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STUDENT PAPER

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Blast Injuries - A Prehospital Perspective

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Introduction

“Australians should feel nervous about a possible terrorist attack”

*Attorney-General Philip Ruddock*¹

On Saturday 12th of October 2002, two explosions in Bali (a popular Australian tourist destination), left a total of 202 people dead¹ including 88 Australians² and many more injured. Further bombings on the 5th of August 2003 and 9th September 2004 in Jakarta, left another 21 dead.¹

On 9th June 2005 the Australian Government published a warning stating that, “terrorists are at an advanced stage of planning attacks in Indonesia.”³ and several months later on 1st of October 2005, a suicide bombing at a restaurant in Kuta, Bali left a further 27 dead,⁴ dispelling any doubts over the danger posed to Australian nationals by terrorist bombings.

In November 2005, Australia was specifically reported to be a possible target for terrorist activity,⁵ and the approach of the Commonwealth Games, held in Melbourne in early 2006, further heightened expectations.

Whilst both Sydney and Melbourne have experienced minor bombings previously, these incidents have been few and unsophisticated when compared to the devastation wreaked in more recent attacks as witnessed in New York in 2001, Madrid in 2004 and London on 7th July 2005, where at least 54 people were killed and over 700 injured.⁶

Therefore, due to the challenges posed by bomb blasts and industrial explosions, prior preparation by prehospital care providers would be prudent, for at some stage, Australia may experience a large scale explosion/bombing. Irrespective of origin, the mechanism of explosive injury is similar and the terms blast and explosion have been used interchangeably.

This paper aims to review literature on the subject of blast injury and discuss the mechanism behind primary, secondary, tertiary and quaternary blast injuries. The author will briefly examine the pathophysiology of these injuries and detail some of the gross injuries that blast injured patients are likely to sustain. The author will discuss why these patients are considered to be time critical and present implications for paramedic practice, with the hope that this may assist the provision of prehospital care to blast injured patients.

Explosions

Explosions are a result of the almost instantaneous combustion of explosives. Explosives can be divided into two categories, high order explosives and low order explosives.

On detonation, high order explosives combust almost instantaneously. This near instantaneous chemical reaction produces heat, light, sound and a highly compressed region of gas⁷ generating pressures of up to 150,000 atmospheres and temperatures rising to 3,000 degrees Celsius.⁸ This highly compressed region of gas propagates outwards through a medium at supersonic speed, creating an over-pressure shock wave known as a blast wave with a shattering force known as brisance. Examples of high order explosives that produce these effects include TNT, C-4, Semtex, nitroglycerin, dynamite, and ammonium nitrate fuel oil.⁹

By contrast, low order explosives combust on detonation in a process known as deflagration.⁷ These explosions lack the highly compressed region of gas generated by high order explosives and hence the brisance and supersonic blast wave. Examples of low order explosive include pipe bombs, gunpowder and Molotov cocktails.

As a result of the differences in detonation, high and low explosives generate different patterns of injury.⁹ As injuries sustained in low order explosions are also sustained in high order explosions, this paper is mainly concerned with injuries stemming from high order explosives.

Blast Wave

The leading edge of the blast wave is known as the blast front. The duration of subject exposure to the overpressure of the blast wave correlates directly to the thickness of the blast wave, which is determined by the duration of detonation.¹⁰

As the blast wave propagates, it decreases in velocity exponentially in relation to distance travelled from the source.¹¹ The blast front encountering a subject see Appendix 1, (A), results in the near instantaneous rise in local medium pressure, to that of the blast wave - Appendix 1, (P), before rapidly decreasing with the passing of the blast front - Appendix 1, (B). This rapid change in pressure combined with the duration of effect, directly correlates to the severity of primary blast injury (PBI).¹⁰

Blast Wind

The pressure differential created by the blast wave results in a blast wind, the magnitude of which can be sufficient to propel fragments, people and large objects, significant distances.¹¹

Blast Trough

The blast front is followed immediately by a trough of low pressure, (Appendix 1, (C)) resulting from the evacuation of medium by the passage of the blast front.

