ORIGINAL ARTICLE

Audiometric Notches in Noise-Induced Hearing Loss: 4K versus 6K as Related to Body Mass Index

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Purpose: The aim of this study was to investigate the association of the body mass index (BMI) with audiometric notches in noise exposed workers.

Materials and Methods: This study is a cross-sectional analysis performed at an academic medical center. The pure-tone audiograms and basic personal information of noise-exposed workers were retrieved from the computerized database. The associations between age, height, weight, and BMI and audiometric notches were analyzed.

Results: The audiograms of 4,598 ears from 2,299 noise-exposed workers were analyzed. Approximately one-third of the ears had notched audiograms. Subjects with left-ear notched audiograms had younger average age than subjects with right-ear notches. There was no significant association between the subjects' height and weight and audiometric notches. The mean BMIs of subjects with left-ear audiograms with notches at 4K and 6K were 25.66±3.23 and 25.09±3.30, respectively; the difference was statistically significant (t-test; p=0.022).

Conclusions: Subjects with higher BMIs tended to have left-ear audiograms with notches at 4K. BMI information may assist in predicting audiogram notch frequency, thus aiding in early detection of noise-induced hearing loss.

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Introduction

A notch at 4 kHz (4K notch) in the audiogram is a basic characteristic of noise-induced hearing loss (NIHL). According to the resonance theory, the classic 4K notch in NIHL is caused by the physiological properties of human external auditory canal[1]. McBride and Williams[2] found that the 4K notch was associated with noise exposure more significantly than notches at other frequencies, and concluded that the 4K notch was valuable in diagnosing NIHL. However, Wu et al.[3] and Chen and Tsai[4] reported a notch at 6 kHz (6K notch) in the audiogram was more closely associated with NIHL among workers in Taiwan than was the 4K notch. The ethnic differences between the participants in these studies were thought to be the major cause of the differences in the findings. In general, Asians have a lower body mass index (BMI) for the same age than Europeans. The average BMI is 1.3 kg/m^2 (±0.1) lower in Asian females and 1.4 kg/m^2 (±0.1) lower in Asian males compared with their European counterparts[5]. The World Health Organization (WHO) announced an international classification of adult underweight, overweight and obesity according to the BMI, and recommended a modification in the definitions of overweight and

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Table 1. BMI Classifications of adult underweight, overweight and obesity

Classifications	Cut-off points		
	WHO	Modification for Asians	Modification for Taiwanesea
Underweight	<18.50	<18.50	<18.50
Normal range	18.50 – 24.99	18.50 – 22.99	18.50 – 23.99
Overweight	25.00 – 29.99	23.00 – 27.49	24.00 – 26.99
Obese	≥30.00	≥27.50	≥27.00

a.: modified by the Department of Health, Executive Yuan, R.O.C. (Taiwan)

obesity for Asian populations (Table 1)[5,6]. Based on the resonance theory and the difference in the body build between Europeans and Asians, we hypothesized that the BMI may be associated with the frequencies most susceptible to NIHL. In this study, we analyzed the relationships between the subjects' age, sex, height, weight, and BMI and audiometric notches, hoping that the results of this study could assist in the early detection of NIHL.

Materials and Methods

Pure tone audiometry (PTA) data from September 1, 2009 to July 31, 2010 were obtained from the database of the Department of Preventive Medicine, Kaohsiung Medical University Hospital. All subjects included in this study were exposed to noise levels exceeding 85 dBA, but limited to 90 dB time-weighted average (90 dB TWA), during their working hours. Thus, they were considered to have experienced a similar degree of noise exposure. Medical history information was collected, and otoscopic examinations were performed on each subject before the PTA tests were administered. Abnormal otoscopic findings and history of ear diseases were recorded. All subjects underwent audiometric testing using a Beltone 120 audiometer (Beltone Electronics Corp. Chicago, IL, USA) and TDH 50-P earphone (Beltone Electronics Corp. Chicago, IL, USA) calibrated to ISO 389 (1975) by trained technicians in sound-attenuating booths that met the requirements of the Council of Labor Affairs, Executive Yuan, Taiwan. The audiometric data were recorded at 250, 500, 1000, 2000, 3000, 4000, 6000 and 8000 Hz. Other data, including the participants' gender, age, weight and height, were also retrieved from the database.

