

Evaluation of cochlear function in patients with normal hearing and tinnitus: a distortion product otoacoustic emission study

Normal işiten tinnituslu olgularda koklear fonksiyonun değerlendirilmesi:
Distorsiyon product otoakustik emisyon çalışması

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Objectives: We investigated cochlear function in normal-hearing patients with tinnitus using distortion product otoacoustic emissions (DPOAE).

Patients and Methods: The study included 20 normal-hearing patients with tinnitus (13 males, 7 females; mean age 25 years; range 17 to 52 years) and 15 controls (10 males, 5 females; mean age 23 years; range 18 to 27 years) with normal hearing. Both groups underwent routine audiological tests including audiometry and tympanometry. Cubic DPOAEs were recorded from both groups. Signal-to-noise ratios (SNRs) lower than the 10th percentile of the control values were regarded as abnormal or undetectable.

Results: Tinnitus was bilateral in seven patients and unilateral in 13 patients. Seven patients with unilateral tinnitus and all patients with bilateral tinnitus had a history of exposure to noise. The mean perceived frequencies for tinnitus were 6.3 kHz and 6.2 kHz in the left and right ears, respectively. Loudness was measured as 8 dB SL in the left ears, and 7 dB SL in the right ears. Compared to unilateral cases, patients with bilateral tinnitus exhibited a higher percentage of abnormal SNRs at most frequencies. Some asymptomatic ears in the patient group had abnormal results.

Conclusion: These findings show that tinnitus in normal-hearing patients is often associated with varying degrees of cochlear dysfunction. The results also suggest that tinnitus may be regarded as an early manifestation of noise-induced hearing loss in patients with a history of exposure to noise.

Key Words: Auditory threshold/physiology; cochlea/physiopathology; evoked potentials, auditory/physiology; hair cells, outer/physiopathology; hearing loss, noise-induced; otoacoustic emissions, spontaneous/physiology; tinnitus/diagnosis/physiopathology.

Amaç: İşitmesi normal olan çınlamalı hastalarda distorsiyon product otoakustik emisyon (DPOAE) testi ile koklear fonksiyon incelendi.

Hastalar ve Yöntemler: Bu prospektif çalışmada işitmesi normal ancak çınlaması olan 20 hasta (13 erkek, 7 kadın; ort. yaş 25; dağılım 17-52) ile herhangi bir şikayeti olmayan 15 gönüllü (kontrol grubu; 10 erkek, 5 kadın; ort. yaş 23; dağılım 18-27) incelendi. Her iki grupta odyometrik ve timpanometrik testler yapıldı. Daha sonra her iki gruba kübik DPOAE testi yapıldı. Testin değerlendirilmesinde kontrol grubunun %10 percentil değerlerinin altında kalan sinyal/gürültü oranı (SNR) değerleri anormal veya DPOAE yokluğu olarak kabul edildi.

Bulgular: Çınlama yedi hastada iki taraflı, 13 hastada tek taraflı idi. Tek kulakta çınlama olan olguların yedisinde, iki kulağında çınlama olan olguların tümünde gürültüye maruz kalma öyküsü saptandı. Ortalama çınlama frekansı solda 6.3 kHz, sağda 6.2 kHz bulundu. Çınlama şiddeti solda ve sağda sırasıyla 8 ve 7 dB SL olarak ölçüldü. Tek taraflı tutulumu olan olgulara kıyasla, iki taraflı çınlama olan olgularda anormal SNR değerlerinin yüzdesi çoğu frekansta daha yüksek idi. Bazı tek taraflı olguların asemptomatik kulaklarında da anormal SNR değerleri elde edildi.

Sonuç: Elde edilen bulgular, işitmesi normal ancak çınlaması olan olgularda belli derecelerde koklear disfonksiyon olduğunu; gürültüye maruz kalma öyküsü saptanan olgularda, çınlamanın gürültüye bağlı işitme kaybının erken habercisi olabileceğini göstermektedir.

Anahtar Sözcükler: İşitme eşiği, fizyoloji; koklea/fizyopatoloji; uyarılmış potansiyeller, işitsel/fizyoloji; saç hücreleri, dış/fizyopatoloji; işitme kaybı, gürültüyle oluşan; otoakustik emisyonlar, spontan/fizyoloji; tinnitus/tanı/fizyopatoloji.

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Distortion product otoacoustic emissions (DPOAE) are widely used to assess cochlear function in distinguishing neural lesions from those of cochlea and also to monitor its function during ototoxic drug therapy in routine clinical audiological setting.^[1-4] The main goal in monitoring cochlear function is to detect cochlear dysfunction as early as possible so that any irreversible change in outer hair cells and other cochlear structures can be prevented.