Blast Sequelae

In addition to the direct effects mentioned above, explosions may also cause structure collapse, ignite combustible materials and disseminate poisons. It is also possible that the primary explosive device may not detonate completely, disseminating unstable explosive throughout the blast site. Furthermore in explosions of malicious intent, there exists the

possibility of secondary explosive devices planted with the intention of delaying and disabling emergency response.¹²



Figure 1 –Lower leg X-ray reveals multiple embedded ‘metallic’ fragments, post explosion.

Image Credit: Captain Toni Wells (RAAMC)

Explosive (Blast) Injury

Explosive injuries are generally classified into four categories. These are primary, secondary, tertiary and quaternary injury, examples of which may be found in Table 1.

Table 1 – Explosive Mechanism of Injury

	Mechanism of Injury	Examples of Injuries
Primary Injury	Caused by exposure to blast wave generated. Injuries hollow organs by spalling, acceleration and shearing.	Tympanic rupture, Blast lung, Body Disruption, Dismemberment.
Secondary Injury	Penetrating and blunt trauma caused by object energized by the blast wind.	Penetrating and blunt injuries to any region of the body.
Tertiary Injury	Mainly blunt injury as a result of violent displacement of the patient and large objects.	Contusions, fractures, lacerations.
Quaternary or Miscellaneous Injury	Injuries as a result of building collapse, fires started by explosion, exposure to toxins and poisons and disease agents distributed by the explosion.	Burns, crush injury, respiratory distress and asphyxiation.

Primary Blast Injury

Primary blast injuries are caused by the large pressure differential of the blast wave, which leads to shearing, spalling, implosion and acceleration/deceleration injuries.⁷

As pressure differentials are more pronounced at medium borders, hollow medium filled tissues and organs such as the ears, lungs and gastrointestinal system, are at higher risk of injury than solid organs.¹³ Examples of primary blast injuries include total body disruption, tympanic perforation, amputation, lung injury and bowel contusion/perforation.¹⁴

Total body disruption is uncommon and occurs to victims in close proximity to the explosion. Suicide bombers wearing explosives and persons in proximity to blasts of great magnitude are candidates for disruption.⁸

Tympanic membrane perforation is the most common primary blast injury.¹¹ It serves as a indicator of exposure to blast overpressure, but is not necessarily indicative of other occult injuries in patients where physical examination and chest radiographs prove normal.¹⁵

Traumatic amputation tends to occur through the shaft of long bones and not at the site of articulate joints as might be expected. It is hypothesised to be as a result of axial stresses acting on the bone as a result of the passage of the blast wave and not as a result of limbs flailing in the blast wind as previously thought.¹⁶

The lungs are the second most susceptible organ to blast injury.¹¹ Injuries include, pneumothoraces, haema-pneumothoraces, lung contusions and alveolovenous fistulas arising from tears in the tissue-air interfaces. These tears are thought to arise from shearing and stress forces generated by the blast front¹⁰ and trough.¹⁷ It is therefore not surprising to find that massive coronary or cerebral air embolism in primary blast injured patients is often the cause of death.¹⁸

Blast lung is a term used to describe a combination of pulmonary symptoms caused by blast wave exposure. Whilst not a common injury amongst survivors (approximately 1-10%),¹⁹ blast lung poses a significant life threat. Blast lung can be described as acute respiratory distress (dyspnoea/apnoea), bradycardia and hypotension post blast exposure.⁹ These patients are likely to suffer hypoxemia, haemoptysis and may require endotracheal intubation. Blast lung may be confirmed at hospital with diffuse opacity of the lung fields visible on chest x-ray.²⁰

The gastrointestinal tract is particularly susceptible to PBI due to build up of gas and fluid in the intestine and colon.²⁰ Bowel contusion/perforation poses a challenge to emergency care providers due to the concealed and often delayed presentation of this injury. Transmural bowel contusions can lead to infarction and perforation over 1 to 14 days and can exist in the absence of other obvious injury.

