Bomb blast injury: effect on middle and inner ear

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Abstract

Objective To study the symptomatology, clinical findings and the effects of blast injury on middle and inner ear in survivors of bomb blast.

Settings City of Mumbai, India.

Methods The study group consisted of 52 patients exposed to the bomb blast that occurred on 25th August 2003.

Result and Analysis The distance of the victim from the blast site has no major influence in producing effects on middle and inner ear in our study of the surviving individuals. Rupture of the tympanic membrane occurs due to the positive wave but both everted and inverted edges can be found in multiple perforations of the tympanic membrane.

Keywords Bomb blast injury · Tympanic membrane rupture · Acoustic trauma.

Introduction

The first instances of hearing loss associated with the blast trauma occurred with the first use of gunpowder. First recorded blast trauma was in 1591 when hearing loss was noted in cannoners following battle [1] and first reported case of deafness due to blast trauma occurred over 150 yrs ago [2]. Injuries due to blast may be primary, secondary, or tertiary [3]. Primary blast injuries are those due to the blast wave alone. Secondary injuries result from flying debris and fragments energized by the blast or falling masonry or other objects consequent upon blast damage. Tertiary injuries are due to bodily displacement of the individual by the blast wave. Thus primary injuries are considered to be unique to the blast and occur due to positive and negative pressure waves.

Primary blast injuries occur predominantly in or near the air containing organs of the body, the ears, the GIT, the lungs. The ears are the most sensitive organs of the body to the effects of the blast. It is assumed that if the blast had been sufficient to cause damage to any other part of the body it will also have affected ears unless they have been specifically protected.

While reviewing literature concerned with hearing loss associated with noise there has been tendency in most papers to group acoustic trauma into one category regardless of etiology but, there is a need to separate blast induced deafness from noise induced deafness. In 1953, IV Congress of the International Audiological Society accepted a classification proposed by Ruedi & Furrer (1947) [2]. According to this blast trauma is associated with single exposure to an explosion where stimulation duration is greater than 1.5 m./sec and where middle ear damage is not uncommon, while noise induced deafness occurs as a result of long term exposure to elevated sound intensities.

On 25th Aug., Monday afternoon, city of Mumbai, India suffered from cruel act of terrorism when two bomb explosions occurred (Gateway of India and Mumbadevi) killing 35 people and injuring 52.

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This study was carried out on survivors of the bomb blast admitted to the hospital (n=52) for the injuries pertaining to head and neck and other parts of the body.

Up to the time of presentation of this paper 52 patients were examined and followed up for the period of 6 weeks. It is hoped that eventually other victims of the explosion will be contacted for review and all patients will be followed up for the period of 6 mths to 1 year to draw definite conclusion of the long term effect of blast injury on middle and inner ear.

This is a preliminary presentation of the data of patients of the blast injury and any conclusion in this paper must be regarded as being provisional.

Materials and methods

52 surviving individuals of the bomb blast admitted to the J.J. Hospital for various causes were screened out (n=52). This includes 48 males and 4 females. All patients were examined within 24 hrs of the blast injury. A bomb blast – Ear questionnaire (Annexure 1) was used to examine all the patients.

Approximate distance of the victim from the blast site was noted and efforts were made to identify the head position of the victim at the time of the blast.

Detailed history was taken. Nature of hearing loss and improvement over period of time was noted. Specific history of noise exposure prior to blast injury was inquired. Character of the tinnitus was noted and complaints of giddiness were noted down. Severity of the symptoms was evaluated on a four point rating scale (None, Mild, Moderate, Severe). All patients underwent thorough ENT examination. Otomicroscopic examination was carried out. Those with tympanic membrane perforation underwent otoendoscopic examination to obtain digital photographs of tympanic membrane.

Out of 52 patients 39 patients had pure tone audiograms done within 24 hours of the blast injury. In 3 patients audiogram was delayed up to 48 hours due to management of the other injuries. In 10 cases audiogram was not possible due to various reasons such as unconsciousness, burns, non-ambulatory patient.

Fig. 1 Effect of distance on symptomatology.

All audiograms were done on audiometer calibrated to ISO standard. BERA was not done immediately as it was not available in the institute. It was done subsequently in patients with sensorineural hearing loss.

Results and analysis

Age group of the study varied from 15–75 years with mean 33.72 years in males. In females, age group varied from 13–33 years with mean 21.25 years.

Approximate distance from blast site ranged from 2 feet to 50 feet with average of 17.03 feet. Out of 52 patients, 17 patients were located at a distance of less than 10 feet from the blast site, 28 patients were located at a distance between 10–20 feet from the blast site and 7 patients were located at a distance of more than 20 feet from the blast site. There was no difference between the severity of symptoms (deafness, vertigo and tinnitus) presented by the patients located at different distances {0–10 Feet, 11–20 Feet, >20Feet} from blast site ($p>0.05$, Kruskal-Wallis test). [Fig. 2].

