelength λ is $4{*}l$, then the corresponding frequency is $f = v / 4{*}l$, where v is 343 m/s. For example, an adult ear canal with a length of 30 mm has a corresponding ear canal reflectance at 2858 Hz. This frequency coincides with the resonance frequency of the ear canal. In other words, if a notch is found in the OAE stimulus spectrum, some information can be gained even in the absence of a response. One aim of this paper is to spread information that the middle ear status in some cases can be deduced from the OAE stimulus spectrum. The other aim is to encourage the equipment producers to place more emphasis on the information contained in the stimulus spectrum.

Material and methods

In experiments 1 and 2, the otoacoustic emissions analyser ILO 92 (Otodynamics, Hatfield, Great

Britain) was used with software version 5.60E and a standard adult TEOAE probe (one speaker, one microphone). Calibration was performed in accordance to the manufacturer's specifications. The stimulus level was adjusted to 82 dB peak SPL in all cases.

In experiment 1, a 2.5 ml plastic syringe served as a simple model of an ear canal with variable length (0-41 mm, diameter 8.7 mm, tip cut away). The conical rubber plunger tip was used to model a reflecting ear drum. The length of the cavity was measured from the probe tip to half the height of the rubber cone (height, 2 mm). The distance between probe openings was 1 mm.

Experiment 2 was performed on a 41-year old, male subject, , with normal middle ear and strong oto-acoustic emissions. The right ear was chosen for all measurements. An experimental pressure chamber in the Malmo ENT department (at sea level) was used.

Experiment 3 was identical to experiment 1, except that a Madsen Capella OAE analyser (GN Otometrics, Denmark) was used.

Results

Experiment 1

The length of the syringe cavity was varied and this changed the position at which a notch could be detected (fig. 3). The notch could barely be visualized if it overlaid the 4 kHz point; this corresponded to an ear canal length shorter than 22 mm. Therefore, no notch can be expected in infants. Table I shows calculated notch frequency data for the same cavity lengths, according to the quarter-wavelength explanation in the introduction.

Experiment 2

The subject was seated in a pressure chamber, with a pressure varied from ambient air pressure to +400 daPa. This resulted in a relative under-pressure in the middle ear. The peak tympanometric pressure at the highest pressure load was –350 daPa. The notch in the TEOAE stimulus spectrum reached different depths with different pressure loads (fig. 4). The middle panel with +200 daPa chamber pressure resulted in a peak tympanometric pressure of –185 daPa and represents a point where the notch is clearly distinguishable. This notch, at 2.3 kHz, corresponds to an eardrum-to-probe length of 37 mm. The corresponding TEOAEs were also measured and are shown in Figure 5, while Table II shows sound pressure levels per frequency band for various degrees of relative under-pressure in the middle ear. As expected, changes in the tympanic membrane pressure load predominantly affected low frequencies. Other results on this experiment have been reported previously[2].

Experiment 3

A syringe model of the ear canal was examined with the Madsen Capella OAE analyser. The same notch as in Experiment 1 was found in the stimulus spectrum. However, the display only showed up to 4 kHz, and therefore the demonstration of a notch required a slightly longer ear canal than when using the Otodynamics OAE analyser (which showed frequencies up to 6 kHz).

Discussion

Experiment no. 1 has shown that the position of the notch depends on the ear canal length, whereas experiment 2 demonstrated that the depth of the notch depends on the degree of stiffness of the tympanic membrane. There are many published reports investigating the connection between middle ear status and OAEs, but these have understandably focused on the emission response rather than the stimulus spectrum. At the Lund and Malmö ENT departments of Scania University Hospital, the notch in the TEOAE stimulus spectrum has been used for many years to identify a stiff tympanic membrane, as reported in previous publications from the department[2-3]. However, it appears that knowledge about this simple but clinically very useful observation is not widespread. A similar notch has also been noted in the work by Marshall et al[4].

In the both types of OAE analyser used in the study, the stimulus spectrum was seen briefly during the “check fit” procedure, but was then hidden from the operator. The only way of viewing the information again was to request a printout copy of the completed test, by which stage it was easy to forget to check whether a notch was present or not. Earlier Otodynamics equipment models had presented the stimulus spectrum routinely on the screen, but unfortunately, this is no longer the case in the version 6 of the software. It is suggested that the software developers include a facility for automatic detection of a stimulus notch is present.

The depth of the observed notch has been shown to depend on the amount of reflectance from the tympanic membrane; it could also be expected to depend on the angle between the eardrum and the ear canal. Curvature of the ear canal may also affect the depth of the notch. It would be possible to examine these factors with a wide-band eardrum reflectance meter.

An important limitation of the notched stimulus spectrum is that the ear canal of the neonate is so short that a notch cannot be seen, since the ear canal resonance falls above the displayed frequency range. On the other hand, in adults and in children from the age of 2 or 3, the presence of a visible notch indicates a stiff tympanic membrane, most commonly due to middle-ear under-pressure or secretory otitis media, whereas the absence of a TEOAE response in combination with a flat stimulus spectrum points towards sensory hearing loss, or possibly a conductive hearing loss without increased tympanic membrane stiffness. The Madsen OAE analyser has a more limited frequency spectrum and consequently requires a slightly longer ear canal to display a notch.