Bradycardia and profound hypotension are occasionally found in primary blast injured patients who have no other obvious injury. It is hypothesised that stimulation of the pulmonary C-fibre receptors (formerly known as J-receptors) results in the activation of a vagally mediated pulmonary defence mechanism. This leads to an increased vagal tone resulting in bradycardia and hypotension.²¹

Due to the blast wave attenuating exponentially in relation to distance, PBI's are normally sustained by patients in close proximity to the explosion. However, the amplification of blast waves in confined spaces, indoors,¹⁸ in car parks and in buses are associated with a higher incidence of PBI, severe injury and mortality rate.²²

Often PBI's prove incompatible with life. Because of this and other aspects associated with explosions, the majority of wounds carried by survivors of a bomb blast are secondary blast injuries.

Secondary Blast Injury

Objects accelerated by the explosion cause secondary blast injuries. The velocity and injury potential of these projectiles is based on the magnitude of the explosion, the weight of the projectile and the distance from the source of explosion.²³ Some of these projectiles reach sufficient velocity to cause injury on impact and this is the mechanism behind secondary blast injury.

This projectile effect is often utilised in military explosive fragmentation devices such as grenades. Improvised explosive devices (IED's) often utilise a variety of additives (nails, metal fragments, glass etc.) to achieve a similar effect. In addition to these additives, an unlimited number of other items can be energised by the blast wind to become missiles, including bricks, plaster fragments, wood and biological remains.²⁴ Even dust and dirt can be energised sufficiently to leave a fairly uniform characteristic tattooing and dusky purple discolouration of exposed skin.⁸

Whilst primary blast injury is likely to be fatal, in the absence of building collapse secondary blast injuries account for the majority of injuries to survivors.²⁵ For example 95% of survivors of the Khobar Towers bombing in Dhahran, Saudi Arabia, had penetrating foreign body (mostly glass) injuries.²⁶

In general, the closer to an explosion the patient is, the greater the number and severity of injuries. In the previous example, 18 people died in the building directly next to the explosion and only 1 person died in next building, 2 to 3 times the distance from the explosion. Overall 61% of persons hospitalised were within 500 feet of the blast and 92% within 1000 feet.²⁶ However, unlike the blast front that attenuates rapidly, isolated energised items can be thrown great distances with considerable force, as was the case in the 1998 US embassy bombing in Nairobi, Kenya, where people were injured by glass up to 2 kilometres away.¹⁰

Tertiary Blast Injury

Tertiary blast injury is a result of displacement of the patient by the blast wind. Often patients are propelled along the ground, resulting in abrasive, contusive and blunt trauma. Occasionally patients are launched through the air and may collide or impale themselves on stationary objects.¹⁰ Once again the severity of tertiary blast injuries depends greatly on proximity and magnitude of the blast. Tertiary injuries are common as demonstrated in the 1995 Oklahoma City bombing where 135 (33%) people reported as being pushed or pulled against an object by the force of the blast.²⁷

Quaternary Blast Injury

Quaternary injuries result from a variety of blast sequale including burns, chemical and toxic dust poisoning/inhalation, radiation exposure, and crush injury due to building collapse. Disorders that develop over an extended period such as post-traumatic stress disorder (PTSD), can also be grouped into this category.

Burns sustained from the action of the primary blast are known as flash burns and are caused by the brief but intense spike in temperature associated with detonation. Flash burns are

cutaneous burns of uniform thickness to exposed skin, from which tight clothing (underwear, footwear etc.) may protect. Full and partial thickness burns are more likely to result from fires ignited by the blast, rather than the blast itself.⁸ These burns are relatively uncommon as demonstrated in the Oklahoma City bombing where 9 of 592 persons had thermal burns covering up to 70% of their body.²⁷

Chemical or toxic inhalation/exposure may result either from the inclusion of weaponised toxins into the explosive device, or from the partial combustion of ignited materials post blast. The onset and presentation of symptoms vary greatly depending on the substance in question and is beyond the scope of this paper.

