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Clinical Characteristics of Acoustic Trauma Caused by Gunshot Noise in Mass Rifle Drills without Ear Protection

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One of the major occupational hazards of working in military service is being subjected to intense impulse noise. We analyzed the clinical presentation of acoustic traumas, induced by mass rifle gunshot noise during military training, in unprotected patients. We evaluated 189 soldiers who had otologic symptoms after rifle shooting exercises without using any hearing protection. All soldiers had been training on the K2 rifle. We took medical histories; conducted physical examinations and hearing evaluations (pure-tone audiometry, speech audiometry, and impedence audiometry); and distributed the Newmann's Tinnitus Handicap Inventory (THI) survey. In addition, we evaluated a normal control group of 64 subjects of similar age who had never fired a rifle. In the patient group, the most common and irritating reported symptom was tinnitus (94.2%), and the average THI score in the patient group was 39.51 ± 14.87, which was significantly higher than the control group score (0.56 ± 3.94) ($p < 0.001$). Average outcomes of post-exposure air conduction thresholds were 21.33 ± 13.25 dB HL in the affected ears. These levels also were significantly higher than those of the control group (9.16 ± 4.07dB HL) ($p < 0.001$). Hearing loss was most prominent at high frequencies. An asymmetry of hearing loss related to head position during shooting was not observed. Acoustic trauma induced by gunshot noise can cause permanent tinnitus and hearing loss. Hearing protection (bilateral earplugs) and environmental reform are necessary.

Keywords ear protective devices, gunshot, hearing protection, military personnel, noise-induced hearing loss, tinnitus

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INTRODUCTION

Acute acoustic trauma may occur after exposure to a loud noise over a short time period; it has been reported to present with sensorineural hearing loss and tinnitus.(1–3) High sound pressures from shocking noises such as the ones emitted by rifle fire are representative of the noise patterns that induce acoustic trauma; permanent hearing loss may occur after only a single exposure without a temporary threshold shift.(4,5) No effective treatment for acoustic trauma has been established. Nonetheless, it is a disease that can be prevented, so it is important to enforce the use of hearing protection. Early detection of acoustic trauma is also required to properly treat the disorder.(6–8)

In acoustic trauma cases related to rifle fire, unilateral hearing loss, especially contralateral to the dominant hand due to the head shadow effect, has been shown.(2,9) However, the natural clinical characteristics of acute acoustic trauma caused by exposure to rifle gunshot noise—during mass military training without hearing protection—have not been reported. Clinical presentations of acoustic trauma caused by mass rifle gunfire may be different from those of a single gunner because noise levels can be affected by adjacent gunners' shooting. We analyzed the clinical pattern of 189 patients who developed acute acoustic trauma caused by rifle gunshot noise in mass training without ear protection.

SUBJECTS AND METHODS

From July 1, 2006, to June 30, 2009, 253 South Korean soldiers visited the Armed Forces Capital Hospital and Chung-Ang University Hospital in Seoul, South Korea, for hearing loss or tinnitus that had suddenly developed after K2 rifle training. Unfortunately, they could not be supplied with any hearing protection devices because no hearing conservation program or any related policies existed in the South Korean military service before 2009. We took medical histories; conducted physical examinations and hearing evaluations (pure-tone audiometry, speech audiometry, and impedence audiometry); and distributed Newman's Tinnitus Handicap

