CME Article

Bomb blast mass casualty incidents: initial triage and management of injuries

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ABSTRACT

Bomb blast injuries are no longer confined to battlefields. With the ever present threat of terrorism, we should always be prepared for bomb blasts. Bomb blast injuries tend to affect air-containing organs more, as the blast wave tends to exert a shearing force on air-tissue interfaces. Commonly-injured organs include the tympanic membranes, the sinuses, the lungs and the bowel. Of these, blast lung injury is the most challenging to treat. The clinical picture is a mix of acute respiratory distress syndrome and air embolism, and the institution of positive pressure ventilation in the presence of low venous pressures could cause systemic arterial air embolism. The presence of a tympanic membrane perforation is not a reliable indicator of the presence of a blast injury in the other air-containing organs elsewhere. Radiological imaging of the head, chest and abdomen help with the early identification of blast lung injury, head injury, abdominal injury, eye and sinus injuries, as well as any penetration by foreign bodies. In addition, it must be borne in mind that bomb blasts could also be used to disperse radiological and chemical agents.

Keywords: blasts in enclosed spaces, bomb blast injuries, bowel perforation, high order explosives, mass casualty incidents, multiple fractures, pulmonary blast injury, tympanic membrane perforation

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INTRODUCTION

Bomb blast injuries to civilians in a non-combat setting have become increasingly common over the last decade, mainly as acts of terrorism. Well-known examples of such acts of terrorism include the Madrid commuter train bombings (March 2004), the London Underground bombings (July 2005) and the Oklahoma City bombing (April 1995). Smaller scale but frequent bombings occur in Israel, Iraq and Pakistan, while within Southeast Asia, major cities and tourist sites such as Bangkok (January 2007), Bali (October 2002 and October 2005) and Jakarta (August 2003, September 2004) have also been targeted. With the ever-present threat of terrorist acts, it is important for medical responders to be well-versed in the spectrum of injuries that are associated with mass casualty incidents resulting from bomb blasts and other similar explosive devices.

Explosives are categorised as high-order explosives (HE) or low-order explosives (LE). HEs produce a defining supersonic over-pressurisation shock wave. Examples of HEs include trinitrotoulene (TNT), C-4, Semtex, nitroglycerin, dynamite and ammonium nitrate fuel oil (ANFO). LEs create a subsonic explosion and lack the over-pressurisation wave characteristic of HEs. Examples of LEs include pipe bombs, gunpowder and most pure petroleum-based bombs such as Molotov cocktails or aircraft improvised as guided missiles.[1] It does not necessarily mean, then, that home-made bombs tend to be LEs, as rogue states that sponsor acts of terrorism might supply HE types of materials in fairly large quantities to militants in their bomb-making activities. Ammonium nitrate, in the form of crop fertilisers, could also be purchased and accumulated over time in large amounts.

The detonation of explosives leads to virtually instantaneous release of large amounts of energy in the form of expanding gases.[2] These gases compress and superheat the surrounding air so rapidly that a shock/blast wave is created. Damage occurs to the human body when the shock waves encounter tissues of different densities, thus creating differential pressure forces, motion, stretching and eventual tearing. Shock waves of low-to-moderate pressure propagated through solid organs of relatively homogenous densities generally do not cause significant effects, although when they are high enough, injuries can still result. However, shock waves in hollow organs constantly encounter different densities at air-tissue interfaces, which result in distortions leading to tissue tearing. Such shearing at tissue/tissue interfaces results in subserous/submucosal haemorrhage and also damage at gas-tissue interfaces. Therefore, hollow organs containing air tend to be injured by shock/blast waves (e.g. the middle ear, bowel and lungs). The position of the victim in relation to the bomb, including the angle and height of the victim in relation to the centre of the explosive device, is also important in determining the extent of injury.

The surroundings in which the blast occurs also affects the pattern and severity of injury. Blasts in enclosed spaces tend to sustain a higher mortality rate than those in the open air. In open air explosions, the blast waves travel outwards and are quickly dissipated with a relatively rapid decline in the velocity of the shock wave

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Table I. Categories of injuries associated with bomb blasts.

