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Otoacoustic emissions and contralateral suppression in tinnitus sufferers with normal hearing

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Abstract

Background: The general consensus on the role of hearing loss in generating tinnitus is not relevant in tinnitus patients with normal hearing thresholds. One source of tinnitus may be related to damage to outer hair cells (OHC) of the cochlea. If the OHC of the human cochlea are to be involved in the generation of tinnitus, testing of Otoacoustic emissions (OAE) could provide a reliable means of recording OHC dysfunction. We investigated the role of OHC and cochlear efferent system in tinnitus development in normal hearing ears through studying of Distortion Product Otoacoustic Emissions (DPOAE) and Transient Evoked Otoacoustic Emissions (TEOAE) amplitudes, contralateral suppression amplitudes and suppression value in 15 normal hearing tinnitus patients and 15 control subjects.

Results: Mean f2 DPOAE amplitudes and contralateral suppression were significantly lower in tinnitus group compared to controls for all frequencies from 1001 to 6348 Hz. Suppression values of DPOAEs revealed lower but not significant difference between tinnitus and control groups for all frequencies except 1587 and 6348 Hz. TEOAE amplitudes and contralateral suppression were significantly lower in tinnitus groups for all frequencies from 1000 to 4000 Hz compared to the control group. Suppression value of TEOAEs revealed no significant difference between the two groups for all frequencies except 3000 and 4000 Hz were significantly lower in the tinnitus group compared to the control group.

Conclusions: Normal hearing manifested by pure tone audiometry in non-vascular tinnitus sufferers does not exclude OHC and/or cochlear efferent pathology.

Keywords: Tinnitus, Normal hearing, Transient otoacoustic emission, Distortion product otoacoustic emission, Contralateral suppression

Background

Tinnitus is characterized by the perception of sound in the absence of an external stimulus [1]. Tinnitus may be buzzing, hissing or ringing in the ears, but it can also be intermittent or pulsatile [2, 3].

Tinnitus might be associated with abnormalities at any level of the auditory pathway; however, it commonly starts in the cochlea [3]. Jastreboff considers that tinnitus usually starts in the cochlea and then generates abnormal activity in the central pathway, which lead to propagation of the symptom [4].

Nonetheless, the absence of audiometric hearing loss challenges the cochlear theories of tinnitus generation in normal hearing tinnitus patients [2]. Evidence indicates that changes in the cochlea can be detected by otoacoustic emissions (OAEs), contralateral suppression, and suppression value testing even before the occurrence of considerable changes in the patient's audiogram [5].

The OAEs are produced by the outer hair cells (OHCs) of the cochlea as a result of nonlinear active

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mechanical feedback processes, which can be either spontaneous or evoked by sounds [6].

Transient evoked otoacoustic emissions (TEOAEs)

They are low intensity responses produced by the cochlea emitted after a short acoustic stimulus (clicks or tone bursts). They occur over a wide range of frequencies, thus permitting broad stimulation of the cochlea [7, 8]. TEOAEs are identified in individuals with normal OHC function at the frequency analyzed, or in individuals with auditory thresholds below 30 dBHL. TEOAE is able to detect impaired hearing but not the type and degree of impairment [9, 10].

For measuring TEOAE, in contrast to the recording techniques utilized for spontaneous otoacoustic emissions (SOAEs), the acoustic probe must incorporate a means for presenting stimuli [11, 12]. To detect TEOAE, signal of the microphone is averaged by time locking it to the transient stimulus. The average waveform is then analyzed to obtain a frequency spectrum of the emissions and validate the response [13, 14]. Dominant TEOAE frequencies are most often measured within the frequency range extending from 0.5 to 4 kHz and in general have the greatest amplitude between l and 1.5 kHz, which reflects the middle ear function as suggested by Kemp [15].

Distortion product otoacoustic emissions (DPOAEs)

Like TEOAE, DPOAEs are sounds generated by OHCs in response to simultaneous stimulation with two pure tones (f1 and f2) with closely related frequencies (f2/f1 = 1.22). The lower-frequency pure tone is referred to as primary f1, and its intensity level is L1. The higher-frequency tone is f2, and its intensity level is L2. The parameters analyzed in DPOAE testing are amplitude of the signal and signal to noise ratio (SNR) [16].

