Audiometric Configurations Following Exposure to Explosions
Ronen Perez, MD; Netta Gatt, MD; David Cohen, MD

Objective: To determine the configurations in pathologic audiograms obtained in patients shortly after exposure to an explosion.

Design, Setting, and Patients: Audiograms were performed in 143 patients (286 ears; 76 males and 67 females, with a mean age of 34.6 years [range, 11-79 years]) sent to the Department of Otolaryngology and Head and Neck Surgery in a city hospital located in the center of Jerusalem, Israel, after being injured in 4 severe explosions occurring in Jerusalem during 1995-1997. Most of the audiograms were obtained within 4 hours after the explosion, and the remaining were obtained within 4 days of the explosion.

Results: Of 200 pathologic audiograms, 93 (46%) showed a downward slope configuration, 82 (41%) showed a dip configuration, and 25 (12%) were flat. There were 38 audiograms (19%) with 6-kHz dips. In 82% of the patients, the audiometric configurations were similar in both ears. Patients with a slope configuration on the audiogram were significantly older than those with a dip configuration (mean age, 40.8 vs 32.8 years; \(P<.01\)).

Conclusions: There does not appear to be a single typical audiometric configuration in patients exposed to explosions. The slope and dip configurations are most frequently seen and are approximately equal in their incidence. This observation may lead to better understanding damage to the inner ear as a result of an explosion. This study is distinctive because of the large number of audiograms obtained and the fact that most of them were obtained immediately after the explosion.


Hearing loss as a result of excessive stimulation of the inner ear was first reported in 1872.\(^1\) The damage may be a result of exposure to continuous noise, impulse noise, or blast waves.\(^2,4\)

In an explosion, the explosive material is suddenly changed from a solid to a gaseous form. This change results in a sudden increase in volume and a consequent rapid change in pressure. The massive pressure change that is generated by the explosion travels in all directions through air at a velocity greater than the speed of sound. Behind it is a region of gas flow consisting of combustion products. These form 2 phases of the blast: a short positive-pressure phase and a relatively long negative-pressure phase. In addition, there is an impulse noise that reaches the inner ear shortly after the blast wave. The distinction between blast and impulse noise is arbitrary, but there are several characteristics that are useful to differentiate between them: (1) Peak high pressures resulting from blast are often 10 to 20 kPa, while those resulting from an impulse noise are usually less than 2 kPa (160 dB). (2) Blast involves the movement of considerable volumes of combustion products and air, while an impulse noise does not. (3) An impulse noise is often associated with low-frequency mechanical clatter.\(^2,4\)

In 2 of the audiological studies on various noise traumas, the authors\(^5,6\) described an audiometric configuration that is typical, especially for long-term exposure, the “4-kHz dip.” There are also reports\(^7\) of hearing loss after explosions that address the configurations of pathologic audiograms. Many audiometric configurations have been described: single and double dips, high- and low-frequency pathologic findings, and flat and slope configurations. In most of these studies, the audiograms were obtained days to weeks after the trauma in relatively small samples (35-81 pathologic audiograms).

In this study, we examined the audiometric configurations that reflect inner ear damage after exposure to explo-
PATIENTS AND METHODS

In the study, we examined 143 patients (286 ears) who were sent to our hospital after receiving injuries in 4 bomb explosions that occurred in Jerusalem, Israel, during 1995-1997. Fifty patients (100 ears) were injured in 2 explosions occurring on city busses (only 14 of these 50 patients were inside the exploding bus; the remaining 36 were in adjacent vehicles or in the immediate area); 93 patients (186 ears) were injured in 2 explosions in open areas in the center of the city (an open-air marketplace and a cafe-lined pedestrian street). The mean ±SE age of the injured patients was 34.6±17.5 years (range, 11-79 years). There were 76 males and 67 females.

Most patients sustained mild or moderate general physical injuries. They received thorough emergency evaluation and treatment in the emergency department. Before admission to the inpatient service or before discharge from the emergency service, each victim received a thorough examination of the ear, nose, and throat. For most patients, an audiogram was obtained within 4 hours of the blast. Patients with severe injuries who required stabilization and acute care underwent audiometry within 4 days. We excluded 12 patients who underwent audiometry later. Audiometry was conducted with a clinical audiometer (Orbit 922; Madsen Electronics, Minnetonka, Minn). The audiograms were obtained in sound-attenuated booths.

The otolaryngology and head and neck evaluation included a detailed history of previous hearing impairment or otological disease. Unfortunately, previous audiograms were not available for the majority of patients with a suspected history of hearing loss or ear disease. These patients were excluded.

