ORIGINAL ARTICLE

Long-term Follow-up of Sensorineural Hearing Loss in Patients Exposed to Explosions

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OBJECTIVE: This prospective follow-up study assesses and quantifies the improvement of sensorineural hearing loss in patients with an abnormal audiogram obtained shortly after exposure to an explosion.

PATIENTS AND METHODS: Fifty-two patients (31 men, 21 women [104 ears]; mean age, 43 ± 18 years) experienced a sensorineural hearing loss confirmed within 4 hours after exposure to an explosion. Fifty-four ears were followed up with repeat audiograms over 4 to 6 years, and 50 ears were monitored for 1 year.

RESULTS: In the 104 ears studied, the mean hearing thresholds shortly after the explosion were 22 dB (pure tone average of speech frequencies) and 41 dB (mean of high frequencies). Of those patients monitored for 4 to 6 years, 56% showed an improvement of more than 10 dB. The average improvement for that period of time was 12 dB for speech frequencies ($P < .0001$) and 10 dB for high frequencies ($P < .03$). No significant difference in the percentage or extent of improvement was found according to the subjects' sex or age. Sixty-three percent of the overall improvement in speech frequencies occurred during the first 2 months, and the remaining improvement was noted during subsequent years.

CONCLUSION: A relatively small but significant improvement in sensorineural hearing loss occurs in patients exposed to an explosion. This study is distinctive because the initial audiograms were obtained within hours after the explosion and because of the long-term follow-up. The results may help to determine the prognosis for hearing in patients exposed to a blast.

In humans, the ear is one of the organs most sensitive to the effects of blast. Many patients exposed to explosions experience degrees of severe temporary deafness, and some have claimed that immediately after the explosion, they could not hear at all.[1] Descriptions of hearing loss after an explosion date from the sixteenth century and have been reported in the otologic literature since that time.[2]

In a typical explosion, the explosive material suddenly changes from a solid to a gaseous state. This change causes a massive increase in volume, which results in a rapid change in air pressure that expands with tremendous force in all directions and is followed by a flow of gas consisting of combustion products. This gaseous flow forms the short positive-pressure phase and the relatively long negative-pressure phase of the blast, both of which damage the middle and inner ear. The resulting hearing loss can be conductive, sensorineural, or mixed.[3,4] Conductive hearing loss is most often a result of tympanic membrane perforation and is only rarely caused by damage to the ossicles.[5,6] In most cases, a conductive hearing loss improves spontaneously or can be resolved with surgical treatment if the perforation does not heal.[6,7] Sensorineural hearing loss (SNHL), which is the focus of this study, poses a significant problem to patients and to date cannot be effectively treated.

During the past few decades, a relatively large number of studies have reported the results of follow-up in patients with a tympanic membrane perforation after exposure to an explosion.[5-10] These reports include the recently published results of the Omagh bombing in Northern Ireland[9] and those from a large series of patients with perforated eardrums sustained during the war in the Balkans.[7] In contrast, the number of studies reporting the monitoring of patients with SNHL caused by blast appears to be limited.[8,11-12] The results in those studies conflict, and the initial audiograms were obtained days to weeks after the trauma occurred.

In a previous study, we described the audiometric configurations of SNHL in a large number of patients exposed to an explosion and found that there was no single typical audiometric pattern, although it appeared that the damage was more evident in high audiometric frequencies.[13] The main purpose of our study was to assess and quantify the extent of the improvement of SNHL in patients with an abnormal audiogram obtained shortly after exposure to an explosion. This is of importance for 2 reasons: to offer clinicians insight into the prognosis for hearing in patients with SNHL after an explosion and to provide a better understanding of the mechanism of damage to the inner ear, which has not been established. This study is distinguished by a long-term follow-up of up to 6 years and the fact that the initial audiograms were obtained within hours after the exposure.

PATIENTS AND METHODS

Fifty-two patients (31 men and 21 women [104 ears]; mean ± SE age, 43 ± 18 years; age range, 12-75 years) who were exposed to 1 of 5 different explosions that occurred in Jerusalem, Israel, from 1995 through 1998 were included in the study. All subjects exhibited SNHL, which was demonstrated in the results of the initial audiogram conducted hours after the explosion. Each subject was diagnosed as having SNHL when his or her audiogram showed a hearing loss of more than 20 dB at any of the frequencies used in testing. All subjects were followed up for 1 to 6 years. Patients who were examined immediately after the explosion but did not return for follow-up examination were excluded. Additional reasons for exclusion from the study were suspicion of malingering or a history of previous hearing loss without a prior audiogram, previous ear disease, or a perforation or pathologic middle-ear condition that had not been assessed with bone-conduction audiometry.