Similarly, there was no significant correlation between the distance from blast site and the incidence and number of perforations of tympanic membrane [Spearman's Correlation (2-Tailed), $r=0.184$]. [Fig. 4]

Out of 52 patients, 47 patients (90.38%) were symptomatic for ear pathology, 5 cases were asymptomatic (9.61%). Hearing loss was the complaint in 39 patients (75%). In three (5.76%) it was severe with difficulty in conversation while in 36 (69.23%) it was mild to moderate in variety. Tinnitus was present in 20 (38.46%) cases with up to 90 % of the patients complaining of tinnitus immediately following blast injury. The character of the tinnitus varied from person to person, 40 % reported ringing variety while 60 % of the cases reported whistling tinnitus. Nine (17.3%) cases

Fig. 2 Blast pressure wave

Fig. 3 Comparison between right and left ear

Fig. 4 Showing otoendoscopic pictures of traumatic tympanic membrane perforations due to bomb blast.

- e1** Showing pars flaccida perforation.
- e2** Showing multiple pars tensa perforations with inverted and everted edges.
- e3** Showing pars tensa perforation with inverted edges.
- e4** Showing pars tensa perforation with everted edges and metallic foreign body.

reported giddiness following blast injury. It was severe in 3 (22.22%) cases, while mild in 6 (77.77%) cases.

Examination of Tympanic membrane revealed very high incidence of the perforations of the tympanic membrane. 40 out of 52 patients had perforations in either or both ears (76.92%), 25 cases (62.5%) had unilateral perforations while 15 cases (37.5%) had bilateral perforations [Fig. 3]. A

foreign body (Metallic fragment) was seen along the tympanic membrane (umbo) in one case which was removed under local anaesthesia. Perforations involved all four quadrants in 50% of cases while poster superior quadrant was involved in 25 % of cases. Antero- superior perforations found in 15 % of cases while ant inf. and postero- inferior perforations were found in 10 % of the cases.

Normal adult ABR waveform response. I-V absolute latencies and interpeak intervals (I-III, III-V, I-V) are within normal limits bilaterally. Interaural differences for the I-V interpeak intervals (1.16ms) and wave V absolute latencies (.08 ms) are within normal limits.

Fig. 5 Normal brain stem evoked response audiometry

Pure tone audiograms were done in 42 out of 52 cases. It revealed normal hearing in 6 (12.5%) of the cases, while 24(57.14%) had conductive hearing loss and 8 (19.04) had sensorineural hearing loss. Four cases had audiometric finding of moderately mixed loss (9.54%). Of the 24 patients with conductive hearing loss, mild conductive loss was the finding in 7 patients (16.66%) moderate conductive loss was noted in 15 patients (35.71%) while bilateral severe conductive hearing loss was noted in 2 patients (4.76%) {AB Gap-60dB}. Out of 8 patients with sensorineural hearing loss 5 (11.9%) had mild Sensorineural hearing loss, while 2 had moderate sensorineural hearing loss and 1 had severe sensorineural hearing loss. Dip at 4 kHz was observed in 3 patients. CT scan did not reveal any significant structural damage to the inner ear. Four cases of safe chronic suppurative otitis media were observed during the screening which was present before blast injury.

All the patients were followed up for 6 weeks after the blast injury. On otomicroscopic examination 30 out of 52 (46.15%) tympanic membrane perforations were seen to be healed spontaneously. 5 (6.66%) tympanic membrane perforations had developed secondary infection

with active mucopurulent discharge. While 30 (46.15%) tympanic membranes showed no evidence of spontaneous closure and were subsequently worked for tympanoplasty.

Pure tone audiometry done 6 weeks following blast injury showed complete improvement (Bone conduction threshold within 25 dB) in 5 patients(62.5%) suffering from sensorineural hearing loss, One patient (12.5%) had persistent high frequency hearing loss with improvement in other frequencies, 2 patients(25%) had persistent sensorineural hearing loss without any improvement over the period of 6 weeks. BERA done in all the 8 patients reporting sensorineural hearing loss, only one patient with severe sensorineural hearing loss had an absent wave 1 and a prolonged wave 1-2 inter peak interval.

