Original Article

Higher serum magnesium concentration is associated with lower hearing thresholds and risk of hearing loss among a Chinese population

Yifei Cao PhD, Yizhen Zhuang MSc, Chenhui Li MSc, Ying Ren MSc, Yinyin Wu PhD, Xiu Wang MD, Fei Wang MD, Haiyan Ma MD, Lei Yang PhD, Liangwen Xu MD

Medical School, Hangzhou Normal University, Hangzhou, Zhejiang, People's Republic of China

Background and Objectives: Hearing loss is a sensory impairment caused by genetic and environmental factors. Previous epidemiological studies of magnesium intake and hearing loss have yielded conflicting results. **Methods and Study Design:** We investigated the association between serum magnesium concentrations and hearing loss in a population from the Zhejiang region of China. A cross-sectional study of 3,267 participants aged 18 years and older from five hospitals was conducted from October 2016 to May 2018. An audiometric examination was conducted, and hearing thresholds were computed as pure-tone averages (PTAs) at speech (0.5, 1, 2, and 4 kHz) and high frequencies (3, 4, and 6 kHz). Magnesium concentrations were measured using an inductively coupled plasma mass spectrometer. **Results:** A linear regression analysis revealed a negative association between magnesium levels and hearing losses from lower to high PTAs. After the adjustment of potential confounders, participants in the highest magnesium quartile had a lower PTA (quartile 4: −1.89%; 95% confidence interval (CI: −3.07 to −0.701); p=0.022) and high PTA (quartile 4: −3.05%; 95% CI: −4.64 to −1.46; p=0.005) than those in the lowest quartile. A logistic regression analysis showed a dose-dependent reduction in the odds of high frequency hearing loss across magnesium quartiles. In model 3, after adjusting for all potential confounders, participants with the highest magnesium quartiles had a 54.0% (OR: 0.460; 95% CI: 0.339–0.587) reduction in the odds of high-frequency hearing loss. **Conclusions:** Higher whole blood levels of magnesium in this population were associated with lower hearing thresholds and risk of hearing loss.

Key Words: magnesium, hearing loss, population, cross-sectional study, linear regression analysis

INTRODUCTION

Hearing loss is a major public health problem and is the fifth leading cause of disability, ahead of many other chronic diseases such as diabetes, dementia, and chronic obstructive pulmonary disease.[1,2] According to the World Health Organization, 3.6 million patients worldwide have hearing loss.[3] The Global Burden of Disease study estimated that adult-onset hearing loss was the third leading cause of disability.[4] Hearing loss is regarded as not only a communication disability, but also a major disease that severely impairs the patient's quality of life because of social withdrawal, psychological alienation, loss of confidence, increased depression, and anxiety.[5] Therefore, it is important to identify protective factors and avoid risk factors to prevent these negative effects.

Hearing loss is caused by genetic and environmental factors.[6,7] However, only a few studies have evaluated patients with hearing loss, and there is limited public awareness of the causes and effects of hearing loss. Recent epidemiological studies showed that the nutritional status was associated with hearing loss.[8] Moreover, higher intake of antioxidant vitamins (β-carotene, vitamins C, and vitamin E) and magnesium were reported to associate with lower risks of hearing loss in the US general population.[9] Attias et al provided evidence that magnesium intake was associated with a lower temporary threshold shift in humans.[10] Indeed, many animal experiments revealed that magnesium supplementation could reduce or slow noise-induced hearing loss (NHL).[10-12] Reports d that free radical formation in the inner ear causes cell death and vasoconstriction and a rebound in cochlear blood flow associated with hearing loss, suggesting that antioxidants may play a preventive role in hearing loss.[13,14] However, some epidemiological studies of the relationship between magnesium and hearing loss reported inconsistent results. One previous study showed that the serum magnesium ion level may not be associated with NHL.[15] In this study, we aimed to evaluate the association between the whole blood magnesium concentration and hearing loss based on a cross-sectional study in a population from the Zhejiang region in China. Through this res-

Corresponding Author: Dr Liangwen Xu, School of Medicine, Hangzhou Normal University, 16 Xuelin Xiasha District Hangzhou, Zhejiang, China.
Tel: (86)57128865510; Fax: (86)57128865510
Email: lwxu2006@163.com
Manuscript received 21 May 2019. Initial review completed 18 June 2019. Revision accepted 16 July 2019.
doi: 10.6133/apjcn.201912_28(4).0012

earch, we aim to provide nutrition-related health education and thus reduce hearing losses in the healthy population.