To analyze the associations among audiometric notches (at 3K, 4K and 6K) with the study parameters, an audiometric notch was defined as thresholds

a. ≥30 dB in the hearing level of the notched frequency

b. At least 5 dB lower than the two adjacent frequencies

c. At least 10 dB worse than the average hearing level (average of the thresholds at 500, 1000, and 2000 Hz) for the same ear

The exclusion criteria were

a. The coexistence of 3K and 6K notches for the same ear

b. Interaural hearing differences ≥15 dB (average of the hearing levels at 500, 1000, and 2000 Hz)

c. Past history of otologic disease with hearing disturbances

d. Abnormal external/middle ear findings from the otoscopic examination

Subjects who met these criteria were excluded from this study because such audiometric features were less likely to have been caused by noise exposure alone.

The distributions of 3K, 4K and 6K notches were examined on both ears of each participant. The associations between age, gender, height, and BMI and audiometric notches were analyzed. All the computerized data were analyzed with SPSS statistical software, version 16.0 (SPSS Inc., Chicago, IL, USA). Differences were considered significant when $p<0.05$.

Ethical considerations

There was no private personal information identifiable in the data retrieved, thus an institutional reviewing board approval was not considered necessary for this study.

However, during all stages of the study, the current ethics standards were taken into account.

Results

Using the database, we obtained data from 2,381 subjects. After screening out 82 cases that met the exclusion criteria, 2,299 subjects (13 women and 2286 men) were included in this study. The average age of the subjects was 45.8±10.3 years. The mean height and weight of the subjects were 169.3±5.9 centimeters and 72.8±10.7 kilograms, respectively. The audiograms of both the right and left ears of the 2,299 subjects were analyzed. None of the 13 women had an audiogram notch in either ear.

Distributions of audiometric notches

The descriptive data and distributions of audiometric notches in right and left ears are presented in Table 2. There was a significant difference between the distributions of audiometric notches in the left and right ears (Chi-squared; $p<0.001$). There were slightly more audiometric notches in the left ears. However, the major difference in the distributions of audiometric notches between the ears was noted in the 4K and 6K notches. The average age of subjects with audiometric notches in either ear and those without was significantly different (t-test; $p<0.001$). There was no significant difference in the mean ages of patients with 3K, 4K, and 6K notches in left ear (ANOVA; $p=0.583$). In the right ear, it seemed to have significant differences in the mean ages of patients with 3K, 4K, and 6K (ANOVA; $p=0.045$); however the posthoc Bonferroni test failed to find any statistically significant relationship between notches in multiple comparisons. . The height and weight analyses revealed no significant association between these factors and audiometric notches in either ear. There was no significant association between BMI and audiometric notches at 3K, 4K and 6K either in the left ear (ANOVA; $p=0.069$) or in the right ear (ANOVA; $p=0.904$).

Associations of the parameters with 4K and 6K notches

Notches at 4K and 6K are widely associated with NIHL. We analyzed the associations between the studied parameters and 4K and 6K notches. The results are presented in Table 3. The distributions of 4K and 6K notches were significantly different in bilateral ears (Chi-squared; $p=0.001$). The subjects' height, weight, and BMI showed no significant difference according to which ear had an audiometric notch (t-test; $p=0.218$ for height, $p=0.717$ for weight, and $p=0.808$ for BMI). The average age of the subjects with notched left-ear audiograms was somewhat younger than that of subjects with right audiometric notches, although this difference did not reach statistical significance (t-test; $p=0.218$). In either ear, there were no significant differences in the age, height, and weight of subjects with 4K notches and those with 6K notches (t-test; $p>0.05$)(Table 3). The association between BMI and audiometric notches was insignificant in the right ear (t-test; $p=0.702$). However, there was a significant difference in BMI between subjects with 4K notches and those with 6K notches in the left ear (t-test; $p=0.022$). To determine the clinical

Table 2. Descriptive data and distributions of audiometric notches of bilateral ears

Side	Audiometric notches	Ears (%)	Age (yr) (Mean±SD)	Height (cm) (Mean±SD)	(Mean±SD) (Mean±SD)	Weight (kg) (Mean±SD)	BMI (Mean±SD)
Right	None	1525 (66.3)	43.7±10.6		169.8±5.8	73.1±10.9	25.34±3.39
	3K notch	106 (4.6)	51.4±8.2	50.0±8.5†	169.0±6.6	73.1±11.2	25.54±3.23
	4K notch	331 (14.4)	50.3±8.2		168.1±5.8	72.2±10.0	25.51±3.00
	6K notch	337 (14.7)	49.2±8.7		168.3±5.7	72.1±10.3	25.42±3.16
Left	None	1473 (64.1)	44.0±10.6		169.7±6.0	73.0±10.7	25.34±3.33
	3K notch	110 (4.8)	48.7±9.2	49.1±8.9†	168.3±6.5	73.0±10.5	25.73±3.11
	4K notch	419 (18.2)	49.4±8.7		168.5±5.5	72.9±10.6	25.66±3.23
	6K notch	297 (12.9)	48.8±9.1		168.8±5.7	71.5±10.4	25.09±3.30
Total		4598 (100)	45.8±10.3		169.3±5.9	72.8±10.7	25.39±3.30

