# Case report: blast injury

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A case of blast injury with tympanic perforation and limb laceration is reported. The classification (into four types), mechanism and pathogenesis of blast injury are discussed. Detection of early air embolism, especially on site, can be very difficult. Victims who appear to have only superficial secondary injuries (by missile fragments) should not be discharged without a careful examination since overt air embolism can occur later. To prevent or reduce air embolism, mechanical ventilation should be avoided. (*Hong Kong j.emerg.med.* 2002;9:46-51)

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## Case

A sudden explosion injured a 43-year-old male driver in his car. On arrival to our A&E Department, the vital signs of the patient were stable and he was alert. The patient complained of bilateral hearing loss and pain over right ankle, left big toe and left hand.

Physical examination showed that left tympanum was perforated while the right one was hyperemic. There were abrasions over left chest wall, left hand and left thigh. There were also lacerations over right ankle (Figure 1) and left big toe. (Figure 2) X-ray showed a foreign body in right ankle. Bed-side abdominal ultrasonography did not reveal any free intraperitoneal fluid. Diclofenac was given intramuscularly to relieve pain. Anti-tetanus toxoid was also given.

Patient was directly transferred to the operation theatre. Exploration and removal of foreign body in right ankle was done. The ENT surgeon was consulted.

Figure 1. Lacerations around the right ankle.

Figure 2. Laceration of the left big toe.

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There was a 40% perforation over left tympanum with a retained foreign body which was removed. Pure tone audiometry showed left conductive hearing loss. The patient was eventually discharged on day 13.

## Discussion

### *Blast injury*

Explosives are those materials that are rapidly converted into gases when detonated.

Blast and blast injury are the respective terms used to describe the gaseous decomposition and the damage occurring in an organism that is subjected to the pressure field produced by an explosion.

The explosive blast in a conventional explosion is caused by the very rapid expansion of a mass of hot gases which cause 4 patterns of injury:

1. Primary injury is caused by the blast wave itself.
2. Secondary injury is caused by the fragments of casing, glass, masonry, etc., propelled by the explosion.
3. Tertiary injury is caused by the acceleration of whole or part of the body by the blast wind resulting from the explosion. Apart from movement of the body, this will result in traumatic amputation of an exposed limb should the remainder of the body be protected from the full force of the blast wind.
4. Miscellaneous: inhalation of dust or toxic gases, thermal burns, radiation and psychological impact, etc.

This had primary blast injuries to his ears and secondary injuries to his limbs.

The relative occurrence of these injuries depends directly on the type and amount of explosive used. In civilian terrorist injuries, the amount tends to be small and hence primary and tertiary injuries are less common than secondary injuries. However, both primary and tertiary injuries do occur and must be recognized in order that the appropriate treatment may be provided.

Psychological injuries are the main objectives of terrorist attacks. There can be short-term panic and fear, and long term post-traumatic stress disorder. Many more will have psychological scars than physical injuries. Consequently, symptoms of stress should also be watched for in carers both at the scene and the hospital.[1]

### *Mechanism of explosive blast injury*

Blasts are characterized by the release of large quantities of energy in the form of pressure and heat, with the exact amount depending on the type and amount of explosive.

If the explosion is confined within some sort of casing such as a bomb, the pressure will rupture the housing and eject the resulting fragments at high velocity. The remaining energy is transmitted to the surrounding environment in the form of a *blast wave, blast winds, ground shock,* and *fire.*

The blast wave begins as a single pulse of increased pressure that rises to the peak level within a few

| Category | Injury caused by | Primary target organ |
|---|---|---|
| Primary blast injury | Blast wave | Ears, lungs, GI tract, CNS |
| Secondary blast injury | Victim struck by flying debris | Skin, CNS, eyes, musculoskeletal system |
| Tertiary blast injury | Acceleration + Impact with stationary objects | Abdominal viscera, CNS, lungs, skin, musculoskeletal system |
| Miscellaneous | Inhalation of dust, toxic gases, burns, radiation, psychological impact | Lungs, skin, musculoskeletal system |

milliseconds and then rapidly falls to a minimum pressure lower than the original atmospheric pressure. It is propagated outward radially from the explosion, with the sharply marginated periphery of the sphere becoming the *blast, over pressure, or shock wave*.

The duration and level of the high-pressure peak depends on the nature of the explosives, the conducting medium, and the distance from the detonation point. This blast wave pressure peak determines the overpressure that an object in its path is subject to and is the main determinant of primary blast injury.

The negative pressure wave, or suction of the blast wave, lasts several times longer than the high-pressure wave but can never be greater than 760 mmHg (14.7 psi). The blast wave front decreases in pressure and velocity exponentially with distance from the explosion, until its velocity reaches that of sound and the explosion is heard.

In underwater explosion the rate of decay is much less since water is virtually incompressible. Hence the lethal zone around an underwater blast is much greater for a given quantity of explosive than for an air blast.

The rapidly expanding gases from an explosion also displace air, causing it to move away at very high velocity and produce transient blast winds that travel immediately behind the shock front of the blast wave. This may be as damaging as the original explosion, bearing in mind that hurricane force winds of 125 mph have an overpressure of only 0.25 psi.