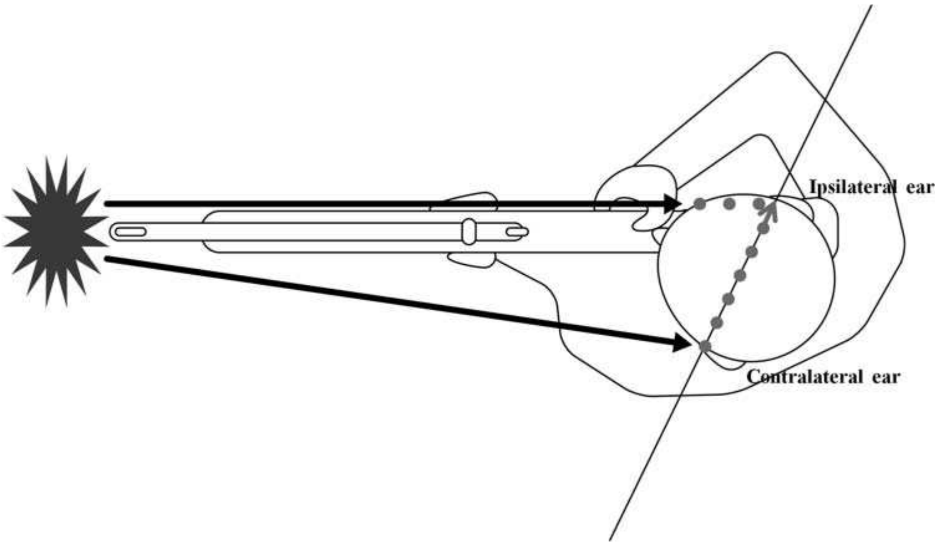

FIGURE 1. Aerial view of the proper position for firing a rifle. Note how the angulation of the head results in a discrepancy in noise exposure between ears. Sound pressure is weakened when it is transmitted to the far ear due to the head shadow effect. (Reproduced from R.J. Keim, Sensorineural hearing loss associated with firearms. *Arch. Otolaryngol. 90(11)*:581–584 (1969). Copyright © (1969) American Medical Association. All rights reserved.)

Inventory (THI) survey. We performed auditory brain stem response and magnetic resonance imaging on some patients. We excluded cases with systemic disease or a history of previous ear disease, cases where an association with rifle fire could not be detected, cases with conductive hearing loss, and cases previously treated with drugs at other hospitals. Ultimately, 189 patients were enrolled in the final analysis. For comparison, 64 men of similar age and who had never fired a rifle were enrolled in the study as a normal control group.

Using K2 rifles, all 189 patients shot 20 times without hearing protection at various shooting ranges, each with 10 shooting lanes. The ear that patients subjectively reported hearing loss or tinnitus in was defined as the affected ear, while the ear with no reported symptoms was defined as the unaffected ear. Cases in which symptoms were reported in both ears were defined as bilateral affected ears. First, we analyzed the asymmetric manifestation of acoustic trauma according to handedness. The ear that was proximal to the muzzle during shooting was defined as the contralateral ear; the ear distal to the muzzle was defined as the ipsilateral ear (Figure 1). In other words, for right-handed patients, the left ear was the contralateral ear, and the right ear was the ipsilateral ear. Differences in the severity of reported symptoms in the contralateral and ipsilateral ear were then examined.

Second, we evaluated the degree and pattern of hearing loss. We conducted pure tone audiometry by the application of a combination method at 0.25, 0.5, 1.0, 2.0, 3.0, 4.0, and 8.0 kHz. Mean hearing levels were expressed as the average of hearing thresholds at 0.5, 1.0, 2.0, and 3.0 kHz (four-tone average). Hearing threshold levels between affected ears, unaffected ears, and control ears were compared. Hearing patterns observed in pure tone audiometry were classified according to the four types of noise-induced hearing loss reported by Kang et al.[10] (Figure 2).

Last, we evaluated the effect of tinnitus using the THI described by Newman et al.[11] The questionnaire is designed to assess the effects of tinnitus on patients. Each of the 25 questions is answered by circling either "yes," "no," or "sometimes." Each "yes" response scores 4 points, each "sometimes" scores 2 points, and each "no" scores 0 points. The total subjective tinnitus score ranges from 0 points to 100 points and was calculated for each patient. Scores between the patient group reporting tinnitus and the control group were compared.