Discussion

In the typical explosion, the explosive material is changed from solid form to gaseous form with massive increase in volume and pressure. Explosive forces under water

are much more devastating than the same force in the air because the pressure wave travels much faster in water. The two main components of this complex wave are a blast pressure wave (known as dynamic overpressure), with a positive and negative phase, and the mass movement of air (known as blast wind) [5]. The positive pressure phase of the blast wave lasts for only a few milliseconds, but close to an explosion it may rise to over 7000 kN/m². As the healthy tympanic membrane ruptures at about 150 kN/m², it is evident that the effects on the human body of such an explosion can be devastating, especially in confined areas. Like sound waves, the blast pressure waves flow over and around an obstruction and affect anyone sheltering behind a wall or in a trench. The pressure affecting such a person is known as the *incident pressure*. Also, any person standing in front of a wall or other vertical surface facing an explosion is subjected to the added effect of a *reflected pressure*. The negative effect of a pressure wave is of low amplitude, lasts longer than the positive wave and is of doubtful clinical significance. The resultant positive pressure blast wave spreads outwards from the point of explosion. The waveform from an explosion is illustrated in Figure 1, called Friedlander Curve [2]. The positive pressure wave is short lived and can reach up to pressures of hundreds and thousands of pounds per square inch depending upon type of explosive used. This is followed by a longer negative phase lasting about 30m/sec.

The shock front wave of the blast may be irregular and can be deflected by obstacles in its pathway. Thus, the devastating effects of the blast wave on ear or any other part of the body depends on

- i) The rise time i.e. Speed with which pressure wave builds up
- ii) The height of the peak pressure
- iii) The duration of the positive wave
- iv) Site of the explosion- explosion in closed confined space produces more deleterious effect due to reflection and augmentation of pressure wave [5].

Most common effect of the blast wave on middle ear is rupture of the tympanic membrane. Dislocation of the ossicles also has been reported. Normal tympanic membrane ruptures at pressures in the region of 5 p.s.i. About 50 % of the normal tympanic membranes are ruptured when pressure reaches 15 p.s.i. Kerr and Byrne (1975) [2] reported 66 tympanic membrane perforations out of 101 cases studied at the explosion in Abercorn restaurant, Belfast.

It is now agreed upon that perforations were caused by positive wave rather than negative wave because edges of the perforation are often inverted, epithelial cysts have been found in the middle ear following the blast, Temporal bone preparations showed squamous epithelium in the middle ear in the patients killed as a result of the explosion (A.G. Kerr 1980) [2].

Effects of the blast on inner ear ranges from mild sensorineural hearing loss to profound sensorineural hearing loss. The inner ear may be damaged at pressures insufficient to rupture the tympanic membrane and damage can occur at pressures as low as 1 pound per square inch. The hearing loss ranges from temporary threshold shifts to permanent threshold shifts. It mainly occurs at higher frequencies particularly around 4 kHz (3 kHz–6 kHz). Teter et al have reported various audiometric configurations in patients exposed to blast injury. These include dip at 1000Hz, 1000 and 4000Hz dip, 4000Hz dip, and sloping loss [1]. Tinnitus is a common complaint in individuals exposed to blast injury. Damage to vestibular apparatus also has been reported following blast injury. Cases of benign paroxysmal positional vertigo have been reported following injury to the utricle.

In our study, the distance of the survivor from blast site did not show any correlation in producing effects on inner and middle ear. This can be explained on the basis of i) irregular shock front of the blast wave, ii) variations in shape and size of external auditory canal, iii) individual variation in thickness and strength of tympanic membrane, and iv) condition of tympanic membrane at the time of the blast Those individuals facing the blast site have been found to be suffered from greater damage to the tympanic membrane, in the form of multiple perforations or larger size of perforation.

There was a varied appearance of the tympanic membrane following exposure to the wave. Few patients with intact TM had congestion of attic or along the handle of the malleus. Perforations were noted in all four quadrants of the pars tensa. In one case perforation was noted in pars flaccida. Perforations varied in size, shape, and number. Posterior quadrant of the pars tensa was found to be affected more than the other quadrant. This can be explained on the basis of angulations of the tympanic membrane and incident blast wave hitting the posterior quadrant first.

There has been lot of controversy in the literature as to whether the perforation is caused by positive or negative phase of the blast wave. In our study, an everted edge of the perforation was a common finding as compared to inverted edges. In few cases of the multiple perforations, one perforation showed everted edge and other showed inverted edge. Based on the following observation, we put forward the theory that perforations would have occurred due to positive blast wave and everted edges would have occurred due to sucking in effect of the negative phase of the blast wave.

Previous literature [2] reported that the rupture of tympanic membrane appears to have protective effect on the inner ear. Our study revealed that 3 patients with perforation of the tympanic membrane had sensorineural hearing loss.

In our series 57.14% had conductive hearing loss. Conductive hearing loss was attributed to defect in tympanic

membrane, loss of phase difference in posterior perforations and disruption of the ossicles. In one case we have found incudostapedial dislocation might be because of the negative phase of blast wave which had produced sucking effect. 90 % of the patients reported tinnitus immediately following blast injury but most of the patients reported some improvement over the period.

