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ORIGINAL ARTICLE

High Frequency Audiometry in Patients Presenting with Tinnitus

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Objectives: In this study, we aimed to assess hearing thresholds of the patients, who have tinnitus and normal hearing thresholds between 250 and 4,000 Hz, via high frequency audiogram and also effects of age, sex and hearing thresholds on tinnitus.

Materials and Methods: A total of 154 patients with tinnitus and 29 healthy volunteers were included. Pure tone thresholds at 250-4,000 Hz were measured. Then, 8,000-20,000 Hz audiograms were performed in the patients with normal hearing. Results were analyzed by general lineer model in order to assess effects of age sex and frequency on tinnitus.

Results: Age range were from 17 to 68. Females consisted of 60.65% and males consisted of 39.35 % of the all patients. Forty patients had right sided, 48 had left sided, and 66 patients had bilateral tinnitus. There were significant hearing loss related to age, sex, and frequency on 8,000-20,000 Hz audiograms of the patients with normal hearing levels on 250-4,000 Hz audiograms. ($p<0.001$). When we looked at sex, female patients had statistically better hearing thresholds than males. ($p<0.001$) Age was detected as an important factor for males. We found that as the age and testing frequency on audiogram increase in males, hearing loss becomes more frequent. $p<0.001$ The frequency was detected as an important factor in tinnitus group. Between 8,000 Hz and 20,000 Hz we detected that as the frequency increases, hearing loss also increases. ($p<0.001$).

Conclusion: We aimed to guide new studies on tinnitus. We propose that high frequency audiogram, especially frequencies above 8,000 Hz, has a value in diagnostic work up of tinnitus. We conclude that frequencies above 8,000 Hz in tinnitus patients should be investigated.

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Introduction

Tinnitus is the perception of sound in the absence of any external stimulus. The prevalence of this condition ranges between 3 and 30% [1]. Tinnitus is a symptom of many diseases and is not an entity onto itself. It is usually seen between the ages 40 and 70 and is very rarely seen in infancy [2]. The severity of tinnitus varies from mild and barely noticeable to severe, in which the individual's life is seriously affected. Tinnitus may be classified as pulsatile and non-pulsatile tinnitus. Non-pulsatile tinnitus is more common in comparison to pulsatile tinnitus. Tinnitus can originate from any part of the auditory system [2]. The reasons of non-pulsatile tinnitus are hardly known; therefore, for many patients with chronic tinnitus, a "cure" is out of question. In many cases, tinnitus is observed in association with or combined with hearing loss, but it can also appear with normal hearing. The most frequently observed condition is when tinnitus occurs with no structural lesion or abnormality and is accompanied by hearing loss. Ultimately, it is not known whether tinnitus arises from the cochlea, the hearing nerve or the central nervous system. Therefore, a detailed patient history and physical examination, followed by further tests, radiological imaging, and pure tone and speech audiometry tests are of utmost importance [1]. The causes of pulsatile tinnitus are variable. The most frequent cause is intracranial hypertension, followed by glomus tympanicum, glomus jugulare, atherosclerosis, persistent stapedial artery, aberrant carotid artery, compression of the cochlear nerve in the internal acoustic canal, and compression of the eighth nerve by the anterior inferior cerebellar artery (AICA) [1]. Anamnesis is of utmost importance in patients with tinnitus [2]. Information about the characteristics of tinnitus is scant and controversial [3]. Studies usually comprise patient populations that are under treatment. Nevertheless, obtaining a generalized notion from these studies regarding prevalence and etiology is quite difficult [4]. Among the most

