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BOMB BLAST: PATTERN AND NATURE OF INJURIES

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HOW TO CITE THIS ARTICLE:

P. Brahmaji Master, V. Chandra Sekhar, Y. K. C. Rangaiah. "Bomb Blast: Pattern and Nature of Injuries". *Journal of Evidence based Medicine and Healthcare*; Volume 2, Issue 2, January 12, 2015; Page: 165-171.

ABSTRACT: Bomb blast cause injury on large groups of people by multiple mechanisms. Bomb blast injuries differ from the conventional description of trauma complexity. Primary injuries are caused by blast wave and over pressure. Secondary injuries are caused by flying debris and cause shrapnel wounds. Tertiary injuries are caused by blast wind due to forceful impact and quaternary injuries are caused by other vectors like heat, radiation etc. Combined injuries, especially blast and burn injury or blast and crush injury, are common during an explosive event. Knowledge about nature of injuries is essential for medicolegal and postmortem reports.

INTRODUCTION: Explosions and blasts occur accidentally or deliberately. Accidentally explosion and blasts arise out of negligence, poor maintenance of factory units or faulty operations. In recent times, bomb explosions and blasts are a casual daily event. No day passes by without reports of terrorist attacks and bomb blasts. The act of bombing is intentionally carried out act for political gains, aimed at civilians and executed by sub-national militant groups. The casualties arising out of blasts are large and victims face serious physical and psychologically repercussions. Minor blasts are deliberately set-off to create a state of fear among the public. Since, the art of making ammunition and executing attacks have become sophisticated and precise, the extent of injury is overwhelming. Explosives used for making explosives may be of high-order explosives or low-order explosives. The pattern of injury that occurs with bombs and explosions are unique and is never seen beyond the combat.¹ The nature of the injury may be blunt or penetrating and often affects multiorgan systems.² In addition, high-pressure air expanding from the detonation center also inflicts injuries.³ A blast or explosion produces numerous casualties and injuries that present with unique triage, diagnostic, and management challenges to the emergency staff.

SEVERITY OF BLAST INJURIES: The type of explosives used determines the severity of blast injuries and fatality of the case.⁴ Severity of injury is dependent on number of factors, which include:¹

- Composition and amount of the explosive materials used.
- The surrounding location of explosion.
- The method of detonation and delivery of bomb.
- The distance between the victim and the blast.
- Any intervening protective barriers or environmental hazards.

EXPLOSIVE MATERIALS AND DEVICES: Explosives may be of high-order explosives or low-order explosives. The former produce a supersonic over-pressurization shock wave and the latter produces subsonic explosion without the production of over-pressurization wave. Manufactured or improvised explosive weapons (explosive and incendiary bombs) are usually high-order explosives

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used for military combat. Improvised explosive devices employed by the terrorists may be high-order explosives, low-order explosives or both.¹ Improvised explosive devices include car and truck bombs; letter and parcel bombs; pipe bombs; and backpack and satchel bombs. Airplane bombs are the incendiary bombs. Other blasting devices are rocket propelled grenades, surface to air missiles and enhanced blast devices. Material used in building high-order explosives are nitroglycerin dynamite plastic ammonium nitrate/fuel oil, trinitrotoluene and triacetone triperoxide.⁵ Petroleum products (Molotov cocktail) or gunpowder are used in low-order explosives. Low-energy explosives can become high-order explosives, if the materials are contained (e.g., pipe bomb).