METHODS

Participants

Between October 2016 and May 2018, 3,500 adults aged 18 years and older who attended medical examinations at five different hospitals (Jianshan People's Hospital, Anji People's Hospital, Jinyun People's Hospital, Jiaxin Armed Police Hospital, and Tonglu People's Hospital) in Zhejiang Province, China, were recruited for this study. All participants were informed about the study and provided informed consent to the hearing survey. The study was approved by the ethics committee of Hangzhou Normal University (2017LL107), and all procedures were performed in accordance with the Declaration of Helsinki. Participants (1) with current otitis media or a history thereof; (2) hereditary hearing loss; (3) a history of occupational noise exposure; (4) missing data regarding age, sex, family history of hearing loss, or other key variables; and (5) who were unresponsive or exhibited unreliable responses during audiometric examinations were excluded. Additionally, 204 adults and 29 participants who refused to provide blood samples were also excluded from the analysis. Finally, 3,267 participants were enrolled in our study.

Sample collection

The blood samples were collected from all participants into tubes containing ethylenediaminetetraacetic acid. The collected specimens were coded using unique identification numbers. All specimens were stored at -70°C until testing.

Questionnaires

Participants' data on age, sex, marriage status (single, married, divorced, or widowed), education (elementary school, middle school, high school, college, or postgraduate), and personal monthly income (≤2,000, 2001–4000, 4000–6000, 6001–8000, and ≥8000 yuan) were obtained based on the standard format. The self-reported family history of hearing loss, hypertension, cigarette smoking, alcohol drinking, sleeping time, and noise exposure were also collected in the same format. Hypertension was defined as a self-reported physician diagnosis, current use of antihypertensive medication, systolic blood pressure ≥140 mm Hg, or diastolic blood pressure ≥90 mm Hg at the time of examination. A participant was categorized as a current smoker if he/she smoked at least one cigarette per week or as an alcohol drinker if he/she drank at least once per week. The sleeping duration (<4, 4–6, 6–8, and ≥8 hours) was also included in the questionnaire. Occupational noise exposure was defined as an exposure to loud noise in the workplace at least once a week, while living noise exposure was defined as an exposure to loud noise outside of the workplace at least once a week.

Audiometric examination

For the audiometric examinations, a Madsen Itera clinical diagnostic audiometer and TDH39 headphones (GN Otometrics, Denmark) were used by trained technicians in a sound-proof chamber with noise levels of <30 dB.[16] Pure-tone air conduction thresholds from 0.5 to 8 kHz across an intensity range of −10 to 120 dB were determined for each ear. Hearing loss at low frequencies was defined as a pure-tone average (PTA) of >25 dB at 0.125 and 0.25 kHz (low PTA) in the worse ear. Speech frequency hearing loss was defined as a PTA of >25 dB at 0.5, 1, and 2 kHz (speech PTA) in the worse ear. High-frequency hearing loss was defined as a PTA of >25 dB at 3, 4, 6, and 8 kHz (high PTA) in the worse ear.[17] In the audiometric examination, participants who did not respond at least once were considered nonresponsive. To determine the reliability of the participants' responses, the 1-kHz frequency was tested twice in each ear. If the results exceeded 10 dB, the response was considered unreliable.[18]

Measurement of magnesium concentration in the whole blood

Magnesium concentrations in venous whole blood were measured using a standard seven-trace elements test kit (Bohui Innovation Photoelectric Technology Co., Ltd, Beijing) and an inductively coupled plasma mass spectrometer (ICP-MS, Thermo Electron Corporation, USA). Quality control was performed using samples prepared in the laboratory and standard materials (Norwegian Semnorm Company) in the detection process (Coefficient of Variation <6.67%).