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commonly known etiologies of tinnitus, hearing loss is the most frequent [5]. In 17% of patients with tinnitus, complaints start after exposure to noise [5]. Symmetric hearing loss is observed in patients with tinnitus due to noise exposure [5]. Tinnitus is also frequently seen in patients with heart failure, anemia, arteriosclerosis, and some metabolic pathologies. Hyperthyroidism can lead to tinnitus by causing tachycardia and increasing cardiac output. Hypothyroidism, on the other hand, can also be a cause of tinnitus. Furthermore, an increase in blood lipids, which causes a narrowing in the diameters of the capillaries, can result in decreased blood flow and tinnitus. In addition, vitamin A and B deficiencies have also been reported to cause tinnitus. Tinnitus is also frequently seen after head trauma and closed fractures of the head. Tinnitus seen after traumas usually begins one week to ten days following the trauma. In addition, severe tinnitus is frequently encountered after meningitis and in multiple sclerosis. Tinnitus may be observed following treatment with certain medications. Temporomandibular joint disorder and developmental craniofacial disorders causing structural tooth malformations can cause tinnitus with a humming characteristic [2]. Every nerve fiber has an electric discharge, even at rest, where this represents the spontaneous activity of the nerve. In patients with tinnitus, there is an increase in this spontaneous activity. According to Tonndorf, there is a chemical imbalance between the cell membrane and the stereocilia. As a result, hyperactive cilia or hyperactive nerve fibers may appear [6]. Eggermont assumes that the cilia is hypersensitive. The reason of the hypersensitivity may be the decreased inhibition exerted by the central pathways of the brain. As a result, the nerve fibers perceive sounds that cannot be heard under normal conditions [7]. With the use of otoacoustic emissions (OAE) in tinnitus patients, the pathological lesions in the cochlea can be localized in some cases. Schreiner et al. and Martin et al. investigated the eighth nerve electrical activity through the round window in cats after causing tinnitus with a salicylate application and detected a peak in the spontaneous electrical activity corresponding to a frequency of 200 Hz [8,9]. Ikner and Hassen investigated patients with hearing loss with or without tinnitus and found that the wave I latency period was substantially prolonged in female patients compared to the male patients with tinnitus [10]. These results contradicted the results of Moller et al., who reported that no significant difference was observed in the auditory brainstem response (ABR) of patients with unbearable tinnitus and normal individuals [11].

We aimed to guide new studies on tinnitus by evaluating high frequency audiograms of patients presenting with tinnitus.

Materials and Methods

This study was performed in 154 tinnitus patients (56 male, 98 female) who were referred to the outpatient clinic and 29 patients (16 male, 13 female) with no complaints. After a full otorhinolaryngologic examination and questioning of the duration of the complaint, the following information was collected: exposure to noise and medication use; a complete blood count; thyroid hormone tests; and serum level measurements of glucose, urea, creatinine, cholesterol, triglyceride, B12, zinc, iron, ferritine, and folic acid. Patients with pathological laboratory results were given the appropriate medical treatment and were not included in the study. Temporal CT scans or MRIs were performed on the patients. The patients were divided into four different age groups (1st group: 17-30 years of age; 2nd group: 31-40 years of age; 3rd group: 41-55 years of age; 4th group: 56-68 years of age). In patients without a structural lesion, pure tone thresholds were determined at 250-4,000 Hz. In patients with normal hearing threshold limits at this frequency range, another test within the frequency range of 8,000-20,000 Hz was performed. In order to investigate effect of gender, age group and hearing loss on tinnitus, the general linear model procedure was utilized using the SPSS 13.OV software. In the statistical model, gender (male/female), age group, tinnitus state, and frequency (250, 500, 1,000, 2,000, 4,000, 8,000, 9,000, 10,000, 11,200, 12,500, 14,000, 16,000, 18,000, 20,000 Hz) were evaluated as the main factors. In addition, a preliminary analysis was performed to evaluate the effect of all interactions among all of the main variables upon the tinnitus results (normal vs. with tinnitus), and interactions that were significant, such as Gender x Age; Gender x Frequency; Frequency x Age group and Frequency x Tinnitus, were included in the statistical model.

Results

Among the patients included in the study, 60.65% were females, and 39.35% were males. Patient ages ranged from between 17 and 68 years with a mean age of 40.5 (±10.790). The duration of the tinnitus complaint ranged between 2 months and 10 years.

Patients with normal hearing thresholds in audiometric tests at the octave frequencies of 250-4,000 Hz were included in the study. Tinnitus complaints were sensed in the left ear in 40 patients, in the right ear in 48 patients, and bilaterally in 66 patients. In the test performed at the frequency interval of 8,000-20,000 Hz the least square means (LSM) values at 8,000-20,000 Hz were as follows: 30.634 dB loss at 8,000 Hz; 33.069 dB at 9,000 Hz; 47.166 dB at 10,000 Hz; 47.783 dB at 11,200 Hz; 57.043 dB at 12,500 Hz; 68.878 dB at 14,000 Hz; 89.051 dB at 16,000 Hz; 94.113 dB at 18,000 Hz; and 95.391 dB at 20,000 Hz (Table 1).

