

Blast Injury of the Ear in a Confined Space Explosion: Auditory and Vestibular Evaluation

Jacob T. Cohen MD¹, Gil Ziv MD PhD¹, Joseph Bloom MD², Daniel Zikk MD¹, Yoram Rapoport MD¹ and Mordechai Z. Himmelfarb MD²

¹Department of Otolaryngology Head and Neck Surgery, and ²Unit of Hearing and Speech Disorders, Tel Aviv Sourasky Medical Center, Tel Aviv, Israel

Affiliated to Sackler Faculty of Medicine, Tel Aviv University, Ramat Aviv, Israel

Key words: blast injury, hearing disorders, balance disorders, electronystagmography, posturography

Abstract

Background: The ear is the most frequent organ affected during an explosion. Recognition of possible damage to its auditory and vestibular components, and particularly the recovery time of the incurred damage, may help in planning the optimal treatment strategies for the otologic manifestations of blast injury and preventing deleterious consequences.

Objective: To report the results of the oto-vestibular initial evaluation and follow-up of 17 survivors of a suicide terrorist attack on a municipal bus.

Methods: These 17 patients underwent periodic ear inspections and pure tone audiometry for 6 months. Balance studies, consisting of electronystagmography and computerized dynamic posturography were performed at the first time possible.

Results: Complaints of earache, aural fullness and tinnitus resolved, whereas dizziness persisted in most of the patients. By the end of the follow-up, 15 (55.6%) of the eardrum perforations had healed spontaneously. Hearing impairment was detected in 33 of the 34 tested ears. Recovery of hearing was complete in 6 ears and partial in another 11. ENG and CDP were performed in 13 patients: 5 had abnormal results on CDP while the ENG was normal in all the patients. Of the seven patients who complained of vertigo, only one improved and was free of symptoms 1 month after the explosion.

Conclusion: Exposure to a high powered explosion in a confined space may result in severe auditory and vestibular damage. Awareness of these possible ear injuries may prevent many of the deleterious consequences of such injuries.

IMAJ 2002;4:559-562

The increasing number of reports on blast injury is not surprising considering the worldwide escalation of violence – both military and among civilians – as well as the increased use of combative means and explosives with the intent of carrying out mass killing.

The main physical damage caused to the ear by a blast, the primary blast injury, is via the positive wave created during a detonation. Secondary injuries may result from flying objects, and tertiary injuries from the hurling of the victims by the force of the explosion [1,2]. Since it is a gas-filled structure that is directly exposed to the surrounding air, the ear is not surprisingly the site most sensitive [3], susceptible [4] and frequently damaged by blast waves [5,6]. Ear injury is mainly due to the mechanical damage of the blast wave [7]. Middle ear injuries include tympanic membrane

rupture, ossicular discontinuity, dislocation and bleeding – all of which might produce a conductive hearing loss [8]. Inner ear injury may result in temporary or permanent sensorineural hearing loss and in tinnitus [8]. Vestibular damage, although conceivably due to the close anatomic location of the utricle and saccule to the footplate of the stapes, has been rarely reported [9,10], with these studies attributing the injury to saccular and utricular damage or to a direct blow to the head. Ruptures of the saccule and the utricle were, indeed, described in postmortem findings in persons killed during an explosion [10].

One of the considerations in planning the management of tympanic membrane rupture and other middle ear injuries is the length of recovery time of such injuries. As a general rule, many of the ear injuries recover or stabilize during the first few months following the incident, without intervention [7]. Less is known about the clinical presentation and recovery time course of the vestibular component.

The purpose of the present study is to describe the initial evaluation and further follow-up of oto-vestibular injuries in 17 survivors of a suicide terrorist attack on a municipal bus in Tel Aviv, Israel.

Patients and Methods

On the morning of 23 October 1994, a terrorist equipped with high powered explosives (equivalent to about 15 kg of TNT) detonated himself while sitting in the front section of a municipal bus. In this attack 22 people lost their lives and 48 were wounded. All the wounded were referred to a tertiary trauma center and 23 were hospitalized. All 23 patients underwent complete physical, otoscopic and oto-neurologic examination upon admission. Seventeen of them were followed for 6 months in the otolaryngology outpatient clinic. Sixteen of the 17 survivors reported in this study had been sitting in the rear of the bus, and the other patient was a woman who had been standing on the sidewalk near the back door of the bus.

