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Patterns of hearing loss in non-explosive blast injury of the ear

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Abstract

A prospective study of hearing loss in 120 cases with non-explosive blast injury of the ear, gathered over a six-year period, is presented. Thirty-three (27.5 per cent) patients had normal hearing, 57 (47.5 per cent) conductive hearing loss, 29 (24.2 per cent) mixed loss and one (0.8 per cent) had pure sensorineural loss. The severity of conductive hearing loss correlated with the size of the eardrum perforation; only a marginal difference was found between water and air pressure injuries, with respect to this type of hearing loss. Of all locations, perforations involving the posterior-inferior quadrant of the eardrum were associated with the largest air-bone gap. Audiometric assessment revealed that none of the patients suffered ossicular chain damage. Three patterns of sensorineural hearing loss were identified: a dip at a single frequency, two separate dips, and abnormality of bone conduction in several adjacent high frequencies. Involvement of several frequencies was associated with a more severe hearing loss than a dip in a single frequency. Healing of the perforation was always accompanied by closure of the air-bone gap, while the recovery of the sensorineural hearing loss was less favourable.

Key words: Blast injuries; Hearing loss, conductive; Hearing loss, sensorineural

Introduction

Non-explosive blast injury of the ear refers to the otological trauma, where a blow to the ear seals the external meatus, and causes a sudden increase of air pressure that strikes the tympanic membrane. A previous publication (Berger *et al.*, 1994) described various aspects of middle and inner ear damage in 91 patients, resulting from non-explosive blast injury of the ear. Common symptoms were hearing loss, earache, tinnitus, vertigo and otorrhoea. All patients had an acute perforation of the eardrum, which healed spontaneously with conservative treatment in 94.8 per cent of the cases.

Although some preliminary conclusions on blast-associated hearing loss were drawn from the first study, a larger sample was needed to elaborate on the following: (1) proportion of patients affected by conductive, sensorineural and mixed hearing loss; (2) correlation between the size as well as the location of the tympanic membrane perforation and the severity of hearing loss; (3) correlation between the mechanism of trauma and severity of hearing loss; (4) probability that conductive hearing loss is related exclusively to eardrum perforation, or is also associated with ossicular disruption; (5) patterns of sensorineural hearing loss associated with non-explosive blast injury of the ear, and, (6) extent of hearing improvement following healing of the tympanic membrane perforation.

Materials and methods

One hundred and forty-four consecutive patients (including the original sample of Berger *et al.*, 1994), who had suffered a recent blow to the ear resulting in tympanic membrane perforation, were treated from May 1990 to April 1996. Twenty-four were excluded due to a history of previous hearing loss, middle-ear disease or a delay of more than five days after the trauma in carrying out the otological and audiometric assessments. Consequently, 120 patients (89 men and 31 women) aged nine to 49 years (mean age 20.8) were found suitable for the study. At the initial examination, gender, age, side, cause of injury, and associated symptoms were obtained in a structured interview. The eardrum was inspected with an operating microscope, and the location and size of the perforation were sketched by hand. Pure tone and speech audiometry were then performed. An associated sensorineural hearing loss was defined when bone conduction was ⩾20 dB HL at any frequency, and the hearing in the contralateral ear was normal.

A conservative management approach was adopted, and follow-up visits were scheduled after

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TABLE I

CONDUCTIVE HEARING LOSS VERSUS SIZE OF PERFORATION AND CAUSE OF INJURY

	Water		Outside water		Total	
	No. of patients	Mean air-bone gap (dB)	No. of patients	Mean air-bone gap (dB)	No. of patients	Mean air-bone gap (dB)
Large perforation	5	19.6 ± 11.94	15	17.06 ± 7.74	20	17.4 ± 9.4
Small perforation	14	11.2 ± 7.47	86	8.26 ± 6.65	100	8.9 ± 7.8
Total	19	13.4 ± 9.8	101	9.7 ± 8.3	120	10.3 ± 8.6

seven, 30, 60 and 90 days, during which the eardrums were examined microscopically, and repeated audiometric tests were carried out at the end of the aforementioned period.

Results were compared by the Student *t*-test and the Chi-squared test.

Results

One hundred and twenty patients with non-explosive blast injury of the ear were enrolled in the study. The right ear was involved in 47 patients and the left in 73. A slap against the ear and injuries suffered during ball games were the cause of trauma in 101 patients. Nineteen others who were hurt while swimming and participating in water sport activities formed a separate group, since their injury was associated with excessive water pressure and contamination.