Table 1. The least square means according to tinnitus results in gender, age, tinnitus state, and frequency and significance level.

Factor		LSM	SE
Gender	***		
	Male	48.872	0.303
	Female	45.387	0.289
Age Group		***	
	1	37.505[d]	0.437
	2	46.368[c]	0.360
	3	47.801[b]	0.320
	4	56.844[a]	0.540
Tinnitus State		***	
	Normal	43.637	0.305
	Tinnitus	50.622	0.273
Frequency (Hz)		***	
	250	24.316[h]	0.772
	500	18.499[j]	0.772
	1,000	15.243[k]	0.772
	2,000	16.042[k]	0.772
	4,000	22.586[h]	0.772
	8,000	30.634[g]	0.772
	9,000	33.069[f]	0.772
	10,000	47.166[e]	0.772
	11,200	47.783[e]	0.772
	12,500	57.043[d]	0.772
	14,000	68.878[c]	0.772
	16,000	89.051[b]	0.772
	18,000	94.113[a]	0.772
	20,000	95.391[a]	0.772
Expected mean		47.130	0.210
Gender x Age		***	
Gender x Frequency		***	
Frequency x Age		***	
Frequency x Tinnitus		***	

*LSM: least squares means; SE: standard error; a, b, c, d, e, f, g, h, j, k: The difference between the LSM expressed by different letters for same factor is significant (***: p < 0.001).*

Significant differences were observed in the hearing loss values with regard to gender, age group, tinnitus state and frequencies ($p < 0.001$). The hearing values in male individuals were higher than in female individuals. These differences were statistically significant ($p < 0.001$). The hearing loss values in ears with tinnitus and without tinnitus were also significantly different ($p < 0.001$). When the difference in hearing thresholds at different frequencies was analyzed, an increase in hearing loss values was observed at the frequencies higher than 8,000 Hz ($p<0.05$). This increase was observed up to 20,000 Hz.

Regarding the effect of age groups upon the measurements, there were significant differences in the hearing loss values between males and females ($p < 0.001$). Mean hearing loss in the male age groups increased with age, while the women's hearing loss values remained constant in the second and third age groups until they increased in the fourth age group (Table 2). There were significant differences between the effect of age and frequencies ($p < 0.001$) (Table 3).

In ears with tinnitus, a greater interaction (frequency-tinnitus) was observed at the frequencies above 8,000 Hz. When the effect of frequency in ears with tinnitus was evaluated, the effect was stronger, compared to patients without tinnitus, as frequency increased (Table 4).

Discussion

Tinnitus is most frequently seen between the ages of 40-50 [3]. There is no difference between males and females [3]. The patients in our study were between 17-68 years of age, and the female/male ratio was 111/72. While a statistically significant difference was observed between the results of males in the second (31-40 years) and third age groups (41-55 years) in our study, the difference was not that marked among females in the same age groups. This difference was important in showing the effect of gender upon age groups. Both the tone and the severity of tinnitus can fluctuate throughout the day. In a study performed in 1990, patients reported bilateral tinnitus at a rate of 52% and unilateral tinnitus 37%. Ten percent of patients localized their tinnitus in their head instead of the ears; only 1% of patients have stated that it came from outside their heads [12]. In our study, tinnitus was found on the right side in 48 (31%) patients, on the left in 40 (26%), and in both sides in 66 (43%). In most cases, tinnitus is accompanied by hearing loss, but it

Table 2. Mean hearing loss in gender-age group and the gender-frequency group.

Factor	Mean	SE
Gender x Age group	***	
Male x		
1 (17-30)	36.490	0.660
2 (31-40)	46.890	0.594
3 (41-55)	50.147	0.491
4 (56-68)	61.963	0.692
Female x		
1 (17-30)	38.520	0.572
2 (31-40)	45.845	0.388
3 (41-55)	45.556	0.401
4 (56-68)	51.726	0.830
Gender x Frequency (Hz)	***	
Male x		
250	23.812	1.117
500	17.427	1.117
1,000	13.946	1.117
2,000	15.217	1.117
4,000	24.826	1.117
8,000	35.088	1.117
9,000	35.660	1.117
10,000	52.621	1.117
11,200	52.038	1.117
12,500	61.319	1.117
14,000	71.521	1.117
16,000	89.054	1.117
18,000	93.273	1.117
20,000	95.411	1.117
Female x		
250	24.820	0.993
500	19.571	0.993
1,000	16.540	0.993
2,000	16.866	0.993
4,000	20.345	0.993
8,000	26.181	0.993
9,000	27.478	0.993
10,000	41.711	0.993
11,200	43.528	0.993
12,500	52.768	0.993
14,000	66.235	0.993
16,000	89.048	0.993
18,000	94.952	0.993
20,000	95.371	0.993