DPOAE testing has been proven to be effective in the detection of noise-induced damage.^[5,6] As there is no effective treatment available for noise-induced hearing loss, the therapy should aim to protect cochlea from repetitive insults, which is also true for ototoxic drug therapy.

In this study, we investigated cochlear function with the use of DPOAE testing in tinnitus patients with normal hearing acuity.

PATIENTS AND METHODS

The study included 20 normal-hearing patients (13 males, 7 females; mean age 25 years; range 17 to 52 years) who presented to the outpatient clinic with a complaint of tinnitus. Patients who met the inclusion criteria had a normal ear canal, tympanic membrane, middle ear, and hearing levels ≤ 25 dB HL throughout the frequencies of 0.25, 0.5, 1, 2, 4, 6, and 8 kHz. Those who had a chronic disease or pulsatile tinnitus were not included. For comparison, a control group consisting of 15 volunteers (10 males, 5 females; mean age 23 years; range 18 to 27 years) with normal hearing, and no chronic disease, familial hearing loss, or a past history of noise exposure was studied.

Upon completion of neuro-otological examination, all patients and controls gave their informed consent to take part in the study and underwent routine audiological tests including audiometry (AC30 Audiometer, Interacoustics, Denmark) and tympanometry (Amplaid 775, Milano, Italy). In suspected cases, auditory brain stem response testing and imaging studies were performed to rule out a retrocochlear lesion. The study group was administered a questionnaire used in our department for tinnitus patients, followed by psychoacoustical measurements, for which the patients were asked to describe the frequency and loudness

of tinnitus using pitch-matching and loudness-matching techniques at Hz and dB sensation levels (SL), respectively.

Recording of DPOAEs were made in a quiet room designed to measure auditory evoked potentials. Cubic DPOAEs (2f₁-f₂) were obtained with the use of the SmartOAE system (version 3.6, Intelligent Hearing Systems, FL, USA) and a 10 C probe (Etymotic Research, IL, USA) with an adult foam probe tip. The test protocol included the following parameters: start frequency 500 Hz, end frequency 8000 Hz with two frequencies per octave, f₂/f₁ ratio 1.22, L1 65 dB SPL, L2 55 dB SPL, and sweeps 32. Calibration of stimulus intensity was verified by means of a software component of the same system. At the beginning of the recordings, the initial noise level was measured and a low ambient noise was maintained throughout the test. Distortion-product audiograms (DP-grams) were plotted as a function of f₂. The signal-to-noise ratio (SNR) was defined as the difference in dB SPL between the DPOAE amplitude and the noise level at a given f₂. Signal-to-noise ratios that fell below the 10th percentile DPOAE values of the control group were regarded as abnormal or undetectable, respectively.

The patients were classified depending on the laterality of tinnitus. DP-grams of control ears were compared with those obtained from unilaterally and bilateral involved ears by means of Mann-Whitney U-test. DP-grams of patients with unilateral involvement were compared with those obtained from the contralateral ears with the use of Wilcoxon signed-rank test. All *p* values were two-tailed. Statistical analyses were performed using the SPSS program for Windows (Release 10.0.1, 1999; SPSS, Inc., Chicago, USA).

RESULTS

Tinnitus was bilateral in seven patients and unilateral in 13 patients, being in the left ear in nine patients and in the right in four patients. Seven patients with unilateral tinnitus and all patients with bilateral tinnitus had a history of exposure to noise in their professional lives. Characteristic features of tinnitus are presented in Table I.

Of the patient group, DP-grams showed markedly low SNRs at 8837 Hz in all the ears. At middle frequencies, asymptomatic ears of patients with unilat-

TABLE I
CHARACTERISTICS OF TINNITUS IN NORMAL-HEARING PATIENTS

Groups	Mean age (year±SD)	Tinnitus pitch (mean kHz±SD)		Tinnitus loudness (mean SL±SD)		Tinnitus duration (mean month±SD)	
		Right ears	Left ears	Right ears	Left ears	Right ears	Left ears
Control ears (n=15)	22.6±3.6						
Symptomatic ears (unilateral tinnitus, n=13)	24.9±8.1	6.2±3.8	6.3±3.1	8±1.4	7.3±2.5	5±1	13.7±22.4
Asymptomatic ears (unilateral tinnitus, n=13)	24.9±8.1						
Bilateral tinnitus (14 ears)	33.1±12.4	7.4±3.5	5.8±3.8	6.7±1.2	7.2±1.8	9.2±5.7	9±5.6

eral tinnitus tended to exhibit the highest SNRs while patients with bilateral tinnitus had the lowest SNRs (Fig. 1). Comparison of SNRs between the three groups indicated that the lowest and the highest number of frequencies showing abnormal SNRs was observed in patients with asymptomatic ears and in those with bilateral tinnitus, respectively. No significant difference was observed between symptomatic ears and asymptomatic ears ($p>0.05$) (Table II). Distribution of abnormal SNRs by frequency is shown in Table III. No correlation was found between the tinnitus pitch and SNRs (Table IV).