In addition to the oto-neurologic examination, the patients underwent an auditory and balance assessment. Pure-tone audiometry (Orbitek 922, Madsen Electronics, Tastrup, Denmark) was first performed between the first and third day after the explosion and then once every 4–6 weeks thereafter (including ear inspection on each visit) for up to 6 months. Their balance system was evaluated by means of electronystagmography (ICS Medical Corporation,

ENG = electronystagmography

CDP = computerized dynamic posturography

Schaumburg, IL, USA) and computerized dynamic posturography (EquiTest, NeuroCom International Inc, Clackamas, OR, USA). ENG assesses the vestibular system by recording eye movements, including nystagmus that results both from changes in a subject's position and in response to a thermal stimulus of the horizontal semicircular canal. The test results of CDP reported in this study relate to the sensory organization test. This subtest evaluates the patient's ability to integrate sensory cues from the vestibular, visual and somatosensory systems and to select the appropriate sensory input(s) in order to maintain balance. These tests were performed in 13 patients at the first time possible. ENG and CDP were not tested in four patients for technical reasons.

Results

The oto-vestibular system of 17 survivors (7 males and 10 females aged 18–65 years, median 28 years) who were subjected to blast injury of the ear was evaluated periodically for 6 months.

The patients' complaints at the time of admission to the hospital and the course of those complaints are presented in Table 1. The most common otologic complaints were aural fullness and pressure (15 patients, 88.2%) and tinnitus (15 patients, 88.2%), followed by otalgia (9 patients, 52.9%) and dizziness (7 patients, 41.2%). Discharge (blood, and later infected matter) was observed in 9 patients (52.9%). Only after the third visit (about 3 months after the explosion) did some of the patients report relief of aural fullness and dizziness. By the end of the 6 month follow-up period, however, 11 patients (73.3%) continued to suffer from aural fullness and 5 (71.4%) from dizziness. Amelioration of tinnitus and otalgia was observed about 2 months after the explosion, but 6 (40%) patients still complained of tinnitus and only 2 (22.3%) complained of earache by the end of follow-up. Discharge from the ears was resolved in all cases by the end of the sixth week after the explosion.

All patients but one had at least one perforated eardrum, with a total of 27 perforated tympanic membranes among them. Perforation of the affected eardrums was large (subtotal) in 16 patients, medium sized in 9 (involving about half of the tympanic membrane), and small in 2 (involving one quadrant of the tympanic membrane). Spontaneous recovery of the tympanic membrane perforation was gradual and, by the end of follow-up, 12 perforations (44.4%) were still present [Table 2].

Table 3 summarizes the types of hearing loss among the study patients. The most common was the mixed type (21 ears, 61.8%). A sensorineural hearing loss was found in 9 ears (26.5%), conductive impairment in 3 ears (8.8%), and normal hearing in only one ear. Recovery of the hearing impairment was gradual during the follow-up period, except the loss at 8.0 KHz that was seen to have already recovered after 4–6 weeks. Hearing resolved in two of the ears with conductive impairment as well as one of the ears with mixed hearing loss. The conductive component of the mixed hearing loss in nine ears healed, leaving a sensorineural hearing loss in these ears. The sensory element of hearing loss recovered in three ears with mixed hearing loss, and complete recovery was observed in three of the ears with sensorineural hearing loss.

Table 1. Symptoms at the Initial and 6 month follow-up evaluations (17 patients)

Symptoms (No. % total)	Improved	Disappeared	No change
Aural fullness (15–88.2%)	1 (6.7%)	3 (20.0%)	11 (73.3%)
Tinnitus (15–88.2%)	2 (13.4%)	7 (46.6%)	6 (40.0%)
Otalgia (9–52.9%)	0	7 (77.8%)	2 (22.3%)
Dizziness (7–41.2%)	1 (14.3%)	1 (14.3%)	5 (71.4%)
Discharge (9–52.9%)	0	9 (100%)	0

Table 2. Healing rate of eardrum perforation (34 ears)

Otосcopy	No. of perforations
First inspection	27 (100%)
Second inspection	23 (85.2%)
Third inspection	21 (77.8%)
Fourth inspection	17 (63.0%)
Fifth inspection	14 (51.8%)
Sixth inspection*	12 (44.4%)

* At the final follow-up, 6 months since the event

Table 3. Initial hearing loss and follow-up (34 ears)

Initial type of hearing loss	Hearing status at the 6 month follow-up			
	SNHL	CHL	MHL	NH
MHL (21 ears, 61.8%)	9	2	9	1
SNHL (9 ears, 26.5%)	6	0	0	3
CHL (3 ears, 8.8%)	0	1	0	2
NH (1 ear, 2.9%)	0	0	0	1

SNHL = sensorineural hearing loss, CHL = conductive hearing loss, MHL = mixed hearing loss, NH = normal hearing.

