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Effect of middle-ear effusion on otoacoustic emissions

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Abstract

Because otoacoustic emissions (OAEs) are transmitted from the cochlea to the ear canal via the middle ear, the transmission properties of the middle ear directly influence OAEs' characteristics. In general, middle-ear effusion (MEE) reduces measured emission amplitudes and sometimes eliminates the response entirely. The purpose of this study was to establish the relationship between the conduction of the middle ear and OAEs' properties and to elucidate the effect of middle-ear effusion on detecting OAEs. Spontaneous otoacoustic emissions (SOAEs), transiently evoked otoacoustic emissions (TEOAEs) and distortion product otoacoustic emissions (DPOAEs) were recorded from 44 normal ears and 32 ears with middle-ear effusion. DPOAEs were collected in two basic forms consisting of distortion product audiograms (DP grams) and input-output (I-O) functions, elicited by two primary tones F1 and F2 and varying geometric mean frequencies between 1–6 kHz. The results of air and bone conduction hearing levels in pure tone audiogram were also analysed. In 21 ears out of 32 otitis media with effusion (OME) ears, SOAEs were absent. In the 28 ears with middle-ear effusion, the response and wave reproducibility were diminished, and in the 17 ears with middle-ear effusion, the DP gram was diminished or eliminated. In particular, I-O function curves at 3 kH and 4 kHz were diminished by the primary tones of 45 and 55 dB under the condition of MEE. The SOAEs, TEOAEs and DPOAEs (DP gram and I-O function curve) are highly reliable and useful tests for monitoring changes in middle-ear condition in children with OME and in predicting the course of OME.

Key words: Ear, Middle; Fluids and Secretions; Otoacoustic Emissions, Spontaneous

Introduction

Gold *et al.* in 1948 suggested the presence of the mechanical feedback system within the cochlea that increases the mobility of the basilar membrane, and predicted the presence of otoacoustic emissions (OAEs).[1] After Kemp in 1978 stimulated the external auditory canal with stimulus sounds using a small microphone and reported the fact that there is a weak acoustic component that shows up a few msec after the effacement of the stimulus sound,[2] many studies have been performed on the physiological mechanism of the cochlea.

OAEs develop due to the constriction of the outer hair cells and the active mechanism of vibration, and their oscillatory wave is transmitted to the external auditory canal through the ossicles and tympanic membrane. Not only the process of otoacoustic emission production in the cochlea itself, but also changes in sound conduction of the middle ear change the otoacoustic emission detected in the external auditory canal. Clinically, among the factors that lower sound conduction of the middle ear, there are the formation of middle-ear effusion and negative pressure within the middle ear, and many authors reported on changes in OAEs that are induced by pressure changes within the middle ear.[3–5] The formation of middle-ear effusion and negative pressure within the middle ear changes elasticity and suppresses conduction of the sounds with the frequencies around 2 kHz.[3,6–8]

However, despite many reports on the relationship between the middle ear and cochlea condition and test results of various OAEs, the roles of input-output (I-O) function curve of DPOAE have not been well established so that there still is much debate over how to analyse the results. Thus, after performing physical examination and tympanometry in paediatric patients who visited the out-patient clinic at the Kangnam St. Mary's hospital to evaluate the condition of the middle ear, we conducted the otoacoustic emissions' tests (SOAE, TEOAE and DPOAE) and examined the relationship between these tests; through the results of the tests, we tried to investigate the role of I-O function curve for the evaluations of middle-ear condition and hearing.

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Subjects and methods

Subjects

This study was performed on 85 ears of 43 paediatric patients who visited the out-patient clinic at the present hospital with major symptoms of otalgia, tinnitus, aural fullness, nasal stuffiness and severe snoring. One case of microtia in one ear was excluded. Physical examination of the middle ear using an otoscope, microscope and tympanometry using an impedence audiometer RS-20 (RION, Japan) were performed. There were 28 boys and 15 girls; the age range was between two years to 11 years with a mean age of 5.3 years. As for the experimental group, we chose 32 ears that had OME with symptoms such as retraction, a dark blue tympanic membrane, fluid line and air bubble upon physical examination and that were classed as 'B' ear on tympanometry. As for the control group, 44 ears that had a normal tympanic membrane and that were classed as type 'A' ear according to the tympanogram were selected. The nine ears that were continually type 'C' on tympanometry were excluded from the study.

