Transient Evoked and Distortion Product Otoacoustic Emission Profile in Patients of Otosclerosis: A Preliminary Report

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Abstract The aim of this study was to investigate the profile of transient evoked and distortion product otoacoustic emissions in patients of otosclerosis and to assess any change in otoacoustic emission profile after surgical intervention. This prospective study under tertiary referral centre setting included 31 patients suffering from otosclerosis, who underwent surgical intervention in the form of stapedotomy. Air-bone gap on pure tone audiometry, pre-operative profile and postoperative profile of transient evoked and distortion product otoacoustic emissions at 1 month and 3 months were the main outcome measures of the subjects. The patients demonstrated subjective improvement in hearing and significant closure of air-bone gap on pure tone audiometry. There was statistically significant improvement in amplitudes of both transient-evoked and distortion product emissions in the low frequency range, after surgery. Cochran's *Q* test was applied to compare the statistical significances among preoperative values, 1 month values and 3 months values for the recorded otoacoustic emissions. It was observed that despite significant improvement in hearing, OAEs were not detected in all patients and correlation with behavioural thresholds was poor. As a result of these findings, the following conclusions can be drawn. The profile of otoacoustic emissions in patients of otosclerosis is variable and does not correlate with hearing thresholds. All patients showed improvement in amplitudes of OAEs after surgical intervention and there was further improvement between the followup profile at 1 month and 3 months, but this was

not found to be statistically significant. However, further studies with larger number of patients of otosclerosis can perhaps establish baseline profile of the evoked OAEs and the effect of fixation of stapes on reverse transmission of OAEs.

Keywords Otoacoustic emissions · Otosclerosis

Introduction

Otoacoustic emissions (OAEs) are a propagation of audiofrequency signal into the ear canal from the cochlea, transmitted through the ossicular chain and tympanum. They are believed to originate from active mechanical force generated by the outer hair cells, as proposed by Brownell [1]. In particular Kemp [2] has proposed that a biomechanical amplifier within the organ of corti underlies the properties of OAEs.

The OAEs can occur spontaneously or can be evoked by an acoustic stimulus. Measurement of OAEs has become an established method for hearing evaluation in neonates, children and adults [3]. Transient evoked otoacoustic emissions (TEOAEs) occur in response to acoustic transients (e.g. clicks and tone bursts) presented to the ear and measured with a simple averaging technique. They can be detected essentially in all normally hearing ears with hearing threshold >30 dB SPL. They are frequently used for hearing screening in newborns [4], patients who have been using ototoxic drugs [5] and noise exposed workers [6].

Distortion product otoacoustic emissions are generated by two stimulus tones of moderate level (55–75 dB SPL) separated in frequency, presented to the ear measured over a frequency range from 0.5 to 8 kHz. The highest amplitude at the frequency $2f_1-f_2$ is mainly used for routine

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audiological evaluations [7, 8]. The frequency selective property of DPOAE suggests that they will make useful monitors of localised cochlear function at any predetermined frequency [9].

Middle ear changes affect the antidromic sound transmission from the inner through the middle ear into the outer ear canal. These ears present with absent or markedly reduced otoacoustic emission amplitudes [10].

Otosclerosis is a primary localized disease of the bony otic capsule. It has a predilection for the oval window and fixes the stapedial footplate within the oval window niche [11]. The profile of OAEs could therefore be altered in patients of otosclerosis. However not much literature is available on the effect of stapes fixation on profile of otoacoustic emissions.

Through our study, we proposed to measure transient evoked and distortion product otoacoustic emissions in patients suffering from otosclerosis in order to evaluate the effect of fixity of stapes on otoacoustic emissions. We also proposed to measure OAEs in these subjects postoperatively at 1 and 3 months after surgery and observe the changes in OAEs after intervention.

Materials and Methods

Thirty-one patients (18 males and 13 females) suffering from otosclerosis were included in the present prospective study. Pure tone audiometry (PTA) and OAE testing (TEOAEs and DPOAEs) was done in all patients. All the patients were taken up for stapes surgery during the period of 1 year from March 2008 to March 2009 and were followed up postoperatively for 3 months. The age at surgery ranged from 15 to 50 years (median 29 years). The right ear was operated in 20 cases and the left ear in 11 cases. One and 3 months after stapes surgery, puretone audiograms (GSI 61 Clinical audiometer), TEOAEs and DPOAEs measurements were repeated.

An otomicroscopic examination to clean the outer ear canal and to verify a normal tympanic membrane in all the patients was done before each testing. Tympanometry (GSI—tymptstarversion-2 middle ear analyser) was performed to verify normal middle ear pressure in each patient. All audiological tests were performed in a sound treated room.