Nuclear explosives have not been utilised since Nagasaki was bombed in August 1945 (28).²⁸ However there exists the possibility that a so-called radiological “dirty bomb” may cause widespread radiological contamination. Symptoms of whole body exposure to low levels of radiation include nausea and vomiting and may develop over hours to days. Sufficient radiation exposure can lead to death through organ failure or cancer and widespread onset of these symptoms should be cause for alarm.²⁹

Building collapse contributes significantly to the seriousness of a bombing incident and can immediately kill the majority of its occupants.³⁰ In the Oklahoma City bombing, persons located in the collapsed region of the building were significantly more likely to die (87%) than persons in non-collapsed regions (5%).²⁷

Problems for emergency personnel associated with building collapse include increased difficulty in communications, site access/ egress, patient retrieval and a higher incidence of crush injury. Crush injury poses unique challenges for rescue personnel and is associated with complications including limb loss and death.

It has been postulated that blast injured patients with a history of concussion may develop symptoms of PTSD as a result of mild brain injury post exposure to blast.³¹ This is unlikely to pose an immediate problem for emergency personnel, but may lead to increased ambulance attendance in the period following a mass casualty bombing.



Figure 2 – EMS personnel wearing protective clothing prior to entering a potential Chemical, Biological or Radiological ‘dirty bomb’ hot zone.

Image Credit: Metropolitan Ambulance Service, Victoria

Author(s): *Brendan Moore*

Time Criticality

The time criticality of a patient is a brief summation of their injuries, physiological disposition and prospects for treatment. It provides emergency medical personnel with a guide to the urgency of which a patient requires treatment. From lowest to highest urgency the time critical categories are Non-, Potential, Emergent and Actual time-critical. (For time-critical category criteria consult Metropolitan Ambulance Service (MAS) Clinical Guidelines.)³²

During a mass casualty incident, so-called battlefield triage (the most good for the most people) may be used to most effectively manage patients and resources. The triage system utilised by the Metropolitan Ambulance Service (MAS) in Victoria, uses the following triage categories (from lowest priority to highest) to triage mass casualty incidents. Dead, Walking wounded, 2nd Priority – expectant, 2nd Priority, Top Priority. These are associated with time-critical patients as described in Table 2.

Table 2 – Time criticality and mass casualty triage

Priority	Triage Level	Time Criticality	Description	Examples of Injuries
4 (low)	Dead	Non time-critical	Life extinct	Injuries incompatible with life (Decapitation, Complete abruption)
3	Walking Wounded	Potential and Emergent time-critical	Patients uninjured or mildly uninjured in Explosion who are not in physiological distress.	Mild lacerations, abrasions, contusions, tympanic perforation, shallow penetrating injuries to extremities.
2	2 nd Priority Expectant	Actual time-critical	Severe injuries resulting in poor prospects of response to medical assistance.	% 100 Burns, Traumatic cardiac arrest, Massive haemorrhage and Multitrauma
1	2 nd Priority	Emergent and Actual time-critical	Patients who may not be in physiological distress with moderate to severe injuries that are not as urgent as priority patients.	Significant burns, crush injury, respiratory distress, lacerations, contusions etc.
0	Top Priority	Actual time-critical	Severe injuries resulting in physiological distress with good prospects of response to medical assistance.	Significant burns, crush injury, tension pneumothorax, amputation etc.

For mass casualty incidents involving chemical biological or radiological (CBR) agents, MAS utilises ‘Sieve’ triage (a triage system modified for use by paramedics dressed in cumbersome personal protective equipment) as described in Table 3. These patients are then re-triaged after decontamination using the previously described system.

Any mass casualty incident resulting from a bomb blast is likely to have a range of time critical patients. However due to the lack of definitive pre-hospital diagnostic facilities, even

relatively uninjured patients who meet additional criteria (as described in the Victorian time critical guidelines) and have been in proximity to an explosion, should be considered potential time critical.