Procedures

Pure tone audiograms using a pure tone audiometer GSI 10 (GSI, USA) were performed for both the air and bone conduction hearing thresholds in 40 patients (26 ears in the OME group and 44 ears in the control group). The air conduction hearing thresholds were measured at 125 to 8 000 Hz, and the bone conduction hearing thresholds were measured at 250 to 4 000 Hz. The otoacoustic emission test was performed in a soundproof room using an ILO-92 otodynamic analyser (Otodynamics, Hatfield, England), and all of the tests were recorded by one audiologist. The ear probe used in the test was a probe for children that was equipped with a small earphone and microphone, and was fitted using a silicon protector without aid from any outside fixture. The appropriateness of fitting was evaluated while watching the click stimulus waveform and power spectrum on the computer.

The measurement of SOAE was done by amplifying the sound transmitted to the external auditory canal for one to two minutes that was registered through the use of a spectrum analyser of the sound in the external ear canal. After converting the average level of the received signals using an analog-digital converter, the value was analysed in an IBM computer using fast Fourier transform (FFT). The SOAE was considered to be measurable if its amplitude was at least 3 dB greater than the level of the noise floor.

TEOAEs were measured using the computer-based ILO 88 analyser (Otodynamics Ltd., Hatfield, England). The stimuli consisted of a standard set of non-linear clicks whose intensity was 75 to 85 dB sound pressure level (SPL), and alternate responses were stored and averaged in two separate buffers, A and B. The correlation between the two averages determined the reproducibility of the TEOAE, that was calculated by the device and expressed as a percentage. The measurements were averaged after 260 responses and were only accepted when reproducibility was greater than 50 per cent, stimulus stability was better than 70 per cent, and the difference between the amplitude of the emission and the associated noise floor was at least 5 dB.

DPOAEs at the 2f1–f2 frequency (f2/f1 = 1.22) were elicited with equilevel primary stimuli (i.e. L1 = L2). Using two types of protocols, DPOAEs were examined as 'audiograms' (i.e. emission levels elicited by 70 dB SPL primary tones as a function of frequency, 1–6 kHz), and as a series of response/growth or input-output (I-O) curves at 1, 2, 3, 4, 6 and 6 kHz, in which emission amplitude was plotted as a function of systematic 1.5 dB increases in the levels of primaries (35–75 dB SPL). DPOAE was considered to be measurable if its amplitude was at least 5 dB greater than the level of the noise floor measured simultaneously at the frequency of the emission.

Statistical analysis was performed with SPSS programme using the unpaired *t*-test Pearson chi-square and Fisher's exact test.

Results

In the control group, the ears showed no abnormal tympanic membrane findings and type 'A' on tympanometry. The average air conduction hearing levels (average hearing levels in 250, 500, 1000, 2000,

TABLE I

MEAN AIR AND BONE CONDUCTION HEARING LEVEL (dBHL) OF EACH FREQUENCY IN A PURE TONE AUDIOGRAM

PTA (Hz)	250	500	1000	2000	3000	4000	6000	8000	Average
Normal ears; N = 44									
AC	10.2	13.4	12.8	12.4	10.1	11.5	13.3	11.6	11.9*
	(8.2)	(7.9)	(6.8)	(7.4)	(9.8)	(9.1)	(6.6)	(7.5)	(7.9)
BC	2.2	2.6	2.4	2.5		2.4			2.4
	(2.4)	(2.5)	(2.4)	(2.3)		(2.3)			(2.4)
OME ears; N = 26									
AC	25.3	24.1	26.1	22.6	24.8	25.2	23.8	24.5	24.6*
	(7.8)	(8.7)	(7.3)	(9.1)	(6.5)	(7.2)	(6.7)	(7.2)	(7.6)
BC	2.4	2.2	2.4	2.3		2.5			2.4
	(2.5)	(2.4)	(2.4)	(2.3)		(2.4)			(2.4)

PTA = pure tone audiogram; OME = otitis media effusion; AC = air conduction; BC = bone conduction; ( ) = standard deviation; *$p<0.01$

TABLE II
DETECTABILITY OF EACH OAE ACCORDING TO THE MIDDLE-EAR STATUS

	SOAE		TEOAE		DPgram	
No. of ears (%) N = 76	+	−	+	−	+	−
Normal ears (%) N = 44	36 (81.8)	8 (18.2)	40 (90.9)	4 (9.1)	44 (100)	0 (0)
OME ears (%) N = 32	11 (34.4)	21 (65.6)	4 (12.6)	28 (87.5)	15 (46.9)	17 (53.1)

OAE = otoacoustic emission; SOAE = spontaneous otoacoustic emission; TEOAE = transiently evoked otoacoustic emission; DPgram = distortion product audiogram; OME = otitis media with effusion; + = detectable wave of 3 dB (SOAE) or 5 dB (TEOAE & DPgram) above the noise level; – = no detectable wave; $p<0.01$: significant difference in detectability of each OAE between normal ears and OME ears

3000, 4000, 6000, 8000 Hz) of 40 ears that could be measured by pure tone stimuli were 11.9 ± 7.9 dBHL. In the study group, all the tympanograms demonstrated type ‘B’ and average air conduction hearing levels of 24.6 ± 7.6 dBHL. The average air conduction hearing levels between the normal control group and study group were significantly different ($p<0.01$) although the hearing level of each frequency in the same group did not show a significant difference ($p>0.05$) (Table I).