We performed power analysis to determine the sample size. The sample size calculation was based on a previous study.[6] Standard deviations of the previous study were 6.87 dB on the affected ear and 1.22 dB on the control ear. We wanted to show a difference of 3 dB for the hearing threshold between groups. With a two-tailed $\alpha = 0.01$ and a power of 95%, and 3:1 ratio of patient group to control group, we needed 189 patients for the patient group and 63 persons for the control group. With approval of the Institutional Review Board of Chung-Ang University Medical Center (No. C2011060255), 189 patients and 64 persons were consecutively enrolled in this study.

For statistical analysis, we used one-way analysis of variance (ANOVA), independent t-test, Chi-square test, and Fisher's exact test with $p < 0.05$ defined as the cut-off for statistical significance. Statistical analyses were performed using SPSS version 16.0 (SPSS Inc., Chicago, Ill.).

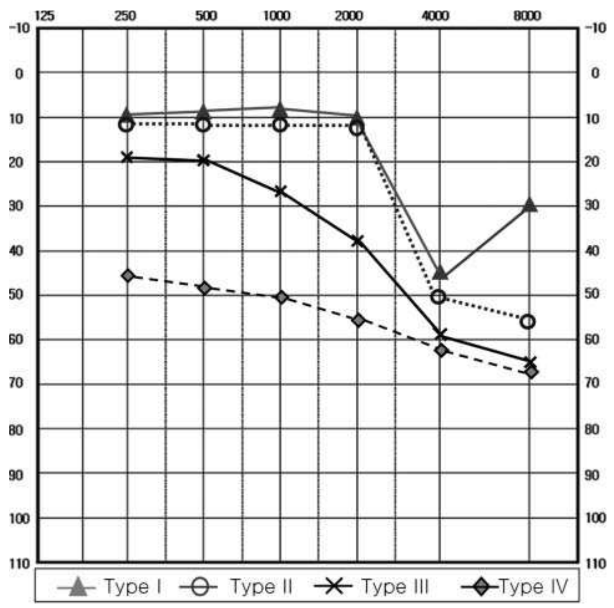

FIGURE 2. Average hearing threshold at each frequency according to audiometric type. Type I: typical C5 dip hearing pattern; Type II: normal hearing in the audible range, but an abrupt decrease in hearing level at high frequencies; Type III: sloping from an audible range and deepening with higher frequencies; and Type IV: a decrease in hearing level at all frequencies. (Adapted from S.H. Kang et al. An epidemiologic and audiometric study of noise-induced hearing loss in subway workers. *Korean J. Otolaryngol. 41(10)*:1248–1253 (1998).

RESULTS

The ages of the all-male patient group ranged from 19 to 30 years, with an average age of 21.0 years. There were 178 right-handed patients and 11 left-handed patients. The interval from the appearance of symptoms to the first hospital visit ranged from 1 day to 310 days, with an average of 50.6 days. Ages of the all-male control group subjects ranged from 21 to 29 years, with an average age of 23.7 years.

With regard to auditory symptoms, tinnitus was observed in 179 patients and was the most prevalent symptom, followed by hearing loss and ear fullness. Concomitant symptoms included headache, vertigo, and insomnia (Table I).

In the cases involving unilateral acoustic trauma, the contralateral side was involved in 83 cases, the ipsilateral side was involved in 58 cases, and bilateral symptoms were reported in 48 cases. The incidence of hearing symptoms between both sides was not statistically different ($p = 0.178$). Following the aforementioned definition, there were 237 affected ears and 141 unaffected ears.

The average pure tone threshold of the affected ears was 21.33 ± 13.25dB HL, which was significantly higher than that of the unaffected ears in both the patient group (10.86 ± 4.15dB HL) and the normal control group (9.16 ± 4.07) ($p < 0.001$). An increase in threshold was markedly observed on high frequencies when measuring various frequencies, with the greatest increase in threshold at 8.0 kHz in affected ears (Figure 3).

