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Original Article

Audiologic Characteristics of Hearing and Tinnitus in Occupational Noise-Induced Hearing Loss

Hee Jin Kang[1], Zhe Jin[2], Tong In Oh[3], Sung Soo Kim[4], Do Yeon Park[5], Sang Hoon Kim[1], Seung Geun Yeo[1]

[1]Department of Otolaryngology-Head and Neck Surgery, School of Medicine, Kyung Hee University, Seoul, Republic of Korea
[2]Department of Otolaryngology-Head and Neck Surgery, First People's Hospital of Wenling, Wenzhou Medical University, Zhejiang, China
[3]Medical Research Center for Bioreaction to Reactive Oxygen Species and Biomedical Science Institute, School of Medicine, Graduate School, Kyung Hee University, Seoul, Republic of Korea
[4]Department of Biomedical Engineering, College of Medicine, Kyung Hee University, Seoul, Republic of Korea
[5]School of Medicine, Kyung Hee University, Seoul, Republic of Korea

ORCID IDs of the authors: H.J.K. 0000-0003-3712-6697; Z.J. 0000-0003-0386-3015; T.I.O. 0000-0003-3820-0107; S.S.K 0000-0002-4195-0980; D.Y.P. 0000-0003-3347-5320; S.H.K. 0000-0001-5045-5060; S.G.Y. 0000-0001-801-1024

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BACKGROUND: To analyze the characteristics of patients with noise-induced hearing loss (NIHL) by comparing audiologic test findings between groups with and without tinnitus.

METHODS: This study involved patients with noise-induced hearing loss (NIHL) who presented to the otolaryngology clinic between January 2016 and April 2019. Tests including 3 pure-tone audiometry (PTA) tests at intervals greater than 1 week, and auditory brainstem response (ABR) were evaluated and patients were screened for tinnitus. The tinnitus patients had otoacoustic emission. Comparison was done between the tinnitus group and the group without tinnitus.

RESULTS: Of the 730 subjects with NIHL, 389 had tinnitus. PTA showed significantly higher thresholds at 2 kHz to 8 kHz in the tinnitus group. Although ABR tests tended to show more prolonged I, III, and V latency in the tinnitus group, the differences were not statistically significant. Distortion product otoacoustic emissions (DPOAE) showed more abnormalities at 3 kHz, and 4 kHz than at 1 kHz and 2 kHz. Transient otoacoustic emission (TEOAE) showed abnormal findings in both ears.

CONCLUSION: In NIHL, hearing loss was more severe in patients with, than without tinnitus. DPOAE showed more abnormalities at 3 kHz, 4 kHz, and 6 kHz than at 1 kHz and 2 kHz, and TEOAE was abnormal at all frequencies.

KEYWORDS: Noise-induced, hearing loss, tinnitus, audiology

INTRODUCTION

Noise-induced hearing loss (NIHL) is generally defined as hearing loss caused by slow, continuous exposure to noise over many years. NIHL can be further classified as acoustic trauma, terminal threshold shift (TTS), or permanent threshold shift. NIHL can be regarded as non-occupational hearing loss, caused by exposure to noise during leisure activities, and occupational hearing loss caused by exposure to noise in work situations, including mining and construction.[1] The World Health Organization has classified a third of the individuals with hearing loss as having NIHL. The prevalence of NIHL is highest among workers in hazardous environments.[1] NIHL can lead to isolation from other people and impair communication, resulting in a lower quality of life.

Tinnitus is frequently associated with NIHL and has a significant impact on quality of life. Moreover, the tinnitus is more directly responsible for mental stress than the hearing loss itself.[2,3] Despite studies assessing the effects of exposure to noise, few studies have evaluated the relationship between noise exposure and NIHL or the effects of tinnitus on auditory measurements in patients with NIHL. The present study therefore evaluated auditory characteristics in a large group of patients with occupational NIHL, and compared these characteristics in NIHL patients with and without tinnitus.

Corresponding author: Seung Geun Yeo, e-mail: yeo2park@gmail.com
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MATERIALS AND METHODS

Study Design

This study included patients exposed to workplace noise of over 85 decibels for more than 3 years, as defined by the Industrial Accident Compensation Protection Law, and who visited the ear, nose and throat (ENT) clinic. The study protocol was approved by the Institutional Review Board of Kyung Hee University Medical Center (KMC 2019-07-065).

