Eardrum Perforation in Explosion Survivors: Is It a Marker of Pulmonary Blast Injury?

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Study objectives: To determine whether isolated eardrum perforation is a marker for concealed blast lung injury in survivors of terrorist bombings.

Methods: Survivors who arrived at hospitals after 11 terrorist bombings in Israel between April 6, 1994, and March 4, 1996, were examined otoscopically by ear, nose, and throat specialists. All patients with eardrum perforation underwent chest radiography and were hospitalized for at least 24 hours for observation. The clinical course and final outcome of patients with isolated perforation of the eardrums and of those with other blast injuries were surveyed.

Results: A total of 647 survivors were examined; 193 (29.8%) of them sustained primary blast injuries, including 142 with isolated eardrum perforation and 51 with other forms of blast injuries (18 with isolated pulmonary blast injury, 31 with combined otic and pulmonary injuries, and 2 with intestinal blast injury). Blast lung injury was promptly diagnosed on admission by physical examination and chest radiography. No patient presenting with isolated eardrum perforation developed later signs of pulmonary or intestinal blast injury (mean 0%; 95% confidence interval, 0% to 2.7%).

Conclusion: Isolated eardrum perforation in survivors of explosions does not appear to be a marker of concealed pulmonary blast injury nor of a poor prognosis. Therefore, in a mass casualty event, persons who have sustained isolated eardrum perforation from explosions may safely be discharged from the emergency department after chest radiography and a brief observation period.

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INTRODUCTION

Terrorist bombings have become an increasing international problem threatening civilian communities worldwide. Injuries incurred in such explosions were until recently a topic of interest mainly to military physicians. Considering the increasing incidence of terrorist bombings in many countries, the typical injuries are apt to challenge medical care providers who are unaccustomed to coping with such trauma in civilian populations.

Traditionally, 4 mechanisms of injury are implicated in trauma caused by explosions.[1,2] Primary blast overpressure injuries are the direct effects of the rapid and strong increase in atmospheric pressure. Secondary blast injuries are penetrating injuries inflicted by flying bomb fragments and other debris. Tertiary blast injuries occur when the victim is propelled by the blast wind and collides with other objects; penetrating and blunt injuries may ensue. Burns are caused by the brisk and intense rise in temperature after the explosion and are termed "flash burns." Deeper and more extensive burns may happen when the clothes catch fire.

The extent of involvement with primary blast injuries depends on the exposure to overpressure. Although recognition of overt pulmonary blast injury is easy and its fulminant course is predictable, the fate of those who present with lesser manifestations of primary blast exposure, such as isolated eardrum perforation, is less clear. Furthermore, because pulmonary blast injury may be occult early after an explosion, only to develop into a full-blown and severe injury later, the predictive significance of evidence of exposure to overpressure should be determined.

Assuming that eardrum perforation may be an early manifestation of occult pulmonary or intestinal blast injury, previous recommendations have been to observe persons with such injuries for at least 6 to 12 hours.[3] The purpose of this article is to challenge this policy.

METHODS AND MATERIALS

Between April 6, 1994, and March 4, 1996, 11 terrorist explosions occurred in Israel, injuring a total of 770 persons, 145 of whom died. Depending on geographic location, survivors were evacuated to 17 hospitals throughout Israel (range, 1 to 6 hospitals per incident). All 11 attacks were executed by suicide terrorists who either carried the bomb on their garments or drove booby-trapped vehicles. The bombs were self-made and incorporated various explosive materials, occasionally including standard military devices wrapped with metal nails. Hand-carried devices were of varying loads, ranging from 5 to 20 kg of explosives; booby-trapped vehicles contained 50 to 150 kg of explosives and flammable gas containers. Because the attacks were carried out by suicide terrorists, the perpetrators had the opportunity to select the precise timing and location of the blast to maximize the number of casualties. Therefore, detonations occurred in close proximity to victims, even in outdoor settings and especially when the explosion took place on a bus.