Expression of SOAE, TEOAE, DPgram

The rate of SOAE expression in the control group was 81.8 per cent in 36 ears out of the total 44 ears; according to sex, this rate was 79.1 per cent in the boys with 19 ears out of 24 ears, and in the girls was 85 per cent with 17 ears out of 20 ears, showing the higher rate of expression in the girls.

In ears with the findings of OME and type ‘B’ on tympanometry SOAE was expressed in 11 ears out of the total 32 pars (34.4 per cent), showing a statistical significance compared with the control group (Table II), and according to sex, this rate was 24 per cent with six out of 25 ears in the boys, and was 71.4 per cent with five out of seven ears in the girls, again showing a higher rate in the girls.

TEOAE were expressed in the control group with 40 out of 44 ears (91 per cent), showing a statistically significant difference compared to 12.6 per cent with four ears out of the total of 32 ears in the OME group (Table II).

The rate of DPgram expression was 100 per cent in the control group and in the OME group was seen in 15 out of 32 ears (47 per cent) again showing a statistically significant difference between the two groups (Table II).

TABLE III
RELATION OF DETECTABILITY BETWEEN SOAE AND TEOAE

No. of ears (N = 76)		SOAE +	SOAE –
TEOAE	+	38	7
	–	10	21

SOAE = spontaneous otoacoustic emission; TEOAE = transiently evoked otoacoustic emission; + = detectable wave of 3 dB (SOAE) or 5 dB (TEOAE) above the noise level; − = no detectable wave; $p<0.01$ = significant relation of detectability between SOAE and TEOAE

Correlation among various OAEs and expression of DP I-O function curve

In the rate of each otoacoustic emission expression, the correlations between SOAE and TEOAE were 77.6 per cent (Table III) with 59 ears out of the total 76 ears; that between SOAE and DPgram was 73.7 per cent (Table IV) with 56 ears out of the total 76 ears; and those between TEOAE and DPgram was 80.3 per cent (Table V) with 61 ears out of the total 76 ears, showing a statistically significant correlation between each pair of groups.

The rate of expression of DP I-O function curve in the control group was 56.8 per cent at 3 kHz with 25 ears out of the total 44 ears at the input threshold of 45 dB, showing a statistically significant difference compared to 3.1 per cent at 3 kHz in one ear out of 32 ears in the OME group. And for the input threshold at 55 dB, the rate in the control group was 84.1 per cent at 3 kHz with 25 ears out of 44 ears, and that in OME group was 9.4 per cent at 3 kHz with three ears out of 32 ears, showing again a statistically significant difference between the two groups. Also, the rates of expression at the input threshold levels of 45 dB and 55 dB at 4000 Hz in the control group were 79.5 per cent and 93.2 per cent, respectively, showing a statistically significant difference from the OME group of 34.4 per cent and 31.3 per cent, respectively. Whereas, the rate of expression at the

TABLE IV
RELATION OF DETECTABILITY BETWEEN SOAE AND DPGRAM

No. of ears (N = 76)		SOAE +	SOAE –
DPgram	+	43	16
	–	4	13

SOAE; spontaneous otoacoustic emission; DPgram = distortion product audiogram; + = detectable wave of 3 dB (SOAE) or 5 dB (DPgram) avove the noise level; − = no detectable wave; $p<0.01$ = significant relation to detectability between SOAE and DPgram

TABLE V
RELATION OF DETECTABILITY BETWEEN TEOAE AND DPGRAM

No. of ears (N = 76)		TEOAE +	TEOAE –
DPgram	+	44	15
	–	0	17

TEOAE = transiently evoked otoacoustic emission; DPgram = distortion product audiogram; + = detectable wave of 5 dB (TEOAE) above the noise level or 5 dB (DPgram) above the noise level; – = no detectable wave; $p<0.01$ = significant relation of detectability between TEOAE and DPgram

TABLE VI

DETECTABILITY OF DP I-O FUNCTION CURVE UNDER VARIOUS GEOMETRIC MEAN FREQUENCIES BETWEEN 1–6 KHZ USING PRIMARY TONE OF 45 DB SPL