Because of the shortage of time, the stressful situation of the patients, and our desire to conduct audiometry immediately, in most cases, we performed only air conduction audiometry. We performed bone conduction audiometry in a minority of the patients. Because we were concerned with the inner ear, possible sensorineural hearing loss was the major focus. Patients whose tympanic membrane was perforated as a result of blast injury and who did not undergo bone conduction audiometry were excluded. For this reason and for suspected previous hearing loss, we excluded 25 ears, leaving 261 ears.

We defined a pathologic audiogram as one that showed a hearing loss higher than 20 dB at any of the frequencies; all others were defined as normal. Using this criterion, audiograms were normal in 61 ears and pathologic in 200 ears. The audiograms were divided according to the audiometric configuration and not according to the degree of hearing loss. The criteria for definition of each audiometric configuration were derived from a previous study and were based on the general configurations observed in the present study. We defined the following configurations in the audiometric results: dip, hearing loss at a given frequency that was 15 dB or more than that of the adjacent frequencies; slope, hearing loss that gradually increased at higher frequencies without recovery of hearing in the highest frequencies; and flat, when the difference in hearing loss between all the frequencies tested did not exceed 15 dB.

To determine the significance of the age difference between the major configuration groups, we used analysis of variance (single factor) and the t test.

RESULTS

We included 143 patients (286 ears; 76 males and 67 females) who were exposed to explosions and underwent audiometry. We excluded 25 ears because of suspected previous hearing loss and perforated tympanic membrane (when bone conduction audiometry was not conducted). Of the remaining 261 audiograms, 200 were pathologic and 61 were normal according to our criteria. The mean age of all the included patients with pathologic audiograms was 36.5 years.

The 200 audiograms were initially grouped according to the general configuration: there were 93 (46%) with a slope configuration, 82 (41%) with a dip configuration, and 25 (12%) with a flat configuration. We then subdivided the first 2 groups. In 58 (62%) of the 93 audiograms with a slope configuration, the downward slope started at high frequencies (≥2 kHz), while in 35 (38%), the downward slope started at low frequencies (<2 kHz). In 67 (82%) of the 82 audiograms with a dip configuration, the peak of the dip was in high frequencies (≥2 kHz), and in only 15 audiograms (18%), the dip was at low frequencies (<2 kHz) (Figure). There were a high number of audiograms with 6-kHz dips (38 audiograms: 19% of all audiograms and 46% of those with a dip configuration).

Of 125 patients (18 were excluded because of suspected previous hearing loss or a perforated tympanic membrane in at least 1 ear), the audiometric configurations in both ears were symmetric in 103 (82%) and asymmetric in 22 (18%). Of the 22 patients with asymmetric configurations, 17 had a normal audiogram in one ear and a pathologic audiogram in the other. Only 5 patients had a different pathologic audiometric configuration in each ear.

The mean ±SE ages of the patients with slope, dip, or flat configurations were 40.8±18.5 years, 32.8±17.4 years, and 32.2±13.8 years, respectively. The difference between the ages of the groups with slope and dip configurations was significant (P<.01). Of the 200 patients with pathologic audiograms, 116 (58%) were male and 84 (42%) were female. The sex distribution was similar among the 3 audiometric configurations.
There were 14 patients (28 ears) who were inside the closed cavity of the exploding bus. This group was small compared with the study group because of the lower survival rate of individuals inside the bus. Of 28 audiograms obtained, 26 were pathologic. Of the 26, there were 19 (73%) with a downward slope configuration, 2 (8%) with a dip configuration, and 5 (19%) with a flat configuration.

Of the 143 patients included in the study, 33 had 44 perforated tympanic membranes (as mentioned previously, we excluded some of the ears in which bone conduction audiograms were not obtained). Of the 44 perforated tympanic membranes, 13 were detected in the small group of 14 patients (28 ears) who were inside the closed cavity of the bus (46% rate). The remaining 29 perforated tympanic membranes were observed in the 129 patients (258 ears) who were in open areas (11% rate).

A range of studies examined the audiological impact of exposure to blast. Some previous studies mentioned the configuration of pathologic audiograms. The first detailed report was a retrospective study published in 1970 by Teter et al., who observed 4 audiogram configurations in 81 ears of soldiers exposed to blast. Of the audiograms, 28% had a slope configuration in high frequencies and the remaining had a dip configuration between 1 kHz and 4 kHz. Singh and Ahluwalia observed a predominantly flat configuration on the audiograms of patients injured in explosions in armed conflict. Ziv et al. observed a high percentage of 4-kHz dips, as well as frequent slope and dip configurations. Pahor observed mainly high-tone slopes and flat curves in the audiograms of patients involved in bombings in Birmingham, England. In a relatively recent detailed work, Bruins and Cawood examined patients exposed to a lorry explosion in Peterborough, England. There were 35 pathologic audiograms, and the following audiometric configurations were noted: slope in high frequencies in 34%, 6-kHz dip in 26%, and flat in 17%.