Acoustic distortion products represent evoked non-linear responses because they consist of new frequencies that are not present in the eliciting stimuli. A bi-tonal stimulus with certain properties can elicit many different distortion products (DP) called “intermodulation products.” It is the non-linear properties of the cochlea that are responsible for generating such distortion that are detected in the ear canal. In human ears, the largest DPOAE is at the frequency described by the expression 2fl-f2 [16].

Contralateral otoacoustic emission suppression

The OAE suppression test assesses the efferent auditory system by measuring amplitude suppression or changes in the latency and phase of evoked OAEs when an acoustic stimulus is introduced simultaneously to the contralateral ear [17].

Analysis of the suppression effect permits evaluation of the cochlear status and the central auditory mechanisms, specifically, the efferent medial olivocochlear system [18].

The suppression value is calculated as the difference between the values obtained in the presence and absence of the stimulus. A suppression effect is considered present when there is a reduction of at least 0.5 dB sound pressure level (SPL) in OAE amplitudes in the presence of a contralateral noise. A suppression effect of 0.5 to 1 dB SPL indicates integrity of the medial olivocochlear system [19, 20].

Several studies have attempted to reveal the relation between tinnitus and OAE amplitudes [21–23] or OAE contralateral suppression amplitudes [24, 25]. Evidence indicates that subtle changes in cochlear function can be detected by OAE testing even before the occurrence of significant changes in the patient’s audiogram.

If the OHCs are to be involved in the generation of tinnitus, testing of OAEs could provide a reliable means of recording OHC dysfunction. We investigated OAE as an objective, non-invasive clinical test for the exploration of OHC integrity and the neurologic evaluation of the descending efferent auditory system in normal hearing tinnitus patients for a better understanding of the function of the auditory pathway.

Aim of the work

- Investigate the role of outer hair cells and cochlear efferent system in tinnitus development in normal hearing ears through studying of DPOAE and TEOAE amplitudes, contralateral suppression amplitudes, and suppression value.

Methods

This prospective research was done on 15 normal hearing tinnitus patients (30 ears) and 15 sex- and age-matched control subjects (30 ears).

Full history taking, otoscopy examination, tympanometry, acoustic reflex, and pure tone audiometry (air conduction, 250–8000 Hz; bone conduction, 250–4000 Hz) were conducted. Otoacoustic emission test was done using the ILO-96 DP Otodynamic analyzer-version 5.

DPOAE measurement

Two pure-tone signals, f1 and f2 (f1 < f2; f2/f1 = 1.22), were presented simultaneously as primary tone frequencies that generate 2f1-f2 distortion product. Otoacoustic distortion product “audiogram” (DP-Gram) was collected at 3 points/octave steps at a stimulus level of 65 dB SPL for L1 and 55 dB SPL for L2. The emitted distortion product at 2f1-f2 was generated at a cochlear site near f2, and therefore, the DP absloute amplitude findings in dB SPL were displayed with respect to frequencies of f2 that ranged from 1 to 6 kHz.

TEOAE measurement

TEOAEs SNR measurements were recorded according to the non-linear protocol, using acoustical bandwidth (1000–4000 Hz) at 88 dB SPL, whose responses were stored and averaged in two 20-ms buffers. Each measurement run was stopped after averaging 260 sweeps.

Measurement in the presence of contralateral suppression (CS)

DPOAEs and TEOAEs were performed with contralateral white noise of 50 dB sensation level (SL).

The suppression value

Suppression value is the difference between the values obtained in the presence and absence of a contralateral stimulus. A suppression effect ≥ 1 dB SPL indicates integrity of the medial olivo-cochlear system. In this respect, absence of suppression was considered when there is no reduction of at least 1 dB SPL in OAE amplitudes in the presence of a contralateral noise.

Statistical analysis of the data

Data were fed to the computer and analyzed using IBM SPSS software package version 20.0. Significance of the obtained results was judged at the 5% level. P values ≤ 0.05 were considered statistically significant

For demographic data: The chi-square test was used for categorical variables, Fisher's exact or Monte Carlo correction was used as a correction for chi-square when more than 20% of the cells have expected count less than 5, and Student's t test was used to compare normally distributed quantitative variables. For comparing DPOAE, contralateral suppression DPOAE, TEOAE, and contralateral suppression TEOAE amplitudes between the study and control groups, Mann-Whitney test was used. The Spearman coefficient was used to study the correlation between TEOAEs and DPOAE amplitudes and between TEOAE and DPOAE CS.