ENG did not disclose any abnormality in the 13 patients who underwent it. The caloric test could not be done in two patients because they had large eardrum perforations. The CDP was within normal limits in 7 and abnormal in 6 of the 13 tested patients. All six patients with abnormalities on CDP complained of dizziness, and five of them continued to suffer throughout the 6 months follow-up. In five of the patients with CDP abnormalities, a multi-sensory dysfunction pattern and a vestibular loss pattern in one case were observed in the sensory organization test. Only one of the patients with normal CDP [Z.S., Table 4] had complained of vertigo but it subsequently disappeared and the symptoms had resolved by the time of the test. This patient was the woman who had been standing on the sidewalk outside the door of the bus, and she was hit by another patient who was ejected through the door by the force of the blast.

Seven patients (41.2%) suffered from dizziness. Five of them complained of a spinning sensation not related to movement, but no nystagmus was observed on physical examination. The other two suffered from positional vertigo. In one patient [Y.A., Table 4], a geotropic positioning nystagmus was observed on the Dix-Hallpike maneuver in the left hanging-head position, indicating paroxysmal positional vertigo syndrome. This subject had also been hit on the head by a flying object. No nystagmus was observed in the remaining patient [S.E., Table 4].

Table 4. Symptoms, signs, balance workup and follow-up of 7 patients with vestibular complaints

Patient Gender/age (yr)	Symptoms	Signs	ENG/CDP	Follow-up
B.M. F/26	Dizziness, left HL, bilateral tinnitus	Right small & left medium perforation, no nystagmus	Normal/MSD	Improvement
BH.T. M/26	Dizziness, bilateral HL, left tinnitus	Bilateral large perforation, no nystagmus	Normal, no caloric/MSD	No change
K.M. F/62	Dizziness, bilateral HL, no tinnitus	Bilateral large perforation, no nystagmus	Normal/MSD	No change
N.M. F/22	Dizziness, left HL, left tinnitus	Right small & left large perforation, no nystagmus	Normal/MSD	No change
Y.A. M/61	P-vert, bilateral HL, bilateral tinnitus	Bilateral large perforation, nystagmus on DH to L	Normal, no caloric/VLP	No change
S.E. M/24	P-vert, bilateral HL, bilateral tinnitus	Bilateral large perforation, no nystagmus	Normal/MSD	No change
Z.S. F/32	Dizziness, bilateral HL	No perforation, no nystagmus	Normal/normal	No dizziness

HL = hearing loss, DH = Dix-Hallpike, P-vert = positional vertigo, MSD = multisensory dysfunction, VLP = vestibular loss pattern

Discussion

The ear is the most common injured organ in the body following an explosion. In contrast to other sites of blast-related injuries, such as the lungs and the intestines, an injury to the ear has no devastating or life-threatening effects on the victims. Eardrum perforations, hearing loss and dizziness may, however, interfere with daily activities and have a telling effect upon the individual's quality of life.

Middle ear and auditory damage due to blast injury are well documented [7–13]. We report the auditory and vestibular workup of a cohort of patients who were exposed to and survived a very high powered explosive in a confined space.

The primary complaints of subjects exposed to blast injury of the ear include tinnitus, aural fullness, otalgia and dizziness [8–11,14]. Tinnitus is as common as hearing loss [9] and, in general, tends to resolve with resolution of hearing loss [8,15]. Tinnitus was reported to cease in almost all the patients [9]. However, a high percentage of persisting tinnitus similar to that of our study was reported by Bruins and Cawood [14]. In contrast to the results of our current study, aural fullness and earache are considered to be rare [14]. Moreover, among our patients, otalgia and aural fullness did not resolve in 20% and 52% respectively at the end of the 6 month follow-up. It is possible that the high percentage of aural complaints and the slow resolution derive from the effect of a very high power explosion within a confined space.

