Blast injuries: a guide for the civilian surgeon

Alastair Beaven

Paul Parker

Abstract

Military clinicians became familiar with the blast injuries during recent conflicts. Management of these complex injuries has advanced significantly, and survival amongst UK service personnel has increased year on year. Civilian casualties from terrorist activities have included multiple casualties with similar blast injuries. Civilian clinicians should now be ready to receive blast-injured casualties in the event of major terrorist attacks. This article outlines the mechanisms by which blast inflicts injury. It describes the management steps required to treat these complex, potentially lethal wounds.

Keywords Amputation; blast lung; blast mechanism; blast triad; damage control surgery; major incident response

Background

Recent conflicts have exposed both soldiers and civilians to explosive methods of wounding. Military clinicians have become increasingly familiar with the management of blast injuries. Many recent terrorist attacks have utilized explosive devices, and civilian trauma clinicians must be aware of how to treat these injuries in the event of a major incident. This article summarizes the basic mechanisms of blast injury, the concept of 'hidden injury' and outlines modern proactive treatment strategies.

Overview of blast injuries

Blast injuries can be divided into five distinct mechanisms. These occur sequentially.[1]

Primary blast injury

Sometimes described as the *blast wave*, the primary blast injury refers to the overpressure generated by the forcibly expanding gases within high explosives. This increased pressure affects all regions where an interface exists between tissues of varying densities as they compress at different rates. This is particularly evident in gas-filled viscera, and results in damage to tympanic membranes and the lung and bowel most commonly. Tympanic membranes rupture at relatively low pressures of 2 psi, whereas lung damage typically occurs at 70 psi. The presence of tympanic membrane rupture is therefore not a reliable marker of associated severe injury. The primary blast effect is modified by the environment. Relative protection is seen at greater distances, with amplification in enclosed spaces. The blast quickly dissipates to the third power of the blast radius (r^3), but is reflected and sustained by solid structures such as walls.

The scene environment is important when considering the injury burden among survivors. A new taxonomy in explosion setting describes five locations; closed space (CS), inside a bus (IB), adjacent to a bus (AB), semi-open spaces (SO), and open spaces (OS). IB can also clearly apply to Underground or Metro systems. This classification has better sensitivity with regard to injury severity compared to traditional *open space* versus *closed space* descriptions.[2] Injury severity, number of operations and ITU admissions are highest in closed space survivors.

Blast lung occurs as a direct effect of the primary shockwave compressing and disrupting tissues,[3] particularly characterized by rupture of alveolar capillaries. Haemorrhage and oedema within the lungs contribute to initial respiratory embarrassment, and also serve to act as a focus for a further pro-inflammatory response.[4] *Blast triad* is the accepted term for the physiological response of bradycardia, apnoea and hypotension and occurs in around 10% of patients suffering traumatic amputation. Lung overstretch mediated via the vagus nerve produces bradycardia and apnoea. The hypotension is dependant on by the concurrent fall in cardiac output and myocardial impairment and also by a release of nitric oxide, a potent vasodilator, from the pulmonary circulation.[4] The effects of the blast triad may last for some time and have profound effects on resuscitation.

Lung protective ventilation is therefore vital. This must be proactively considered and started as early as possible. Low tidal volumes (6 ml/kg predicted body weight) are used to reduce ventilator-associated lung injury, decrease volutrauma (hyperinflation and shearing injury), barotrauma (alveolar rupture and pneumothorax) and biotrauma (release of inflammatory mediators).

Primary blast traumatic brain injury (bTBI) is a controversial topic. First diagnosed in World War 1 as 'shell shock', where a long-lasting neurological deficit was noted in the absence of visible injury to the neuro-axis. Although different models have been hypothesized, it is now widely accepted that the neurological injury is a result of physiological and anatomical disruption of the blood–brain barrier.[5] Symptoms may include physical, emotional, cognitive and behavioural manifestations, and may occur alongside affective disorders.

Secondary blast injury

Secondary blast injury includes projectiles propelled by energy from the exploding device. These may originate from the device itself or from the environment. In military ordnance these fragments are often pre-formed (e.g. ball bearings or notched wire) resulting in a more predictable blast pattern. This is desirable in weapon design, to better anticipate the effect of the weapon. In improvised explosive devices (IEDs), fragments are makeshift, and can include the use of nails, screws, scrap metal or any other implements to hand. As the fragments are heterogeneous, they are variably subjected to air drag and therefore produce a less predictable blast pattern.