Although many investigators have described one configuration as dominant, the configurations vary across studies. In general, previous research has been limited by relatively small samples, few pathologic audiograms, and delay in obtaining audiograms. In our series, there was no single dominant configuration in the 200 pathologic audiograms that were obtained soon after the explosion. We observed a high incidence of 6-kHz dips (19%), a finding that is consistent with the high rate (26%) observed by Bruins and Cawood. This finding might have implications for understanding the mechanism of the damage to the inner ear.

COMMENT

We studied the audiograms of 143 patients (286 ears) exposed to explosions, and we characterized the audiometric configuration of their hearing loss. We observed the following audiometric configurations: slope (46%), dip (41%), and flat (12%). We found a significant difference between the mean age of patients with slope and dip configurations (40.8 and 32.8 years, respectively; P < .01). In 82% of the patients, the audiometric configurations were similar in both ears.

A range of studies examined the audiological impact of exposure to blast. Some previous studies mentioned the configuration of pathologic audiograms. The first detailed report was a retrospective study published in 1970 by Teter et al., who observed 4 audiogram configurations in 81 ears of soldiers exposed to blast. Of the audiograms, 28% had a slope configuration in high frequencies and the remaining had a dip configuration between 1 kHz and 4 kHz. Singh and Ahluwalia observed a predominantly flat configuration on the audiograms of patients injured in explosions in armed conflict. Ziv et al. observed a high percentage of 4-kHz dips, as well as frequent slope and dip configurations. Pahor observed mainly high-tone slopes and flat curves in the audiograms of patients involved in bombings in Birmingham, England. In a relatively recent detailed work, Bruins and Cawood examined patients exposed to a lorry explosion in Peterborough, England. There were 35 pathologic audiograms, and the following audiometric configurations were noted: slope in high frequencies in 34%, 6-kHz dip in 26%, and flat in 17%.

Although many investigators have described one configuration as dominant, the configurations vary across studies. In general, previous research has been limited by relatively small samples, few pathologic audiograms, and delay in obtaining audiograms. In our series, there was no single dominant configuration in the 200 pathologic audiograms that were obtained soon after the explosion. We observed a high incidence of 6-kHz dips (19%), a finding that is consistent with the high rate (26%) observed by Bruins and Cawood. This finding might have implications for understanding the mechanism of the damage to the inner ear.

Audiograms with slope, dip, and flat audiometric configurations in patients with various degrees of hearing loss (see the “Patients and Methods” section for the definitions of the configurations).
Another possible limitation of the present study is that we were unable to measure the conductive component of hearing loss in most of the audiometric examinations in this study. Since we could not perform bone conduction tests on most of the patients, we examined only the sensorineural hearing loss and excluded patients with perforated tympanic membranes without bone conduction studies.

Sensorineural hearing loss shortly after an explosion is composed of temporary threshold shift and permanent threshold shift.\(^2\)\(^-\)\(^4\) The temporary component may last for hours to days; the exact time varies between patients and different studies. Pratt et al\(^1\)\(^2\) attempted to differentiate between the 2 components using auditory brainstem evoked potentials in patients who had been exposed to a blast. Since our audiograms were obtained soon after the explosion, an important issue is to assess the role of the temporary threshold shift in our findings. We conducted follow-up audiometry in 92 of the ears with pathologic audiograms in this series, weeks to months after the exposure. Of the 92 follow-up audiograms, 87 (95%) retained the same audiometric configuration. In a study by Kerr,\(^1\)\(^3\) a series of audiograms were obtained in one patient between 2 hours and 12 days after the explosion. A recovery in hearing loss was noted, but the audiometric configuration remained the same. This finding implies in most cases that the audiometric configuration remains constant with time and that the temporary threshold shift component of the hearing loss does not affect the audiometric configuration.

In conclusion, based on the large number of patients in this study, there does not appear to be a single typical configuration on the audiograms of patients exposed to explosions. These findings support the fact that the damage to the inner ear as a result of an explosion is different from that of impulse noise without blast or noise-induced hearing loss, in which typical curves are more often shown on the audiograms.

Accepted for publication April 11, 2000.

We thank our audiologist, Marcia Romm, for her assistance in the study and Donald J. Cohen, MD, for his valuable comments.

Corresponding author: Ronen Perez, MD, Department of Otolaryngology and Head and Neck Surgery, Shaare Zedek Medical Center, PO Box 3235, Jerusalem, Israel (e-mail: perezro@internet-zahav.net).

REFERENCES