*SE: standard error; ***: p < 0.001.*

can also present with normal hearing. There may be an underlying acoustic neuroma or Meniere's disease. Therefore, a CT or MRI was performed in all patients. Only patients who did not exhibit any pathology in the tests were included in the study. The condition most frequently encountered was tinnitus with hearing loss without any structural lesions [1]. In 17% of the

Table 3. Arithmetic mean of the hearing loss in frequency-age group.

Frequency (Hz)	Age Group	Mean***	SE
250	1	22.472	1.623
	2	24.184	1.272
	3	25.900	1.182
	4	24.708	1.995
500	1	18.937	1.623
	2	18.590	1.272
	3	18.511	1.182
	4	17.959	1.995
1,000	1	15.648	1.623
	2	14.390	1.272
	3	15.428	1.182
	4	15.507	1.995
2,000	1	14.978	1.623
	2	16.536	1.272
	3	17.139	1.182
	4	15.513	1.995
4,000	1	18.564	1.623
	2	23.445	1.272
	3	24.019	1.182
	4	24.314	1.995
8,000	1	21.615	1.623
	2	28.835	1.272
	3	30.277	1.182
	4	41.810	1.995
9,000	1	21.643	1.623
	2	31.927	1.272
	3	30.918	1.182
	4	47.786	1.995
10,000	1	31.729	1.623
	2	43.883	1.272
	3	45.607	1.182
	4	67.444	1.995
11,200	1	31.254	1.623
	2	43.472	1.272
	3	44.682	1.182
	4	71.725	1.995
12,500	1	36.562	1.623
	2	82.187	1.272
	3	56.058	1.182
	4	83.366	1.995
14,000	1	47.912	1.623
	2	65.397	1.272
	3	71.704	1.182
	4	90.501	1.995
16,000	1	68.718	1.623
	2	92.003	1.272
	3	95.528	1.182
	4	99.954	1.995
18,000	1	82.905	1.623
	2	97.217	1.272
	3	97.760	1.182
	4	98.568	1.995
20,000	1	92.135	1.623
	2	97.078	1.272
	3	95.684	1.182
	4	96.666	1.995

*SE: standard error; ***: p < 0.001.*

Table 4. Mean hearing loss in the frequency-tinnitus group.

Frequency (Hz)	Tinnitus state	Mean***	SE
250	Normal	24.350	1.126
	Tinnitus	24.283	1.003
500	Normal	18.152	1.126
	Tinnitus	18.847	1.003
1,000	Normal	14.973	1.126
	Tinnitus	15.513	1.003
2,000	Normal	15.535	1.126
	Tinnitus	16.548	1.003
4,000	Normal	21.272	1.126
	Tinnitus	23.899	1.003
8,000	Normal	27.457	1.126
	Tinnitus	33.811	1.003
9,000	Normal	27.900	1.126
	Tinnitus	38.237	1.003
10,000	Normal	41.707	1.126
	Tinnitus	52.625	1.003
11,200	Normal	42.020	1.126
	Tinnitus	53.547	1.003
12,500	Normal	50.624	1.126
	Tinnitus	63.462	1.003
14,000	Normal	61.424	1.126
	Tinnitus	76.333	1.003
16,000	Normal	84.056	1.126
	Tinnitus	94.046	1.003
18,000	Normal	89.681	1.126
	Tinnitus	98.544	1.003
20,000	Normal	91.762	1.126
	Tinnitus	99.020	1.003

*SE: standard error; ***: $p < 0.001$*

patients, tinnitus started after exposure to loud noise [5]. There was symmetrical hearing loss in patients with tinnitus due to noise [5]. For this reason, the occupation information and noise exposure were obtained from all of the patients. Patients who had been exposed to noise were excluded from the study.