Rupture of the tympanic membrane is due to the mechanical pressure of the positive phase of the blast wave [8]. The incidence of eardrum perforation depends on the pressure parameters of the blast wave and reflections of power waves from the walls of confined spaces [7–10,12]. This may explain why all but one of our patients had at least one perforated eardrum, and why most of the perforations were large. It could be expected, then, that as high as 44.4% of the perforations did not heal completely by the end of the

6 month follow-up, since spontaneous healing relates to the size of the perforations [15,16] and to the blast intensity [17].

It has been postulated [18,19] that damage to the middle ear may have a protective effect on the inner ear. However, the high incidence of sensorineural hearing loss (isolated or mixed) in association with blast injury does not support this hypothesis [10]. This may be explained by the slowness of the defensive capacity of the middle ear muscles compared to the velocity of the blast wave, a characteristic that would prevent it from effectively protecting the inner ear [11,14]. Indeed, in the present study, 21 affected ears (61.8%) had a mixed (conductive and

sensorineural) hearing loss, whereas only 3 affected ears (8.8%) had a conductive loss alone. In agreement with other studies [11,13], isolated sensorineural hearing loss was found in 26.5% of the ears in our study.

Spontaneous closure of eardrum perforations is responsible for recovery of pure conductive losses and for the conductive component of mixed hearing losses. The sensorineural hearing loss is reversible immediately after the blast and in some cases may resolve as late as months after the injury [7]. Temporary threshold shift of hearing was attributed to reversible changes in the permeability of the lamina propria of the organ of Corti [7]. In fact, as reported by others [9], three of the ears with a sensorineural loss recovered completely as well as one ear with mixed loss at the end of the 6 months of follow-up in the present study. Looking at the overall picture, however, of the 33 originally recorded hearing losses of all types and severity, only 6 had returned to normal at the closure of this study [Table 3].

Balance disorders as a consequence of blast injury are considered uncommon [8–10]. When present, they were attributed to head injury [10]. Rare cases of perilymphatic fistula [16] and paroxysmal positional vertigo were also reported [8,10]. On the other hand, Shupak et al. [20] reported three subjects with evidence of peripheral vestibular damage following blast injury. In contrast to the other studies, 7 of our patients (41.2%) complained of dizziness. One of them was diagnosed as suffering from paroxysmal positional vertigo, and CDP indicated a multi-sensory deficit of the balance system in the others. At 6 months after the event, five patients continued to suffer from balance disorders. Similar results were described by Van Campen et al. [21]. These results indicate that vestibular damage as a consequence of primary or secondary blast injury should not be overlooked and should be evaluated with proper means such as ENG and CDP.

The high rate of spontaneous closure of eardrum perforations [9,10,22] favors a conservative approach. Cleaning the ears of foreign bodies, debridement and keeping the ears dry are recommended. Eardrops and antibiotics should be reserved for infected ears [7–9]. It should be noted that some studies recommend debridement of the perforation margin under local anesthetic and the insertion of a patch over the perforation [13,23,24]. It was found that this intervention could prevent penetration of infected material into the middle ear and allow a high percentage of eardrum closure relative to conservative treatment. Furthermore, it was documented that early closure of the tympanic membrane may also prevent cholesteatoma in 3–12% of the affected ears [24]. We chose an expectant therapeutic management and were gratified that 15 of the 27 perforations healed without intervention. The other 12 perforations have since been successfully closed by surgery.

The findings of this study indicate that damage to the middle and inner ear in victims of a high powered explosion in a confined space may involve most of the subjects and result in more severe damage to the tympanic membrane and a higher rate of hearing loss and balance disorders. The various symptoms and signs may resolve over a long time and may persist in some cases. Awareness of possible ear blast injuries, early detection of damage, proper treatment and appropriate consultation with the patients may prevent many of the deleterious results of such injuries.

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Correspondence: Dr. M.Z. Himmelfarb, Unit of Hearing and Speech Disorders, Dept. of Otolaryngology Head and Neck Surgery, Tel Aviv Sourasky Medical Center, 6 Weizmann St., Tel Aviv 64239, Israel.
Phone: (972-3) 697-3433
Fax: (972-3) 697-4662
email: motihim@hotmail.com