CATEGORIZATION OF BLAST INJURIES: Blast injuries are categorized by the manner in which the injury is inflicted (Figure 1).^{1,4,5} Besides the four categories, there is the quinary blast injury, which is induced by the systemic inflammatory response in the victim after a blast injury.⁴

Primary injury is caused by blast waves released upon the rapid detonation of high-order explosives detonates. The generated blast wave rapidly magnifies from the detonation point and within a fraction of a second, fills the surrounding space with the supersonic over-pressurization wave.⁵ The impact of blast wave is intense within closed areas as the blast waves reflect off the walls.^{5,6} The blast wind succeeding the blast wave is composed of superheated air, which carries victims and things across causing blunt or penetration injury.⁶ Secondary injury are caused by flying objects or debris. High-energy explosions triggered blast wind causes tertiary blast injuries as people are lifted off the ground through the air and thrown against other objects. Other injuries related to blast (burns, crush injuries, toxic inhalations, asphyxia, and exacerbations of victims' underlying medical conditions) are classified as quaternary injury.⁷

MECHANISM OF INJURY: Injury inflicted by high-order explosives can occur by spalling, implosion inertia and irreversible work. Spalling refers to displacement and fragmentation of less denser medium in to denser medium resulting in molecular disruption. Implosion causes visceral organ damage. In implosion, the entrapped gases in hollow organs get compressed and then when they expand they cause visceral disruption. Inertia refers to the shear stress produced by the blast wave penetrating at different velocities through tissues of differing densities.^{5,6} When the blast force exceeds the tensile strength of the tissue then irreversible work results, which is suggested to be the most likely mechanism of injury.

PRIMARY INJURIES: The most common injuries are blast lung injury; ocular injury, traumatic brain injury; concussion; tympanic membrane rupture; middle ear damage; abdominal haemorrhage and abdominal organ perforation.^{5,7}

Tympanic membrane rupture: This is the most common type of injury inflicted by blasts. Injury to tympanic membrane occurs at as low as 5 pounds per square inch (psi) above the atmospheric pressure. At higher pressures, ossicle fracture or dislocation and tympanic membrane rupture occurs. Injury to other organs can occur at pressure gradients of 56 to 76 psi (3.8 to 5.2 atm).⁵ Therefore, in the absence of any injury to the tympanic membrane, other organ damage may not be seen.

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BLAST LUNG INJURY: The second most common organ that sustains injury is the lung. Blast lung injury is a major cause of morbidity and mortality among blast victims. Blast lung injury is characterized by respiratory difficulty and hypoxia, which may occur with or without external injury. The lung injury might cause hemorrhage, pulmonary contusion, pneumothorax, hemothorax, pneumomediastinum, and subcutaneous emphysema.⁵ Patients usually present with dyspnea, hemoptysis, cough, hemodynamic instability and chest pain.⁸ On physical examination tachypnea, hypoxia, cyanosis, wheezing, and decreased breath sounds may be observed. Chest radiography, computerized tomography, and arterial blood gases may assist with diagnosis and management. A butterfly appearance or a pneumothorax on chest x-ray is typical presentation of pulmonary contusion. The blast lung severity score, proposed by Pizov et al., can be used to classify patients in to severe, moderate and mild injury.⁹ The blast lung severity score is based on the PaO₂/FiO₂ (partial pressure of oxygen in arterial blood/fraction of inspired oxygen ratios), chest x-ray findings and the presence of bronchopleural fistula (Table 1).⁹

TRAUMATIC BRAIN INJURY: Traumatic brain injury is signified by cerebral contusion, intracranial hemorrhage (subdural hematoma and subarachnoid haemorrhage), direct tissue damage, and diffuse axonal injury. Mild, moderate, and severe brain injury may be caused by primary blast waves that traverse across a human head. Direct shear force arising out of blast can impair the axonal transport and cause focal axonal swellings. Diffuse axonal injury is common followed by closed head injuries affecting the tracts at gray/white matter junctions, particularly in frontal and temporal regions.¹⁰ A sudden change in the intracranial pressure might trigger cerebral contusion brain injury. No typical symptoms could be identified as unique to or diagnostic of traumatic brain injury. Headache, hearing impairment and balance dysfunction are the major symptoms of mild traumatic brain injury. There are reports of loss of consciousness; headache; fatigue; and poor concentration, lethargy, amnesia, or other constitutional symptoms following exposure to blast. At times, the symptoms of concussion and post-traumatic stress disorder cannot be differentiated.