Category	Body part affected	Types of injuries
Primary injury	Gas-filled structures are the most susceptible – lungs, GIT, middle ear	- pulmonary barotrauma - tympanic membrane rupture and middle ear damage - abdominal haemorrhage and perforation - eye globe rupture - concussion without physical signs of external head injury
Secondary injury	Any body part can be affected	- penetrating ballistic or blunt injuries - eye penetration (can be occult)
Tertiary injury	Any body part can be affected	- fracture and traumatic amputation - closed and open brain injury
Quaternary injury	Any body part can be affected	- burns of all degrees - crush injuries - closed and open brain injury - breathing problems from blast, smoke, toxic fumes

front. This results in the majority of cases sustaining low immediate and late mortalities and also predominantly non-critical injuries. In contrast, within confined spaces (such as a bus or classroom), blast waves tend to be reflected back from the walls, thus striking the victims more than once.[3] The effects are therefore amplified, and Israeli surgeons have noted that such victims have a higher rate of mortality.[4-6]

To complicate matters, there are worries that the initial bomb blasts could very well be a *"primary/diversion attack"* to draw emergency medical service responders to the scene. Terrorists could then detonate secondary explosives to target emergency responders. There are also worries that nuclear materials and chemical agents could be mixed with the explosives and thus dispersed when the bomb is set off. The former is commonly known as a "dirty bomb" – primarily a radiological dispersion device.[7] The latter might contain chemicals such as nerve agents, like those encountered by US troops who found such roadside bombs in Iraq.[8] It is therefore important that a thorough scene survey is done and the site secured as soon as possible to minimise any such danger to emergency personnel. If necessary, special HAZMAT teams can be called in to screen for chemical, biological and radiological (CBR) threats. If such threats are found, a decontamination centre may need to be set up for victims, while caregivers and rescuers will need to don personal protection equipment in the form of masks and suits. Biological agents would most likely not be deployed by a dirty bomb because of the heat from the explosion denaturing and destroying the viability of living organisms.[9]

CLASSIFICATION AND SEVERITY OF BLAST INJURIES

It is helpful to visualise the effects of a bomb blast on the human body in four phases, as described by Wightman and Gladish.[1] As mentioned earlier, detonation of explosives lead to virtually instantaneous release of large amounts of energy in the form of expanding gases. These gases compress and superheat the surrounding air so rapidly that a shock/blast wave is created (blast wind). *Primary injuries* occur when the initial blast wave strikes the victim's body. *Secondary injuries* are sustained by the victim when flying objects such as debris, broken glass, loose pieces of concrete and metal strike the victim's body. As the victim's body is picked up by the blast wave and then thrown onto the ground or against a wall, *tertiary injuries* are sustained from the impact. Any miscellaneous injuries that occur thereafter are termed *quaternary injuries*; examples of these include chemical burns, smoke inhalation and crush injuries from being trapped inside collapsed buildings (Table I).

Bomb victims tend to be more severely injured and take up more resources. Mayo and Kluger in Israel found that, compared to conventional trauma victims, the number of severely injured (injury severity score ≥ 16) was three times higher, and for those with Glasgow Coma Scale score ≤ 5 the figure was four times higher.[3] The number of body regions injured was also significantly higher in bomb blast victims, with approximately 18% having three injured body regions and 11% four or more regions, compared to 5% and 1.5%, respectively, in the conventional trauma group.

ACUTE MANAGEMENT

With the above in mind, it is possible for caregivers to then predict the pattern of injuries by organ systems (Table II). However, this is by no means exhaustive, and the doctors in charge must continue to maintain vigilance for subtle and delayed manifestations. Almost invariably, there will be multiple organ system involvement. As such, the trauma team should manage such patients using a systematic approach, such as that advocated by the Advanced Trauma Life Support course.[10] If possible, it should determine the patient's location relative to the centre of the explosion.

- An explosion that occurs in an enclosed space (including a building, a mine or a relatively lightly constructed enclosed space such as a bus) or in water tends to cause more serious injuries.[5-7] This is because blast waves are reflected by solid surfaces; thus, a person standing next to a wall may suffer an increased primary blast injury.

Table II. Spectrum of injuries categorised by organ systems.