†: mean age of subjects with audiometric notches

Table 3. Comparisons between 4K and 6K notches of bilateral ears

Side	Audiometric notch	Number (%)	Age (yr) Mean	p-value	Height (cm) Mean	p-value	Weight(kg) Mean	p-value	BMI Mean	p-value
Right	4K	331 (49.6)	50.3±8.2	0.094	168.1±5.8	0.755	72.2±10.0	0.841	25.51±3.00	0.702
	6K	337 (50.4)	49.2±8.7		168.3±5.7		72.1±10.3		25.42±3.16	
	Total	668 (100)	49.7±8.5	168.2±5.7	72.1±10.1	25.47±3.08				
Left	4K	419 (58.5)	49.4±8.7	0.359	168.5±5.5	0.466	72.9±10.6	0.083	25.66±3.23	0.022*
	6K	297 (41.4)	48.8±9.1		168.8±5.7		71.5±10.4		25.09±3.30	
	Total	716 (100)	49.2±8.9		168.6±5.6		72.3±10.6		25.42±3.27	

**: statistic significant at the level p<0.05*

application of BMI for the prediction and early identification of NIHL, we tested the BMI cut-off points for the left ear to determine their correlations with the audiometric notches. In addition to the cut-off points of 25.09 and 25.66 (based on the mean BMI of subjects with 6K left-ear notches and those with 4K left-ear notches, respectively), we also tested cut-offs of 25.00 and 25.50 for possible clinical application. The prediction of 4K notch of the left ear was performed with the receiver operating characteristics (ROC) curve (Figure 1). Table 4 revealed the test results for these cut-off points. The BMI cut-offs of 25.00 and 25.09 were found to best predict the presence of a 4K notch related to NIHL. However, the sensitivity and specificity of the BMI cut-off points were only approximately 55% for predicting the type of audiometric notch.

Discussion

In this study, approximately one-third of the subjects met our definition of an audiometric notch. This prevalence was similar to that reported by Nondahl et al.[7], using the criteria of Coles et al.[8]. The Coles et al. criteria for a notched audiogram is well-correlated with clinical judgment regarding the noise-induced audiometric notch[9]. Hence, we believe that our criteria for the notched audiogram also correlated well with the definition of a noise-induced audiometric notch.

The classification of regulated potentially dangerous work and health examination guidelines, which were published by the Bureau of Health Promotion, Department of Health, R.O.C. (Taiwan), essentially bases the detection of NIHL on the presence of a 4K notched audiogram. Following this guideline, however, would ignore some NIHL patients with a 6K audiometric notch. There were similar percentages of 4K and 6K notches in the right ear and a higher percentage of 4K than 6K notches in the left in our study. The distributions of 4K and 6K notches in this study were somewhat different from the results of previous studies in Taiwan, which reported that 6K notches were more prominent in Taiwanese workers[3,4]. Although a higher percentage of audiometric notches was at 4 kHz, nearly 48% of the notched audiograms in our study exhibited 6K notches (Table 3). The 6K audiometric notch remains significant for detecting NIHL in Taiwanese workers.