Environmental projectiles can include damaged components from the structures affected in the blast, e.g. car parts, concrete

***Alastair Beaven** MRCS is a Specialist Registrar in Orthopaedic Surgery affiliated with the Royal Centre for Defence Medicine, Queen Elizabeth Hospital, Birmingham, UK. Conflicts of interest: none declared.*

***Paul Parker** FRCS(Ed) FIMC FRCS(Orth) is a Consultant in Orthopaedic Surgery at the Royal Centre for Defence Medicine, Queen Elizabeth Hospital, Birmingham, UK; and Senior Lecturer in SOF Medicine at University College Cork, Ireland. Conflicts of interest: none declared.*

Please cite this article in press as: Beaven A, Parker P, Blast injuries: a guide for the civilian surgeon, Surgery (2018), https://doi.org/10.1016/j.mpsur.2018.05.007

from a building, and debris from the blast origin. Special mention should be given to suicide bombers: bone, teeth, clothing and worn equipment can all be classed as components of secondary blast injury. *Candida*, hepatitis B and C, and human immunodeficiency virus (HIV) may theoretically be transmitted from suicide bomber to casualties via biological fragmentation, although there have been no proven cases of blood borne virus (BBV) transmission from suicide bomber to victim in this mode of attack[6,7]

Guidelines for post exposure management of this situation are available in the UK.

Tertiary blast injury

Tertiary blast injury occurs when casualties are displaced by the explosive energy of the blast. Injuries occur from collision, impalement and abrasion with the environment. Limb loss can also occur (in-bone or through joint), where limb flail or axial shear waves can cause primary amputation. Hidden spinal injuries should always be suspected in these cases.

Quaternary blast injury

Quaternary blast injury is the term given to 'other' mechanisms that have the ability to cause harm such as thermal, radiological or psychological injury. Thermal injury can result from the products of combustion of the device itself. Most common are superficial flash burns to areas of exposed skin, but deeper burns may be inflicted. In certain types of explosion (i.e. nuclear) radiological injury is also a risk. There can also be further injury from weakened structural elements like a collapsing roof. After-blast psychological injury (e.g. post traumatic stress disorder) is now considered a quaternary effect.

Quinternary blast injury

Quinternary blast injury is a relatively new concept. It includes delayed effects such as chronic pain, malnutrition and immunosuppression. There is evidence to suggest that the immunosuppression from blast injury can reactivate latent diseases such as malaria, osteomyelitis and fungal infection. Injury Severity Score (ISS), massive transfusion, marketplace bombs and surgical operation time have also been identified as risk factors.

Patterns of injury

Blast injuries produce a unimodal pattern of mortality, with the vast majority of deaths (>90%) occurring within the first 10 minutes of injury. Bleeding is the main reversible cause of death, and the Hartford Consensus[8] has identified strategies to improve survivability from terror attacks. This includes arrest of life-threatening bleeding by first responders. The UK CitizenAID app[9] is a free resource available for the public to save lives in the event of a mass casualty event. It outlines Public Immediate Actions that include immediate haemorrhage control.

The nature of blast injuries means they are also always heavily contaminated (Figure 1). Organic matter, dirt and debris is driven through tissue planes reaching areas some distance away from the injury. Blast wounds may harbour between four to six species of bacteria, and wounds over 6 hours old should be treated as infected rather than just contaminated. Early antibiotic administration is vital.

Figure 1 Extensive tibial soft tissue stripping with heavy contamination.

Treatment of injuries

Ten-step blast checklist:

- preparation
- resuscitation
- penicillin anti-tetanus
- damage control
- debridement
- wash
- fasciotomize
- pack/topical negative therapy
- stabilize
- leave.

Preparation

Incident response

Blast injuries in civilian practice are often part of multiple casualty situations and should generate a major incident response. The most senior surgeon present at the receiving facility should immediately begin to coordinate the surgical reaction. While the hospital major incident plan is clearly a guide, the following didactic advice may benefit most medium-to-large size UK hospitals.

At Major Incident Standby: Do not wait for the first casualty to arrive. Stop all elective operating. Clear six bays in the emergency department (ED), clear six ITU beds, and clear six theatres. Station a dedicated senior clinical coordinator at the ED entrance and direct the most severely injured patients appropriately to these 18 spaces. Plan for four units of red cells and four units of plasma for each of these 18 patients. Send walking wounded elsewhere (remote from the ED, to a pre-determined appropriately staffed area). Do not wait for Major Incident Declared to start this process.

The response to a terrorist incident mandates a hospital-wide approach. This involves emergency theatres, staff cascades, blood bank and intensive care. However, do not forget imaging, mortuary and portering services. Many trusts will have action cards for distribution in the event of a major incident as role-specific aide-memoirs. The UK National EPRR initiative has developed action cards for trauma conditions in much the same way. An example for blast injury can be found at Figure 2.

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