Results

Demographic data

Patients were selected between 20 and 49 years because in this age group the OAEs are fairly stable [26]. The two study groups were homogeneous with respect to age and gender. A comparable number of right and left ears were present in both groups. All subjects had normal auditory thresholds (25 dB) in the frequencies from 250 to 8000 Hz; normal otoscopy, normal tympanometry results, and stapedial reflexes were present. In our research, there was no statistically significant difference between sex and age of tinnitus subjects and controls.

Table 1 DPOAE amplitudes in dB SPL according to 2f1-f2 in tinnitus patients and control groups

2f1-f2	Cases (*n* = 15) Ears = 30	Control (*n* = 15) Ears = 30	*U*	*p*
818(f1) 1001(f2)				
Min.–max.	− 8.80 to 12.50	3.90 to 16.30	198.50*	< 0.001*
Mean ± SD.	7.42 ± 4.87	11.04 ± 2.58		
Median	8.40	11.60		
1038(f1) 1257(f2)				
Min.–max.	− 12.80 to 14.90	3.20 to 14.0	223.50*	0.001*
Mean ± SD.	6.77 ± 5.83	10.95 ± 2.95		
Median	8.25	12.05		
1306(f1) 1587(f2)				
Min.–max.	− 9.30 – 15.80	5.90 to 16.50	122.50*	< 0.001*
Mean ± SD.	5.49 ± 6.18	12.23 ± 2.60		
Median	6.50	12.20		
1636(f1) 2002(f2)				
Min.–max.	− 16.10 to 15.0	6.20 to 21.0	189.00*	< 0.001*
Mean ± SD.	5.56 ± 8.26	12.49 ± 3.50		
Median	8.20	12.10		
2063(f1) 2515(f2)				
Min.–max.	− 9.30 to 15.60	8.20 to 19.60	176.50*	< 0.001*
Mean ± SD.	7.18 ± 6.95	13.77 ± 3.31		
Median	8.95	13.55		
2600(f1) 3174(f2)				
Min.–max.	− 7.30 to 16.10	− 5.30 to 17.30	200.50*	< 0.001*
Mean ± SD.	5.73 ± 6.77	12.14 ± 5.20		
Median	6.20	12.85		
3284(f1) 4004(f2)				
Min.–max.	− 9.90 to 15.20	1.0 to 17.10	98.50*	< 0.001*
Mean ± SD.	5.37 ± 5.57	12.49 ± 3.20		
Median	5.75	12.55		
4126(f1) 5042(f2)				
Min.–max.	− 13.0 to 19.40	4.40 to 21.40	271.00*	0.008*
Mean ± SD.	8.26 ± 7.44	13.15 ± 4.23		
Median	8.35	12.75		
5200(f1) 6348(f2)				
Min.–max.	− 18.60 to 11.0	− 21.20 to 12.20	127.50*	< 0.001*
Mean ± SD.	− 7.92 ± 8.43	4.47 ± 8.24		
Median	− 11.85	7.60		

U, *p*, *U* and *p* values for Mann-Whitney test for comparing between the two groups
*Statistically significant at $p \leq 0.05$

Analytic data

DPOAE amplitudes

Table 1 shows significantly lower DPOAE amplitudes in tinnitus patients at all frequencies.

Table 2 Contralateral suppression (CS) of DPOAE amplitudes in dB SPL according to 2f1-f2 in tinnitus patients and control group