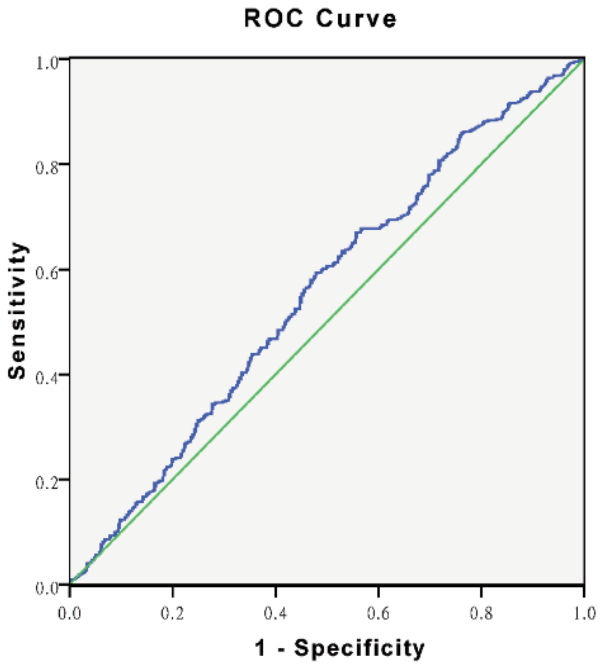

Figure 1. The receiver operating characteristics (ROC) curve for the prediction of a 4K notch in the left ear based on the body mass index (BMI). The area under the curve is 0.556, which rejects the null hypothesis: true area = 0.5 with p = 0.011.

Table 4. Prediction of 4K audiometric notch based on BMI in the left ear

BMI cut point	P value (chi-square test)	Sensitivity	Specificity	P value (ROC curve)
25.00	0.007**	0.557	0.545	0.011*
25.09	0.013*	0.541	0.552	
25.50	0.052	0.476	0.596	
25.66	0.055	0.455	0.616	

**: significance level p<0.05*

***: significance level p<0.01*

In this study, notched audiograms were found to be more frequent in left ears. The left ear is believed to be most useful for monitoring NIHL because it is more susceptible to noise, regardless of whether the subject is right- or left-handed[10-14]. We found an association between left-ear noise-induced audiometric notches and the subjects' BMIs. More obese subjects tended to have 4K notches, whereas more slender subjects tended to have 6K audiometric notches. To examine the clinical usefulness of this value, several BMI cut-points were tested to determine their sensitivity and specificity for predicting a 4K notch in NIHL audiograms (Table 3). The BMI cut-off point of 25.00 seemed to have the best predictive value. The receiver operating characteristics (ROC) curve revealed a significant correlation between the BMI value of 25.00 and the presence of a 4K notch; however, the sensitivity and specificity of BMI in predicting a 4K notch were not high enough to be used as a single predictive parameter.

In the study by Gerhardt et al.[15], the authors found that variations in NIHL patterns were closely related to the subjects' ear canal volume or length. The subjects with smaller ear canal volumes suffered peak hearing losses at 6 kHz, and subjects with larger volumes were more like to suffer the greatest loss at 3 or 4 kHz. Based on the resonance theory, the longer the ear canal, the lower the frequency at which the ear canal maximally resonates. Subjects with higher BMIs may have relatively larger anatomic structures, including larger ear canal volumes/lengths. This may explain our finding that subjects with higher BMIs tended to have a 4K notch, whereas those with lower BMIs tended to have a 6K notch.

Obesity was reported as a risk factor for age-related hearing impairment (ARHI)[16,17]. The link between obesity and ARHI may be caused by obesity-related problems, such as Type II diabetes mellitus and cardiovascular diseases. These obesity-related diseases may cause auditory dysfunction through the oxidative stress pathway and the deposit of advanced glycation end products[18]. Obesity-related diseases are also thought to be risk factors for NIHL[19,20]. The mechanism linking obesity to NIHL risk may be similar to the link between obesity and ARHL. In this study, although the average BMI value was higher in subjects with notched audiograms, the results were not statistically different from those of subjects without notches. This result indicated obesity had far less of an impact on NIHL than noise itself.

Age is an important factor in whether noise-exposed subjects developed an audiometric notch. Subjects with notched audiograms were approximately 6 years than those without audiometric notches (Table 2). The result is to be expected, because the longer an individual is exposed to noise, the more likely he or she is to develop NIHL. Older subjects indicated they began working at their job at an earlier age and had been exposed to noise for a longer time than the younger subjects. This finding may also indicate that a noise-induced audiometric notch may be detectable after 6 years of occupational noise exposure. Audiometric notches developed approximately one year earlier in the left ear than the right ear. This indicates that the left ear is more susceptible to NIHL than the right ear, which corresponds to the discussion earlier in this article.

Conclusion

The left ear is more susceptible to NIHL; thus, the audiogram of the left ear is a better indicator of NIHL. Subjects with higher BMI values tended to have an audiometric notch at 4K, whereas those with lower BMI values tended to have a 6K notch. The BMI value could be considered when predicting notch frequency and used to increase the sensitivity of NIHL detection with notched audiograms. The findings in this study may thus assist in the early detection of NIHL.

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