These patients are at risk of significant occult delayed onset injuries such as blast lung, and bowel contusions that while not immediately symptomatic, may pose a significant threat to patient health. In addition, as terror victims sustain more severe injuries when compared with other forms of trauma, it is appropriate to include explosions as a mechanism of injury.³³

Table 3 – Sieve mass casualty triage

Priority	Triage Level	Physiological Description	Examples of Injuries
4 (low)	Dead	Life extinct, Absent vital signs	Injuries incompatible with life (Decapitation, Complete abruption), unconscious patients with nil spontaneous respiratory effort.
3	Walking wounded	Patients who regardless of injuries are able to walk	Lacerations, abrasions, contusions, upper body fractures. Injuries that might otherwise be considered significant.
2	2 nd Priority	Injured patients who are unable to walk with a spontaneous respiratory effort of 10-29 breaths per minute and/or distal capillary refill <2 seconds	Unconscious patients, leg fractures, mild to moderate respiratory distress.
1 (High)	Top Priority	Injured patients who are unable to walk with a spontaneous respiratory effort of <9 or > 30 breaths per minute and/or distal capillary refill >2 seconds	Unconscious patients, leg fractures, severe respiratory distress, patients with significantly decreased perfusion.

Implications for Paramedics

As part of a combined emergency response to an explosion, paramedics are likely to be amongst the earliest responders on scene and are liable to be operating in an environment that is unsecured and potentially hazardous. Furthermore, the range and scale of injuries sustained by victims are likely to test even the most experienced personnel. Therefore, paramedics should take into account the following implications:

Scene Control

Post explosion, extreme care should be exercised by responding paramedics with priority placed on minimal medical intervention and rapid removal of the seriously injured from a potentially dangerous and unsafe scene.

Explosions may cause mass casualties over multiple scenes, aggravating difficulties with patient management and inter/intra service command and communication. Therefore, paramedics should be prepared to activate disaster plan (DISPLAN) arrangements accordingly.

Author(s): Brendan Moore

A high index of suspicion should be maintained regarding possible chemical, biological or radiological contamination, particularly during industrial accidents and terror attacks.

Paramedics should be aware of the potential for communications breakdown due to infrastructure damage and network congestion. After the London bombings, the Metropolitan Police casualty bureau took 42,000 calls in one hour. Scene location may also contribute to poor communications as conventional forms of radio and mobile telephone communication will not work in locations such as tunnels and underground stations.⁶ Therefore, alternative communications should be sought when entering these sites.

Patient Treatment and Management

Confined space blasts involve complex physics and increased blast overpressures, resulting in greater injury potential. Therefore persons involved in a confined space blast should be treated with an increased index of suspicion for occult PBI. Due to the significant mechanism involved in blast injuries, advanced hospital notification of incoming patients should be strongly considered.

For patients suffering respiratory distress secondary to lung or chest injury, care should be taken when utilising positive pressure ventilation (PPV). Low vascular pressures due to haemorrhage and bronchopleural fistulas as a result of trauma may result in arterial air embolism leading to cerebral embolism and death.¹⁰ Therefore lower ventilation pressures, reduced volumes and increased rates of respiration should be considered.³⁴

As symptoms of toxin, chemical and radiological exposure may develop over a significant period of time, patients may present to the ambulance service for several days after an explosion.

The use of intra-vascular fluid replacement in blast injured patients remains contentious with some studies suggesting that fluid resuscitation may be detrimental in blast injured patients.³⁵ Therefore new research on blast-injured patients should be consulted periodically and where applicable, incorporated into paramedic practice.

As tympanic rupture is strongly indicative of exposure to blast overpressure, the use of portable otoscopes may assist pre-hospital triage of patients. Asymptomatic patients with tympanic rupture may be assigned a higher priority than those without, due to the often-delayed onset of PBI.

In massive haemoptysis secondary to blast lung, the use of an endotracheal tube placed to full depth may allow the mobile intensive care paramedic (MICA) to isolate either the left or right lung field and achieve more effective ventilation. However, due to the difficulties associated with prehospital practice, this procedure should be used with caution and reserved for patients in life threat secondary to haemoptysis.¹⁰

Due to the strong relationship between distance and blast injury, paramedics may expect to find (in order of increasing distance from the explosion), the following injuries; Total body disruption, burns and toxic inhalation injuries, traumatic amputations, PBI of the lung and bowel, tertiary blast injuries, PBI of the ear, with the possibility of secondary blast injuries remote to the blast.¹⁰ Thus any information on the location of the patient at time of injury, combined with the type and extent of injury may provide valuable information as to the magnitude and location of the blast and should be recorded on the patient care record.