CS DPOAE (2f1-f2)	Cases (*n* = 15) Ears = 30	Control (*n* = 15) Ears = 30	*U*	*p*
818(f1) 1001(f2)				
Min.–max.	− 15.80 to 10.80	− 3.40 to 11.50	297.00*	0.024*
Mean ± SD.	1.58 ± 6.82	5.08 ± 4.18		
Median	3.90	6.15		
1038(f1) 1257(f2)				
Min.–max.	− 15.90 to 12.70	− 6.10 to 10.90	305.00*	0.032*
Mean ± SD.	1.06 ± 7.21	4.86 ± 4.77		
Median	1.80	6.20		
1306(f1) 1587(f2)				
Min.–max.	− 13.40 to 14.20	− 10.20 to 14.50	264.00*	0.006*
Mean ± SD.	0.78 ± 6.62	5.55 ± 5.92		
Median	1.65	7.60		
1636(f1) 2002(f2)				
Min.–max.	− 28.90 to 11.40	− 8.70 to 15.60	240.50*	0.002*
Mean ± SD.	− 1.03 ± 8.74	5.47 ± 6.09		
Median	0.55	6.55		
2063(f1) 2515(f2)				
Min.–max.	− 20.0 to 10.20	− 9.90 to 15.20	241.00*	0.002*
Mean ± SD.	− 1.42 ± 7.37	4.86 ± 6.34		
Median	0.10	5.20		
2600(f1) 3174(f2)				
Min.–max.	− 13.40 to 10.10	− 13.40 to 12.70	241.00*	0.002*
Mean ± SD.	− 1.44 ± 5.75	3.51 ± 6.74		
Median	− 2.85	5.25		
3284(f1) 4004(f2)				
Min.–max.	− 14.20 to 11.80	− 19.0 to 11.20	183.00*	< 0.001*
Mean ± SD.	− 0.86 ± 6.42	4.72 ± 6.61		
Median	0.90	5.95		
4126(f1) 5042(f2)				
Min.–max.	− 16.50 to 19.10	− 2.0 to 16.90	305.5*	0.033*
Mean ± SD.	5.67 ± 8.55	10.08 ± 3.88		
Median	4.20	10.15		
5200(f1) 6348(f2)				
Min.–max.	− 20.90 to 10.10	− 33.50 to 8.60	213.00*	< 0.001*
Mean ± SD.	− 11.03 ± 9.32	− 1.59 ± 10.0		
Median	− 15.70	1.65		

U, *p* *U* and *p* values for Mann-Whitney test for comparing between the two groups
*Statistically significant at $p \leq 0.05$

DPOAE amplitudes with contralateral suppression

Table 2 shows significantly lower contralateral suppression of DPOAE amplitudes in tinnitus patients at all frequencies.

Suppression value of DPOAE amplitudes

Table 3 shows significant reduction of DPOAE suppression value in tinnitus patients in 1587 and 6348 Hz (f_2 frequencies) compared to the control group.

Table 3 Comparison between the two studied groups according to suppression value in DPOAE amplitudes (dB SPL)

Suppression value	Cases (*n* = 15) Ears = 30	Control (*n* = 15) Ears = 30	*U*	*p*
818(f1) 1001(f2)				
Min.–max.	0.10 to 14.70	2.0 to 12.0	424.50	0.706
Mean ± SD.	5.84 ± 4.39	5.96 ± 2.68		
Median	6.10	5.10		
1038(f1) 1257(f2)				
Min.–max.	0.10 to 21.50	1.40 to 13.0	375.50	0.271
Mean ± SD.	5.70 ± 5.17	6.10 ± 3.59		
Median	4.05	4.90		
1306(f1) 1587(f2)				
Min.–max.	0.50 to 16.20	1.80 to 19.10	297.00*	0.024*
Mean ± SD.	4.71 ± 3.69	6.68 ± 4.05		
Median	3.35	6.0		
1636(f1) 2002(f2)				
Min.–max.	0.0 to 20.40	1.60 to 16.80	404.00	0.496
Mean ± SD.	6.60 ± 5.17	7.02 ± 4.18		
Median	6.80	5.70		
2063(f1) 2515(f2)				
Min.–max.	0.20 to 21.60	1.20 to 19.60	429.50	0.762
Mean ± SD.	8.60 ± 5.56	9.11 ± 5.46		
Median	8.05	9.05		
2600(f1) 3174(f2)				
Min.–max.	0.20 to 17.60	1.90 to 18.0	353.50	0.154
Mean ± SD.	7.13 ± 5.03	8.62 ± 4.31		
Median	6.90	8.05		
3284(f1) 4004(f2)				
Min.–max.	0.30 to 23.20	1.20 to 20.0	337.50	0.096
Mean ± SD.	6.22 ± 5.72	7.77 ± 4.71		
Median	5.35	7.35		
4126(f1) 5042(f2)				
Min.–max.	0.0 to 10.60	− 8.1 to 17.90	342.0	0.110
Mean ± SD.	2.60 ± 2.95	3.07 ± 4.68		
Median	1.50	3.30		
5200(f1) 6348(f2)				
Min.–max.	0.10 to 7.60	1.0 to 20.80	260.50*	0.005*
Mean ± SD.	3.08 ± 2.07	6.06 ± 4.38		
Median	2.95	4.60		

U, p U and *p* values for Mann-Whitney test for comparing between the two groups
*Statistically significant at $p \leq 0.05$

TEOAE amplitudes

Table 4 shows significant decrease of TEOAE amplitudes in tinnitus patients in all five frequencies (1000–4000 Hz) compared to the control group.