All 120 patients demonstrated acute perforation of the eardrum that was confined solely to the pars tensa and occurred in all of its quadrants. They were located in a descending order of frequency as follows: in the anterior-inferior quadrant (33 per cent), the posterior-superior quadrant (26 per cent), the posterior-inferior quadrant (22 per cent) and in the anterior-superior quadrant (19 per cent). Perforations were small in size in 100 patients (84.3 per cent), while larger ones occupying one-half or more of the eardrum area were observed in only 20 (15.7 per cent). The latter were found almost twice as often in injuries associated with water than in those with other aetiologies.

Thirty-two of the 120 patients were lost to follow-up. The eardrum perforation closed spontaneously in 81 of the remaining 88 patients (92 per cent).

Hearing

An assessment of hearing status among 120 patients who underwent audiometric testing at their initial examination reveals that thirty-three (27.5 per cent) had normal hearing, whereas 57 (47.5 per cent) had conductive hearing loss, 29 (24.2 per cent) mixed loss and only one (0.8 per cent) pure sensorineural loss. The mean conductive loss in the speech frequencies (500–2000 Hz) was 10.3 dB. The maximal air-bone gap was 35 dB. The mean conductive hearing loss associated with perforations, occupying one-half or more of the eardrum area, was twofold higher than that associated with smaller perforations (Table I). It is noteworthy that in spite of the direct correlation between the size of the perforation and the extent of the air-bone gap, there were two patients with large perforations whose audiograms showed normal hearing. The Table also shows that patients whose injury occurred in water had a larger conductive hearing loss than others. Moreover, water sports injuries have a greater proportion of large perforations, yet statistical analysis confirms that the magnitude of conductive hearing loss is linked more to the size of perforation ($p = 0.0001$) than to the cause of injury ($p = 0.0846$). Table II shows the mean conductive hearing loss of perforations located in various quadrants of the tympanic membrane. Statistical analysis reveals a significantly higher conductive hearing loss ($p = 0.0001$) in perforations involving the posterior-inferior quadrant compared to other locations.

It has been established that in 29 out of 30 patients with a sensorineural hearing loss a conductive element was also present, while only one had a pure sensorineural hearing loss. Furthermore, approximately one fourth of the patients with non-explosive blast injury of the ear, suffered from sensorineural hearing loss irrespective of the mechanisms of trauma (Table III). Most patients with this type of injury had a high frequency loss, whereas impairment of bone conduction in the speech frequencies was demonstrated in only three cases. Three patterns of sensorineural hearing loss were identified. The first was characterized by a dip that involved a hearing loss in one frequency: a dip at 4000 Hz in four patients and at 8000 Hz in six. The second showed abnormality of bone conduction in several adjacent high frequencies: 18 patients had

TABLE II

CONDUCTIVE HEARING LOSS VERSUS PERFORATION'S LOCATION

Location	Mean air-bone gap (dB) ± Std. dev.
Anterior-superior	8.97 ± 8.85
Anterior-inferior	11.68 ± 8.87
Posterior-superior	11.66 ± 10.56
Posterior-inferior	14.14 ± 8.60

TABLE III

SENSORINEURAL HEARING LOSS IN DIFFERENT TYPES OF TRAUMA

	No. of patients	No. of patients with SNHL	Percentage
Water sports accidents	19	5	26.3
Injuries outside water (aggression and ball games)	101	25	24.7
Total	120	30	25

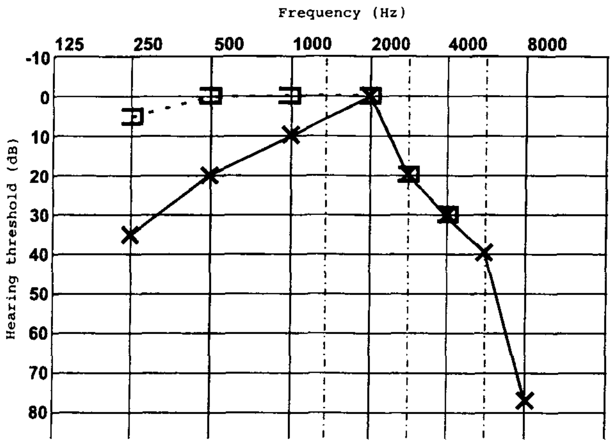

FIG. 1a

Left ear audiogram shortly after injury, showing a low frequency conductive hearing loss and abnormal bone conduction thresholds in several adjacent frequencies