The blast wave is similar to a sound wave in that it flows over obstacles in its path. Thus there is pressure that acts at right angles to the direction of travel of the blast wave, known as the *incident pressure*. Hence, victim behind a low wall would not be protected from the effects of the blast. Victims between the explosion and a wall may suffer blast magnified two- or three-fold by reflected pressure.

## *Pathogenesis of blast injury*

### *The primary injury*

As the blast wave passes though the body, it causes damage by means of three distinct phenomena: acceleration, spalling and implosion.

a) *Acceleration* is the movement of viscera initiated by motion of the body wall in the direction of the blast wave. Solid organs simply vibrate as the blast wave passes through them. However, adjacent structures having differing inertial properties collide, while mesenteries tear if stretched beyond their elastic limits.
b) *Spalling* may occur at the interface of two different media when shock waves move from a high density to a lower density medium. For example, when air meets water, the water surface is broken up into a shower of droplets. This is due to the creation of a negative reflection at the interface and thus fragmenting the surface of the heavier medium.
c) *Implosion* is the momentary concentration of gas-filled spaces as the high pressure in the surrounding fluid or solid compresses these spaces. Similarly, because there is a pressure differential between the air-filled and vascular spaces, blood and fluid are forced into the air-filled spaces. The mechanism is of particular importance in the lungs, where it contributes to pulmonary haemorrhage. In addition, as the negative pressure wave follows the initial positive pressure, smaller internal secondary explosions occur as the compressed gas re-expands.

Tissues vary in their susceptibility to primary blast injury, with homogeneous or solid tissues being at least risk because they are essentially non-compressible and merely vibrate as a whole when subjected to a blast wave. Conversely, gas-filled organs are compressible and have tissue-gas interfaces, which means that displacement occurs wherever tissue-gas interfaces, which means that displacement occurs wherever tissues of different densities interface, resulting in tissue distortion and tearing.

Thus, primary blast injury mainly affects organs containing air and causes the most severe damage at the junctions between tissues, where loose, poorly supported tissue is displaced beyond its elastic limit. While those containing fluid (urinary bladder, gallbladder) are almost never damaged by these mechanisms.

*The ears*

The ears are most often affected by explosive blasts, with hearing loss being the primary manifestation. Hearing can be damaged by one of three ways:

a) *The tympanic membranes may rupture*. This usually occurs in adults at a pressure differential between the middle and external ears of around 360 mmHg (7 psi), and most often present as a linear perforation of the pars tensa (after effect of the implosion).
b) Dislocation of the ossicles which may be accompanied by tympanic membrane rupture or occurring as the sole injury. (Acceleration)
c) Deafness may result from blast effects on the inner ear, causing perilymph fistula and other damage. In addition to hearing loss, primary symptoms of inner ear damage include vertigo and tinnitus.[2]

The paranasal sinuses are also susceptible to blast injury, usually manifesting as barotraumatic damage similar to the squeeze syndromes that occur with compressed air diving.

*If the tympanic membrane is clinically intact, then a serious blast injury is very unlikely.*

*The lungs*

The lungs are generally the organs most severely affected by blast injury, and these injuries are likely to present a threat to life. The susceptibility of the lungs to blast waves depends on the peak overpressure and its duration. They may be severely damaged with an overpressure of 50 psi lasting for more than 4 ms.

The blast wave causes widespread alveolar damage because of its effects in tissue-gas interfaces, producing interstitial and intra-alveolar haemorrhage and edema, parenchymal and pleural lacerations, and alveolar-venous fistulas.

Because of the widespread nature of this damage, a variety of specific injuries may be found, including pulmonary edema, pneumothorax and other extra-alveolar air syndromes, and air embolism. The air that enters the cerebral and coronary arteries via the pulmonary veins may cause severe brain damage and sudden death.

The actual symptoms experienced by victims of blast lung injury will vary with the severity and nature of their specific injuries, but, in general, they will present with dyspnoea and other signs of pulmonary insufficiency, chest pain, haemoptysis, rales, rhonchi and other signs of pulmonary edema or haemorrhage.

*Gastrointestinal tract*

It is more likely to occur in underwater explosions because the blast is more efficiently transmitted in this medium. Implosion and spalling cause contusion and perforations of the gas-containing organs when the gas re-expands. Since the large bowel usually contains more gas than the small bowel, it tends to be more severely affected. The shearing effect caused by acceleration of tissues with different inertial properties may be responsible for submucosal and subserosal hemorrhages in the gut, and mesenteric injuries.

Common clinical manifestations include abdominal pain, melaena, signs of peritonitis, and free air in the abdomen. Evisceration and other gross damage may be found in victims who were very close to the detonation site, but these types of injury are nearly always fatal.

*Solid viscera*

These are more likely to be damaged when the victim is thrown against a solid object than by the blast wave itself, although their mesenteries may be torn.