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Legends

The legends also appear on each table/figure sheet.

Table I. Calculated notch frequency for different cavity lengths according to the quarter wavelength model.

Table II. Sound pressure levels per frequency band (dB SPL) at various degrees of relative under-pressure in the middle ear.

Figure 1. Examples of notched stimulus spectra from transient evoked oto-acoustic emission measurements on children and adults with otoscopically verified secretory otitis media.

Figure 2. Reflectance of the stimulus from the eardrum back to the probe at a frequency corresponding to one-quarter wavelength.

Figure 3. Influence of length of the ear canal model. Stimulus spectrum in an ear canal model made from a 2.5 cc syringe with a length of 35 mm (upper panel), 29, 22, 19, 16 and 13 mm (lower panel).

Figure 4. Influence of various degrees of eardrum stiffness. Stimulus spectrum in the ear canal at various degrees of underpressure in the middle ear. Chamber pressure 0 daPa (upper panel) to +400 daPa (lower panel), in 100-daPa-steps.

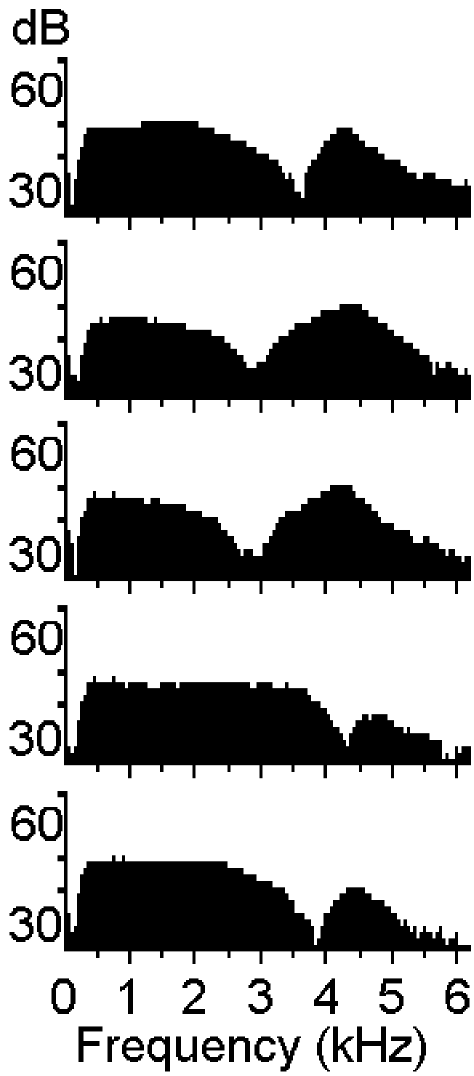
Figure 5. TEOAE waveforms, conditions as in Fig. 4.

l (mm)	f = v / 4 l (Hz)
35	2450
29	2957
22	3898
19	4513
16	5359
13	6596

Table I. Calculated notch frequency for different cavity lengths according to the quarter wavelength model.

	Chamber pressure (daPa)				
f(kHz)	0	100	200	300	400
1	7.0	6.1	4.0	-0.5	-3.4
1.4	8.4	5.2	2.7	2.0	-0.1
2	3.7	1.8	-0.2	-3.1	-3.2
2.8	3.2	5.6	3.2	0.2	-2.5
4	4.4	1.7	4.0	3.8	3.3
Total	12.8	11.5	10.0	8.1	6.7
Tympanogram(daPa)	0		-185		-350

Table II. Sound pressure levels per frequency band (dB SPL) at various degrees of relative underpressure in the middle ear.



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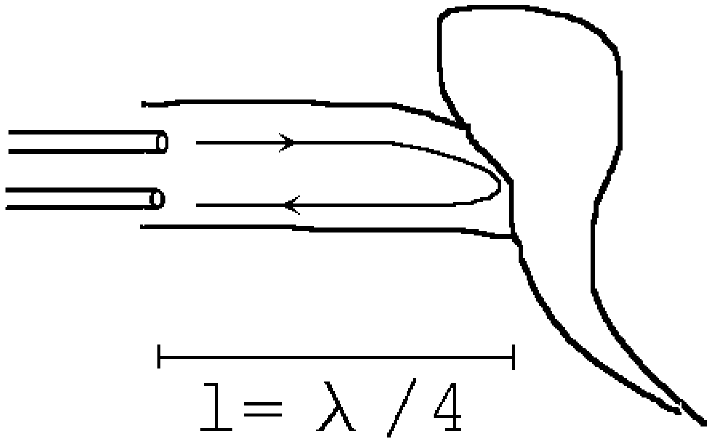