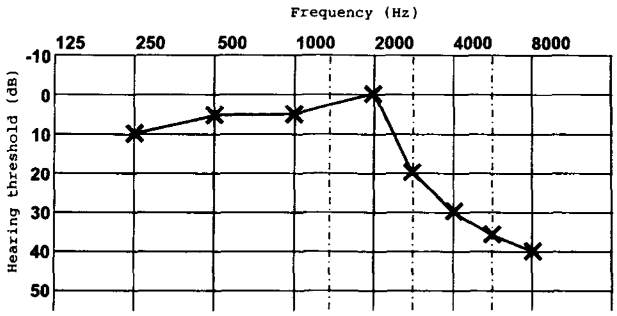

FIG. 1b

Left ear audiogram (the patient in Figure 1a) after perforation closure showing partial recovery of sensorineural hearing loss.

different combinations of hearing loss (e.g., 2000 Hz-8000 Hz, 3000 Hz-8000 Hz, 4000 Hz-8000 Hz, 4000 Hz-6000 Hz and 6000 Hz-8000 Hz). Involvement of several frequencies was associated with a more pronounced hearing loss than a dip in a single frequency. Indeed, the bone conduction thresholds of the affected frequencies in the former group were 40 dB or worse (Figure 1a), but dips never exceeded 40 dB (Figure 2a). The third pattern of sensorineural hearing loss appeared as separate dips. There were two patients in this category, the first had one at 1000 Hz and another at 4000 Hz, while the second had dips at 3000 Hz and 8000 Hz.

Follow-up audiometry revealed that a spontaneous healing of the perforation was always associated with closure of the air-bone gap, but recovery of sensorineural hearing loss was less favourable. Of the 23 patients with sensorineural hearing loss, who concluded the follow-up period, 10 enjoyed a complete recovery of their hearing and another 10 had a partial improvement, while no recovery was noticed in the remaining three. As a rule, there was a better recovery of sensorineural hearing loss in cases with a single affected frequency (Figure 2b), than in those with several affected frequencies (Figure 1b).

Discussion

The ear is the most vulnerable organ to the effects of blast (Kerr, 1980). In wartime or terrorist explosion, solid or liquid material transfers rapidly into a gaseous form, with a massive increase in volume and consequently in pressure. A comparable process occurs quite often in peacetime, when a sudden blow seals the external auditory meatus, causing a significant increase of air pressure within the ear canal and a rupture of the tympanic membrane. This sudden increase of air pressure resembles the short-lived positive phase of the blast wave, responsible for traumatic eardrum perforations in explosions. Since a similar mechanism operates in both injuries, it was coined 'non-explosive blast injury of the ear' (Berger *et al.*, 1994). Physical aggression and ball game accidents accounted for most of the cases in this type of insult to the ear, while water sport accidents formed another distinct cause of this injury to the ear. In the latter cases, the perforation is probably related to the hydraulic compression of air against the tympanic membrane, as water is forced into the external ear canal.

Hearing loss is a fairly common symptom in cases of blast injury. Singh and Ahluwalia (1968) reported on 134 ears with blast injury in the Indo-Pakistan conflict of 1965. In their series, the hearing loss was conductive in 13, sensorineural in 81 and mixed in 40. Teter *et al.* (1970) studied 81 ears with blast

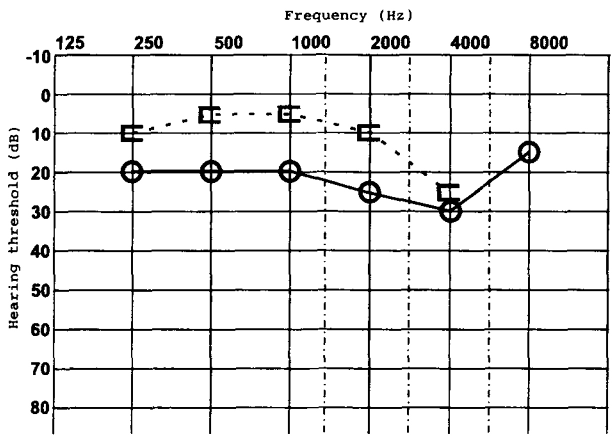

FIG. 2a

Right ear audiogram shortly after injury, showing a 15 dB conductive hearing loss in the speech frequencies and a dip at 4000 Hz.