DISCUSSION

Tinnitus remains a dilemma as the most common otologic symptom. Its etiology and pathogenesis are still under investigation. In the presence of sensorineural hearing loss, tinnitus may be perceived as a secondary irritating symptom. It becomes even more irritating especially when it is the only symptom in patients with normal hearing.

The relationship between DPOAEs and tinnitus is well-known when the latter is associated with hearing loss.^[7,8] A significant correlation was demon-

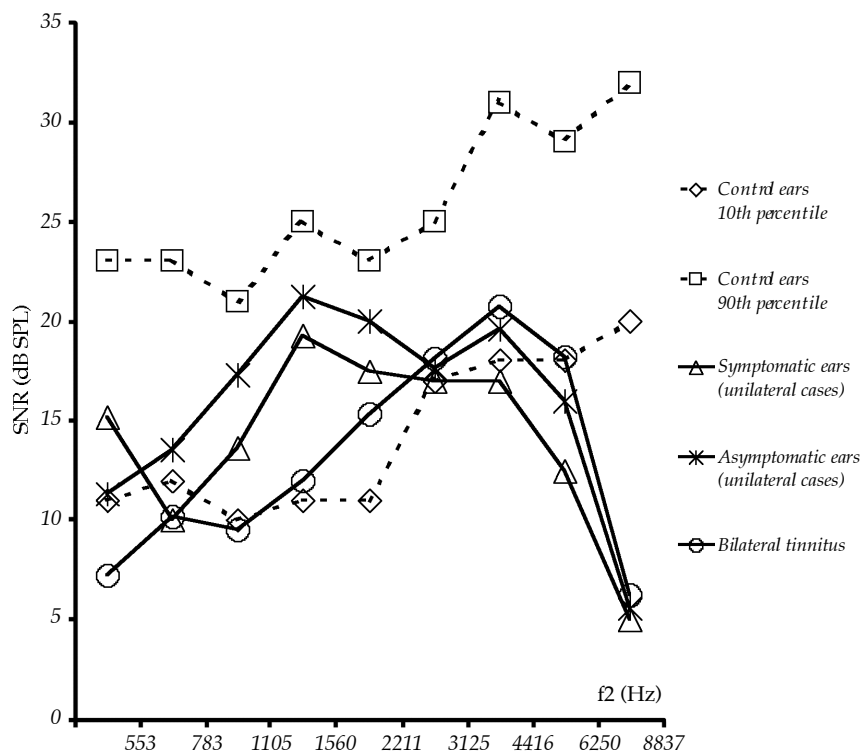


Fig. 1 - Signal-to-noise ratios of tinnitus patients in comparison with the 10th and 90th percentiles of the control group.

TABLE II

COMPARISON WITH CONTROLS AND THE FREQUENCIES AT WHICH SIGNIFICANT DIFFERENCES WERE OBTAINED

	Symptomatic ears (unilateral cases)	Asymptomatic ears (unilateral cases)	Bilateral tinnitus
Comparison with control ears	783 Hz (p=0.15)	553 Hz (p=0.04)	553 Hz (p=0.004)
	4416 Hz (p=0.007)	6250 Hz (p<0.001)	783 Hz (p=0.009)
	6250 Hz (p=0.007)	8837 Hz (p<0.001)	1105 Hz (p=0.004)
	8837 Hz (p<0.001)		1560 Hz (p=0.007)
			8837 Hz (p<0.001)
Comparison with symptomatic ears (unilateral tinnitus)		p>0.05 at all frequencies	553 Hz (p=0.014) 1560 Hz (p=0.007)

strated between DPOAEs and pure-tone audiometry at 1, 2, 4, and 6 kHz.^[9] However, there is little data on individuals suffering from tinnitus in the face of normal hearing acuity. In this study, we focused on DPOAE findings in that patient population, together with an effort to interpret DPOAEs in asymptomatic patients with unilateral tinnitus.