The Israeli prehospital trauma care system comprises a nationwide network of ambulances, known as the Red Star of David, that is capable of providing basic and advanced life support and fast evacuation. Military medical aid via trauma teams, ambulances, and helicopters is available as backup for large-scale incidents associated with many casualties or in remote areas where prolonged evacuation is anticipated. Both systems provided medical care for the injured in all 11 bombing incidents that occurred during this study, allowing for rapid and efficient evacuation from the scene to medical centers. Nine of the 11 incidents occurred in urban places, with an average distance from scene to hospital of 8 km and the last of the injured persons leaving the scene 40 minutes after the explosion. The remaining 2 bombings occurred in rural places, at Nezarim and Bet-Lid. Victim transfer was expeditious at the Bet-Lid event and ended within 30 minutes after the explosion; at Nezarim the evacuation time was comparatively longer, about 100 minutes. Therefore, although some casualties arrived at hospital 100 minutes after being injured, the great majority were evacuated within 15 minutes. At the admitting hospitals, triage was based on the physiologic status of the patient (ie, Revised Trauma Score [RTS]) and was undertaken by senior surgeons.

All persons who arrived alive at the emergency departments after the incidents were examined otoscopically by ear, nose, and throat (ENT) specialists as part of the secondary survey. The diagnosis of tympanic membrane perforation was established by otoscopic findings of rupture and air passage into the middle ear on air insufflation. All survivors who had sustained either unilateral or bilateral perforation of their tympanic membranes had chest radiographs taken and interpreted immediately and were hospitalized for at least 24 hours for observation. After this observation period, patients who did not manifest any signs of pulmonary injury and had sustained no other complications were discharged. The clinical course of these patients in terms of the evolution of pulmonary injury and overall morbidity and mortality were determined retrospectively.

Survivors complaining of tinnitus, sudden hearing loss, or a sensation of ear fullness in whom otoscopy did not disclose eardrum perforation were not included in the study.

Survivors with other forms of primary blast trauma were also surveyed. Blast lung injury was defined as respiratory distress and hypoxia in the absence of penetrating or blunt chest wall trauma, cardiogenic pulmonary edema, or smoke inhalation. Radiologic signs of adult respiratory distress syndrome, which included diffuse and extensive bilateral alveolar infiltrates consistent with pulmonary edema, or pneumothorax in the absence of penetrating thoracic injury were also used to define blast lung injury. Cardiogenic pulmonary edema was ruled out on the basis of absence of previous ischemic heart disease, normal or decreased central venous pressure, absence of cardiographic manifestations of ischemia, and no discrete ventricular wall hypokinesia on echocardiography.

Blast intestinal injury was defined as intestinal perforation in the absence of penetrating injury or any sign of blunt abdominal trauma. The diagnosis was established on imaging of free subphrenic gas on plain abdominal radiographs or computed tomographic scans, or at laparotomy. The finding of intestinal hematoma at laparotomy was not considered to be diagnostic of intestinal blast injury.

Medical charts of all patients were collected and reviewed by the authors, who, during the study period, served as officers at the Trauma Branch, Israeli Defence Forces, Medical Corps.

Coded notation was made of each patient's age, sex, and accurate diagnosis. The RTS was determined on arrival at the ED, and the type of primary blast injury and final outcome were observed at discharge. Physiologic status was defined as favorable when the RTS was 11 or 12; any lower value was considered to indicate physiologic compromise.

Patients who had isolated eardrum perforation were compared with those who had other forms of primary blast injury in regard to RTS, concomitant nonprimary blast-related injuries accounting for an abbreviated injury score (AIS) greater than 1, and final outcome. Late manifestations of pulmonary or intestinal blast injuries in patients who initially presented with isolated eardrum perforation were determined.

The χ^2 test was applied to determine the statistical differences between the groups, and 95% confidence intervals (CIs) were calculated with the use of GPIS software (Summit Software Technology).