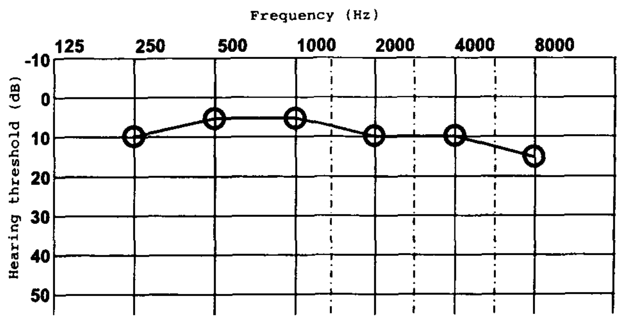

FIG. 2b

Right ear audiogram (the patient in Figure 2a) after perforation healing, showing air-bone gap closure and recovery of the 4000 Hz dip.

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trauma and described four types of audiometric configurations, which represented either a mixed or a sensorineural hearing loss. Type A was characterized by a dip at 1000 Hz, and type B by two separate dips at 1000 Hz and at 4000 Hz. Type C had a dip at 4000 Hz and the loss in type D had a sloping configuration above 2000 Hz. Kerr and Byrne (1975) reported on the Abercorn Restaurant explosion in Belfast, and described a predominance of high frequency sensorineural hearing loss. Pahor (1981) reported on the Birmingham explosions, and stated that 25 per cent of the victims suffered sensorineural hearing loss, the majority of which were high tone losses, but some had a flat curve affecting most frequencies. Bruins and Cawood (1991) studied the effects of the Peterborough lorry explosion and found that the initial audiometric assessment showed abnormal findings in 87.5 per cent of the cases. Ears with perforated tympanic membranes had a mixed hearing loss, and those without perforation sustained a sensorineural hearing loss. They described four patterns of hearing loss in their series: a) a trough-shaped configuration wherein three or more adjacent frequency thresholds were abnormal (17.1 per cent), b) dips that involved a single frequency loss of hearing threshold (34.1 per cent), c) sloping curves which occurred at any frequency above 1000 Hz and involved all subsequent higher frequencies (34.2 per cent), and d) low frequency hearing loss which was predominantly conductive in nature (14.6 per cent).

Although the aforementioned data reveal important information regarding hearing loss in blast injury, its incidence, type and extent vary considerably among these studies. Oddly enough, the amount of knowledge concerning hearing loss in non-explosive blast injury is quite limited, while this kind of injury is common in clinical practice and may often have medicolegal implications.

Our findings indicate that non-explosive blast injury of the ear resulting in eardrum perforation is not necessarily linked to hearing loss, since more than one-quarter of the cases disclosed normal hearing at the initial audiometric assessment carried out shortly after the trauma. Most of these ears had tiny to small perforations, except for two large ones with subtotal perforations. Conductive hearing loss affected 72 per cent of the patients, and its severity was statistically correlated with the size of the perforation. The fact that the largest air-bone gap occurred in perforations involving the posterior-inferior quadrant of the tympanic membrane is probably related to the loss of round window protection, as sound waves reach both windows simultaneously and cause phase cancellation within the cochlea. Results also show that the mean conductive hearing loss in cases associated with water pressure injury was 3.7 dB higher than in those with air pressure changes. This gap becomes even more narrow, when the comparison takes into account the size of the perforation (2.9 dB in small perforations and 2.6 in large ones). Indeed, statistical analysis showed a marginal difference between the two mechanisms of trauma, with respect to conductive hearing loss.

Another issue concerns a possible ossicular chain disruption induced by the trauma inflicted to the ear. Interpretation of early and late audiometric assessment strongly suggests that ossicular damage did not occur in any of the 120 patients enrolled in the study; as initial conductive hearing loss seldom exceeded 30 dB, and a complete air-bone gap closure was observed following perforation healing. The absence of ossicular chain damage was also reported by Pahor (1981) in his article on the Birmingham bombings.