Table 4 TEOAE amplitudes (SNR) in dB SPL in tinnitus patients and control group

TEOAEs	Cases (*n* = 15) Ears = 30	Control (*n* = 15) Ears = 30	*U*	*P*
1000				
Min.–max.	1.0 to 17.0	7.0 to 20.0	241.50*	0.002*
Mean ± SD.	8.17 ± 4.36	12.0 ± 4.11		
Median	8.0	11.0		
1500				
Min.–max.	4.0 to 27.0	9.0 to 25.0	296.00*	0.022*
Mean ± SD.	13.87 ± 6.32	17.60 ± 4.45		
Median	14.50	17.0		
2000				
Min.–max.	7.0 to 26.0	6.0 to 28.0	291.50*	0.019*
Mean ± SD.	15.27 ± 5.10	18.30 ± 5.43		
Median	14.0	19.0		
3000				
Min.–max.	1.0 to 19.0	14.0 to 24.0	24.00*	< 0.001*
Mean ± SD.	10.23 ± 4.49	20.40 ± 2.59		
Median	9.0	20.50		
4000				
Min.–max.	2.0 to 20.0	11.0 to 26.0	200.50*	< 0.001*
Mean ± SD.	10.43 ± 5.10	15.87 ± 3.06		
Median	9.0	15.0		

U, p U and *p* values for Mann-Whitney test for comparing between the two groups
*Statistically significant at $p \leq 0.05$

TEOAE amplitudes with contralateral suppression

Table 5 shows significant reduction of TEOAE amplitudes in tinnitus patients in all five frequencies (1000–4000 Hz) compared to the control group.

Suppression value of TEOAE amplitudes

Table 6 shows significant reduction of TEOAE amplitudes in tinnitus patients in high frequencies (3000 and 4000 Hz) compared to the control group.

Suppression value in tinnitus patients

The percentage of tinnitus ears with DPOAE suppression ≥ 1 dB SPL was 40 % (Fig. 1) while the percentage of tinnitus ears with TEOAE suppression was 60% (Fig. 2).

Correlation between TEOAE and DPOAE amplitudes

Table 7 shows the correlation between TEOAE amplitudes and f2 of DPOAE amplitudes without noise in tinnitus patients (30 ears) in five test frequencies. No correlation was found between the two tests.

Table 5 Contralateral suppression of TEOAE SNR amplitudes (dB SPL) in tinnitus patients and control group

CS TEOAE	Cases (*n* = 15) Ears = 30	Control (*n* = 15) Ears = 30	*U*	*p*
1000				
Min.–max.	− 5.0 to 17.0	2.0 to 18.0	245.50*	0.002*
Mean ± SD.	4.20 ± 4.44	8.07 ± 4.45		
Median	4.0	7.0		
1500				
Min.–max.	0.0 to 18.0	4.0 to 20.0	299.50*	0.026*
Mean ± SD.	8.07 ± 5.52	11.17 ± 4.51		
Median	7.0	10.50		
2000				
Min.–max.	0.0 to 24.0	5.0 to 23.0	282.0*	0.013*
Mean ± SD.	10.40 ± 5.37	13.57 ± 4.59		
Median	9.50	14.0		
3000				
Min.–max.	0.0 to 16.0	6.0 to 19.0	261.50*	0.005*
Mean ± SD.	7.70 ± 4.57	10.83 ± 2.72		
Median	6.50	11.0		
4000				
Min.–max.	0.0 to 18.0	6.0 to 21.0	308.50*	0.036*
Mean ± SD.	7.93 ± 5.51	10.40 ± 3.31		
Median	6.0	10.0		

U, *p* *U* and *p* values for Mann-Whitney test for comparing between the two groups
*Statistically significant at $p \leq 0.05$

Table 6 Comparison between the two studied groups according to suppression value in TEOAE amplitudes (dB SPL)