Shiomi et al.^[10] studied tinnitus in 15 ears of nine patients with normal hearing and found abnormally low DPOAE amplitudes in 93%. DP-grams of the normal-hearing tinnitus group were different from those of a control group at 4-7 kHz. Castello^[11] compared DP-grams of 20 normal-hearing tinnitus patients with those of normal-hearing subjects and reported abnormal DPOAEs in 60% of the patient group. He identified three abnormal patterns of DP-grams, being characterized by the absence of distortion products at middle frequencies, at mid-

dle and high frequencies, and at high frequencies, respectively.

In our study, compared to the controls, the mean SNRs were lower at the frequency band of 2 kHz to 8 kHz in symptomatic ears of the unilateral tinnitus cases. Interestingly, asymptomatic ears showed the same trend at frequencies higher than 3 kHz. On the other hand, the mean SNRs were lower throughout the frequencies examined in patients with bilateral tinnitus. Taking into account the 10th and 90th percentiles of the control group, SNRs of all the patients were out of these percentiles at frequencies higher than 6 kHz. The percentage of abnormal SNRs obtained in patients with bilateral tinnitus greatly exceeded those obtained from symptomatic and asymptomatic ears at most frequencies. Asymptomatic ears also showed abnormally low SNRs at low and high frequencies. These findings show that tinnitus in normal-hearing patients is often

TABLE III

DISTRIBUTION OF ABNORMAL SIGNAL-TO-NOISE RATIOS

f2 (Hz)	Symptomatic ears (unilateral cases) (%)	Asymptomatic ears (unilateral cases) (%)	Bilateral tinnitus (%)
553	15.4	46.2	57.1
783	53.8	46.2	64.3
1105	15.4	7.7	35.7
1560	-	-	21.4
2211	23.1	7.7	35.7
3125	61.5	53.8	57.1
4416	46.2	15.4	7.1
6250	38.5	53.8	28.6
8837	76.9	76.9	57.1

TABLE IV
SIGNAL-TO-NOISE RATIOS FOR UNILATERAL AND BILATERAL TINNITUS

Tinnitus pitch (Hz)			Signal-to-noise ratios (dB SPL) at f2 frequencies (Hz)									
			553	783	1105	1560	2211	3125	4416	6250	8837	
Unilateral ears	1	10000	18	16	8	21	17	13	15	23	-10	
	2	1000	14	3	14	17	10	1	6	6	-7	
	3	250	25	23	19	30	18	9	11	6	0	
	4	10000	16	9	13	21	18	27	29	17	1	
	5	10000	17	8	11	21	28	29	33	19	1	
	6	6000	14	5	13	20	24	9	6	4	2	
	7	6000	2	-6	3	6	4	31	11	8	5	
	8	6000	18	22	19	33	42	40	12	11	9	
	9	8000	12	7	10	16	0	16	27	11	9	
	10	6000	21	15	18	13	12	12	18	18	11	
	11	9000	22	14	24	14	14	8	25	25	12	
	12	6000	7	12	14	17	12	7	12	5	13	
	13	4000	12	3	12	23	29	19	17	10	20	
Bilateral ears	1	Right	7000	14	15	14	-1	2	5	9	1	-2
		Left	5000	17	10	9	6	-1	2	6	9	-1
	2	Right	10000	-10	10	14	13	27	29	24	26	39
		Left	10000	-7	31	12	29	26	29	32	25	24
	3	Right	10000	4	-2	-9	10	14	18	25	25	9
		Left	4000	17	10	11	20	27	14	22	22	1
	4	Right	250	11	22	18	12	23	35	35	29	-10
		Left	250	1	6	11	12	23	36	37	31	3
	5	Right	10000	5	5	4	15	6	12	14	16	7
		Left	10000	10	7	10	13	20	14	19	14	-7
	6	Right	9000	5	0	0	7	15	29	6	22	8
		Left	9000	2	0	5	0	4	4	7	1	4
	7	Right	6000	19	13	18	20	22	12	33	24	7
		Left	3000	13	17	17	13	7	15	21	11	5

associated with varying degrees of cochlear dysfunction. As 70% (14/20) of the patient group had a past history of noise exposure, the results also suggest that tinnitus may be regarded as an early manifestation of noise-induced hearing loss. However, no correlation could be found between the tinnitus pitch and the frequency at which lower SNRs were measured. Shiomi et al.^[10] also observed no correlation in almost 70% of patients either with normal-hearing or hearing loss. This may cast considerable doubt on the reliability of the pitch-match test in tinnitus patients.

Based on abnormal DPOAE findings, outer hair cells may be implicated both in cochlear dysfunction

and the etiology of tinnitus, which is supported by the fact that almost 70% of patients with tinnitus had a history of noise exposure. However, in patients with normal DPOAEs, the source of tinnitus is still unknown, for which further follow-up and serial audiograms are required in tinnitus patients with normal hearing.

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