ABDOMINAL AND PELVIC INJURY: Perforation of the fixed colon and mesenteric arteries ischemia or infarct is the common injuries related to the alimentary system. In addition, there are reports of subcapsular hematomas of the solid organs, lacerations, retroperitoneal hematomas and mesenteric bleeding.⁷ Clinical manifestations include abdominal or testicular pain, tenesmus, rectal bleeding, solid organ lacerations, rebound tenderness, guarding, absent bowel sounds, signs of hypovolemia, nausea, and vomiting.

EYE INJURIES: Globe rupture, retinitis, and hyphema are the most common ocular blast injuries.⁵

SECONDARY INJURIES: Secondary blast injuries are inflicted by the flying debris generated by the explosion. The injury is more fatal when the explosives are filled with screws, nails, and other sharp objects. The most common types of secondary blast injuries are penetrating and blunt trauma occurring in the head, neck, chest, abdomen, and extremities. The manifestations include

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fractures, traumatic amputations, and soft tissue injuries. Penetrating trauma (shrapnel wounds) is caused by foreign bodies and may have a low threshold for imaging. All the wounds are to be considered as contaminated and should not be closed.⁵

TERTIARY INJURIES: Tertiary injuries result from individuals being thrown by the blast wind and the nature of injury may be blunt or penetrating. Head injuries, skull fractures and bone fractures are the most common types of tertiary blast injuries.⁵ The extent of damage depends on the surroundings of the blast area.

QUATERNARY INJURIES: Quaternary blast injuries comprise of all explosion-related injuries, illnesses, or diseases that is not due to primary, secondary, or tertiary mechanisms. Quaternary blast injuries include burns, toxic exposures, inhalation injuries, poisoning from carbon monoxide, other breathing problems, and crush injuries. Acute exacerbation of chronic medical conditions, such as asthma, chronic obstructive pulmonary disease, hyperglycemia, hypertension and angina is classified under quaternary injuries.⁵

CRUSH INJURIES AND CRUSH SYNDROME: Crush injury and crush syndrome results from the collapse of a building or other structure. Injury from sustained pressure of objects on part of body may lead to acute traumatic ischemia, irreparable tissue damage and loss of function. Lower extremities, upper extremities, and trunk are the typically affected areas of the body. Crush syndrome is localized crush injury with systemic manifestations of traumatic rhabdomyolysis and the release of potentially toxic muscle cell components and electrolytes into the circulatory system. Toxins released from necrotic muscles in to the circulatory system might lead to renal failure. The consequence of crush syndrome includes local tissue injury, organ dysfunction and metabolic abnormalities (acidosis, hyperkalemia, and hypocalcemia). Patients usually present with hypothermia or hyperthermia, dehydration/shock and altered mental status (alert to comatose). Compartment syndrome as a secondary complication might further worsen vascular compromise.¹¹

SEPSIS: Victims who survive blast exposure are at risk of developing of severe sepsis or systemic inflammatory response, multiple organ dysfunctions, which may lead to significant morbidity and mortality.⁴

CONCLUSION: Bomb blasts and injuries have become common in the past decade leading to thousands of casualties. Blasts cause injuries multiple organs and both civilian as well as military surgeons must be aware of the complexities of such injuries to manage such terrorist attacks effectively. Injuries may be primary, secondary, tertiary or quaternary. In addition, sepsis as a late consequence increases the risk for high mortality. Forensic expert should be familiar about the pattern, severity, mechanism, nature of injuries.