Suppression value	Cases (*n* = 15) Ears = 30	Control (*n* = 15) Ears = 30	*U*	*p*
1000				
Min.–max.	0.0 to 11.0	1.0 to 8.0	424.50	0.703
Mean ± SD.	3.97 ± 2.81	3.97 ± 1.87		
Median	3.0	4.0		
1500				
Min.–max.	0.0 to 17.0	3.0 to 15.0	366.00	0.211
Mean ± SD.	5.80 ± 4.87	6.20 ± 3.09		
Median	4.50	5.0		
2000				
Min.–max.	0.0 to 15.0	-3.0 to 10.0	425.0	0.710
Mean ± SD.	4.87 ± 3.66	4.73 ± 3.59		
Median	4.0	5.0		
3000				
Min.–max.	0.0 to 7.0	3.0 to 16.0	17.00*	< 0.001*
Mean ± SD.	2.53 ± 1.78	9.60 ± 3.11		
Median	2.50	9.0		
4000				
Min.–max.	0.0 to 11.0	2.0 to 9.0	114.00*	< 0.001*
Mean ± SD.	2.50 ± 2.19	5.47 ± 1.93		
Median	2.0	6.0		

U, *p* *U* and *p* values for Mann-Whitney test for comparing between the two groups
*Statistically significant at $p \leq 0.05$

Correlation between contralateral suppression of TEOAE and DPOAE amplitudes

Figure 3 shows the correlation between CS TEOAE and CS DPOAE (f2) amplitudes in tinnitus patients (30 ears) in four test frequencies. A positive correlation was found between the two tests in frequencies (1000, 1500, 2000, and 3000 Hz), and no correlation was found in 4000 Hz.

Discussion

Demographic data

In this research, the tinnitus female patients were 80% (12 patients) and the tinnitus male patients were 20% (3 patients) that might be due to the higher incidence of annoyance in females as compared to males.

Davis [27] and Coelho et al. [28] found that female patients gave significantly higher annoyance levels than males. On the other hand, Hiller and Goebel [29] found that males have higher severity of tinnitus.

Analytic data

Many researchers attempted to reveal an association between tinnitus and OAE amplitudes [21–23] or OAEs contralateral suppression amplitudes [24, 25].

Previous studies have demonstrated that OAE can be used to reveal subclinical OHC damage in audiometrically normal ears [30, 31].

DPOAE amplitudes

In the present research, significant reduction of DPOAE amplitude was found in all frequencies in tinnitus

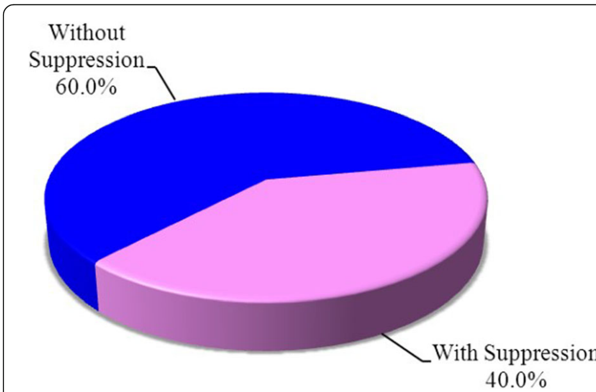

Fig. 1 Percentage of DPOAE suppression in tinnitus ears (according to suppression value)

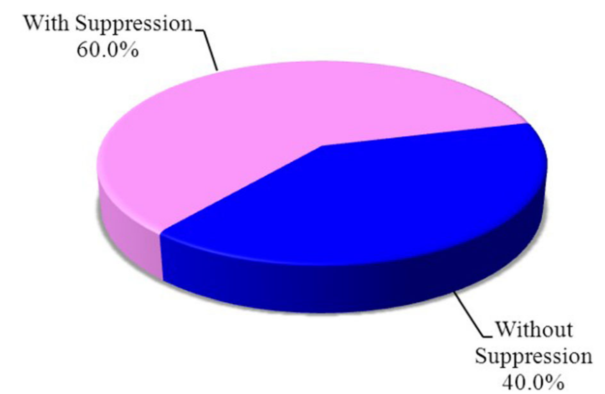

Fig. 2 Percentage of TEOAE suppression in tinnitus ears (according to suppression value)

sufferers. Reduction in DPOAE amplitudes indicates dysfunction of the OHCs. This may be due to the decrease in the OHC activity which results from the imbalance between the OHCs and IHCs. The OHCs are more liable to damage, and when it occurs, they fail to perform the inhibition over the IHC function. This loss of IHC inhibition results in tinnitus.