Upon arrival to the hospital, all patients underwent a thorough emergency evaluation and treatment for their general physical injuries in the emergency department. Before being either admitted to the inpatient service or discharged from the emergency department, each patient also received a thorough otolaryngologic examination. For most patients, an audiogram was obtained within 4 hours after the blast as part of this emergency evaluation. Injured subjects who required stabilization and acute care underwent an audiometric evaluation within 4 days after the explosion. The 104 ears included in this study were examined in 2 to 3 follow-up audiograms obtained during the first year after the explosion that caused injury. During 2001 (4 to 6 years after the explosion), each subject was recalled to our clinic for an audiogram and interview. Twenty-seven subjects (54 ears) returned for an audiometric examination in 2001. The initial evaluation and subsequent follow-up interviews included a detailed history of previous hearing impairment and otologic disease, although the results of audiograms performed before the respective explosion were not available for most of the subjects. Audiometric assessment was performed with a clinical audiometer (Orbiter 922; Madsen Electronics, Minnetonka, Minn, USA) in a sound-attenuated booth.

Initial and follow-up hearing levels were quantified by 3 values: the average of speech frequencies (0.5, 1, or 2 kHz), the average of high frequencies (4, 6, or 8 kHz), and the average of all frequencies. First, the extent and percentage of improvement were assessed. Then, the extent of improvement was compared between female and male subjects and between young (< 50 years) and old (≥ 50 years) age groups. To determine the significance of the improvement and to compare the extent of improvement according to age group and sex, the Student t test was used. We also attempted to determine when during the follow-up period most of the improvement occurred and after which point in time no additional improvement occurred. We classified all the audiograms into groups based on 4 points in time after the blast: initial (hours after the blast), 2 months, 1 year, and 4 to 6 years after the exposure. Because only 8 patients (16 ears) underwent an audiometric assessment at all 4 points in time, we averaged the results of all the audiograms conducted at each time point (104 initial audiograms, 64 audiograms performed 2 months after the explosion, 50 performed 1 year after the explosion, and 54 performed 4-6 years after the explosion).

RESULTS

Initial hearing loss

Fifty-two patients (104 ears) who were exposed to an explosion and underwent audiometry shortly after the blast were included in the study. The mean hearing threshold immediately after the explosion was 22 ± 11 dB for the average of speech frequencies (0.5, 1, and 2 kHz), 41 ± 22 dB for the average of high frequencies (4, 6, and 8 kHz) and 33 ± 16 dB for the average of all frequencies.

Long-term hearing follow-up

Twenty-seven subjects (54 ears) who were monitored for 4 to 6 years had an initial average hearing loss similar to that of the subjects in the larger group (104 ears). The average improvement for that period of time was 12 dB for the average of speech frequencies (P < .0001), 10 dB for the average of high frequencies (P < .03), and 10 dB for the average of all frequencies (P < .001). The results of the average initial audiogram and the audiogram after 4 to 6 years for the 54 ears are shown in Figure. Fifty-six percent of the patients showed an improvement of more than 10 dB for speech frequencies, and 33% showed an improvement of more than 15 dB. With respect to high frequencies, 33% showed an improvement of more than 10 dB, and only 26% of the ears evaluated showed an improvement of more than 15 dB. There appeared to be no statistically significant difference in the extent of improvement in speech and high frequencies between the young and old age groups and between the sexes, according to the results of the Student t test (Table).

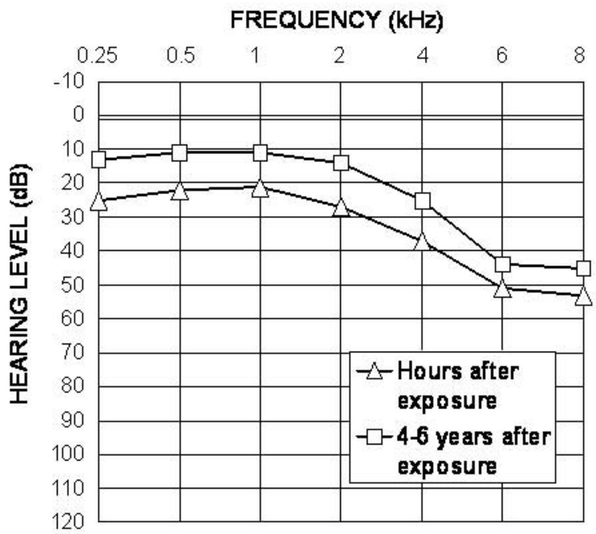

Figure: Results of audiometric testing in patients exposed to an explosion.