ENT	- deafness (no longer considered a strong indicator of blast injury) - petechia of the tympanic membrane or haemotympanum may be seen on otoscopy - tympanic membrane may rupture - ossicles may be fractured or dislocated - vertigo and tinnitus - bleeding from paranasal sinuses
Eye	- perforations from high-velocity projectiles - symptoms include eye pain or irritation, foreign body sensation, altered vision, periorbital swelling or contusions - decreased visual acuity, hyphaema, globe perforation, subconjunctival haemorrhage, foreign body, or lid lacerations
Respiratory system	- sudden severe contusion causing instant fatal respiratory failure - pneumothorax and pneumomediastinum - bronchopleural fistula may cause tension pneumothorax - haemothorax, parenchymal haemorrhage and haemorrhage into alveolar spaces - pneumatocoele - ARDS - air embolism - diffuse lung damage can cause delayed effects after two days
Gastrointestinal tract	- visceral contusion and haemorrhage - acute or delayed intestinal perforation - pneumoperitoneum - bleeding from the walls of the gastrointestinal tract
Limb injury	- avulsion amputation from blast wind - traumatic amputation, fractures - crush injuries - compartment syndrome - burns, cuts, lacerations - acute arterial occlusion, air embolism-induced injury
Central nervous system	- abnormal signs - intracranial, subdural and extradural haemorrhages - concussion syndrome - effects of air embolism upon the cerebral circulation
Psychiatric manifestations (immediate or delayed)	- Post-traumatic stress disorder with its attendant features of guilt, anxiety, depression, sleep disorders

- The intensity of an explosion pressure wave declines with the cube root of the distance from the explosion. A person three metres (ten feet) from an explosion experiences nine times more overpressure than a person six metres (twenty feet) away. Proximity of the person to the explosion is an important factor in a primary blast injury.

There is a long-cherished belief among rescuers that otoscopic examination of the tympanic membrane (TM) is a quick way to triage victims for lung and bowel blast injuries. The TM can be ruptured by an increase in atmospheric pressure as low as 5 psi above normal. If there is no TM rupture, it is said that the chance of hollow organ injury is therefore significantly lower. Unfortunately, this is now no longer a reliable rule, as it has been disproved by the Israeli experience. In their series, Leibovici et al discovered that out of 193 patients who sustained primary blast injuries, only 31 (16%) victims had combined otic and pulmonary injuries. The vast majority, 142 (74%) had isolated eardrum perforation only, 18 had isolated pulmonary blast injury and two had isolated intestinal blast injury.(11) Similarly, in the Madrid train bombings, four of 17 (24%) critically-injured patients had intact tympanic membranes.(12) Bleeding from the various sinuses of the face (such as the maxillary and frontal sinuses) has been described, but seldom is there significant bony injury. Besides deafness, other long-term ENT sequelae include tinnitus, dizziness and ear pain.(13)

While TM perforation is the most common injury, it was pulmonary blast injury that carried the highest mortality and morbidity, and consumed the most resources in the major bombings described.(14,15) Those who immediately die on the scene often sustain a sudden severe contusion causing instant fatal respiratory failure. This is a result of damage to the alveolar septae, causing alveolar rupture. Tearing of pulmonary tissue results in pulmonary lacerations, haemothorax or pneumothorax (in any combination). Large tears of the bronchi or lungs may create bronchopleural fistulae with unilateral or bilateral tension pneumothoraces.(16) Air can escape into pulmonary tissues resulting in pseudocyst formations called pneumatocoeles. Acute respiratory distress syndrome (ARDS) and air embolism are dangerous complications; this makes such patients a therapeutic challenge, especially when implementing positive end-expiratory pressure (PEEP) and intermittent positive pressure ventilation (IPPV), because in the presence of low blood pressure, such ventilation modalities predispose to arterial air embolism, which carries a high mortality risk.

Air entry into the pulmonary venous circuit can cause an arterial air embolism with lodging of the emboli in any organ and subsequent distal ischaemia. This diagnosis should be considered whenever there is any evidence of localised ischaemia of the skin or mucous membranes, or such findings as altered mental status, seizures, focal neurological deficits, chest pain, arrhythmias, pulmonary oedema, abdominal pain or haematuria.[1,2,16] These findings tend to occur after the initiation of IPPV. Other clues may be an acute myocardial infarction in the young victim without evident chest trauma, paraplegia in the absence of spinal cord injury or the presence of focal neurological deficits without head trauma. In fact, an air embolism from positive pressure ventilation is the most common cause of early death among immediate survivors. Unfortunately, the only specific treatment is hyperbaric oxygen therapy, which is not easily available.