Our results are consistent with Shiomi et al. [32], Igna et al. [33], Favero et al. [34], and Liu et al. [35] that there was a significant reduction in DPOAE amplitudes over a wide range of frequencies (1000–7000 Hz) observed in the normal hearing tinnitus group.

TEOAE amplitudes

In this research, TEOAE amplitude was significantly reduced in the tinnitus sufferers group in all five frequencies from 1000 to 4000 Hz.

Tinnitus was related to a decrease in TEOAE amplitudes. Fernandes and Santos [25] found a decrease in amplitude in all frequencies in both ears of tinnitus sufferers with normal hearing. Rita and de Azevedo [36] observed a difference in the cases of unilateral tinnitus, with the overall amplitude being lower in the tinnitus ear.

Table 7 Correlation between TEOAE and DPOAE (f2) amplitudes in the patient group (n = 15, ears = 30)

	r_s	p
TEOAE 1000 vs. DPOAE 1001(f2) amplitude	− 0.031	0.869
TEOAE 1500 vs. DPOAE 1587(f2) amplitude	0.335	0.070
TEOAE 2000 vs. DPOAE 2002(f2) amplitude	0.267	0.154
TEOAE 3000 vs. DPOAE 3174(f2) amplitude	0.053	0.781
TEOAE 4000 vs. DPOAE 4004(f2) amplitude	0.254	0.176

r_s Spearman coefficient
*Statistically significant at $p \leq 0.05$

Contralateral suppression:

In the current research, suppression was elicited by using contralateral white noise of 50 dB SL, based on the previous studies on normal hearing subjects without tinnitus [37–39]. So different hearing thresholds differ in the absolute intensity of the suppressor noise.

In this research, the CS DPOAEs were significantly decreased in all nine frequencies in tinnitus sufferers. Also CS TEOAE amplitude was significantly decreased in tinnitus sufferers for all frequencies.

Contralateral suppression DPOAE amplitudes

Riga et al. [24] investigated CS DPOAEs in 18 tinnitus sufferers with normal hearing using noise of 55 dB HL. Non-significant lower amplitudes were reported in the tinnitus group compared to controls.

Chéry-Croze et al. [40] evaluated CS DPOAEs using noise of 55 dBSPL. They observed that emission suppression was lower in ears with tinnitus.

Contralateral suppression TEOAE amplitudes

Our results are consistent with the findings of Paglialonga et al. [41] who found lower TEOAE amplitudes and TEOAE suppression in tinnitus groups. This is because of dysfunction of the cochlear active mechanisms implicated in the generation of otoacoustic emissions. Since tinnitus sufferers in this research had normal hearing, poor OAEs indicate subclinical damage to OHCs.

Suppression value

In the current research, the number of tinnitus subjects without suppression according to the suppression value in DPOAE was 60% and in TEOAE was 40%. This could be due to the frequency-specific analysis of DPOAE from 1001 to 6348 Hz which included higher frequencies than TEOAE (1000 to 4000 Hz). Additionally, TEOAE stimulates all the cochlear basilar membrane; thus, it gives an overall information of the cochlear hair cell function. Therefore, DPOAE is superior to TEOAE in detecting subtle cochlear anomalies especially at high frequencies.

Correlation between TEOAE and DPOAE amplitudes:

In this research, no correlation was found between TEOAE and DPOAE amplitudes in tinnitus sufferers in five test frequencies. This could be because of the different protocols used in measurements.

Correlation between CS TEOAE and CS DPOAE amplitudes

A significant positive correlation was found between CS TEOAE and CS DPOAE amplitudes in tinnitus sufferers in four frequencies (1000, 1500, 2000, 3000 Hz).