RESULTS

A total of 770 persons were injured in the 11 explosions, 145 (18.8%) of whom died. Of the latter group, 123 were found dead at the scene of the explosion and 22 died from their injuries after admission to the hospital. Of the 647 persons who were admitted to hospitals, 193 (29.8%) were diagnosed as having sustained primary blast injuries, including 142 with isolated eardrum perforation and 51 with other forms of primary blast injuries.

The average age of those who sustained primary blast injuries was 31.8 years (range, 8 to 81 years); 98 (50.7%) were males. The physiologic status was considered favorable (RTS, 11 or higher) in 137 (96.5%) of those who presented with isolated eardrum perforation, compared with 31 (61%) of those with other manifestations of primary blast injuries (risk difference, 36%; 95% CI, 22% to 49%; χ^2=42.4).

Concurrent nonprimary blast injuries (AIS greater than 1) were diagnosed in 31 (21.8%) of those patients with isolated eardrum perforation and in 36 (70.6%) of those with other primary blast injuries (risk difference, 49%; 95% CI, 35% to 63%; χ^2=39.36). Such concomitant traumatic injuries among patients with isolated eardrum perforation included penetrating abdominal or limb trauma in 17, burns in 8, limb fractures in 5, and brain concussion in 1. Among those with pulmonary blast injury, coexisting injuries included penetrating injuries to the brain, abdomen, or thorax in 8; burns in 17; traumatic limb amputations in 2; and severe blunt or crush injuries in 9. None of the 137 patients initially diagnosed as having isolated eardrum perforation and well enough to be discharged developed later manifestations of pulmonary or intestinal blast injury (95% CI, 0 to 2.7).

Two (1.4%) of the patients with isolated eardrum perforation died after admission to hospital. The first died within a short time after arrival at the ED from extensive burns and hemorrhagic shock; the other died later from a lethal brain injury. Six patients (11.7%) with pulmonary or intestinal primary blast injury died after being admitted to hospital. The difference in death rate between patients with isolated eardrum perforation and those with blast lung or intestine injuries was statistically significant (risk difference, 10%; 95% CI, 19% to 1%; χ^2=10.13). Three deaths in the latter group were related to refractory respiratory failure caused by severe pulmonary blast injury. In the fourth case, pulmonary blast injury was a contributing factor to death. The deaths of the other

2 patients occurred as a consequence of lethal trauma caused by penetrating injuries and were unrelated to primary blast injuries.

DISCUSSION

The reported proportion of primary blast injuries among all types of blast injuries ranges from 2% to 76%, depending on the magnitude of the explosive charge and on-scene characteristics.[4,5] The majority of persons affected by primary blast injuries have merely perforated eardrums; life-threatening blast injuries are less common. We investigated the fate of explosion survivors in whom the only primary blast injury was eardrum perforation. We assumed that perforated eardrums may indicate a more significant occult blast injury. Therefore, mandatory hospitalization for observation was chosen as the policy for such casualties. According to our findings, patients with isolated eardrum perforations almost always had a normal physiologic status on admission, and none of them manifested later evidence of extraotic primary blast injuries. In addition, concomitant nonprimary blast injuries were milder in patients with isolated eardrum perforation, compared with those with pulmonary and intestinal primary blast injuries. The clinical course of these patients was not influenced by their primary blast injury, and the rare deaths in this group were unrelated to this mechanism of injury.

In contrast, about 40% of the patients with pulmonary or intestinal primary blast injuries presented with hypovolemic shock, respiratory distress, or both. Such persons need immediate diagnosis and prompt resuscitative effort to survive. Given the history of exposure to blast and the characteristic clinical findings, diagnosis of primary blast injury in such patients is usually straightforward. Patients with pulmonary blast injuries who are physiologically intact on admission usually demonstrate typical radiologic findings,[6] and hypoxia often develops early after injury.[7] Despite previous reports suggesting a gradual onset of manifestation of pulmonary blast injuries, our patients with pulmonary blast injuries had a fulminant clinical course that was evident soon after admission. None of our patients had an occult lung injury that took time to develop.