Figure 3 – Explosions will typically require a multi-agency response with the potential for ‘DISPLAN’ procedures to be activated.

Image Credit: Metropolitan Ambulance Service, Victoria

Conclusion

This paper has reviewed a selection of literature on the subject of explosions and blast injuries. The author has briefly examined the physical nature of explosions and described the components of an explosion that cause tissue damage and explosive injury.

These explosive or blast injuries were categorised into primary, secondary, tertiary and quaternary injuries based on the blast component responsible for injury. Each category of blast injury was examined in further detail and examples given. Blast injuries were found to be many and varied, ranging from isolated mild contusions to severe multi trauma. In many cases, for a given size of explosion, the severity of injury was related to patient proximity to the blast, although isolated fatal secondary blast injuries could be sustained at locations remote to the blast.

Not all blast injuries are immediately obvious, with the delayed onset of symptoms from PBI of the bowel and lungs possible and dangerous. The possibility of occult injury combined with the severity of other injuries, posed several reasons for patients involved in explosions to be considered time critical when combined with additional criteria as per the Victorian time critical guidelines.

Paramedics attending a blast site should be aware of the possibility of danger to their person from a variety of sources. Care should be exercised when attending to patients and efforts focussed on rapid evacuation to safer grounds for further treatment. It was also suggested, that portable otoscopes might be considered as a tool for assisting in triage, with tympanic perforation an indicator of exposure to the blast front. As further research is conducted and new procedures developed, the author recommended that these be reviewed for incorporation into paramedic practice where appropriate.

In conclusion, whilst a terror incident or large-scale industrial explosion may seem to be an unlikely occurrence, events of the recent past indicate that the possibility exists in Australia of just such an event. To this end, the author hopes that this paper may provide a source of information for paramedics and health professionals who may constitute the emergency medical response to explosions in the future.

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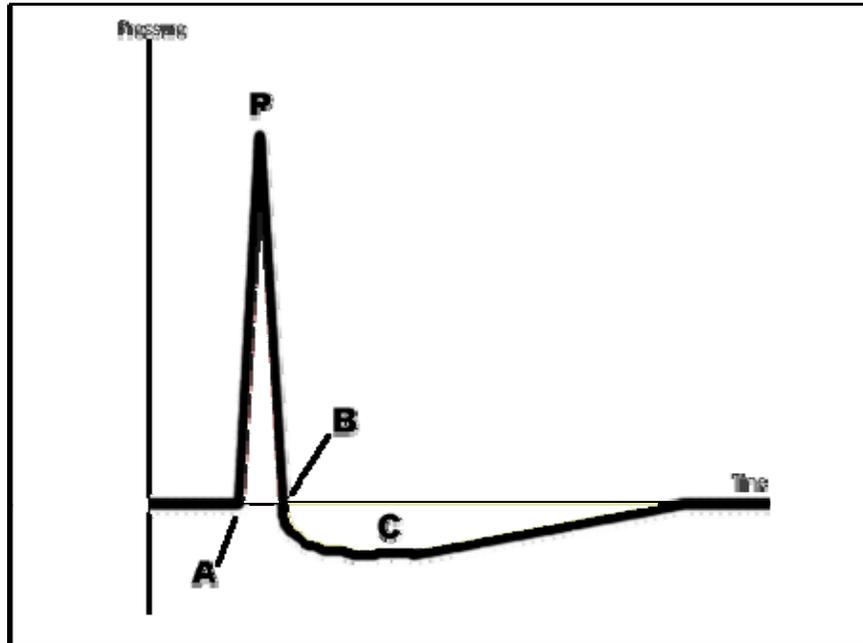
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Appendix 1 – Blast pressures Diagram



Derived from: "Explosions and blast injuries." By Wightman J and Gladish S.
Annals of Emergency Medicine. 2001;37(6); 666.