Hyperthyroidism, hypothyroidism, high serum levels of blood lipids, and vitamines A and B deficiencies can cause tinnitus. Tinnitus can also appear following the use of some medications [2]. Therefore, full biochemical analysis was performed in all of our patients, and patients with pathology were offered medical treatment and were excluded from the study.

In this study, audiometry was performed at the octave frequencies of 250 and 20,000 Hz in patients with tinnitus. As a result, proportional change in hearing according to frequency was assessed.

In patients with tinnitus, an audiometric evaluation is usually done at 250-6,000 Hz. 8,000 Hz frequency was tested as a high frequency audiometry [3]. In our study, measurements were done at 250 and 20,000 Hz frequencies. Therefore, we could evaluate differences in the results that paralleled the increase in frequency.

High frequency audiometry has been used for different purposes in the recent years, and it has been successful especially in the diagnosis and follow-up of ototoxicity (effect of noise and presbyacusis) [13,14]. The ciliary cells that are sensitive to high frequencies are situated in the basal part of the basilar membrane. In postmortem microdissection studies, age-related cochlear degeneration started in this region [15]. High frequency audiometry can diagnose cochlear damage in the early stages and can be used in the routine audiometric evaluation of individuals with a risk of hearing loss [16].

Until today, pure tone audiometry tests were performed at the frequencies of 250-8,000 Hz, and normal results were considered to suggest that patient complaints did not originate from hearing problems [1,3,17]. However, the characteristics of the changes in the measurements of pure tone audiometric tests above 8,000 Hz were not known until recently. Shim compared 18 tinnitus patients who had normal hearing at 250 Hz and 8 kHz with normal controls with regard to the ability of each group to hear extended high-frequency pure tone thresholds. Only some patients with tinnitus who had normal hearing below 8 kHz have decreased hearing ability at extended high-frequencies [18]. Sakata tested 5 patients suffering acute tinnitus without hearing loss and recognized acute idiopathic sensorineural hearing impairment at a frequency exceeding 8 kHz (high-frequency range) in this patients. All patients showed abnormalities in the threshold in the high-frequency range on the affected side [19].

In our study, a marked increase in hearing loss was observed above 8,000 Hz frequency in both men and women. Hearing thresholds decreased as the frequency increased. In other word, hearing threshold was inversely proportional to frequency. It was more significant at frequencies higher than 8,000 Hz. The increase was limited until 8,000 Hz; the results were markedly increased above this frequency and paralleled the increase in age and frequency. This increase was also significantly different between the age groups. Thus, the data obtained allowed us to compare the results of high frequency audiometric tests performed at 8,000-20,000 Hz with those of 250-4,000 Hz. Audiometric studies proved that hearing loss

of ears (measured as decibel) with tinnitus was much more prominent at frequencies higher than 8,000 Hz compared to normal ears.

In our opinion, even if the pure tone audiometric tests were performed below 8,000 Hz frequency [3] are normal, patients should be evaluated for higher frequencies, and whether the complaints are originating from the ears [1,17] can best be decided by evaluating the changes seen above 8,000 Hz. We think that the evaluations based on lower frequencies are of limited value. Even when evaluated together with gender and the increase in age, the increase in hearing thresholds is remarkably higher above 8,000 Hz.

When we evaluated the effect of frequency upon tinnitus-positive ears, the hearing loss values increased as frequency increased (Table 4). But, we have to emphasize that hearing thresholds followed relatively flat audiogram line at 250-4,000 Hz, whereas a marked increase in hearing loss was observed above 8,000 Hz. Although an increase in hearing loss was also observed in normal ears above 8,000 Hz, the increase in tinnitus-positive ears was statistically significant. As a result, we propose that high frequency audiometry should be performed in every patient with tinnitus. Otherwise, as a result of normal hearing threshold obtained at 250 and 4,000 Hz may mislead to unnecessary diagnostic work up and misdiagnose.

In conclusion, tinnitus is an annoying and real symptom that affects a patient's quality of life. It is a symptom for a variety of diseases and is not a disease in itself. It can be well tolerated by some patients but can be devastating for others. Though there are many studies investigating treatment options, an effective treatment has not been found yet. However, before treatment is considered, a thorough investigation for diagnosis and etiology should be performed. In this study, we evaluated data that can be of help in future studies.on tinnitus. Keeping the frequency range above 8,000 Hz in both men and women can be of the uttermost importance in evaluating tinnitus. We think that only the marked changes above this frequency level can evaluate hearing loss.