Table: Mean values of improvement in sensorineural hearing loss by subgroup of study subjects

Subgroup	All ears	Male	Female	Young <50	Old ≥50.
Improvement in speech frequencies (dB)	12	11	12	12	11
Improvement in high frequencies (dB)	10	9	10	11	6

Timing of improvement

Speech frequencies: Sixty-three percent of all improvement was seen within 2 months of the explosion, and 72% occurred within 1 year. The remaining improvement occurred between the 1-year and the 4- to 6-year audiograms. The difference between hearing 1 year and 4 to 6 years after the exposure was statistically significant ($P < .03$).

High frequencies: Sixty-seven percent of the improvement occurred within 2 months after the explosion, and the remaining improvement occurred within the first year. There was no additional improvement between the 1-year and the 4- to 6-year measurements. The difference between hearing 2 months after the blast and hearing 1 year after exposure was not significant.

DISCUSSION

This follow-up study has shown that there is a relatively small but significant improvement in SNHL in patients with an abnormal audiogram obtained immediately after an explosion. We found that the average extent of the improvement was 12 dB in speech frequencies and 10 dB in high frequencies. Most of the improvement occurred within the first few months after the explosion. A small additional improvement that occurred primarily in the low frequencies was noted during the following years. It appeared that improvement did not depend on the patient's age or sex.

As mentioned in the introduction, most follow-up studies on patients with a blast injury address tympanic membrane perforation and conductive hearing loss; only a limited number of studies focus on SNHL. Ziv and colleagues[11] monitored patients from 2 blast incidents and showed that 1 to 3 years after exposure, 60% of those subjects had hearing within the normal range. The initial hearing loss and extent of improvement were not noted. Kerr[14] conducted a series of audiograms on 1 patient from 2 hours after an explosion until 12 days later, and in that subject, a substantial recovery in hearing was noted. Walsh and colleagues[8] monitored 9 patients with SNHL caused by the London Bridge explosion. The hearing loss resolved within weeks in all patients except 2, who demonstrated a residual hearing loss 8 to 12 months after the explosion. In a detailed report, Van Campen and colleagues[12] conducted a follow-up study of the victims of the Oklahoma City bombing. The auditory status of the group monitored was significantly compromised and remained unchanged at the end of the year after the blast. Our study is distinctive because the initial audiograms were obtained within hours after the explosion and because a relatively large number of subjects were monitored for a long period of time (up to 6 years). Our results are somewhat between those of Ziv and colleagues,[11] whose subjects showed a substantial sensorineural hearing improvement, and those of Van Campen and colleagues,[12] whose patients demonstrated no improvement during the first year after the exposure.

Although the 12-dB improvement in the speech frequencies of our subjects appears to be small, the average initial hearing loss of the group was only 22 dB. Thus an improvement of 12 dB indicates a return to a hearing zone within normal limits. However, the 10-dB improvement in high frequencies showed that abnormal hearing persisted in that category.

One of the problems of our study was the substantial number of patients who were lost to follow-up. There were several reasons for that attrition: Many of the injured patients were not residents of Jerusalem and returned to their home after their initial treatment, a few other patients suffered severe psychologic trauma and refused to return to the hospital, and others who did return for follow-up examinations were suspected of malingering and were therefore excluded from the study. We were concerned that the large number of patients lost to follow-up might influence the results of the study, but the SNHL was similar in the initial group and the long-term follow-up group.

The question of previous hearing impairment poses a problem in our study. We were careful to exclude patients with a history or suspicion of prior hearing loss; however, most of the subjects had not undergone a previous audiogram. Surprisingly, old age did not influence the overall recovery rate of the inner ear. It seems that with respect to speech frequencies, the older inner ears improved to the same extent as did the younger ones. In the high frequencies, there seemed to be a small difference in improvement, which was not significant. We chose to show the results of the comparison between the subgroups of patients younger and older than 50, but similar results were obtained when additional different subgroups were compared. This finding might be important in the understanding of the mechanisms that cause inner ear damage after a blast.

Another issue that should be addressed is the timing of the improvement in SNHL. Because only 8 patients (16 ears) underwent audiometry at all time points, we initially averaged the results of all the audiograms conducted at each time point and compared the results. We found that most of the improvement occurred during the first few months after the explosion, but there was an additional minor improvement during the following years. Definite conclusions cannot be drawn regarding this issue because of the relatively small group studied and because of the methodological limitations of this study. However, physicians with patients who have sustained a blast injury must remember that an improvement in SNHL can last longer than previously thought, especially in the low frequencies. The possible difference in the timing of improvement between the low and high frequencies may also reflect the mechanism of injury.

It appears there is a relatively small (10-12 dB) but significant improvement in SNHL after blast exposure. Most of the improvement in hearing occurs within the first few months after the explosion, but additional improvement may occur during subsequent years. In our study, the extent of the improvement did not depend on the subject's age or sex. These results contribute to a better understanding of the mechanism of inner ear damage resulting from blast injury and provide information useful in determining the prognosis for hearing in patients exposed to an explosion.

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