Blast intestinal injury is also common as the bowel is filled with air. Signs of peritonitis may or may not be immediately obvious, as intestinal perforation may not always be acute and could present in a delayed fashion. In one case report, subacute pneumoperitoneum and bleeding from the walls of the terminal ileum presented as late as after a week.[17] Blunt trauma to the abdomen can cause liver, renal and splenic contusion, lacerations and haemorrhage. Fortunately, the abdomen lends itself well to imaging by FAST (focused abdominal sonography for trauma) or computed tomography (CT).

Abbotts et al did a literature review to assess the incidence of ocular blast injury in survivors.[18] Overall, they found that there is little conclusive evidence that primary ocular blast injury occurs in survivors of explosions. However, some case reports do surmise its occurrence and it cannot be unequivocally ruled out. At present, however, the most severe and damaging threat to the eyes from a blast remains the impact of fragments and debris. Up to 10% of all blast survivors have significant eye injuries, including perforations from high-velocity projectiles, hyphaema, retinal detachment, globe perforation, subconjunctival haemorrhage, foreign body and lid lacerations. Where there is decreased visual acuity, liberal referral for ophthalmological screening is encouraged.

Head injuries can also result from direct and indirect impact. These include intracranial, subdural and extradural haemorrhages, and the concussion syndrome. Limbs injuries run the gamut from avulsion amputation from blast wind to closed and open traumatic amputations, fractures, crush injuries, compartment syndrome, burns and acute arterial occlusion. Traumatic amputation of a limb above the wrist or ankle from the force of a blast is a bad prognostic sign, as it is a surrogate marker for severe internal injuries from a powerful blast wind. Also, such detached parts are often non-viable and unsuitable for re-implantation.

In pregnant patients, the foetus does not possess gas-filled structures, protecting it from this component of the primary blast wave.[9] However, the primary blast wave is amplified threefold in an aqueous environment, so this should prompt concern about potential foetal injury as the amniotic fluid surrounds the foetus. In the evaluation of the obstetrical patient after blast injury, attention should be directed to ultrasonographical examination of the gravid uterus to rule out uterine rupture or abruptio placenta. Rhogam should also be given to Rhesus negative mothers.

EMERGENCY IMAGING

During the Madrid bombings, the staff at University Hospital La Paz managed 36 patients, of which 17 suffered from severe or life-threatening injuries, and 19 had mild injuries.[19] The most common lesions were thoracic trauma and blast lung injury, acoustic trauma, and orbital and paranasal sinus fractures. Within the abdomen, common injuries were hepatic and splenic lacerations, while the orthopaedic injuries comprised mainly vertebral and limb fractures. Other than limb injuries, these were diagnosed with the generous use of CT, and were useful in early diagnosis and definitive treatment.

Similarly, with experience borne from the London Underground bombings, Hare et al recommended the following roles for the radiology department in case of future bombings and other possible mass casualty incidents:[20]

(1) All elective and non-urgent patients are to be cleared from the hospital, in particular from the emergency and radiology departments. Radiologists and radiographers are thus available to be allocated to key areas of the radiology and emergency departments.
(2) A radiologist should be stationed in the major trauma bays to perform FAST to exclude free abdominal fluid or haemodynamically-significant abdominal injury. Radiologists are also stationed in the emergency department, immediately reporting all radiographs and communicating with the supervising clinicians, with a similar set-up in the CT scan room.
(3) All critically-ill patients require chest, cervical spine and pelvic radiographs as a routine, as well as radiographs based on the site of penetrating wounds as these can cause complex internal injuries.
(4) Unstable, critically-ill patients should be transferred straight to the operating theatre for exploratory laparotomy/thoracotomy or other operative procedures to treat the cause of haemodynamic instability without a need for imaging.
(5) Stable but critically-ill patients can be transferred to the CT scan room before being sent to the operating theatre or ICU. The scout CT should cover the entire body (to look for shrapnel and undetected fractures)

and be followed by a more definitive CT of the head, and chest to pelvis, where indicated.

In addition, the London team advised that radiologists should, in addition to the usual spectrum of head and abdominal injuries, familiarise themselves with special radiological features of blast injuries, namely:[20]

(1) Injury to eyes, facial bones and sinuses.
(2) Blast lung with accompanying pneumothorax, haemothorax and pneumomediastinum, as well as bronchopleural fistulae and air emboli.
(3) Complex comminuted fractures of the lower limb long bones.
(4) Often multiple fractures elsewhere.
(5) Presence of penetrating foreign bodies (often multiple).