Statistical analysis

The data analysis was performed using SPSS, version 20.0 (SPSS Inc., Chicago, IL, USA). Descriptive analyses were performed, and the distributions of all key variables were tested. The survey t-test and analysis of variance were used to analyze continuous variables. The chi-square test and Kruskal–Wallis test were used for comparisons of categorical variables. Linear regression and logistic regression analyses were used to evaluate the associations of magnesium levels (in quartiles) with hearing thresholds (in PTA) and hearing loss. All regression models were constructed based on the blood magnesium concentration to observe the effects of this variable, with adjustments of different covariates. In model 1, we adjusted age, sex, marriage, education level, personal income, family history of hearing loss, and hypertension. In model 2, we included smoking, drinking, and sleeping time as additions to model 1 to determine the influences of these variables on the association between blood magnesium and hearing loss. In model 3, occupational noise exposure and living noise exposure were included as additions to model 2. The odds ratios (ORs) and 95% confidence intervals (CIs) for hearing loss were calculated for each of the upper three magnesium level quartiles relative to the lowest quartile using a logistic regression. Statistical significance was defined as a p value <0.05.

RESULTS

Study participants

A total of 3,267 adults participated in the study. Table 1 summarizes the characteristics of the study cohort. The mean (±standard error of the mean) age of the participants was 50.0±15.8 years, the mean whole blood magnesium

Table 1. Characteristics of the study population (n=3267)†

Characteristic	Distribution
Age	50.0±15.8
Sex	
Male	47.0%
Female	53.0%
Marriage status	
Single	7.50%
Married	89.1%
Divorce	1.90%
Bereft of one's spouse	1.50%
Education level	
≤Elementary school	14.9%
Middle school	22.8%
High school	25.3%
College	36.0%
Postgraduate	1.00%
Income (yuan)	
≤2000	14.0%
2001–4000	23.6%
4001–6000	36.9%
6001–8000	14.0%
≥8001	4.40%
Hearing loss family history	
No	87.0%
Yes	13.0%
Hypertension	
No	77.8%
Yes	20.1%
Smoking	
Never	77.2%
Former	5.90%
Current	16.9%
Alcohol drinking	
Never	84.3%
Former	2.10%
Current	13.6%
Sleeping time	
<4 hours	1.00%
4–6 hours	4.70%
6–8 hours	65.1%
≥8 hours	29.2%
Living noise exposure	
Never	76.3%
At least once a week	15.3%
At least once a day	8.40%
Occupational noise exposure	
Never	62.5%
At least once a week	26.8%
At least once a day	10.7%
Mg (μmol/L)	1.46±0.14
Low frequency PTA‡ (dB)§	27.0±13.1
Any low-frequency hearing loss§	40.4%
Speech frequency PTA (dB)¶	25.7±13.7
Any speech-frequency hearing loss¶	36.1%
High-frequency PTA (dB)††	33.1±19.3
Any high-frequency hearing loss††	53.8%

†Participants included individuals for whom data were available on all variables of interest: age, sex, marriage status, education level, income, hearing loss family history, hypertension, smoking, alcohol drinking, sleeping time, living noise exposure, occupational noise exposure, and magnesium concentration at different frequency PTAs.
‡PTA: pure-tone average.
§At 0.125, 0.25 kHz.
¶At 0.5, 1, 2 kHz.
††At 3, 4, 6, 8 kHz.

concentration was 1.46±0.14 mmol/L, and the mean low, speech, and high PTA values were 27.0±13.1, 25.6±13.7, and 33.1±19.3 dB, respectively.

Approximately 40.4%, 36.1%, and 53.8% of participants had low-frequency, speech-frequency, and high-frequency hearing losses, respectively.

The distribution of magnesium levels in the cohort is presented in Table 2. Significant inter-group differences in the blood concentrations of magnesium were observed with respect to age, sex, education level, and income level ($p<0.001$). The magnesium levels were also affected by smoking and alcohol drinking ($p<0.001$). There were no difference in PTA with respect to age and noise exposure.

Relationship between magnesium level and hearing threshold

A linear regression analysis showed a negative association of the serum magnesium concentration (in quartiles) as the PTA increased (Table 3). Compared to participants in the lowest quartile, those in the highest magnesium quartile exhibited a significant reduction in the PTA after the adjustment of confounders such as age, sex, marriage status, education level, income level, and hypertension status (model 1). The reductions in speech- and high-frequency PTAs remained significant after further adjustments in model 2 (smoking, drinking, and sleeping time) and model 3 (life noise and occupational noise exposure). In patients with a low PTA, a significant reduction was observed in model 3 but not in model 2.