Methodology of Otoacoustic Emissions Testing

OAEs were measured with Vivosonic Integrity system, Model V500. For TEOAE measurement, ear tip was inserted tightly in the cartilaginous part of the ear canal and the ear was stimulated using the non-linear stimulus method. The amplitude of click was 80 dB SPL with click

duration of 80 μ s and click interval of 21 ms, taking high pass and low pass filter of 750 and 6000 Hz respectively with artefact rejection threshold of 55 dB SPL. The TEOAEs were recorded at the frequencies of 1.0, 2.0, 3.0 and 4.0 kHz, with the recording window of 2.8–12 ms.

After inserting ear tip into ear canal, DPOAEs were obtained with primary tone level of L1 and L2 as 65 and 55 dB SPL respectively in ascending frequency order and frequency ratio F2/F1 as 1.22. Accurate setting of DPOAE DPS stability requires the DPOAE signal to be stable for 0.4 s within ± 1 dB SPL from its median value. It yields the most accurate DPOAE measurement and was our default setting. The DPOAE amplitudes were recorded and plotted as DP gram as a function of F2 frequencies at 0.5, 1.0, 2.0, 4.0, 6.0 and 8.0 kHz.

Surgical Procedure

Ear surgery was performed under local anesthesia by one surgeon in all the patients, after taking informed consent. The approach was either transcanal or endaural. The ossicular chain and round window niche were evaluated. Once fixation of the stapedial footplate was confirmed, stapes surgery was performed in all 31 patients.

The stapedotomy was performed with 0.6 or 0.7 mm diamond bur, followed by insertion of the piston prosthesis into the vestibule and fixation of the prosthesis loop or clip around the long process of the incus. The crural arch was removed after separating the incudostapedial joint and cutting the stapedius tendon. 3.75, 4.0, 4.25, 4.50, 5.0 mm soft clip titanium and Teflon piston for ossicular chain reconstruction were used. After the loop or clip of the piston was secured around the long process of incus, the oval window niche was sealed with either blood clot or fat. None of the patients had any complication during or after the surgery.

Statistical Analysis

Repeated measures ANOVA with simple contrast was taken as preoperative reference. The *p*-value of simple contrast was adjusted by Bonferroni correction. Cochran's *Q* test was applied to compare, the statistical significance between preoperative values, 1 month values and 3 months values for recorded otoacoustic emission values. SPSS version 13.0 statistical software was used to analyse the data.

Results

Preoperative Findings

All patients presented with normal outer ear canals and tympanic membranes. The stapedial reflex was absent in all

patients. The mean air-bone gap calculated for four frequencies in 31 patients tested was 41.03 dB in the speech frequency range between 500 and 4000 Hz. For the purpose of analysis the frequencies were divided into low frequencies (0.5, 1, 2 kHz) and high frequencies (3, 4, 6, 8 kHz). DPOAEs amplitudes significantly exceeding the background noise level were detected at low frequencies in 13 patients and at high frequencies in 21 patients. TEOAEs amplitudes significantly exceeding the background noise level were detected at low frequencies in 17 patients and at high frequencies in 9 patients.

Post Operative Findings

Two patients did not present for follow-up, so for statistical calculation, comparison was made among 29 patients for their values at different time domains.

All patients described an improved hearing in the operated ear. The mean air bone gap was 15.93 dB (at 1 month) and 14.31 dB (at 3 months) with a significant improvement at 500, 1000, 2000, & 4000 Hz when compared to preoperative pure tone audiometric results as shown in Fig. 1.

On comparison of mean values of air bone gap at different time intervals (preoperative, postoperative 1 month and 3 months) the change observed was statistically significant.

DPOAEs and TEOAEs amplitudes significantly exceeding the background noise level were measured at low frequencies in 16 and 19 patients after 1 month and 24 & 26 patients after 3 months. At high frequencies DPOAEs & TEOAEs amplitudes were measured in 22 and 5 patients after 1 month and 26 and 12 patients after 3 months respectively. Group data revealed significant changes in DPOAEs and TEOAEs amplitudes at low frequencies when compared to preoperative results (Fig. 2).

DPOAEs amplitudes on comparison at different time domains (preoperative, postoperative 1 month and 3 months)

Fig. 1 Pre and postoperative findings of air bone gap on pure tone audiometry

Fig. 2 Pre and postoperative findings of DPOAEs and TEOAEs

were found statistically significant at low frequencies ($p = 0.001$) as compared to at high frequencies, where no statistically significant difference was observed ($p = 0.324$).