Singh and Ahluwalia [4] have reported lack of recruitment in patients exposed to blast injury, while such tests were not done in this series. In our series, sensorineural hearing loss was reported in 8 cases. 3 patients had definite audiometric pattern with dip at 4 kHz. Definite audiometric patterns as described by Perez et al [8] were not observed in our series.

Kronenberg et al [7] have reported spontaneous closure of the tympanic membrane perforations in almost 74 % of the cases in their series of 210 perforations while in our study of 65 tympanic membrane perforations only 30(46.15%) healed spontaneously at the end of the six weeks.

Korkis et al [5] have reported high incidence of the secondary infection of the tympanic membrane (11–56%), Teter et al have reported secondary infection in 10% of the cases and Singh and Ahluwalia [4] have reported incidence of 9.5%. while in our series, it was 6.66%. All of our patients received prophylactic oral antibiotic treatment to prevent secondary infections. Antimicrobial ear drops and aural toilet was avoided to reduce rate of secondary infection.

Sudden sensorineural hearing loss was found in 8 patients with spontaneous complete recovery in 5 cases. Ruedi and Furrer [6] in their studies on effects of blast on guinea pig have found tearing of basilar and Reissner's membrane in basal turns of cochlea as a cause of inner ear damage. All patients with sudden onset sensorineural hearing loss were treated with high doses of steroids, vasodilators, H1 receptor agonists.

Conclusion

Distance of the victim from the blast site has no correlation with the severity of the damage on middle and inner ear in survivors of the bomb blast. Head position and size of the ear canal also has a role in deciding the side of the ear to be affected.

Rupture of the tympanic membrane occurs due to the positive wave but both everted and inverted edges can be found in multiple perforations of the tympanic membrane. Everted margins indicate sucking in effect of negative pressure wave. Perforation can occur anywhere in the pars tensa although postero-superior part is found to be affected more. Perforations can also involve pars flaccida. Ossicular disruption can also occur in blast injury probably due to negative pressure wave. Sudden sensorineural hearing loss from blast injury tends to, but not always recovers spontaneously.

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Annexure 1 Blast injury questionnaire

Name:

Age:

Sex:

Religion:

Local Address:

Permanent Address:

Symptomatic / Asymptomatic:

History:

- 1) Deafness: A) Onset: Sudden / Slowly progressive.
B) Degree of hearing loss: mild / moderate / severe.
C) Improvement: within 24 hrs / 1 wk / 2 wk / 4 wk / 6 wk.
D) Approximate distance from blast site:
E) Directionality from blast: Right / Left / Center.
- 2) Tinnitus: A) Onset: Sudden / Slow.
B) Mode: Continuous / Intermittent.
C) Type of sound/ tinnitus:

- 3) Giddiness: A) Onset: Sudden / Slow.
B) Severity: Mild / Moderate / Severe.
C) Presence of: Syncopal attacks , Imbalance , Unconsciousness, Rotatory nystagmus.
D) Mode: Continuous / Intermittent.
E) Association with neck movements: Yes / No.
F) Tendency to fall: Right / Left / Forward / Backward.
G) Associated symptoms: Nausea / Vomiting / Heaviness in head.
- 4) Ear Discharge: A) Type: Blood stained / Watery / Purulent.
B) Onset: Immediate / After ____ Hrs / Days.
C) Quantity: Scanty / Profuse.
- 5) Earache: A) Type: Continuous / Intermittent.
B) Severity: Mild / Moderate / Severe.
C) Associated with jaw movement: Yes / No.
- 6) Heaviness in the ear: Yes / No; Intermittent / Continuous.
- 7) History of previous ear disease: Deafness, Ear discharge, Giddiness, Earache, Heaviness in ear.
- 8) History of previous ear surgeries / Treatment for ENT diseases in past: Yes / no.
Details:
- 9) Family history of ear disease: Yes / No.
Details:
- 10) Personal history: Allergy , Diabetes , Hypertension .
- 11) On Examination: Consciousness:
Eye Injury:
Skull and Spine:

12) ENT Examination:

A) Ear:

- a) Pinna / EAC:
- b) Preauricular region:
- c) Post auricular area:
- d) Tympanic Membrane:

Perforation: I) Presence:

II) Margins: Ragged / Smooth / Linear / Punched Out.

III) Number: Single / Multiple.

IV) Edges: Inverted / Everted / Both.

- e) Presence of mastoid tenderness:
- f) Fistula sign:
- g) Tuning Fork tests:

- i) Rinne: 256:
512:
1024:

ii) Weber's:

iii) Absolute Bone conduction:

B) Otoneurological examination:

- a) Nystagmus: Spontaneous , Gaze evoked , Peripheral , Central.
- b) Cranial Nerve Examination:
- c) Cerebellar signs:

C) Nose:

D) Throat:

E) Neck:

F) Pure Tone Audiometry:

Diagnosis: