Chapter 7: Bomb, Blast, and Crush Injuries

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BOMB AND BLAST INJURIES

EPIDEMIOLOGY

Blast injuries using conventional weapons have emerged as the terrorist weapon of choice. Terrorist attacks have increased dramatically over the last decade. The National Counterterrorism Center reported more than 14,000 terrorist attacks in 2007, with 44,000 injuries and 22,000 deaths, which was a 20% to 30% increase over 2006.1 Explosive devices in military conflicts have killed or injured more than 25,000 U.S. and Coalition forces and more than 100,000 Iraqis.1 Blast injuries are increasing in the civilian setting, particularly suicide bombings, and emergency personnel must be familiar with the management and treatment of blast injuries, ad potential mass casualty incidents.2,3,4,5,6,7,8,9 The United States is not immune from intentional bombings, with about 36,000 bombing incidents reported from 1983 to 2002 - including explosive, incendiary, premature, and attempted bombings.6 There were 281 injured in the 2013 Boston Marathon bombing, with most injuries involving the lower extremities and soft tissue.8 Death, survival, and hospitalization rates vary greatly, depending on the type of explosive, distance from the explosion, and whether the explosion occurred in an open or closed space. Although some victims die immediately at the scene, the majority of injuries suffered by the immediate survivors of bombings are potentially survivable. Blast injuries commonly occur not as isolated incidents, but as part of multiple-casualty incidents of varying sizes. This pattern, combined with the fact that most emergency physicians have never encountered a blast injury victim or a true mass casualty incident, makes the care of often eminently salvageable victims contingent upon appropriate training and skill retention by the individual emergency physician, along with appropriate institutional leadership, planning, and preparation.

Terrorist bombings result in high injury scores for victims as well as higher hospital resource use by victims than by victims of other trauma. Blast victims have increased immediate scene mortality, greater hospital mortality, more frequent need for surgical intervention, longer hospital stays, and greater use of critical care.

PATHOPHYSIOLOGY

An explosion is the instantaneous transformation of a solid or liquid into a gas, releasing tremendous kinetic and heat energy. Detonation of a conventional high explosive generates a blast wave that spreads out from the detonation point and displaces air, water, or anything in its path. The blast wave consists of two parts: a
shock wave of high pressure followed closely by a blast wind, which is air mass in motion. The blast wave loses its energy over distance and time.

BLAST INJURIES

There are four main types of blast effects. A primary injury is caused by a direct effect of blast wave overpressure on tissue. Primary blast injury mostly (but not exclusively) affects air-filled structures such as the lungs, ears, and GI tract, by the following mechanisms: spalling, shearing, and implosion. Spalling is displacement and fragmentation of a dense medium into a less dense medium. An example is a blast wave causing the lung parenchyma to explode into the alveolar space like a geyser. Shearing, sometimes called inertia, is a stress caused by the blast wave traveling through different tissue densities at different velocities. An example of shearing is the blast wave traveling through the pulmonary vessels and air spaces, resulting in ruptured vascular and bronchial pedicles. Implosion is the opposite of spalling, where the less dense material is displaced into denser material. An example of implosion is the blast wave causing the flexible air spaces to rebound to greater than original size, sometimes causing air embolism from the alveoli into the pulmonary vessels. A secondary blast injury is due to collateral damage from flying objects and shrapnel (Figures 7-1 and 7-2). Tertiary blast injury results from the victim being propelled through the air and striking stationary objects. A quaternary blast injury is a result of burns, smoke inhalation, or chemical agent release.

FIGURE 7-1.
Secondary blast injury to the chest and abdomen due to flying debris. It is difficult to assess the degree of underlying internal organ injury without imaging and careful clinical follow-up, especially if the patient is unconscious. [Image used with permission of Tel Aviv Medical Center.]

FIGURE 7-2.
This young patient came in fully conscious and hemodynamically stable. Multiple externally visible shrapnel wounds required imaging. This x-ray image shows severe lung injury due to shrapnel. She also suffered

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FIGURE 7-2.
This young patient came in fully conscious and hemodynamically stable. Multiple externally visible shrapnel wounds required imaging. This x-ray image shows severe lung injury due to shrapnel. She also suffered
multiple abdominal injuries, including major liver lacerations and bowel perforations, and required extensive surgery. [Image used with permission of Tel Aviv Medical Center.]

FACTORS AFFECTING BLAST INJURY

The effects of a bomb blast are difficult to predict in the individual victim, as well as in the group. However, a number of important principles are known:

Distance of victim from explosion: The intensity of an explosion pressure wave declines with the cubed root of the distance from the explosion. A person 3 m (10 ft) from an explosion experiences eight times more overpressure than a person 6 m (20 ft) away. Proximity of the victim to the explosion is an important factor in a primary blast injury.

Enclosed versus open space: The effects of an explosion in a closed space, like a room, bus, or train, are much greater than in an open space. Injuries are more severe, and mortality is greater.

Surrounding environment: Blast waves are reflected by solid surfaces; thus, a person standing next to a wall may suffer increased primary blast injury.

Quantity of explosive: A greater quantity of explosive produces greater potential for damage at any distance.

Type of explosive: Explosives are commonly classified as either low-order or high-order. Low-order explosives burn rapidly and produce a blast wave of less than 1000 m/s. 11 Black powder is an example of a low-order explosive. High-order explosives detonate when a shock wave passes through them, causing an...
almost instantaneous transformation of the original explosive material into gases occupying the same volume of space under extremely high pressure. These high-pressure gases expand rapidly, compress the surrounding medium, and produce a supersonic, overpressure blast wave, moving at greater than 4500 m/s, followed closely by a negative pressure wave.

Embedded shrapnel: Many terrorists purposefully embed multiple pieces of metal and plastic in the explosive, maximizing the number and severity of secondary injuries.

CLINICAL FEATURES

The nature of the injury may produce a multiplicity of external signs (Figure 7-3), making detection of important internal injuries challenging. Insufficient or suboptimal resources need to be prioritized in a mass casualty incident. High-grade clinical expertise is even more in demand to allow optimal use of resources.\(^2\,^3\,^4\,^5\,^6\,^7\,^8\,^9\)

FIGURE 7-3.
The severe external injuries often seen with explosive blast may or may not indicate associated severe internal injury. Clinical examination is difficult and requires a high degree of experience and suspicion as well as early use of imaging. [Image used with permission of Tel Aviv Medical Center.]

CARDIOPULMONARY SYSTEM

The lung is very susceptible to primary blast injury. Pulmonary barotrauma is the most common fatal primary blast injury and the most common critical injury in people close to the blast center. Pressure differentials across the alveolar-capillary interface can cause disruption, hemorrhage, pulmonary contusion, pneumothorax, hemothorax, pneumomediastinum, and subcutaneous emphysema. Air embolism is another well-recognized consequence of blast lung injury and is probably one of the major factors leading to cardiac
dysfunction and immediate death after blast wave exposure, although it is usually difficult to diagnose specifically. The resulting neurologic symptoms caused by air embolism must be differentiated from the direct effects of CNS trauma. Pulmonary fat embolism is a finding of clinical importance in survivors of blast trauma because it can lead to the development of acute respiratory distress syndrome and significantly affects clinical outcomes.

In general, managing blast lung injury is similar to caring for pulmonary contusion and acute respiratory distress syndrome, except that early recognition of the syndrome may be complicated by initially benign symptoms, especially in the context of hectic mass casualty incident situations. Hypoxia is an almost universal finding. Monitoring of respiratory rate and room-air pulse oximetry, as well as serial chest radiographs, may be needed. Fluid administration should ensure tissue perfusion without volume overload. The decision to institute mechanical ventilation must be made carefully because it entails the assignment of what may be scarce critical care unit beds and ventilators and also exposes the patient to the potential complications of pulmonary barotrauma, commonly seen with the friable lungs associated with blast lung syndrome. Keep tidal volume to 6 to 7 mL/kg ideal body weight to limit the peak inspiratory pressure and to minimize ventilator-induced lung barotrauma. Often, neuromuscular paralysis and early institution of pressure-limited ventilation (plateau pressures <30 cm H$_2$O), with the lowest pressures compatible with adequate ventilation, may be the best strategy. Inverse inspiratory-to-expiratory ratio ventilation may be useful. Permissive hypercapnia is acceptable depending on cerebral perfusion pressure or increased intracranial pressure. Aggressive methods of oxygenation, such as extracorporeal membrane oxygenation or intravascular oxygenation, may become necessary within hours of the injury.

There are no definitive guidelines for observation, admission, or discharge of patients with possible blast lung injury. Admit patients requiring complex management to an intensive care unit. In general, asymptomatic patients with normal chest radiographs and normal room-air pulse oximetry may be considered for discharge after 4 to 6 hours of observation as long as there is no clinical deterioration. Survivors of this type of injury typically have no long-term pulmonary complaints, and most have normal physical examinations, chest radiographs, and normal lung function tests.

**EARS**

The tympanic membrane ruptures at 1 to 8 psi of dynamic overpressure. Dislodgement of ossicles may also occur. Patients with an isolated tympanic membrane perforation and no other immediately identified injuries should have a chest radiograph ordered but do not automatically require an extended period of observation. Conversely, intact tympanic membranes do not imply the absence of serious injury, and the use of the perforation of tympanic membrane as an indicator of primary blast injury missed up to 50% of those suffering a primary blast injury to the lung. Clinical judgment is necessary, and limited observation is reasonable for patients with intact tympanic membranes.

**ABDOMEN**
Abdominal injuries from explosions may be occult. Reported injury rates are low, but missed injuries may carry significant morbidity due to delayed intestinal perforation and necrosis. A review of the literature on abdominal trauma from primary blast injury reveals an incidence of 1.3% to 33%, and the terminal ileum and cecum were the most commonly injured areas. \(^\text{15}\) Serial clinical examinations, serial imaging as needed, and 24- to 48-hour observation are indicated whenever the suspicion arises. \textit{Air is a poor conductor of blast-wave energy; thus, patients who were subjected to enough energy to damage abdominal organs probably were situated near the explosive device.}

**BRAIN INJURY**

The conflicts of the Global War on Terror in Iraq and Afghanistan have resulted in over a quarter of a million diagnosed cases of traumatic brain injury. \(^\text{16}\) Mild traumatic brain injury has been labeled the "signature injury of the war in Iraq."\(^\text{1,17,18,19,20,21,22}\) The clinical examination may be misleading for penetrating injuries. Shrapnel are low-velocity missiles, often producing small entry wounds in survivors. Small entry wounds may be missed under the hair, and evidence for traumatic brain injury may initially be benign or masked by anesthesia as the patient undergoes treatment for other life-threatening injuries. Neuroimaging is an important early diagnostic tool (\textbf{Figure 7-4}).

**FIGURE 7-4.**
A. CT scan image of a 17-year-old female patient injured in a terrorist bomb blast in Israel. This girl walked into the ED unassisted, was triaged "green," but deteriorated after 30 minutes. Fortunately the clinical deterioration was noted, she underwent emergent CT, and then extensive neurosurgical intervention. B. A 1-cm metal ball bearing was extracted. Prolonged rehabilitation was later required for residual brain damage. [Image used with permission of Tel Aviv Medical Center.]
VASCULAR INJURY
Small entry wounds from shrapnel may mask severe vascular injuries (Figure 7-5). Compartment syndrome (see "Crush Injury and the Crush Syndrome," below) may develop and is difficult to diagnose, especially in patients receiving anesthesia. Carefully assess and document pulses and perfusion in affected limbs. **Observe for delayed presentation of compartment syndrome, and measure compartment pressure if any signs or symptoms develop.** Early angiography and intervention are indicated if pulses are lost.

**FIGURE 7-5.**
Vascular injuries may occur with externally minor penetrating injury. This young woman was triaged "green." The significance of a small penetrating injury in her lower limb, one of many throughout her body, was initially misinterpreted, but she lost her pulses after 1 hour and was rushed to angiography and subsequent vascular surgical intervention. [Image used with permission of Tel Aviv Medical Center.]

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**EXTERNAL HEMORRHAGE**

Bleeding from wounds is likely to be the most commonly encountered life-threatening finding. Whether venous or arterial, blood loss from multiple wounds (internal and external) may be sufficient to cause hypovolemic shock. Quickly control external bleeding with direct pressure. Military experience has shown
that hemorrhage is the most common cause of preventable death in penetrating trauma.\textsuperscript{9} Apply tourniquets for extremity hemorrhage whenever blood loss cannot be controlled with direct pressure, or if the resources required to maintain direct pressure are insufficient during either treatment or transportation. Tourniquets have been successfully used for up to 6 hours in battlefield situations.\textsuperscript{23} Angiographic vascular occlusion is an attractive treatment option if the time and staff are available. Victims of blast mass casualty incidents may require massive amounts of blood and blood products.\textsuperscript{24}

**OCULAR INJURIES**

Eye injuries from a blast wave may cause shearing damage to the orbit, but ocular injuries are from a combination of primary and secondary processes.\textsuperscript{25} Ocular injuries include lid or brow lacerations, conjunctival lacerations, open globe injuries, orbital fractures, retinal detachment, retained intraocular foreign body, lens dislocation, vitreous hemorrhage, retinal tears and retinal detachment.\textsuperscript{25} Eye examination is needed for all moderately to severely injured blast victims, and a poor initial visual acuity is not a guarantee of a poor final result.

**DIAGNOSIS**

Order diagnostic imaging judiciously in a mass casualty incident. Visualization of a metallic object on a single-plane radiograph is often inadequate for thorough evaluation, but it can direct the treatment team on the need for urgent surgery or for additional imaging. Use the FAST examination liberally. Plain chest radiographs, ultrasonography, and diagnostic peritoneal lavage are the most rapid studies used to evaluate for life-threatening injuries. Order laboratory tests sparingly.

**TREATMENT**

When blast injuries occur, they tend to be unexpected, occur outside of regular working hours, and often produce moderate to large numbers of simultaneously arriving casualties. Drills and checklists are critical for successful implementation of rarely used protocols. Checklists should be concise, never more than one to two pages, and available in a location known to everyone. Implement the hospital plan for management of mass casualty incidents.

Obtain details about the explosion from patients and rescue teams. \textit{The nature and location of the blast, including size and type of charge, location in open or closed space, structural collapse, associated fire or smoke, and toxic agent release, will be helpful in making informed clinical decisions, especially with regard to disposition of moderately to severely injured casualties.}

Patient triage will be needed when multiple patients arrive. Station an experienced emergency physician or surgeon at the ED entrance to triage patients to appropriate, predetermined locations in the ED or elsewhere in the hospital. Patients must be triaged to categories of urgency based on relevant criteria, such as those
listed in Table 7-1. Many triage methods have been in use in various parts of the world, with varying success and scientific foundation.\(^2\,^3\,^4\,^5\,^6\,^7\)

<table>
<thead>
<tr>
<th>Severe Injured</th>
<th>Lightly Injured</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airway compromise</td>
<td>Minor wounds</td>
</tr>
<tr>
<td>Breathing difficulty</td>
<td>Burns, first or second degree</td>
</tr>
<tr>
<td>Hemodynamic instability</td>
<td>Isolated trauma to a limb</td>
</tr>
<tr>
<td>Altered level of consciousness</td>
<td>Anxiety states</td>
</tr>
<tr>
<td>Vascular trauma</td>
<td>Most walking patients</td>
</tr>
<tr>
<td>Extensive second- to third-degree burns</td>
<td></td>
</tr>
</tbody>
</table>

Apply the basic advanced trauma life support principles of primary and secondary surveys within the logistic limitations that may occur temporarily or permanently. Administer IV fluids and blood products judiciously. Preventing fluid overload is important for lung- and brain-injured patients. Activated factor VII administration or tranexamic acid may be considered in select cases of uncontrollable bleeding.

**Copiously irrigate and disinfect wounds urgently, but definitive debridement and closure may wait a few hours.** Temporary splinting, traction, and dressings are generally sufficient for initial management of musculoskeletal injuries. Consider prophylactic antibiotics for severely soiled wounds, penetrating abdominal and thoracic wounds, and open fractures, and in patients with diabetes or who are immunocompromised.

Address pain management after life-threatening emergencies have been evaluated. Reserve opiates for patients with severe pain because opiate supplies may become limited (Figure 7-6).

**FIGURE 7-6.**
Patients exposed to open-space explosions and who have no apparent significant injury, normal vital signs, and an unremarkable physical examination generally can be discharged after a few hours of observation. Asymptomatic patients may be discharged after 4 to 6 hours of observation. Admit all patients with significant burns, suspected air embolism, radiation or chemical contamination, abnormal vital signs, abnormal lung examination findings, clinical or radiographic evidence of pulmonary contusion or pneumothorax, abdominal pain, vomiting, hypoxia, or penetrating injuries to the thorax, abdomen, neck, or head to the hospital.

Patients appropriate for discharge need to be given proper follow-up instructions. Given the austerity of initial care and the propensity to miss injuries in a mass casualty incident, secondary assessments of all casualties should be done before discharge. Because symptoms of pulmonary contusion and intestinal hematoma may take 12 to 48 hours to develop, instruct all discharged patients to return for reevaluation if they develop breathing problems, abdominal pain, or vomiting. Provide relevant follow-up instructions in writing, including audiologic and ear, nose, and throat follow-up, wound care, immunization schedules, medications, psychological support, and social services.

SPECIAL POPULATIONS

PREGNANT WOMEN

Because the fetus is surrounded by amniotic fluid, direct injury to the fetus is uncommon. Injuries to the placenta, however, are more common. After life-threatening conditions have been stabilized, admit patients in the second or third trimester of pregnancy who have been exposed to blast injury to the labor and delivery area for continuous fetal monitoring and further testing and evaluation. Pelvic US, fetal nonstress test
monitoring, and obstetrics consultation should always be obtained. Consider Rh immune globulin administration if the mother's blood type is Rh negative.

CHILDREN

Children may suffer significant tertiary blast injury because their lighter bodies are more easily hurled by the blast wind. Imaging, such as total-body CT, may be difficult to perform in anxious and frightened children. Children typically require sedation to facilitate imaging.

SPECIAL CONSIDERATIONS

STAFF SAFETY

Issues that may affect staff safety include: (1) possible infiltration of the ED by perpetrators intent on causing second explosions or attacks in the hospital; (2) unexploded explosives inadvertently brought into the ED; (3) transmissible disease in the setting of body fluid exposure or needle sticks during stressful, rapid work; and (4) contamination of victims by chemical, radiologic, and biologic hazards, either accidental or intentionally caused by the perpetrators.

FORENSIC ISSUES

Police and crime scene investigators, as well as counterterrorism and other security services, have legitimate interests in securing forensic and other information. Efforts should be made to accommodate them, but never at the expense of medical care. Prior coordination with all relevant authorities should establish protocols, such as who and how many persons from these agencies are allowed in, when, into which parts of the ED, who controls them, and who is empowered to limit their entry and work. As a rule, however, although a terrorist event is a crime, forensics in the hospital are of minor relevance compared with the actual crime scene. Investigators may wish to interrogate victims with minor injuries regarding the event and obtain shrapnel or clothing from patients for forensic analysis.

INFORMATION MANAGEMENT

Because blast injury is often part of a large event, information becomes a critical component of appropriate management. Such information concerns include: (1) clinical charting and other patient care–centered information, such as imaging; (2) command and control information, such as casualty flow data, resource management data, and interface with other agencies; (3) information provided to relatives; (4) information provided to the media; and (5) information recorded for quality improvement and research. An information center is an indispensable component of such events, providing relief for the relatives and also preventing them from crowding patient care spaces and impeding caregiver workflow.

CRUSH INJURY AND THE CRUSH SYNDROME
A crush injury occurs when a body part is subjected to a high degree of force or pressure, usually after being squeezed between two heavy or immobile objects. **Crush injury that produces ongoing ischemia of a fascial muscle compartment is termed compartment syndrome**, defined as increased pressure within a confined space that leads to microvascular compromise and ultimately to cell death as a result of oxygen starvation. Crush syndrome is the systemic manifestation of muscle cell damage resulting from pressure or crushing with or without subsequent compartment syndrome. This chapter discusses crush injury and treatment measures specifically in the context of mass natural disasters. Specific discussion of detailed physiology, compartment anatomy, and compartment pressure measurement is found in chapter 278, "Compartment Syndrome."

**EPIDEMIOLOGY**

Crush injuries may be seen in two different scenarios: in single-patient situations and in disasters of varying magnitude, like earthquakes or tsunamis. Catastrophes have occurred throughout history, but the recognition of crush syndrome in the twentieth century and the advent of effective treatment for some of the components of the systemic and local injury have made it one of the important aspects of the medical care of natural disaster victims. The increasing number of vehicular and workplace accidents has also led to a rise in the incidence of crush syndrome and in the importance of its timely recognition and treatment. In various reports, the incidence of crush syndrome and subsequent renal failure varies from 1% to 25%, probably resulting from reporting differences, the nature of the disaster, and the timeliness and effectiveness of the rescue efforts and medical care.26

Crush injuries are most commonly seen in the extremities, because crush of the trunk or head and neck is quickly lethal. There is a high incidence of associated injuries such as fractures, lacerations, and degloving injury.

**PATHOPHYSIOLOGY**

Injury to muscles, including crush and ischemia, causes rupture of the sarcolemma and the release of the intracellular contents of the myocytes into the surrounding tissues. Calcium ion is one of the most destructive components released from the myocytes, because calcium stimulates proteolytic enzymes and oxygen free radicals are released. This causes more myocyte destruction, and potassium, phosphate, myoglobin, creatine kinase, and uric acid leak into the bloodstream. Serum haptoglobin binds some of the myoglobin, but its binding capacity is quickly overwhelmed, and myoglobin causes direct kidney injury. Membrane damage to the myocytes and to the systemic capillary endothelium causes vascular volume loss and hypovolemia. Hyperkalemia and hypocalcemia may cause arrhythmias and cardiac arrest. Metabolic acidosis caused by hypovolemia and shock aggravates arrhythmogenicity. **Renal failure is the most serious complication of crush syndrome.** The pathogenesis of renal failure is multifactorial, including systemic hypoperfusion, renal vasoconstriction, nephrotoxicity from myoglobin, and uric acid and phosphate precipitation in the distal tubules. Low urine pH and renal vasoconstriction promote precipitation of
nephrotoxins. Myoglobin is indirectly nephrotoxic through the formation of ferrihemate, which produces free hydroxyl radicals and, combined with lipid peroxidation, damages the kidney.\(^{27}\)

Reperfusion syndrome is a paradoxical phenomenon of exacerbation of cellular dysfunction after restoration of blood flow to previously ischemic tissues. It involves biochemical and cellular changes causing oxidant production and complement activation, which culminates in an inflammatory response, mediated by neutrophils and platelets interacting with the endothelium. The inflammatory response has both local and systemic manifestations.\(^{28}\) Systemic manifestations include hypotension, vasodilatation, hypovolemia, myocardial depression, hyperkalemia, and acidosis.

**Normal muscle compartment pressure is <10 mm Hg.** After crush injury, trauma to the microcirculation leads to edema formation, interstitial bleeding, stasis, and obstruction, and the myocytes are no longer able to retain intracellular water. Edema in a closed space causes increased pressure, which further collapses the microcirculation and potentiates the problem.\(^{29}\) **Pressures >30 mm Hg produce muscle ischemia; irreversible nerve and muscle damage occurs after 4 to 6 hours.**

**CLINICAL FEATURES**

Obvious external signs of crush injury are usually evident, as is a suggestive history. Lacerations, degloving, deformity, pain, and ischemia may occur in varying degrees.

Compartment syndrome often presents with the five "P's": pain, paresthesias, passive stretch, pressure, and pulselessness. Pain is the most common and consistent symptom, described as diffuse and intense; exacerbated with movement, touch, or pressure; and out of proportion to physical examination findings.

Paresthesias are numbness, tingling, or burning sensations in the affected area. Severe pain results when muscles in the affected compartment are stretched.

The affected compartment is very tight to the examiner's touch and sometimes warm, and there are measurable increases in tissue pressure. Pulselessness occurs only in the late stages. Examining for a pulse, or its lack, is the least reliable because compartment syndrome is a disorder of the microvasculature; the major vessels are frequently unaffected.

Crush syndrome is due to the manifestations of muscle toxin release and hypovolemia. Hypovolemic shock may occur, aggravated by hyperkalemic, hypocalcemic, or acidemic cardiotoxicity. Thromboplastin release may cause disseminated intravascular coagulation, which is especially critical in the face of tissue damage, open wounds, or the need for surgery. Renal failure may ensue quickly and is the primary cause of delayed death.\(^{26}\)

**DIAGNOSIS**

Testing of the compartment pressure will confirm the diagnosis. A compartment pressure of >30 mm Hg is considered to be a positive test. Measurement is best accomplished with a dedicated device (Stryker STIC;
Stryker Co., Kalamazoo, MI) or by inserting a saline-filled needle connected to an intravascular pressure measurement system (arterial or central venous pressure gauges) into each compartment and recording the pressures. See chapter 278 for detailed description of compartment pressure measurement.

Crush syndrome is characterized by protean and rapid metabolic changes. Laboratory tests are crucial to help direct management. Serum creatine kinase levels may not necessarily predict disease severity and risk of renal failure, but they are a useful initial triage and subsequent follow-up tool. Pay close attention to serum potassium, calcium, phosphorus, pH, creatinine, hemoglobin, coagulation indices, and urine pH and electrolytes. A preplanned sequence of laboratory tests every 2 to 4 hours is useful, rather than sporadic checks. Urine collection for total electrolyte excretion and creatinine clearance calculations may be considered.