	(+) I-O function curve					
No. of ears (%) N = 76	1 kHz	2 kHz	3 kHz	4 kHz	5 kHz	6 kHz
Normal ears (%) N = 44	5 (11.4)	6 (13.6)	25 (56.8)*	35 (79.5)*	41 (93.2)	42 (95.5)
OME ears (%) N = 32	2 (6.3)	2 (6.3)	1 (3.1)*	11 (34.4)*	24 (81.3)	27 (87.4)

$p<0.05$ = significant difference in the detectability of DP I-O function curve between normal ears and OME ears; DP I-O = function curve, distortion product input-output function curve; OME, otitis media with effusion; + = detectable wave of 5 dB above the noise level according to each frequency

TABLE VII

DETECTABILITY OF DP I-O FUNCTION CURVE UNDER VARIOUS GEOMETRIC MEAN FREQUENCIES BETWEEN 1-6 KHZ USING A PRIMARY TONE OF 55 DB SPL

	(+) I-O function curve					
No. of ears (%) N = 76	1 kHz	2 kHz	3 kHz	4 kHz	5 kHz	6 kHz
Normal ears (%) N = 44	12 (27.3)	15 (34.1)	37 (84.1)*	41 (93.2)*	41 (93.2)	43 (97.7)
OME ears (%) N = 32	3 (9.4)	9 (28.1)	3 (9.4)*	12 (37.5)*	26 (81.3)	28 (87.5)

$p<0.05$ = significant difference in the detectability of DP I-O function curve between normal ears and OME ears; DP I-O function curve, distortion product input-output function curve; OME = otitis media with effusion; + = detectable wave of 5 dB above the noise level according to each frequency

input threshold levels of 45 dB and 55 dB at the other frequencies (1, 2, 5, 6 kHz) did not show a significant difference between the OME and control groups (Tables VI and VII). Also, in the OME group, we could not find any significant relationship between the PTA threshold and the expression of the I-O function curve at each frequency.

Discussion

Measuring otoacoustic emissions is objective, non-invasive and saves time when determining the function of the cochlea so it is used for many clinical purposes. Before being measured in the external auditory canal, all otoacoustic emissions must pass through the middle ear so that changes in sound conduction of the middle ear change the characteristics of OAEs. The sound stimulus that induces OAEs also changes according to the condition of the middle ear. Therefore, we can easily predict that measurement of various OAEs in children in the OME group who show a type B tympanogram with mild conductive hearing loss in PTA may be different from those in normal children in this study.

The effects of pathologic conditions of the middle ear on OAEs are complex. Generally, pathologic conditions of the middle ear decrease the amplitude of OAEs and sometimes completely efface the response.[6,9] Clinically, pathologic conditions that reduce sound conduction of the middle ear are middle-ear effusion and changes in negative pressure within the middle ear.

Negative pressure or effusion of the middle ear was known to affect the expression of otoacoustic emission at frequencies under 2 kHz.[7] Lonsbury-Martin *et al.* reported that the examiner should always check for the presence or absence of pathologic conditions within the middle ear in children when analysing results of OAE, and emphasized that tympanometry should be always performed to confirm the formation of effusion or negative pressure of the middle ear in children whose OAE could not be measured.[10]

The rate of SOAE expression has mainly been studied in people with normal hearing and could change according to the sensitivity of the microphone, the degree of noise, the equipment for lowering noise level, and the standard of determining positivity; however, the reported rate was usually between 35 to 40 per cent and has been reported to be up to 72 per cent in recent years according to Talmadge *et al.* with the introduction of equipment for lowering the level of noise.[11,12] The rate of expression determined in the present study was 61.8 per cent, showing a similar result, and also, the rate of SOAE expression according to sex was higher in the girls as reported in previous studies. The rate of SOAE expression in the normal control group was especially high at 81.8 per cent, showing a statistically significant difference from OME group with the rate of of 34.4 per cent ($p<0.05$). Compared to the previous reports about the SOAE expression rate, we found a higher rate of its expression in the normal control group. This could have been the result of the study subjects being younger (two to 11 years old) than in previous studies and who might have bigger OAEs than adults in this study. The different expression rate of SOAE between the normal and OME group might reflect the influence of middle-ear effusion on SOAE measurement.

When the positivity of TEOAE was determined at a response higher than 5 dB and with a reproducibility of more than 50 per cent as in most studies,[3,6,9] the rate of TEOAE expression was high with 90.9 per cent in the normal middle-ear group and was 12.6 per cent in the OME group; thus, this rate could be used as an index reflecting the middle-ear condition.

DPgram has the largest amplitude for the stimuli of the two frequencies of pure tones, f1 and f2(primary, f2, f1), at 2f1-f2 and shows a frequency specificity related to the condition of the cochlea around the geometric means of the two pure tones,[13] and the expression of DPgram is shown in more than 90 per cent of people with normal hearing.[14] The rate of DPgram expression was 100 per cent in all of the 44 normal control ears, showing the same rate of expression as in the study by Bonfils *et al*. at a stimulation level of 70 dB.[15] Also, in the present study, the rate of the expression was 46.9 per cent in the OME group, showing a statistically significant difference compared to the control group ($p<0.05$). Thus, it was confirmed that middle-ear effusion affects the DPgram as in other studies.[15]

Also, the correlations between the expression rates in each otoacoustic emission showed statistically significant results in SOAE, TEOAE, and DP gram so that at the time of determining positivity in one type of otoacoustic emission, the result could be predicted.

As described previously, despite reports on the effects of the condition of the middle-ear on the DPgram, the correlation between DP I-O function curve and middle-ear condition has not been elucidated. The DP I-O function curve has an advantage in determining the level of threshold by recording each response while raising stimulation of the pure tone for each frequency that is measured at the time of routine hearing test with pure tone. Generally, the positivity is determined at an amplitude that is more than 3 dB over the level of noise, and we determined a positivity at an amplitude of 5 dB higher over noise level in order to raise specificity. Although clinical studies on the threshold level of DPOAE are currently still not completed, they would help in predicting the sensitivity for hearing. In this study, when the DP I-O function curve for the stimulus strength from 35 dB to 75 dB was compared and analysed at each frequency of 696, 1001, 1501, 2002, 3003, 4004, 5005 and 6006 Hz, the results showed that a statistically significant difference was seen between the control group and OME group at the frequencies of 3000 Hz and 4000 Hz with a stimulus strength of 45 dB and 55 dB. For those frequencies under 2000 Hz, the DPOAE amplitude became smaller and the noise level became higher so that the DPOAE amplitude was not expressed even in the normal middle-ear group. For those high frequencies above 5000 Hz, the DPOAE amplitude was expressed higher than 5 dB over the level of noise also in many of the OME group. This may be due to the fact that most of the children in the OME group showed conductive hearing loss within 20–30 dB and from the fact that the presence of the middle-ear effusion itself would have less effect on the expression of I-O function curve at those frequencies. Furthermore, there was no significant difference in air conduction hearing levels from 250 to 8000 Hz in PTA within the OME group, and also no significant relationship between the PTA threshold and expression of the I-O function curve in this group, which suggests that the frequency specific DPOAE response, especially at frequencies of 3000 and 4000 Hz, may be due to middle-ear status rather than the hearing level itself.

Thus, the present study demonstrates that measurements of SOAE, TEOAE and DPOAE reflect the middle-ear condition in children, and since high correlations are seen among these emissions, it was determined that these measurements would be affected equally by the middle-ear condition. Furthermore, OAE may reflect cochlear function and middle-ear status at the same time so that measurement of OAE not only supports the tympanogram but gives additional information, especially if a PTA is not possible. A positive response was found in the TEOAE and DPgram in three of six OME ears in this study, which reflects their normal cochlear function even though they showed type B tympanogram and could not perform PTA. It was found that the DP I-O function curve could be used as a tool for monitoring middle-ear condition in patients with MEE. Middle-ear effusion could effect the expression of DPOAE at frequencies of 3000 Hz and 4000 Hz, and could change the response to the stimulus strength of 45 dB and 55 dB on the DP I-O function curve. Positive conversion of DP I-O function curve at 3000 and 4000 Hz at a stimulus strength of 45 dB and 55 dB may provide the normalized middle ear with normal hearing range during treatment of MEE.

Conclusions

The results of this study suggest that middle-ear effusion affects the expression rate of not only SOAEs, TEOAEs but also DPOAEs. Their expressions were significantly related to one another. Measurement of SOAE, TEOAE and a DPgram would help in evaluating the middle-ear condition, and measuring DP I-O function curve at the frequencies between 3000 Hz and 4000 Hz would suggest the middle ear status.

Thus, we believe that the measurement of otoacoustic emissions, especially the consecutive measurement of DP I-O function curve at the frequencies of 3000 Hz and 4000 Hz, would aid in evaluating the middle-ear condition as well as hearing screening in children with OME during the course of treatment. The result of this study about DP I-O function curve in the normal and OME group may provide a basis for further clinical studies of OAE characterization.

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