References

1. Jastreboff PJ, Gray WC, Mattox DE. Tinnitus and hyperacusis. In: Cummings CW, Fredrickson JM, Harker LA, Krause CJ, Richardson MA, Schuller DE editors. Otolaryngology- Head&Neck Surgery. 3 rd ed. St.Louis: Mosby-Year Book; 1998. p. 3198-3222.

2. Akyıldız N.Tinnitus Diseases and microsurgery of the ear. Ankara: Bilimsel Tıp Yayınevi; 2002.

3. Savastano M Characteristics of tinnitus: investigation of over 1400 patients. J Otolaryngol. 2004 Aug; 33(4):248-53.

4. Demeester K, van Wieringen A, Hendrickx JJ, Topsakal V, Fransen E, Van Laer L, De Ridder D, Van Camp G, Van de Heyning P. Prevalence of tinnitus and audiometric shape. B-ENT. 2007; 3 Suppl 7:37-49.

5. Nicolas-Puel C, Akbaraly T, Lloyd R, Berr C, Uziel A, Rebillard G, Puel JL Characteristics of tinnitus in a population of 555 patients: specificities of tinnitus induced by noise trauma. Int Tinnitus J. 2006; 12(1): 64-70.

6. Tonndorf J. Stereociliary dysfunction, a case of sensory hearing loss, recruitment, poor speech discrimination and tinnitus. Acta Otolaryngol. 1981 May-Jun; 91(5-6):469-79.

7. Eggermont JJ. On the pathophysiology of tinnitus; a review and a peripheral model. Hear Res. 1990 Sep; 48(1-2):111-23.

8. Schreiner CE, Snyder RL, Johnstone BM. Effects of extracochlear direct current stimulation on the ensemble auditory nerve activity of cats. Hear Res. 1986; 21(3):213-26.

9. Martin WH, Schwegler JW, Scheibelhoffer J, Ronis ML. Salicylate-induced changes in cat auditory nerve activity. Laryngoscope. 1993 Jun; 103(6):600-4.

10. Ikner CL, Hassen AH. The effect of tinnitus on ABR latencies. Ear Hear. 1990 Feb; 11(1):16-20.

11. Møller AR, Møller MB, Jannetta PJ, Jho HD. Compound action potentials recorded from the exposed eighth nerve in patients with intractable tinnitus. Laryngoscope. 1992 Feb; 102(2):187-97.

12. Stouffer JL, Tyler RS. Characterization of tinnitus by tinnitus patients. J Speech Hear Disord. 1990 Aug;55(3):439-53.

13. Stuchly MA. Biomedical concerns in wireless communications. Crit Rev Biomed Eng.1998; 26(1-2):117-51.

14. Göçer C, İriz A, Dağlı M, Taştan E, Boynueğri S, Uzun A, Eryılmaz A. The Investigation of the effects of Mobile Phone Usage on Hearing with High Frequency Audiometry KBB ve BBC Dergisi, 2003; 11(3): 115–120.

15. Löppönen H, Sorri M, Bloigu R. High-frequency air-conduction and electric bone-conduction audiometry. Age and sex variations. Scand Audiol. 1991; 20(3):181-9.

16. Güngör N, Böke B, Belgin E, Tunçbilek E. High-frequency hearing loss in Ullrich-Turner syndrome Eur J Pediatr. 2000 Oct; 159(10):740-4.

17. Mattox, Douglas E. Assessment and management of tinnitus and hearing loss. Continuum: Lifelong Learning In Neurology August 2006; Volume 12(4); 135-150.

18. Shim HJ, Kim SK, Park CH, Lee SH, Yoon SW, Ki AR, Chung DH, Yeo SG. Hearing abilities at ultra-high frequency in patients with tinnitus. Clin Exp Otorhinolaryngol. 2009 Dec; 2(4):169-74. Epub 2009 Dec 31.

19. Sakata T, Ueno T, Takase H, Shiraishi K, Nakagawa T. Acute idiopathic sensorineural hearing impairment at frequency exceeding 8 kHz. Acta Otolaryngol. 2010 Mar 18. [Epub ahead of print]