Relationship between magnesium level and the risk of hearing loss

A logistic regression analysis revealed an association of a higher magnesium concentration with a lower risk of high-frequency hearing loss (Table 4). After the adjustment of age, sex, marriage, education, income, and hypertension (model 1), participants in the fourth serum magnesium level quartile had a 55.0% lower risk of high-frequency hearing loss (OR: 0.450, 95% CI: 0.344–0.590) than those in the lowest quartile level. This association remained significant after further adjustments of other covariances (models 2 and 3). No significant association was observed between the magnesium level and speech or low-frequency hearing loss.

DISCUSSION

In this study, we found that more than half of the participants had a high-frequency hearing loss and more than a third had a speech-frequency hearing loss, which are often ignored because they do not generally affect daily communication. Moreover, high-frequency hearing loss occurs in most patients with hearing problems and should be given more attention.[19]

Only a few epidemiologic studies reported the protective association between blood magnesium levels and hearing loss. However, a previous study of 7,445 workers reported that the serum magnesium ion level may not be associated with NHL.[15] Our results found an apparent protective dose-response relationship between the whole blood magnesium level and speech- and high-frequency hearing thresholds via linear regression. We identified the ORs for high-frequency hearing loss after adjusting for

Table 2. Blood magnesium concentrations stratified by different groups (n=3267) †

Characteristic	Magnesium (umol/L) mean±SE	*p*
Age		<0.001
18-39 y	1.47±0.14	
40-59 y	1.47±0.13	
60-89 y	1.44±0.13	
Gender		<0.001
Male	1.52±0.14	
Female	1.43±0.13	
Marriage		0.113
Single	1.48±0.15	
Married	1.47±0.14	
Divorce	1.45±0.14	
Bereft of one's spouse	1.51±0.16	
Education		0.001
≤Elementary school	1.46±0.13	
Middle school	1.46±0.14	
High school	1.49±0.15	
College	1.48±0.15	
Postgraduate	1.51±0.12	
Income		<0.001
≤2000	1.44±0.13	
2001-4000	1.45±0.13	
4001-6000	1.46±0.13	
6001-8000	1.47±0.13	
≥8001	1.51±0.15	
Hearing loss family history		0.036
No	1.46±0.13	
Yes	1.47±0.14	
Hypertension‡		0.39
No	1.46±0.13	
Yes	1.46±0.14	
Smoking§		<0.001
Never	1.46±0.14	
Former	1.50±0.14	
Current	1.52±0.14	
Drinking¶		<0.001
Never	1.46±0.14	
Former	0.115±0.01	
Current	0.131±0.01	
Sleeping time		0.497
<4 hours	1.47±0.12	
4-6 hours	1.45±0.13	
6-8 hours	1.46±0.13	
≥8 hours	1.46±0.14	
Living noise exposure		0.246
Never	1.46±0.14	
At least once a week	1.45±0.13	
At least once a day	1.47±0.14	
Occupational noise exposure		0.16
Never	1.46±0.13	
At least once a week	1.45±0.14	
At least once a day	1.46±0.13	

†Participants included individuals with all variables of interest: age, gender, marriage, education, income, hearing loss family history, Hypertension, smoking, drinking, sleeping time, living noise exposure and occupational noise exposure.
‡Current use of antihypertensive medication, systolic blood pressure ≥140 mm Hg, or diastolic blood pressure ≥90 mm Hg at the time of examination.
§Smoked at least one cigarette per week as a current smoker.
¶ Drank at least once per week as an alcohol drinker.
p: probability for statistic testing.

Table 3. Multivariate-adjusted pure-tone average (95% CIs) of hearing thresholds by magnesium concentration quartile

Characteristic	Q1	Q2	Q3	Q4	*p* trend
Low-frequency					
Model 1†	0 (Reference)	-1.33 (-2.47, -0.20)	-0.44 (-1.56, 0.68)	-1.48 (-2.65, -0.32)	0.061
Model 2‡	0 (Reference)	-1.31 (-2.45, -0.16)	-0.38 (1.51, 0.76)	-1.43 (-2.61, 0.25)	0.081
Model 3§	0 (Reference)	-1.34 (-2.48, -0.20)	-0.25 (-1.38, 0.88)	-1.41 (2.59, -0.23)	0.105
Speech-frequency					
Model 1†	0 (Reference)	-0.87 (-2.01, 0.27)	0.04 (-1.09, 1.17)	-1.71 (-2.88, -0.54)	0.032
Model 2‡	0 (Reference)	-0.94 (-2.09, 0.22)	0.02 (-1.12, 1.16)	-1.85 (-3.04, -0.66)	0.022
Model 3§	0 (Reference)	-0.96 (-2.11, 0.18)	0.12 (-1.02, 1.26)	-1.89 (-3.07, -0.70)	0.022
High-frequency					
Model 1†	0 (Reference)	-1.29 (-2.79, 0.22)	0.03 (-1.47, 1.53)	-2.86 (-4.44 -1.28)	0.007
Model 2‡	0 (Reference)	-1.31 (-2.83, 0.22)	-0.01 (-1.52, 1.50)	-2.98 (-4.57, -1.38)	0.005
Model 3§	0 (Reference)	-1.39 (-2.91, 0.13)	0.134(-1.37, 1.65)	-3.05(-4.64, -1.46)	0.005