Intestinal damage caused by primary blast injuries is uncommon and depends on exposure to a very high air pressure. This form of primary blast injury is more characteristic of underwater explosions.[1] Although intestinal blast injury may be occult initially and manifest only later,[8] in this study there were 2 patients with intestinal blast injury who were in agonal condition on arrival at the hospital, and a diagnosis of pulmonary and intestinal trauma was established early in their clinical course. Because the decay of blast waves is faster in air than in liquid media,[1] these patients must have been close to the focus of detonation to have sustained such intense blast injuries. Therefore, intestinal blast injury in explosion survivors is rare and typically is associated with other severe injuries.

Patients who sustain primary blast injuries experience different clinical courses depending on whether they have only eardrum perforation or also pulmonary involvement. The differences between these 2 patient populations are related not only to the involvement of vital organs (ie, the lungs) but also to overall exposure to overpressure. Because the pressure amplitude generated by explosion is inversely related to the cubic distance from the focus of the detonation,[7] the extent of primary blast injury in a specific victim was probably strongly related to the distance of the victim from the bomb. Other mechanisms of injury are also more deleterious at closer distances, and as a result persons with more severe forms of primary blast injury manifested other concomitant severe injuries and their general condition was poor.

Eighteen patients with pulmonary blast injuries did not have eardrum perforation. Because their exposure to pressure was sufficient to provoke lung injury, it is unclear why their eardrums remained intact. We suspect that patent Eustachian tubes in these patients allowed inflow of air that counterbalanced the pressure gradient on both sides of their tympanic membranes.

Because eardrum perforation may go undiagnosed in persons who are unconscious or arrive at the hospital in extremis, otoscopy is recommended for all explosion survivors. In addition to being a form of primary blast injury, blast-related eardrum perforation may also have local consequences, including infection, tinnitus, temporary or permanent hearing loss, and vertigo. After their discharge from hospital, such patients need further follow-up by ENT specialists.

The establishment of clinical guidelines carries the risk that patients who do not fall into the predetermined categories might be jeopardized by adherence to a rigid policy, especially in a mass casualty situation. However, the policy suggested by this study, permitting discharge from hospital for primary blast survivors with isolated eardrum rupture, does not rely merely on the relatively small population of 193 casualties reported here. It is rather based on the observation that pulmonary primary blast injuries inflicted by bombings manifest quickly and

are readily diagnosed on arrival at the ED. Probably, the setting of bombings in civilian environments characterized by large victim density, mainly in confined spaces, causes this fulminant pattern of primary blast lung injury while sparing other, more distant victims, who may experience eardrum rupture only.

None of the patients with isolated eardrum rupture had any evidence of immediate or subsequent pulmonary involvement, whereas all patients with blast lung injuries had a fully developed clinical picture in the first hour after admission. However, based on the size of our study (137 patients), up to 3 in 100 patients may demonstrate late pulmonary barotrauma (95% CI, 0% to 2.7%).

In a mass casualty situation, the decision to discharge home survivors with isolated eardrum rupture seems reasonably prudent and allows the release of much-needed hospital resources. This is especially important when demands outstrip care resources. It is crucial to use the available resources judiciously and to vacate resources as quickly as possible to allow optimal treatment for the most endangered patients. Therefore, it is imperative to be able to identify patients at low risk and discharge them early from the hospital. In the single-victim situation, in contrast, the resources easily meet the demand, and prolonged observation and other precautionary means may be used liberally.

In summary, we suggest that isolated eardrum perforation in explosion survivors does not appear to be a marker of occult or impending pulmonary blast trauma. These patients may safely be discharged from hospital after a chest radiograph and a brief period of observation, decreasing the overload in the admitting hospital.

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