Hearing patterns determined by the pure tone audiometry test were classified into four categories according to the classification of noise-induced hearing loss described by Kang et al.[10] (Figure 2). In affected ears, normal hearing accounted for 18.5% of the cases, Type 1 for 21.8%, Type 2 for 40.3%, Type 3 for 18.5%, and Type 4 for 0.9%. In general, noise-induced hearing loss exhibits a Type 1 hearing loss pattern at earlier stages; however, in this study Type 2 hearing loss was more prevalent than Type 1. Finally, with regard to the effects of tinnitus, the THI score of affected patients was 39.51 ±

TABLE I. Clinical Characteristics and Differences Between the Patient and Control Groups

	Patients (n = 189)	Control (n = 63)	p Value
General Characteristics			
Age	21.05 ± 1.76	23.68 ± 1.23	0.104^A
Gender	All male	All male	
Symptoms at Presentation			
Tinnitus	178 (94.2%)	1 (2.0%)	$< 0.001^B$
Hearing impairment	104 (55.0%)	0 (0.0%)	$< 0.001^B$
Ear fullness	93 (49.2%)	0 (0.0%)	$< 0.001^B$
Headache	72 (38.1%)	2 (4.0%)	$< 0.001^B$
Dizziness	53 (28.0%)	0 (0.0%)	$< 0.001^B$
Insomnia	38 (20.1%)	0 (0.0%)	$< 0.001^B$
Hearing Threshold (dB HL)	21.33 ± 13.25^C	9.16 ± 4.07^D	$< 0.001^A$
Tinnitus Handicap Inventory Score	39.51 ± 14.87	0.56 ± 3.94	$< 0.001^A$

[A]The independent t-test was used; the Bonferroni procedure was used for the post-hoc test.
[B]Fisher's exact test was used.
[C]The number of ears is 237 because there were 48 bilateral affected ears in the patient group.
[D]The number of ears is 126 because both ears of the subjects in the control group were enrolled.

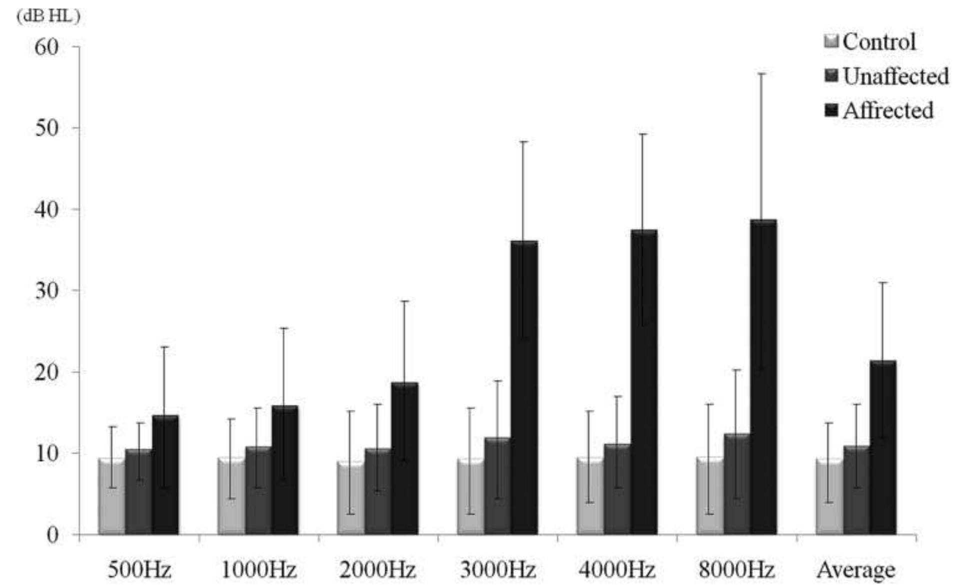

FIGURE 3. At all frequencies, affected ears had a significantly higher threshold than control or unaffected ears. Differences were especially prominent at high frequencies (one-way ANOVA and independent t-test). Unaffected ears from the patient group and control ears showed no significant differences except at 8000 Hz (independent t-test).

14.87 points, which was significantly higher than that of the control group (0.56 ± 3.94 points) ($p < 0.001$).