Therefore, contralateral suppression of OAEs is a consistent measurement tool for the determination of

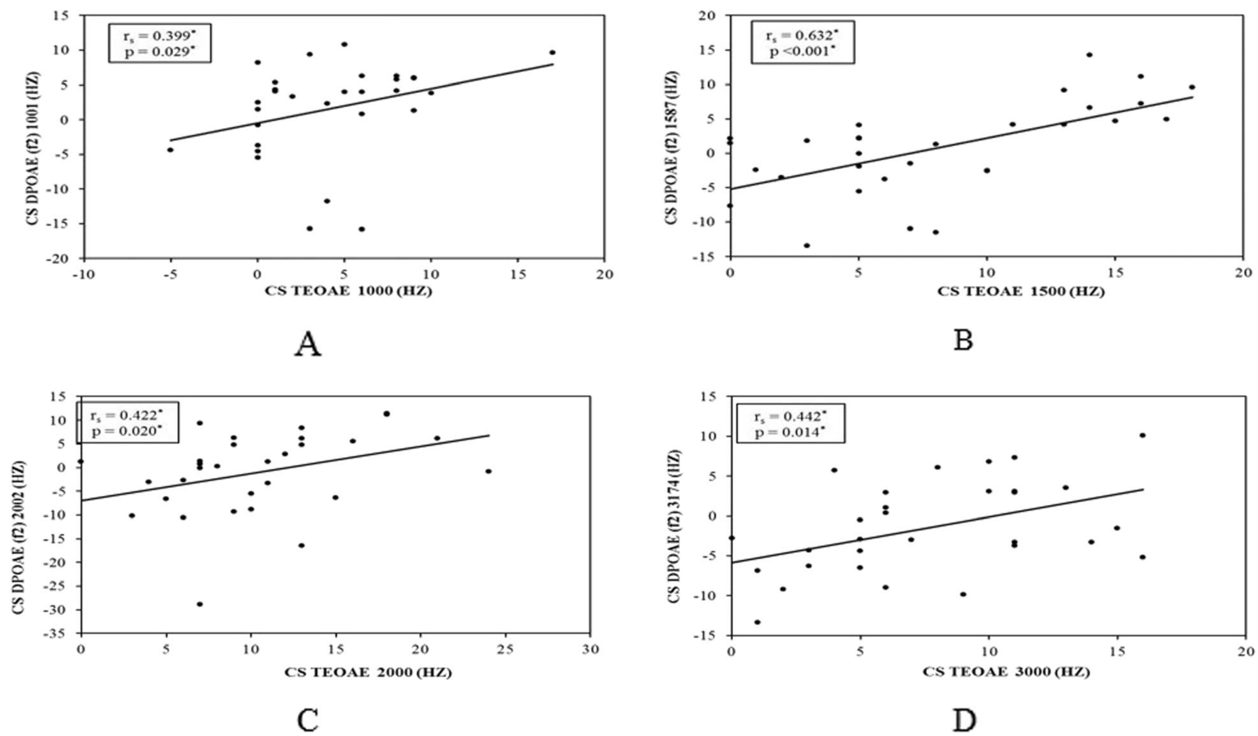

Fig. 3 Correlation between CS TEOAE amplitudes and CS DPOAE (f2) amplitudes in cases group (n = 15, ears = 30) in 1000, 1500, 2000, and 3000 Hz (**a**–**d**)

abnormal cochlear efferent pathology in tinnitus subjects with normal hearing.

Conclusion

- Normal hearing manifested by pure tone audiometry in non-vascular tinnitus sufferers does not exclude OHC and/or cochlear efferent pathology.
- DPOAEs are superior to TEOAEs because they are more frequency specific and so more sensitive in detecting subclinical cochlear dysfunction.
- Contralateral suppression of OAEs can be confidently used in detecting abnormal cochlear efferent pathology in tinnitus sufferers with normal hearing.

Abbreviations

CS: Contralateral suppression; dB: Decibel; DP: Distortion products; DP-Gram: Distortion product "audiogram"; DPOAEs: Distortion product otoacoustic emissions; Hz: Hertz; kHz: Kilohertz; OHCs: Outer hair cells; OAEs: Otoacoustic emissions; SL: Sensation level; SNR: Signal to noise ratio; SOAEs: Spontaneous otoacoustic emissions; SPL: Sound pressure level; TEOAEs: Transient evoked otoacoustic emissions

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Authors' contributions

All authors have read and approved the manuscript. DE, HK and BE done the Statistical analysis. DE and HK done the design, Definition of intellectual content and Manuscript review. DE and BE done the Data analysis and Clinical studies. DE done the Manuscript editing. HK done the Concepts. BE done the Literature search, Data acquisition and Manuscript preparation.

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Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

Informed written consent to participate in the study was provided by all participants and approved by Faculty of medicine, Alexandria University Ethics Committee on 24/1/2018 (reference number not available).

Consent for publication

Not applicable

Competing interests

The authors declare that they have no competing interests.

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