Sensorineural hearing loss is a common feature of blast injury originated by explosions, yet its incidence varies widely, from 25 per cent to 87.5 per cent. It appears that several variables may influence the severity of the damage: the amount of explosive material, the proximity of the blast, the orientation of the ear *vis-à-vis* the blast wave, the environment (an open or a confined space), the susceptibility of the exposed individual and others. In our series, the incidence of sensorineural hearing loss did not differ significantly between water and air pressure injuries, and its total percentage was 25. Moreover, with the exception of three cases, sensorineural hearing loss did not affect the speech frequencies, whereas Kerr and Byrne (1975) reported that 10 per cent of their patients had residual sensorineural hearing loss in the speech frequencies, one year after injury. Consequently, it is suggested that non-explosive blast injury of the ear could represent a mild form of blast injury, responsible for a limited trauma to the organ of Corti.

The underlying pathology of the cochlear damage induced by a blast is not yet fully understood. Garth (1994) postulated that temporary threshold shift results from changes in the integrity of the tight cell junctions of the reticular lamina. These breaches allow some mixing of perilymph and endolymph, which alters the ionic environment and interferes with physiological events within the cochlea. As the breaches in the reticular lamina are repaired, the temporary threshold shift resolves. With respect to permanent threshold shifts, animal experimentation disclosed tearing of the basilar and Reissner's membranes in the basal coil (Ruedi and Furrer, 1947), loss of hair cells, and in more severely damaged ears, long segments of the organ of Corti became detached to float in the scala media. Cilia of the outer hair cells were bent, fused or broken. The inner hair cells were damaged to a lesser extent (Hamernik *et al.*, 1984). Regarding the possible effects of the blast on the ascending auditory pathways, Pratt *et al.* (1985) did not detect any central effects of blast by using brain stem audiometry to assess 37 human blast survivors.

The profile of sensorineural hearing loss in cases with non-explosive blast injury of the ear demonstrated three patterns of bone conduction abnormalities. The first showed a loss in a single frequency, either a 4000 Hz dip (similar to Teter's Type C), or an 8000 Hz dip. The second was characterized by a loss in several adjacent high frequencies, and the third showed two separate dips, either at 1000 Hz and 4000 Hz (similar to Teter's Type B), or at 3000 Hz and 8000 Hz. It should be emphasized that involvement of several frequencies was associated with a more pronounced sensorineural hearing loss when compared to a single frequency loss. Moreover, recovery was better in a single dip than in multiple frequency loss.

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References

Berger, G., Finkelstein, Y., Harell, M. (1994) Non-explosive blast injury of the ear. *Journal of Laryngology and Otology* **108:** 395–398.

Bruins, W. R., Cawood, R. H. (1991) Blast injuries of the ear as a result of the Peterborough lorry explosion: 22 May 1989. *Journal of Laryngology and Otology* **105:** 890–895.

Garth, R. J. N. (1994) Blast injury of the auditory system: A review of the mechanisms and pathology. *Journal of Laryngology and Otology* **108:** 925–929.

Hamernik, R. P., Turrentine, G., White, C. G. (1984) Surface morphology of the inner sulcus and related epithelial cells of the cochlea following acoustic trauma. *Hearing Research* **16:** 143–160.

Kerr, A. G. (1980) Trauma and the temporal bone. The effects of blast on the ear. *Journal of Laryngology and Otology* **94:** 107–110.

Kerr, A. G., Byrne, J. E. T. (1975) Concussive effects of bomb blast on the ear. *Journal of Laryngology and Otology* **89:** 131–143.

Pahor, A. L. (1981) The ENT problems following the Birmingham bombings. *Journal of Laryngology and Otology* **95:** 399–406.

Pratt, H., Goldsher, M., Netzer, A., Shenhav, R. (1985) Auditory brain stem evoked potentials in blast injury. *Audiology* **24:** 297–304.

Ruedi, L., Furrer, W. (1947) Das akustische trauma. S. Karger, Basle (Cited from Kerr, A. G. (1980) Trauma and the temporal bone, the effects of blast on the ear. *Journal of Laryngology and Otology* **94:** 107–110.

Singh, D., Ahluwalia, K. J. S. (1968) Blast injuries of the ear. *Journal of Laryngology and Otology* **82:** 1017-1028.

Teter, D. L., Newell, R. C., Aspinall, K. B. (1970) Audiometric configurations associated with blast trauma. *Laryngoscope* **80:** 1122–1132.

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