DISCUSSION

The head shadow effect refers to the effect of sound delivered directly to one ear and impeded by the head from directly reaching the other ear. With the head as a barrier to sound conduction, sound intensity is reduced.[12] During rifle shooting, when a shooter assumes the appropriate shooting posture, the head is turned. In a right-handed person, the left ear is closer to the muzzle and exposed directly to gun noise; the right ear is farther from the muzzle and is subjected to the head shadow effect, as shown in Figure 1. As such, given the frequency characteristics of the K2 rifle,[4] the sound delivered to the right ear is reduced by approximately 40 dB.

It has been reported that acoustic trauma caused by solo rifle shooting is asymmetrical and unilateral due to the head shadow effect. However, in this study of mass training, such an asymmetry was not readily observed. To evaluate this difference, we retrospectively measured the distance between the firing lanes at six military firing ranges. The distance ranged from 2.4 m to 3.5 m, with an average of 3 m. Lee and Lee[4] have investigated the properties of the K2 rifle's firing noise by measuring the noise at a distance of 50 cm from the rifle using the Kistler pressure sensor 601A. The noise at the lateral side was measured at 155.8 dB, which decreased by approximately 5 dB as the distance doubled (Table II). Considering the characteristics of K2 rifle noise and the acoustic characteristics of the military firing ranges, a unilateral effect was not observed in this study. This may be because during mass rifle drills, the distance between firing lanes and the width of the lanes is great enough to prevent gunshot noise from other shooters from affecting the patient. Thus, the level of noise exposure experienced by each patient was influenced by the gunshot noise of adjacent shooters (Figure 4). Therefore, during mass training shooting, soldiers should be required to wear bilateral hearing protection (earplugs). In addition, either

TABLE II. Peak Sound Pressure Level of the K2 Rifle

Spatial Relationship to Muzzle	Distance from Muzzle		
	50 cm	1 m	2 m
Front	161.2 dB	154.6 dB	152.7 dB
Lateral	155.8 dB	149.8 dB	146.0 dB
Gunner's ear	143.6 dB		

Note: Adapted from Mrena, R., S. Savolainen, U. Pirvola, et al.: Characteristics of acute acoustical trauma in the Finnish Defense Forces. *Int. J. Audiol. 43*:177–181 (2004).

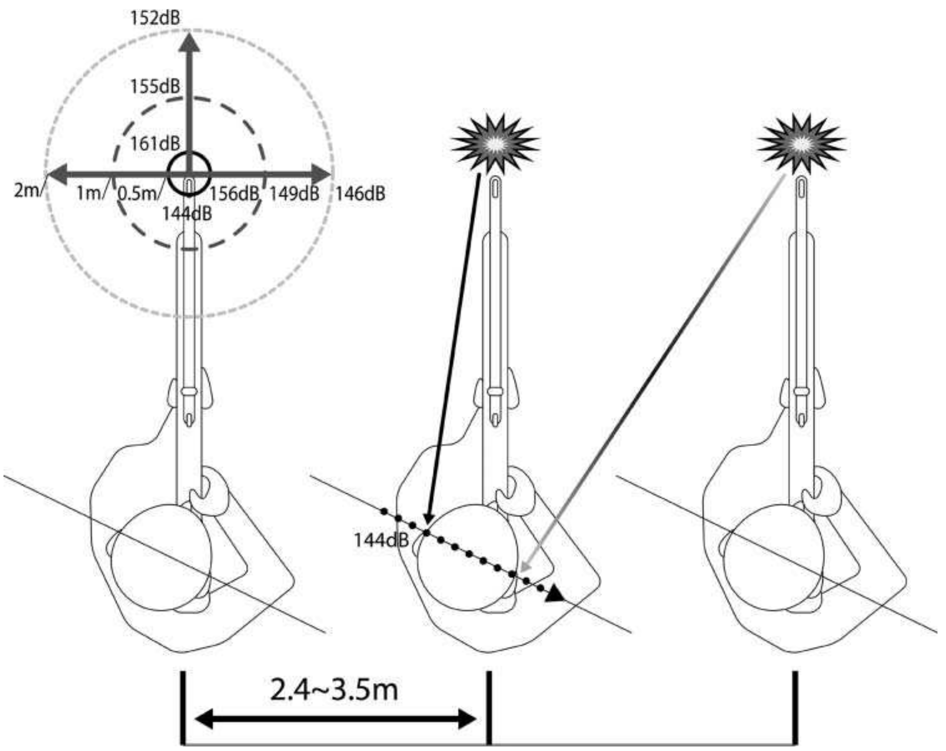

FIGURE 4. No significant lateralization of symptoms was found. Considering the proximity of lanes to each other and the characteristics of K2 rifle noise, the distant ear could be affected by an adjacent gunner's rifle noise.

a sufficient distance should be established between firing lanes, or soundproof walls should be installed between lanes.

Acoustic noise trauma has been reported to be caused by an abrupt explosive sound that causes mechanical injuries to the structures of the middle and inner ears. It is now widely accepted that biochemical changes or changes in the functional unity of the outer hair cells and auditory nerve fibers can induce cell destruction and hearing loss.[2,5,13] While the pathophysiology of subjective tinnitus is not well established, perhaps the most accepted hypothesis is that loud noise or trauma to the head or neck causes injury to intracochlear hair cells. This consequently causes the activation of repeated electric simulation of the central auditory pathway, which is perceived as sound by the patient.[14] In cases of acute noise trauma, most patients report tinnitus as an early symptom.[1,3,6] Therefore, if the cause-and-effect relationship of rifle shooting were clear, then patients complaining solely of tinnitus should be included in the diagnostic criteria and analysis. Consequently, of all the symptoms reported by acoustic trauma patients, the most prevalent was tinnitus. In cases without subjective hearing loss, the result of hearing loss on the affected side was more severe than the unaffected side, but the patients did not report subjective discomfort with regard to their hearing. In comparing THI scores, the patient group had a higher mean score (Table I).

The most common subjective symptom was tinnitus, and the level of discomfort expressed by these patients with regard to tinnitus was more severe than their discomfort associated with hearing loss. Currently, noise-induced hearing loss, or acoustic trauma, is not diagnosed by tinnitus alone. Although the level of hearing loss is not proportional to the level of tinnitus, the greatest source of discomfort for patients was tinnitus. Therefore, it should be included as a criterion for diagnosing acoustic trauma, and special attention should be paid to its treatment.

In general, occupational noise-induced hearing loss exhibits a C5 dip pattern, with the largest decrease at 4.0 kHz in the early period.[15,16] In contrast, cases of acoustic trauma demonstrate a normal hearing threshold in conversational range, with a pattern of gradual increase observed with higher tones. Since the frequency characteristics of the K2 rifle exhibit a maximal value in the vicinity of 1500 Hz,[4] it is believed that the frequency of the causative noise and the frequency of hearing loss are not related.[17] As such, in acoustic trauma cases, a high frequency hearing test should be performed regardless of the frequency level of the causative noise. If hearing tests are performed only in the range of the inciting sound and not in the higher frequencies, acoustic trauma could be overlooked.

Reference audiograms and terminal audiograms should be obtained at enrollment and discharge from the army, respectively. Such tests were often ignored in South Korea before 2009, and such was the case in our study. A reference audiogram at the time of enrollment was performed on only a few patients. Consequently, the hearing level prior to and after the development of acoustic trauma could not be compared.

Thus, our comparison between the patient group and the control group was limited to the same time point, but paired comparison was not possible.

Effective treatments for noise-induced hearing loss, particularly acoustic trauma, are not available. However, it is a disease that can be prevented by wearing earplugs.[6–8,18] Considering the acoustic characteristics of mass rifle gunfire, the military should enforce bilateral earplug use, improve firing range environments, and consistently evaluate hearing at high-frequency levels. Alternative means of managing tinnitus are also important.

CONCLUSION

Based on the results of this study, acoustic trauma induced by gunshot noise during mass rifle shooting has different characteristics from solo rifle shooting.

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REFERENCES

1. **Nottet, J.B., A. Moulin, N. Brossard et al.:** Otoacoustic emissions and persistent tinnitus after acute acoustic trauma. *Laryngoscope 116*:970–975 (2006).
2. **Kim, H.J.:** Noise induced hearing loss. In *Otorhinolaryngology Head and Neck Surgery*, J.S. Kim (ed.). Seoul, South Korea: Ilchokak Publishers, 2002. pp. 691–697.
3. **Mrena, R., S. Savolainen, U. Pirvola, et al.:** Characteristics of acute acoustical trauma in the Finnish Defense Forces. *Int. J. Audiol. 43*:177–181 (2004).
4. **Lee, S.T., and Y. Lee:** The measurement of firing noise of K2 rifle at close distance. *In Proceedings of the Korean Society for Noise and Vibration Engineering 14*(*11*):1123–1128 (2004).
5. **Dobie, R.A.:** Noise induced hearing loss. In *Head and Neck Surgery-Otolaryngology*, 2nd ed. B.J. Bailey, R.I. Kohut, and J.T. Vrabec (eds.). Philadelphia: Lippincott-Raven Publishers, 1998. pp. 2153–2163.
6. **Moon, I.S.:** Noise-induced hearing loss caused by gunshot in South Korean Military service. *Mil. Med. 172*(*4*):421–425 (2007).
7. **Demaertrlaere, L., and M. Van Opsral:** Treatment of acoustic trauma with hyperbaric oxygen. *Acta Otorhinolaryngol. Belg. 35*:303–314 (1981).
8. **Cakir, B.O., I. Ecran, S. Civelek, et al.:** Negative effect of immediate hyperbaric oxygen therapy in acute trauma. *Otol. Neurotol*. *27*:478–483 (2006).
9. **Keim, R.J.:** Sensorineural hearing loss associated with firearms. *Arch. Otolaryngol*. *90*:581–584 (1969).
10. **Kang, S.H., K.T. Song, B.K. Hong, et al.:** An epidemiologic and audiometric study of noise-induced hearing loss in subway workers. *Kor. J. Otolaryngol*. *41*(*10*):1248–1253 (1998).
11. **Newman, C.W., J.A. Wharton, and G.P. Jacobson:** Retest stability of the tinnitus handicap questionnaire. *Ann. Otol. Rhinol. Laryngol*. *104*:718–723 (1995).
12. **Anold, S., and R. Bukard:** Studies of interaural attenuation to investigate the validity of a dichotic difference tone response recorded from the inferior colliculus in the chinchilla. *J. Acoust. Soc. Am*. *107*(*3*):1541–1547 (2000).
13. **Lim, D.J.:** Functional structure of the organ of corti: A review. *Hear. Res*. *22*:117–146 (1986).
14. **Schleuning, A.J. Jr.:** Tinnitus. In *Head and Neck Surgery- Otolaryngology*, 2nd ed. B.J. Bailey, R.I. Kohut, and J.T. Vrabec (eds.). Philadelphia, Pa.: Lippincott-Raven Publishers, 1998. pp. 2199–2206.
15. **Johnsson, L.G., and J.E. Hawkins:** Degeneration patterns in human ears exposed to noise. *Ann. Otol. Rhinol. Laryngol*. *85*:725–739 (1976).
16. **Daniel, E.:** Noise and hearing loss: A review. *J. Sch. Health 77*:225–231 (2007).
17. **Jeon, J., K.M. Chon, E.K. Goh, et al.:** Frequencies of tinnitus and noise of the factory in noise-induced hearing loss. *Korean J. Otolaryngol*. *48*:142–145 (2005).
18. **Carter, N.L.:** Effectiveness of foam earplug hearing protection for artillerymen firing L118/119 105 mm howitzers. *Mil. Med. 154*(*9*):473–476 (1989).