Patients were excluded if they had noise-dependent auditory TTS, acoustic trauma, chronic otitis media (COM), normal hearing loss, or unilateral hearing loss, as were patients who underwent insufficient testing. In addition, to exclude the possibility of presbycusis, patients aged >65 years were estimated to have 1 dB reductions on pure-tone audiometry (PTA) for each 1-year increase in age.[4]

The medical records of patients were reviewed at the ENT clinic. All patients underwent 3 PTA tests at intervals greater than 1 week, and impedance audiometry and auditory brainstem response (ABR) evaluations. We obtained the waveform of ABR by decreasing the stimulus from the threshold 90 dB nHL to 10 dB nHL in steps of 10 dB nHL. Hearing thresholds on PTA tests were calculated using the 6-division method {500 Hz + (1000 Hz × 2) + (2000 Hz × 2) + 4000 Hz/6}, with the best hearing threshold among the 3 PTA results selected.[5-8]. Patients with tinnitus were also evaluated by ABR, transient otoacoustic emission (TEOAE) tests, distortion product otoacoustic emissions (DPOAE), and tinnitogram, performed simultaneously. Response and nonresponse on DPOAE tests were analyzed at each frequency. Signal-to-noise ratios (SNRs) on TEOAE were determined for each frequency, with SNRs >3 dB considered abnormal.

Statistical Analysis

The differences between patients with and without tinnitus were analyzed by independent *t*-tests and Mann–Whitney *U*-tests. All statistical analyses were performed using SPSS 20.0, with $P < .05$ considered statistically significant.

RESULTS

Of the 910 patients who were reviewed, 180 were excluded (Figure 1). Thus, this study included 730 patients with occupational NIHL, including 389 (53.3%) with and 341 (46.7%) without tinnitus.

Demographically, diabetes mellitus and hypertension were the most prevalent comorbidities, with both being significantly more frequent in patients with tinnitus than in those without tinnitus ($P < .01$). Evaluation of the symptoms of NIHL showed that rates of ear fullness and vertigo were significantly higher in the tinnitus group than in the non-tinnitus group ($P < .01$; Table 1).

The 6-division method showed that PTA tended to decrease in both the tinnitus and non-tinnitus groups from low to high frequencies, resulting in moderate hearing loss. However, hearing ability was significantly lower in the group with tinnitus, than without tinnitus ($P < .05$) (Table 2). In the tinnitogram, most subjects heard sound in the middle and high frequency ranges, with no differences between right and left ears ($P > .05$; Tables 3and 4).

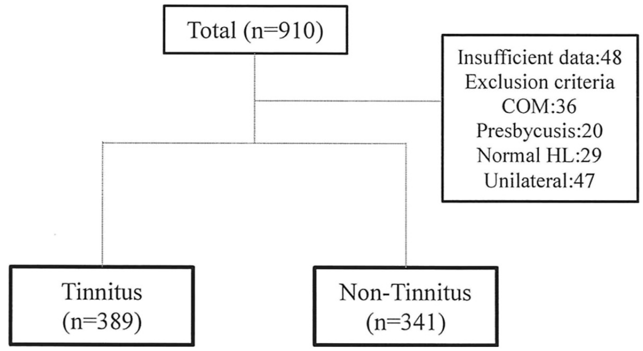

Figure 1. Flow chart of the study. Patients with insufficient data, chronic otitis media (COM), presbycusis, normal hearing loss, and unilateral hearing loss were excluded. The 730 patients evaluated included 389 with tinnitus and 341 without tinnitus.

In the ABR test, I, III, and V latencies tended to be longer in subjects of the tinnitus group, but the differences between the 2 groups were not statistically significant ($P > .05$). Interpeak latency (IPL) I-III was significantly more prolonged ($P < .01$), and IPL III-V tended to be more prolonged ($P = .055$) in the left ears of patients with tinnitus than in those without (Table 5). In addition, 108 (14.8%) patients showed wave I loss on ABR tests, whereas 69 (9.5%) showed wave III loss and 7 (1.0%) showed wave V loss.

Assessment of responses to DPOAE tests in patients with tinnitus showed that response rates were higher at 1 and 2 Hz than at 3, 4, and 6 Hz. TEOAE tests showed SNR <3 dB in both ears, which was regarded as abnormal (Table 6).

DISCUSSION

Studies of the mechanisms and clinical manifestations of NIHL have shown that during its early stages, hearing loss occurs mainly in the 4–6 kHz region. Hearing loss at these frequencies is likely related to the resonance characteristics of the outer ear and middle ear, the protection function at 2 kHz or the stapedius reflex, and the characteristics of propagating waves starting in the 4 kHz region. Most previous studies of occupational NIHL included relatively few patients. Although the hearing threshold notch is formed at 4 kHz in early-stage patients, gradually affecting the 3-6 kHz range,[9] presbycusis in elderly patients results in severe hearing loss at high frequency and

Table 1. Demographic and Clinical Characteristics of Patients with NIHL, Including Those With and Without Tinnitus

	Total	With Tinnitus ($n = 389$)	Without Tinnitus ($n = 341$)	P[a]
Age, years; mean ± SD	68.6 ± 7.92	69.1	68.65	0.414
Gender	704:26	M : F = 377 : 12	M : F = 327 : 14	0.458
Diabetes mellitus	111	19.8% (77/389)	10% (34/341)	**<0.01**
Hypertension	183	29.8% (116/389)	19.6% (67/341)	**<0.01**
Vertigo	85	14.7% (57/389)	8.2% (28/341)	**<0.01**
Autophonia	89	14.4% (56/389)	9.7% (33/341)	0.052
Ear fullness	248	45% (175/389)	21.4% (73/341)	**<0.01**

[a]Mann–Whitney *U*-test.
Significant associations are highlighted in bold ($P < .05$).