TEOAEs amplitudes on comparison at different time domains (preoperative, postoperative 1 month and 3 months) were found statistically significant at low frequencies ($p = 0.031$, $p < 0.05$) as compared to at high frequencies, where no statistically significant difference was observed ($p = 0.052$, $p > 0.05$).

Improvement in the amplitudes of DPOAEs and TEOAEs both at low and high frequencies was also observed at third month follow-up when compared with values at 1 month, but statistical significance could not be calculated due to small sample size.

Mean DP-grams recorded before surgery, 1 month and 3 months after stapedotomy showed improvement in emission amplitudes both at low frequencies and high frequencies, as depicted in Fig. 3.

Mean TE-grams recorded before surgery, 1 month after and 3 months after stapedotomy showed improvement in

Fig. 3 Mean DP-grams before surgery, 1 month and 3 months after stapedotomy

emission amplitudes both at low frequencies and high frequencies, as shown in Fig. 4.

Discussion

The aim of our study was to assess the profile of OAEs in patients of otosclerosis and study the change in the profile after surgical intervention. We also proposed to assess the utility of using OAE profile in evaluation of the outcome of stapes surgery. As otoacoustic emissions are objective and non-invasive they can be used in postoperative hearing evaluation as an adjunct to conventional hearing testing. In our study of 31 patients, a significant closure of the air bone gap on pure tone audiometry and a subjective hearing improvement described by the patients indicated the benefit of surgery.

Pathological changes within the middle ear will usually affect the sound transmission to the inner ear and subsequently lead to a conductive hearing loss. Since these changes also affect the antidromic sound transmission from the inner through the middle ear into the outer ear canal, these ears present with absent or markedly reduced OAE amplitude [10]. The middle ear status has to be considered when OAE results are interpreted [12]. OAE measurements have been used in various studies to evaluate the outcome of middle ear surgery. Acoustically evoked OAEs reoccurred in the majority of children suffering from otitis media with effusion after myringotomy and insertion of ventilation tubes [10]. TEOAEs were detected postoperatively in six out of sixteen ears following myringoplasty regardless of the graft material chosen, but in none of the ears where the ossicular chain had to be reconstructed [13].

In our study we detected DPOAEs at low frequencies in 13 patients and at high frequencies in 21 patients. TEOAEs were detected at low frequencies in 17 patients and at high

frequencies in 9 patients. These results are not comparable to other studies where OAEs were not detected preoperatively in any patients of otosclerosis. However the numbers of subjects studied have been very less in these studies [14–16].

With normal middle ear conditions, TEOAEs and DPOAEs are measurable in individuals having hearing threshold better than 30 and 55 dB respectively [3, 8]. After stapes surgery the mobility of the ossicular chain is restored and thus, TEOAEs and DPOAEs should be measurable postoperatively at those frequencies where the individual's hearing threshold reaches the criteria given above. In the present study, the postoperative mean air bone gaps were significantly reduced and in all patients, the individual hearing thresholds between 500 and 4000 Hz were within the range (i.e. a maximum 55 dB hearing loss) that DPOAEs and TEOAEs should have been measurable. In our study, group data reveals statistically significant improvement in postoperative DPOAEs and TEOAEs amplitudes in the low frequency range. Improvement in amplitudes is also seen in the high frequency range, though it is not in the statistically significant range.

Reports on the effect of stapes surgery on evoked OAEs are rare in the reviewed literature and have shown varying results. Herzog et al. could measure TEOAEs and DPOAEs in only one out of 34 otosclerotic patients, 3 and 6 months after stapes surgery [14]. Preoperatively neither TEOAEs nor DPOAEs were detected in any of the patients tested. The mean air bone gap for different frequencies ranged between 26.2 and 38.4 dB in the speech frequency range between 500 and 4000 Hz. Postoperatively after 3 and 6 months valid TEOAEs and DPOAEs with low amplitude in the 1–2 kHz range could be measured in only one patient, and group data did not reveal significant differences between pre and post-operative TEOAE or DPOAE amplitudes, although mean air bone gap had improved at 500, 1000, 2000 Hz ranging from 8.4 to 19.0 dB.

In another study by Rossi G and Solero P, OAEs were detected in four out of four otosclerosis patients after stapes surgery [15]. In normal hearing subjects, evoked OAEs by bone conduction stimulus (BCS) showed the same characteristics as those evoked by air conduction stimulus (ACS). In subjects with unilateral otosclerosis, no EOAE could be elicited by ACS from the otosclerotic ear, whereas they could be recorded by BCS. After stapedectomy, EOAE could be obtained by ACS too. The authors hypothesized that ossicular chain is important but not essential in the transfer of the EOAE to the eardrum.