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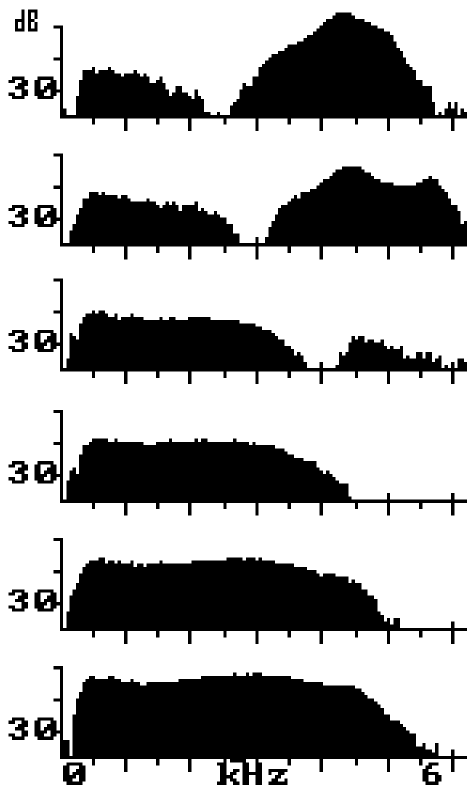

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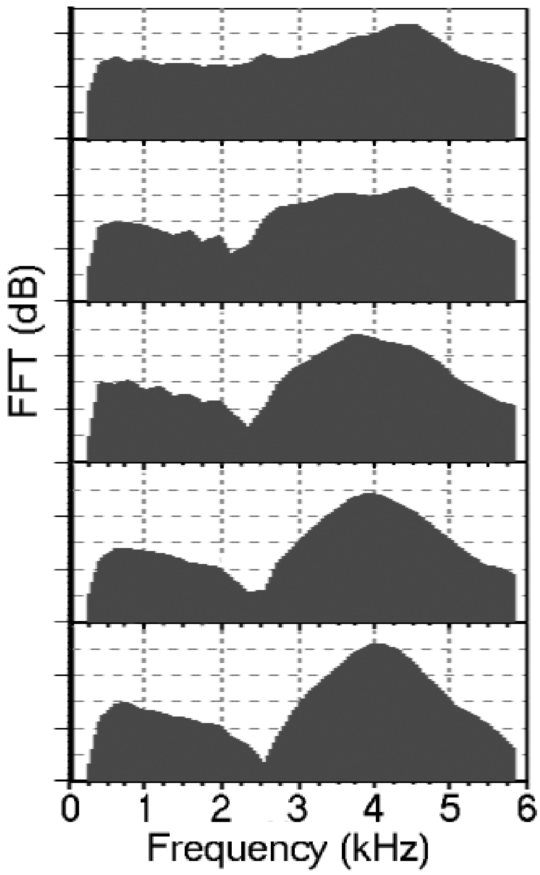

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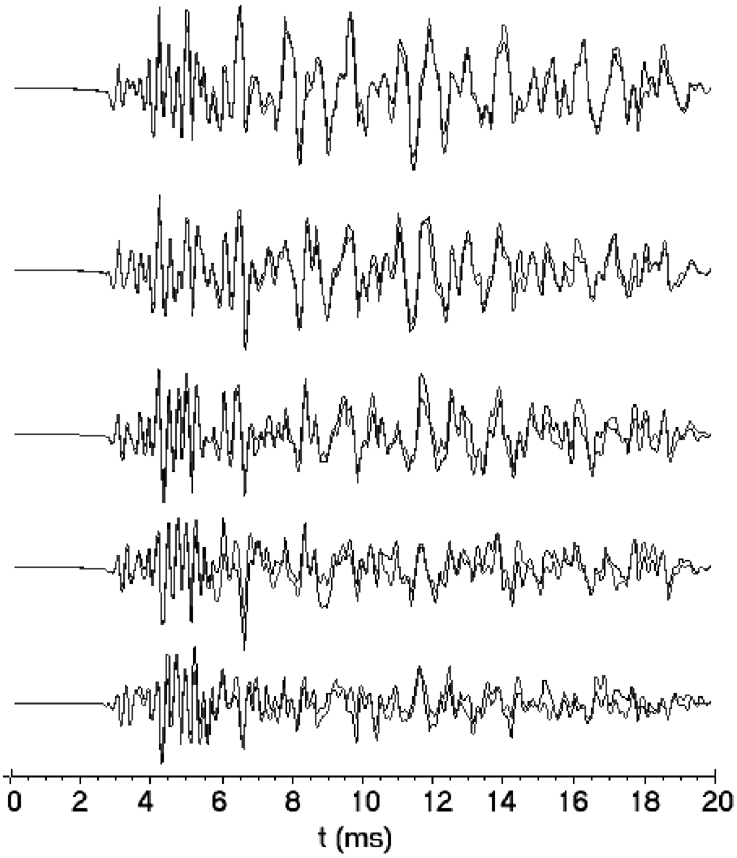

Figure 5. TEOAE waveforms, conditions as in Fig. 4.

Summary

- Pay attention to the stimulus spectrum during OAE measurements
- A notched stimulus spectrum indicates a stiff tympanic membrane
- Notches will not be found in infants