Table 2 . Pure-Tone Audiometry Analysis of Patients with NIHL, Including Those With and Without Tinnitus

	Total (*n* = 730)		With tinnitus (*n* = 389)		Without tinnitus (*n* = 341)		*P*[a]	
	Rt	Lt	Rt	Lt	Rt	Lt	Rt	Lt
125 Hz	44.94 ± 14.60	47.45 ± 16.18	44.97 ± 14.78	48.25 ± 16.25	44.04 ± 12.92	46.55 ± 16.09	.06	.158
250 Hz	47.04 ± 16.57	48 ± 17.71	48.03 ± 17.54	49.6 ± 18.31	45.92 ± 15.36	47.48 ± 16.98	.084	.106
500 Hz	47.31 ± 16.90	50.28 ± 18.01	48.43 ± 17.9	51.12 ± 18.35	46.04 ± 15.63	49.34 ± 17.61	.054	.182
1000 Hz	54.08 ± 15.94	56.13 ± 16.95	55.32 ± 16.7	57.03 ± 17.27	52.67 ± 14.94	55.10 ± 16.55	.024	.125
2000 Hz	63.29 ± 15.34	65.82 ± 15.93	65.10 ± 15.25	67.40 ± 15.51	61.24 ± 15.22	64.02 ± 16.23	<.01	<.01
3000 Hz	71.34 ± 15.13	73.43 ± 15.18	73.65 ± 14.12	75.58 ± 14.32	68.71 ± 15.82	70.98 ± 15.78	<.01	<.01
4000 Hz	77.45 ± 14.28	78.72 ± 14.25	79.43 ± 13.53	80.85 ± 13.33	75.21 ± 14.80	76.30 ± 14.89	<.01	<.01
8000 Hz	82.77 ± 10.58	83.10 ± 10.86	84.28 ± 9.53	82.20 ± 15.30	81.06 ± 11.44	79.63 ± 15.05	<.01	.023
Total	59.92 ± 13.93	62.15 ± 14.78	61.44 ± 14.34	63.50 ± 14.79	58.19 ± 13.23	60.62 ± 14.66	<.01	<.01

Mann–Whitney *U*-test. Results are reported as mean ± SD.
Significant associations are highlighted in bold ($P < .05$).

Table 3. Distribution of Tinnitus Pitch Among Patients with NIHL and Tinnitus

Tinnitus Pitch	Patients (*n*, %)
"Woong" (low frequency)	80, 20.6
"Schae" (middle and high freq.)	67, 17.3
"Weeing" (full frequency)	37, 9.5
"Phee" (high frequency)	34, 8.7
Unclassified	37, 9.5

Table 4. Mean Frequency and Loudness of Tinnitus in the Left and Right Ears of Patients with NIHL and Tinnitus

	Right ear	Left ear	*P*[a]
Frequency	4828.93 ± 3021.77	4757.81 ± 3085.79	.77
Loudness (dB)	74.41 ± 19.72	74.06 ± 20.51	.83

[a]Mann–Whitney *U*-test.
Results are reported as mean ± SD.

slower notch formation.[10] As NIHL progresses, hearing is also lost at low frequencies. Both aging and noise contribute to hearing loss, and therefore, it is unclear whether high frequency hearing loss should be regarded as a result of noise.[9-11] In our study, the hearing threshold tended to decrease from low to high frequencies in patients with and without tinnitus.

The average age of our study patients was over 65 years, and they had been exposed to noise for several years. Therefore, we attempted to correct for presbycusis reducing the hearing threshold by 1 dB for every year over age 65 years and including only those patients with a hearing threshold over 25 dB.[11] However, despite these efforts, the effect of presbycusis could not be completely ruled out. In future studies, hearing threshold should be analyzed in younger patients or in longitudinal studies of NIHL.