*The nervous system*

Blast injuries of the CNS are of two main types. The first is the direct shock wave effect which produces a concussion syndrome and various types of intra- and extra-axial haemorrhage, and the second is the effect of cerebral air embolism.[3]

Although skull fracture is commonly seen, this is rarely if ever due to the blast wave except around air-filled sinuses where spalling and implosion occur.

*The heart*

This may be damaged by acceleration causing contusion, but sudden cardiac arrest may occur due to air emboli in the coronary arteries arising from alveolar-pulmonary vein fistulas.

*The secondary injuries*

These are caused by pieces of casing of the explosive device and secondary missiles (pieces of debris impelled by the blast). These fragments often travel at very high velocities and result in contaminated wounds with much local and distant tissue destruction.

*The tertiary injuries*

These result directly from movement of the body by the blast wind. This may be as destructive as the blast wave itself. Their body may be carried a considerable distance by the blast wind, but if partially protected, traumatic amputation of the unprotected part may occur. This is an avulsing type of injury and so nerves and blood vessels will be seriously damaged some distance from the level of amputation. Limb replantation in these cases is not feasible.

Type IV blast injuries include:

1. Wide variety of injuries resulting from inhalation of dust and toxic gases,[4] exposure to radiation, thermal burns, and so on.
2. Very high temperatures are generated for relatively short periods during the explosion, resulting in local fires and flash burns to victims close to the explosion, even those who may escape its other effects.
3. The numerous bodily insults that can result from these types of blast injury are far too many to list here.

*Management of blast casualties*

Resuscitation both on site and in hospital should follow standard lines and disaster contingency plan should be activated through the proper channels if indicated.

The following specific point should be noted:

1. Diagnosis, especially on site, can be very difficult. Initially a blast-injured patient may have no signs of external damage and appear unhurt but may suddenly deteriorate either in next few minutes or a few hours later. Associated injuries, such as inhalation burns or penetration by small fragments, which may initially appear to be of minor importance may in fact be severe.
2. A very conservative approach, therefore, should be taken. Victims who appear to have only superficial secondary injuries should not be dismissed without a careful examination.
3. Blast injury victims should be managed in the same manner as any multiple trauma victims following the golden principles of A, B, C but particular attention should be directed to the respiratory system.
4. This includes giving special attention to maintenance of a patent airway (especially when maxillofacial, cervical spine or other head and neck injuries are present), administering supplemental oxygen, judiciously using intravenous fluids[5] and analgesics, evacuating pneumo- and haemothoraxes, and promptly implementing mechanical ventilation if signs of respiratory failure or inadequate oxygenation are present.[6]
5. However, some authorities advocated that oxygen should be administered by mask in the early stages after a blast injury and if possible mechanical ventilation should be avoided for as long as possible, in order to lower the risk of air embolism (since the diffuse alveolar-capillary damage present in blast lung greatly increases the risk of causing extra-alveolar extravasation of air, including air embolism). For the same reason, positive expiratory pressure (PEEP) ventilation should be avoided for several days.
6. It has been suggested also that there is a high risk of these patients developing pneumothoraces on ventilation, due to traumatic bronchopleural fistulas, and prophylactic chest drains have been advocated.
7. It is useful to examine the tympanic membrane. If it is not perforated, the patient is unlikely to have sustained a significant blast injury.[7,8]
8. It is worth noting whether the patient is anosmic since the olfactory plate is often damaged by spalling and implosion in the ethmoid sinuses. While this is of little importance clinically, it may become important if compensation is sought at a later date.
9. A careful neurological assessment is important, bearing in mind that the neurological state may deteriorate rapidly due to air embolism. Air emboli may be seen in the retinal vessels on fundoscopy. If neurological deterioration can be attributed to

air emboli then hyperbaric therapy has been advocated, although it must be stressed that there is little experience in this field.

10. The abdomen should be carefully examined for evidence of intraperitoneal bleeding or perforation of a hollow viscus.
    10.1. Severe injuries to the gastrointestinal tract from blast rarely occur in isolation although bowel contusion is probably quite common.
    10.2. There are generally few survivors of blast injury sufficiently severe to cause bowel perforation.
    10.3. Generalized abdominal tenderness is common due to multiple small internal hemorrhages and since such patients do not fare well with general anesthesia because of the accompanying pulmonary injury, a conservative line should be taken whenever possible.
    10.4. Nasogastric suction with carefully monitored intravenous therapy is required.
    10.5. Laparotomy is indicated if there are signs of local peritoneal irritation, massive intraperitoneal hemorrhage due to rupture of the spleen or liver or radiological evidence of free gas in peritoneal cavity.
11. Secondary injuries must be treated as if they were caused by high velocity missiles; i.e. with adequate debridement and delayed primary closure. As extensive tissue destruction may be incurred locally with loss or disruption of the wound parts to form a cavity. Sites distant to the point of impact may be injured as a result of shock waves. The extent of injury in these complex wounds is difficult to assess and primary closure is ill advised.
12. Antibiotics may have an important role in helping prevent infection, but these are effective only if given early.
13. Traumatic amputations caused by the blast winds will require aggressive life-saving first aid measures and immediate care personnel should not be afraid to use a tourniquet.

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