A study was done by Filippo et al. [16] to investigate changes in middle ear dynamic characteristics caused by both otosclerosis and stapes surgery and to evaluate DPOAEs before and following surgery. Fifteen patients of otosclerosis were evaluated with the use of pure-tone

Fig. 4 Mean TE-grams before surgery, 1 month and 3 months after stapedotomy

audiograms (preoperatively, 5 and 30 days after surgery), stapedial reflexes (preoperatively), and DPOAE recording (preoperatively, at the end of surgery, and 5 and 30 days after surgery). Preoperative tests showed conductive hearing loss, with a mean air-bone gap of 36.6 dB HL ranging from 0.25 to 1 kHz, and no stapedial reflexes were detected. DPOAEs were not measurable preoperatively, and they were detected only in two patients at the end of surgery, with low amplitudes in a narrow frequency range. No significant changes occurred in DPOAEs 5 days postoperatively. A month after surgery, improvement in conductive hearing loss was observed; the mean air-bone gap from 0.25 to 1 kHz was 12.9 dBHL, whereas the higher frequencies were still affected by the disease. DPOAEs increased in amplitude in 4 patients but this was not significant. Through our study we have studied more number of patients and we have found statistically significant improvement in amplitudes of DPOAEs and TEOAEs achieved in the low frequency range. Improvement in amplitudes was observed in the high frequency range too, though it was not statistically significant. On comparison of results at the first month and the third month, there was further improvement in amplitudes of OAEs.

On review of literature we found that the utility of Otoacoustic emissions in evaluation of effects of ototoxic drugs, effect of noise exposure and use in the screening of hearing status in newborns has received much attention in comparison to effects of stapes surgery [4–6]. This prompted us to take up this prospective study to evaluate the profile of OAEs in patients of otosclerosis and the change observed after surgical intervention in these patients.

After analysis of our data we have found that the mean air bone gap preoperatively was 41.03 dB and postoperatively at 1 month, 3 month, was 15.93 and 14.31 dB at different speech frequencies between 500 to 4000 Hz. Due to fixation of the stapes TEOAEs or DPOAEs were not measured preoperatively in all the cases, but postoperatively, valid TEOAEs and DPOAEs amplitudes in the 500–2000 Hz range were measured in 26 and 24 patients, and group data reveal significant difference between pre and postoperative TEOAE or DPOAE amplitudes at low frequencies.

According to Herzog et al. [14], their group data did not reveal significant differences between pre and post-operative TEOAE or DPOAE amplitude, although mean air bone gap had improved at 500, 1000, 2000 Hz ranging from 8.4 to 19.0 dB.

The reasons remain somewhat unclear why OAEs can not be recorded at high frequencies in most of cases after successful stapes surgery although the individual's air bone gap is sufficiently closed and the hearing threshold is within the measurable range for TEOAEs and DPOAEs (30 or 55 dB HL, respectively). In one study [14] the authors

hypothesized that this could be due to three conditions: (1) an increase in the mass, (2) an increase in stiffness, (3) a clinically inapparent perilymph leak. According to them an increase in mass of the middle ear sound transmitting structures does not appear to play a crucial role. An increase in stiffness of the middle ear structures after stapes surgery appears to be more likely reason for the fact that OAEs are only measured in a narrow frequency range postoperatively, which may be due to scar formation around the inserted piston in the oval window niche and/or because of clamping the prosthesis loop around the long process of the incus. The third factor could be a functionally incomplete coupling of the piston within the vestibule. Both conditions i.e. an increase in stiffness as well as an incomplete coupling, can hamper the reverse propagation of OAEs. OAE measurements are much more sensitive to changes of the inner or middle ear status when compared to pure tone audiometry testing. This could explain why any of the above factors prevents recording of OAEs while the air bone gap is found to be sufficiently closed after surgery.

Though OAEs can contribute towards the evaluation of hearing, certain areas such as otosclerosis and otitis media where the reverse—transfer function of middle ear with respect to OAE transmission is affected; need further study [3].

Conclusions

- (a) The measurement of otoacoustic emissions in otosclerosis needs to be studied further in order to generate more normative values.
- (b) The use of OAEs in evaluation of the outcome of successful stapes surgery requires further studies with a larger number of patients.
- (c) Conventional pure tone audiometry remains the choice for outcome evaluation of stapes surgery in patients of otosclerosis.

Conflict of interest None.

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