LONG-TERM MANAGEMENT

Of the target organs in blast injuries, the syndrome of pulmonary blast injury is the one with the greatest likelihood of causing long-term morbidity in terms of respiratory insufficiency. Hirshberg et al in Israel studied 11 victims with pulmonary injury as a result of a bus bomb blast incident.[21] One year later, none had any pulmonary-related complaints. Physical examination of the lungs was normal. Most of the patients demonstrated normal lung function tests and complete resolution of the chest radiograph findings. They concluded that most patients who survive lung blast injury will regain good lung function within a year.

Survivors carry a heavy psychiatric burden in the form of post-traumatic stress disorder (PTSD). This was seen in the Madrid, Israeli and Bali bombings.[14,15,22] It is not known how many more were not injured physically and yet suffered from PTSD. Such sufferers would include the family members of those killed, family members of the perpetrators, as well as bystanders and witnesses to the scenes of carnage.

CONCLUSION

With the ever present threat of terrorism, we should be prepared for bomb blasts. Bomb blast injuries tend to affect air-containing organs more, as the blast wave tends to exert a shearing force at air-tissue interfaces. Commonly-injured organs include the TMs, sinuses, lungs and bowel. Of these, blast lung injury is the most challenging to treat. The clinical picture is a mix of ARDS and air embolism, and the institution of positive pressure ventilation in the presence of low venous pressure could cause a systemic arterial air embolism. The presence of TM perforation is not a reliable indicator of the presence of blast injury in the other air-containing organs. Radiological imaging of the head, chest and abdomen will help with the early identification of blast lung injury, head injury, abdominal injury, eye and sinus injuries, as well as any penetration by foreign bodies.

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SINGAPORE MEDICAL COUNCIL CATEGORY 3B CME PROGRAMME
Multiple Choice Questions (Code SMJ 200901B)

	True	False
Question 1. Besides inflicting injuries to the masses from the primary attack, terrorists could also use the bomb explosion to:		
(a) Disperse chemical agents.	☐	☐
(b) Disperse biological hazards.	☐	☐
(c) Disperse radiological materials.	☐	☐
(d) Attract rescuers to the scene and then mount a secondary attack.	☐	☐
Question 2. Bomb blasts injuries:		
(a) Tend to be more severe in enclosed places.	☐	☐
(b) Are best approached with the Advanced Trauma Life Support protocols.	☐	☐
(c) Tend to have higher injury severity scores and involvement of multiple body regions.	☐	☐
(d) Can be subtle and delayed.	☐	☐
Question 3. Primary bomb blasts injuries tend to include:		
(a) Penetrating ballistic injury.	☐	☐
(b) Burns and inhalation injury.	☐	☐
(c) Injury to bowel.	☐	☐
(d) Pulmonary barotrauma.	☐	☐
Question 4. Principles in emergency imaging of bomb blast victims include:		
(a) Unstable critically-ill patients should be transferred straight to the CT scan room for imaging.	☐	☐
(b) A scout CT should cover the entire body to look for shrapnel and undetected fractures.	☐	☐
(c) Generous use of CT is important in diagnosing chest and abdominal injuries.	☐	☐
(d) Use of FAST to detect fluid in the abdomen.	☐	☐
Question 5. Special considerations in bomb blast victims:		
(a) Rupture of the tympanic membrane is a reliable marker for hollow organ injury elsewhere.	☐	☐
(b) Pregnant mothers should be investigated for the possibility of uterine rupture or abruptio placenta.	☐	☐
(c) Traumatic amputation of a limb above the wrist or ankle from the force of a blast is a bad prognostic sign.	☐	☐
(d) Management of ARDS in such victims carries a high risk of arterial air embolism.	☐	☐

Doctor's particulars:

Name in full: ______________________________

MCR number: ______________________ Specialty: ______________________

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SUBMISSION INSTRUCTIONS:
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(1) Answers will be published in the SMJ March 2009 issue. (2) The MCR numbers of successful candidates will be posted online at www.sma.org.sg/cme/smj by 15 March 2009. (3) All online submissions will receive an automatic email acknowledgment. (4) Passing mark is 60%. No mark will be deducted for incorrect answers. (5) The SMJ editorial office will submit the list of successful candidates to the Singapore Medical Council.

Deadline for submission: (January 2009 SMJ 3B CME programme): 12 noon, 8 March 2009.