Q1 is the reference; Q, quartile (~25th percentile, ~median, ~75th percentile, ~100th percentile)
†Model 1: Adjusted for age, gender, marriage, education, income and hypertension (add gender at high-frequency)
‡Model 2: On the basis of model 1, additional adjustment for smoking, drinking and sleeping time
§Model 3: On the basis of model 2, adjusted for life noise expose and occupational noise expose
p: probability for statistic testing

Table 4. Multivariate-adjusted ORs (95%CIs) of hearing loss by magnesium concentration quartile

Characteristic	Q1	Q2	Q3	Q4	*p* trend
Low-frequency					
Model 1†	1 (Reference)	0.84 (0.66, 1.07)	0.96 (0.76, 1.22)	0.89 (0.70, 1.15)	0.62
Model 2‡	1 (Reference)	0.85 (0.66, 1.09)	0.98 (0.77 1.25)	0.89 (0.69, 1.15)	0.62
Model 3§	1 (Reference)	0.84 (0.66, 1.08)	0.99 (0.78, 1.27)	0.90 (0.70, 1.16)	0.72
Speech-frequency					
Model 1†	1 (Reference)	0.99 (0.77,1.27)	1.19 (0.92,1.52)	0.84 (0.64,1.1)	0.53
Model 2‡	1 (Reference)	0.98 (0.76,1.27)	1.20 (0.93,1.55)	0.81 (0.61,1.06)	0.40
Model 3§	1 (Reference)	0.964(0.74,1.25)	1.21 (0.94,1.57)	0.82 (0.62,1.08)	0.51
High-frequency					
Model 1†	1 (Reference)	0.74 (0.58,0.96)	0.79 (0.61,1.02)	0.45 (0.34,0.59)	<0.001
Model 2‡	1 (Reference)	0.76 (0.58,0.98)	0.79 (0.61,1.03)	0.44 (0.34,0.58)	<0.001
Model 3§	1 (Reference)	0.76 (0.59,0.99)	0.82 (0.63,1.07)	0.45 (0.34,0.59)	<0.001

Q1 is the reference; Q, quartile (~25th percentile, ~median, ~75th percentile, ~100th percentile)
†Model 1: Adjusted for age, gender, marriage, education, income and hypertension (add gender at high-frequency)
‡Model 2: On the basis of model 1, additional adjustment for smoking, drinking and sleeping time
§Model 3: On the basis of model 2, adjusted for life noise expose and occupational noise expose
p: probability for statistic testing

demographic factors, noise exposure, and other potential risk factors in a logistic regression analysis. Several animal studies have also reported a protective effect of magnesium against hearing loss.[20] Prell et al found that dietary supplements containing magnesium protected the function and morphology of hair cells in the inner ears of mice exposed to noise.[21,22] Another study observed a reduction in hearing losses in guinea pigs that received dietary antioxidants in combination with magnesium, suggesting that magnesium and other antioxidants protect hearing by inhibiting free radicals.[23,24]

Free radicals can be induced by noise exposure and can subsequently cause cell injury and death in the inner ear. These molecules may play a critical role in the negative association between blood magnesium levels and the risk of hearing loss.[20] Despite extensive evidence from basic research and animal studies, it is extremely important to carefully examine the prophylactic effects of magnesium in human participants before preventing or implementing the use of this supplement, given the differences between humans and animals. In a controlled clinical trial conducted by David et al., magnesium can also influence hearing directly by increasing blood viscosity and blood flow, or indirectly via its effects on the cell energy cycle. Magnesium treatment improved the hearing of patients with sudden sensorineural hearing loss.[25] Choi et al. suggested that the combined intake of magnesium and antioxidants was associated with a lower risk of hearing loss in humans.[9] Moreover, oral magnesium intake may reduce NHL.[26] These studies provide a scientific rationale to support our findings.