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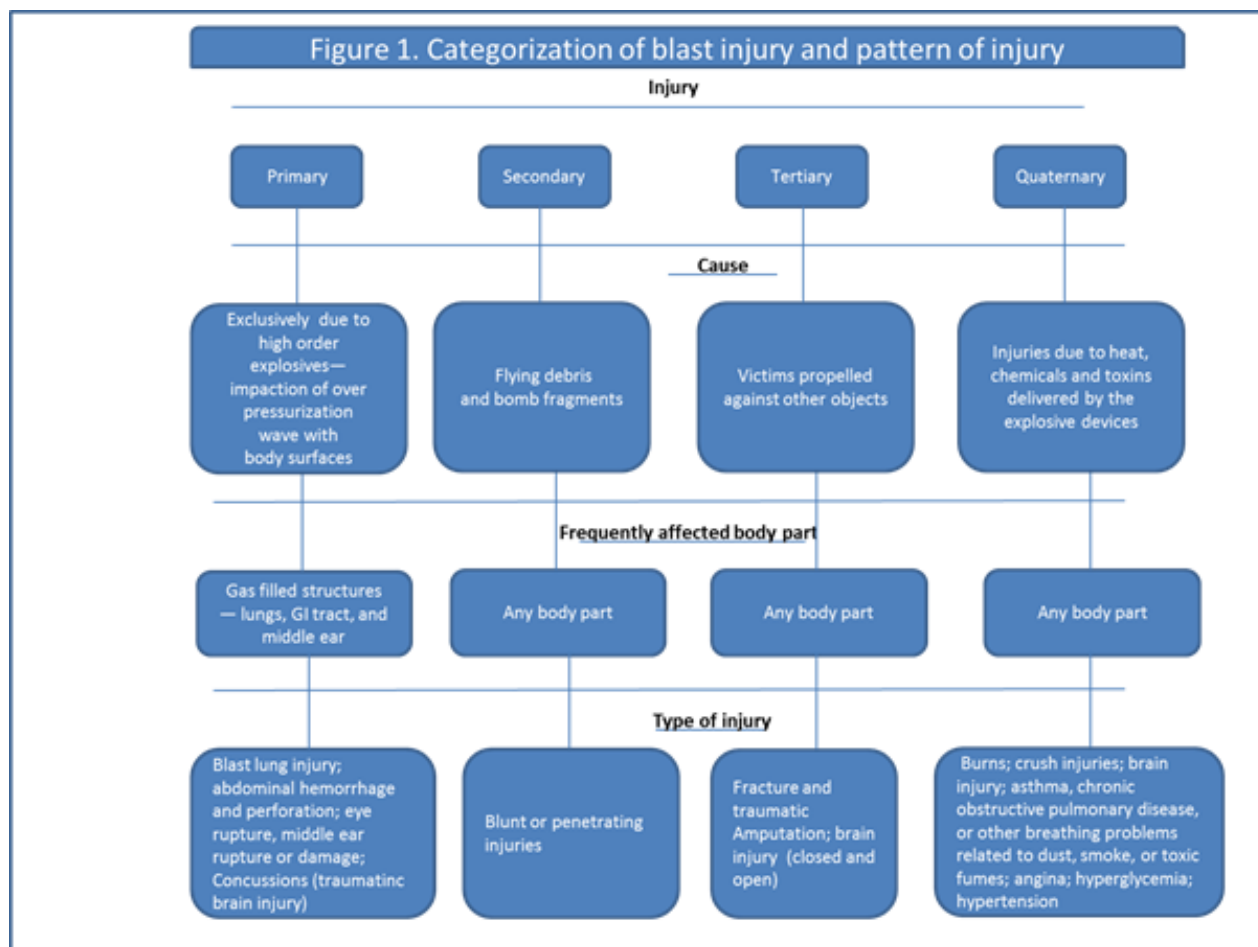


Table 1. Blast lungs everitys care for patient stratification

	Severe BLI	Moderate BLI	Mild BLI
PaO ₂ /FiO ₂	<60	60-200	>200
CXR	Massive bilateral infiltrates	Bilateral or unilateral infiltrates	Localized lung infiltrates
Bronchial pleural fistula	Yes	Yes/no	No

BLI, blast lung injury; CXR, chest x-ray; FiO₂, fraction of inspired oxygen ratios; PaO₂, partial pressure of oxygen in arterial blood

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Date of Submission: 15/06/2014.
Date of Peer Review: 17/06/2014.
Date of Acceptance: 01/07/2014.
Date of Publishing: 09/01/2015.