Table 6. TEOAE and DPOAE Results Showing SNR Response Rate in Each Ear of Patients with NIHL and Tinnitus

SNR			Response rate[a]		
kHz	Right	Left	kHz	Right	Left
1	−3.27	−2.64	1	32.9	35.2
1.5	0.51	0.70	2	32.1	27.8
2	−1.19	−0.83	3	8.9	10
3	−4.06	−4.16	4	6.2	5.7
4	−5.14	−5.47	6	4.6	4.9

[a]Response rates were calculated by dividing the number of patients with normal responses by the total number of patients with tinnitus ($n = 389$).
SNR, signal-to-noise ratio.

NIHL is one of the 2 most common causes of subjective tinnitus, along with presbycusis. In this study, 53.3% of the patients had tinnitus, with a higher prevalence of tinnitus symptoms than previously reported. The degree of hearing loss was shown to be associated with louder tinnitus noises, but there was no association between

Table 5. ABR Results of Left and Right Ears Patients with NIHL, With and Without Tinnitus

	Total (*n*=730)		With tinnitus (*n* = 389)		Without tinnitus (*n* = 341)		*P*[a]	
	Right	Left	Right	Left	Right	Left	Right	Left
I latency	1.54	1.87	1.55 ± 0.2	1.56 ± 0.21	1.53 ± 0.2	1.55 ± 0.18	.23	.41
III latency	3.83	3.86	3.85 ± 0.27	3.87 ± 0.36	3.81 ± 0.33	3.84 ± 0.22	.15	.23
V latency	5.85	5.89	5.86 ± 0.38	5.89 ± 0.41	5.83 ± 0.39	5.88 ± 0.41	.23	.61
I-III IPL	2.30	2.32	2.27 ± 0.18	2.29 ± 0.17	2.29 ± 0.17	2.36 ± 0.45	.15	.013
III-V IPL	1.97	1.96	1.97 ± 0.16	1.96 ± 0.17	1.97 ± 0.18	1.94 ± 0.18	.97	.055
I-V IPL	4.24	4.24	4.24 ± 0.25	4.25 ± 0.25	4.23 ± 0.36	4.22 ± 0.33	.49	.18

[a]Mann–Whitney *U*-test. Results are reported as mean ± SD.
Significant associations are highlighted in bold ($P < .05$).
IPL, interpeak latency.

the frequency of hearing loss and the pitch of tinnitus noises.[12] In contrast, another study found that tinnitus pitch tended to occur at the same frequency where hearing loss was most severe,[13] making the relationship between frequency of hearing loss and tinnitus pitch unclear. The present study found that hearing loss was most severe at middle and high frequencies, with tinnitus pitch at low frequency being common. It was difficult to determine from these results whether the properties of tinnitus differ between patients with, and without NIHL.[2, 12-14]

This study used the pitch-match method, which can objectively assess the frequency and loudness of tinnitus. The average frequencies in the right and left ears were 4828.93 Hz and 4757.81 Hz, respectively, and the average loudness was 74 dB, with no significant differences between right and left ears. Noise was similar, with both ears in patients with tinnitus having hearing thresholds of about 4,000 Hz. Tinnitus in patients with acoustic trauma appears in the transition region between the damaged and intact parts of the organ of Corti.[9] Pathologically, these findings are related to changes in the outer hair cells at the site of injury in patients with occupational noise exposure who may repeatedly experience acoustic trauma. Thus, tinnitus of about 4 kHz may be a result of the most serious type of damage to the inner ear.

The ABR test is an electrophysiologic measurement that has been shown useful in detecting noise-induced synaptopathy.[1,9,15,16]. In the present study, the I, III, and V waves tended to be more prolonged, and the IPL I-III in the left ear shorter in the tinnitus group, which may reflect the effects of wave I prolongation in patients with tinnitus. In particular, wave I was relatively less extended than the other waves, which may have been due to the exclusion of a large number of patients with wave I loss. Latency was extended in all waves of ABR.[16,17] Although several studies have utilized ABR to test patients with NIHL, to our knowledge, this study was the first to compare subjects with and without tinnitus.[17-20]

Otoacoustic emission (OAE) testing is useful for early detection of NIHL prior to hearing loss, but its usefulness in patients with chronic hearing loss has not been clearly determined.[21] TEOAE testing involves the stimulation of the entire cochlea, making it unsuitable for frequency discrimination. However, it can screen for hearing loss >30 dB. In contrast, DPOAE testing can determine frequency characteristics by detecting reduced or lost frequencies. The DPOAE results of this study showed that normal response rates were higher at 1 kHz and 2 kHz than at other frequencies, which may correlate with high PTA thresholds. In addition, in the TEOAE test, SNR at all frequencies were below 3, which is considered abnormal. OAE tests may be good tools for auditory examination and research in patients with both tinnitus and NIHL.

Ethics Committee Approval: Ethical committee approval was received from the Ethics Committee of Kyung Hee University, (Approval No: KMC 2019-07-065).

Informed Consent: Verbal/Written informed consent was obtained from all participants who participated in this study.

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