To our knowledge, this was the first population-based epidemiological study to report the association between magnesium and hearing loss. However, this study also had several potential limitations. First, data on many influential factors were obtained through self-reporting, (e.g., hypertension, socioeconomic data, and occupational noise exposure), which might have led to measurement errors. Second, the hearing thresholds were determined using the worse-performing ear, which led to an increase in the prevalence of hearing loss. Third, the study only included participants of Chinese Han ethnicity. Therefore, the study findings may not be generalizable to other ethnic groups. Finally, as this was a cross-sectional study, the cause-and-effect relationship cannot be inferred, and reverse causation and other mechanisms cannot be ruled out.

We found that higher whole blood levels of magnesium were associated with lower hearing thresholds and the risk of hearing loss, even after adjusting for confounding factors. Therefore, we believe that dietary or nutritional supplements rich in magnesium may reduce hearing loss. However, magnesium's ability to affect favorably health outcomes is apparently dependent on a biodiverse background diet.[27] In addition, this study provides an epidemiological basis for the clinical application of magnesium therapy for hearing loss. In further studies, we will conduct a continuous examination of blood magnesium concentrations in this population to confirm the association with hearing loss. Subsequently, we will provide nutrition-related health education to prevent hearing loss in the normal population.

ACKNOWLEDGEMENTS

The authors appreciate the assistance given by the staff members at Jianshan People's Hospital, Anji People's Hospital, Jinyun People's Hospital, Jiaxin Armed Police Hospital, and Tonglu People's Hospital. They would also like to thank all the participants.

AUTHOR DISCLOSURES

The authors declare no conflicts of interest.

This study was supported by the Zhejiang Key Research and Development Program (No. 015C03050), the Major Scientific and Technological Innovation Projects of Hangzhou (No. 0152013A01), and the Natural Science Foundation of Zhejiang Province (LY19H260002).