**TREATMENT**

Establish two large-bore IV lines and administer normal saline with a 1- to 2-L bolus. Avoid Ringer’s lactate and other potassium-containing fluids, because fatal hyperkalemia may occur, even in the absence of renal failure. Initiate IV fluid rate at 1000 mL/h, and then reduce to 500 mL/h after 2 hours. Urine output should be approximately 200 to 300 mL/h (5 to 7 L every 24 hours) for an adult. Monitor serial serum potassium levels. Admit the patient to an intensive care unit setting to monitor fluid administration and electrolyte status.

**FASCIOTOMY**

In reports of mass casualties from earthquakes, most of the fasciotomy procedures were performed >12 hours after the time of trauma. Reviews of these cases showed high infection rates with increased mortality and amputations and poor long-term outcomes. Fasciotomy creates open wounds, which increases the risk for sepsis, amputation, hemodynamic instability, chronic nerve dysfunction, and death. Most recommendations discourage the use of routine fasciotomy, particularly for crush wounds, and fasciotomy is only indicated for absence of distal pulses, a requirement for debridement of necrotic muscle, compartment pressures >30 mm Hg (measured within 6 hours of injury), and differences between compartmental pressure and diastolic blood pressure of >30 mm Hg. If initial compartment pressures are normal and delayed compartment syndrome develops, fasciotomy may be needed, but infection rates have been reported to be high and prolonged, and profuse local bleeding may develop.

**HYPERBARIC OXYGEN THERAPY**

Hyperbaric oxygen therapy is a useful adjunct in the treatment of crush injury and compartment syndrome because it supplements oxygen availability to the hypoxic tissues in the early postinjury period. With hyperbaric oxygen therapy at 2 atm, the blood oxygen content (oxygen carried by hemoglobin and plasma) is increased by 125% (by increasing plasma oxygen content), and the oxygen tension in plasma and tissue fluid is increased 10-fold compared to room air breathing. Edema reduction secondary to oxygen-induced
vasoconstriction is another beneficial effect of hyperbaric oxygenation. Hyperbaric oxygenation reduces blood flow by 10% to 20%, thereby reducing tissue edema caused by blood flow, but oxygen delivery to the tissues is increased because of higher tissue oxygen tensions. The immediate effects of hyperbaric oxygen therapy are threefold: enhanced oxygen at the tissue level, increased oxygen delivery per unit of blood flow, and edema reduction. Long-term effects may include improved wound repair after fasciotomy, diminished infection rates, and improved outcome of skin grafts.

**SPECIAL POPULATIONS**

Care of crush injury patients in the setting of mass casualty incidents is radically different than that of the individual victim. Extrication may be delayed, medical treatment during extrication may be unavailable, initial management may occur in makeshift or suboptimal conditions, and medical personnel may have little experience working under such conditions. Transportation to definitive care may be prolonged; critical equipment, such as dialysis machines, may be in short supply; and laboratory, monitoring, and intensive care facilities may be insufficient for the volume demands. Healthcare workers should anticipate these obstacles and develop flexible treatment protocols.

**REFERENCES**


[PubMed: 23827955]

[PubMed: 25386862]

[PubMed: 24139220]

[PubMed: 22411082]

[PubMed: 19631372]

[PubMed: 22372014]

[PubMed: 21149366]

[PubMed: 21305971]

[PubMed: 21104699]

[PubMed: 22836523]

[PubMed: 18234750]
[PubMed: 22012085]

[PubMed: 23884075]

[PubMed: 20483376]

[PubMed: 21604927]

[PubMed: 21725164]

[PubMed: 23481155]

[PubMed: 22809430]

[PubMed: 21149360]

[PubMed: 23024157]

[PubMed: 21206687]


**USEFUL WEB RESOURCES**

Definitions of terrorism. United Nations Office on Drugs and Crime Web site—

http://www.nationmaster.com/encyclopedia/List-of-terrorist-incidents

Explosions and blast injuries: a primer for physicians—http://www.bt.cdc.gov/masscasualties


Improvised explosive devices (IEDs)/booby traps—
http://www.globalsecurity.org/military/intro/images/vbied-standards-chart.jpg


Patient Plus—http://www.patient.co.uk/showdoc/40001216

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