REFERENCES

1. Editorial Board. Hearing loss: time for sound action. Lancet. 2017;390:2414.
2. Wilson BS, Tucci DL, Merson MH, O'Donoghue GM. Global hearing health care: new findings and perspectives. Lancet. 2017;390:2503-15. doi: 10.1016/S0140-6736(17)31073-5.
3. Schiller JSLJ, Ward BW, Peregoy JA. Summary health statistics for U.S. adults: National Health Interview Survey, 2010. National Center for Health Statistics. Vital Health Stat. Washington, DC: US Department of Health and Human Services; 2012.
4. Edmond K, Clark A, Korczak VS, Sanderson C, Griffiths UK, Rudan I. Global and regional risk of disabling sequelae from bacterial meningitis: a systematic review and meta-analysis. Eur J Public Health. 2013;20:146-52. doi: 10.1016/S1473-3099(10)70048-7.
5. Oh IH, Lee JH, Park DC, Kim M, Chung JH, Kim SH, Yeo SG. Hearing loss as a function of aging and diabetes mellitus: a cross sectional study. PLoS One. 2014;9:e116161. doi: 10.1371/journal.pone.0116161.
6. Dror AA, Avraham KB. Hearing loss: mechanisms revealed by genetics and cell biology. Annu Rev Genet. 2009;43:411-37. doi: 10.1146/annurev-genet-102108-134135.
7. Roth TN, Hanebuth D, Probst R. Prevalence of age-related hearing loss in Europe: a review. Eur Arch Otorhinolaryngol. 2011;268:1101-7. doi: 10.1007/s00405-011-1597-8.
8. Puga AM, Pajares MA, Varela-Moreiras G, Partearroyo T. Interplay between nutrition and hearing loss: state of art. Nutrients. 2019;11:35. doi: 10.3390%2Fnu11010035.
9. Choi YH, Miller JM, Tucker KL, Hu H, Park SK. Antioxidant vitamins and magnesium and the risk of hearing loss in the US general population. Am J Clin Nutr. 2014;99:148-55. doi: 10.3945/ajcn.113.068437.
10. Attias J, Sapir S, Bresloff I, Reshef-Haran I, Ising H. Reduction in noise-induced temporary threshold shift in humans following oral magnesium intake. Clin Otolaryngol Allied Sci. 2004;29:635-41. doi: 10.1111/j.1365-2273.2004.00866.x.
11. Abaamrane L, Raffin F, Gal M, Avan P, Sendowski I. Long-term administration of magnesium after acoustic trauma caused by gunshot noise in guinea pigs. Hear Res. 2009;247:137-45. doi: 10.1016/j.heares.2008.11.005.
12. Sendowski I, Holy X, Raffin F, Cazals Y. Magnesium and hearing loss. Magnesium in the central nervous system. Adelaide (AU): University of Adelaide Press; 2011.
13. Heman-Ackah SE, Juhn SK, Huang TC, Wiedmann TS. A combination antioxidant therapy prevents age-related hearing loss in C57BL/6 mice. Otolaryngol Head Neck Surg. 2010;143:429-34. doi: 10.1016/j.otohns.2010.04.266.
14. Tavanai E, Mohammadkhani G. Role of antioxidants in prevention of age-related hearing loss: a review of literature. Eur Arch Otorhinolaryngol. 2017;274:1821-34. doi: 10.1007/s00405-016-4378-6.
15. Jiao J, Gu GZ, Chen GS, Zheng YX, Zhang HL, Geng Q, Cheng YB, Yu SF. Association between serum magnesium ion level and risk of noise-induced hearing loss. Zhonghua Lao Dong Wei Sheng Zhi Ye Bing Za Zhi. 2016;34:884-8. doi: 10.3760/cma.j.issn.1001-9391.2016.12.002. (In Chinese)
16. CDC. NHANES. 2001–2002 Data documentation: audiometry. Hyattsville, MD: National Center for Health Statistics, CDC; 2005.
17. Agrawal Y, Platz EA, Niparko JK. Prevalence of hearing loss and differences by demographic characteristics among US Adults: data from the National Health and Nutrition Examination Survey, 1999–2004. Arch Intern Med. 2008;168:1522-30. doi: 10.1001/archinte.168.14.1522.
18. Gelfand S. Essentials of audiology. 2nd ed. New York, NY: Thieme; 2001.
19. Choo OS, Yang SM, Park HY, Lee JB, Jang JH, Choi SJ, Choung YH. Differences in clinical characteristics and prognosis of sudden low- and high-frequency hearing loss. Laryngoscope. 2017;127:1878-84. doi: 10.1002/lary.26382.
20. Le Prell CG, Yamashita D, Minami SB, Yamasoba T, Miller JM. Mechanisms of noise-induced hearing loss indicate multiple methods of prevention. Hear Res. 2007;226:22-43. doi: 10.1016%2Fj.heares.2006.10.006.
21. Le Prell CG, Gaqnon PM, Bennett DC, Ohlemiller KK. Nutrient-enhanced diet reduces noise-induced damage to the inner ear and hearing loss. Transl Res. 2011;158:38-53. doi: 10.1016%2Fj.trsl.2011.02.006.
22. Le Prell CG, Dolan DF, Bennett DC, Boxer PA. Nutrient plasma levels achieved during treatment that reduces noise-induced hearing loss. Transl Res. 2011;158:54-70. doi: 10.1016/j.trsl.2011.02.003.
23. Haupt H, Scheibe F. Preventive magnesium supplement protects the inner ear against noise-induced impairment of blood flow and oxygenation in the guinea pig. Magnes Res. 2002;15:17-25.
24. Scheibe F, Haupt H, Vlastos GA. Preventive magnesium supplement reduces ischemia-induced hearing loss and

blood viscosity in the guinea pig. Eur Arch Otorhinolaryngol. 2000;257:355-61.

25. Nageris BI, Ulanovski D, Attias J. Magnesium treatment for sudden hearing loss. Ann Otol Rhinol Laryngol. 2004;113: 672-5. doi: 10.1177/000348940411300814.
26. Attias J, Weisz G, Almog S, Shahar A, Wiener M, Joachims Z, Netzer A, Ising H, Rebentisch E, Guenther T. Oral magnesium intake reduces permanent hearing loss induced by noise exposure. Am J Otolaryngol. 1994;15:26-32.
27. Huang YC, Wahlqvist ML, Kao MD, Wang JL, Lee MS. Optimal dietary and plasma magnesium statuses depend on dietary quality for a reduction in the risk of all-cause mortality in older adults. Nutrients. 2015;7:5664-83. doi: 10.3390/nu7075244.