Prehospital Care Algorithm for Blast Injuries due to Bombing Incidents

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Abbreviations:
ALS = advanced life support
BLS = basic life support
EMS = emergency medical services
EMT = emergency medical technician
HMAS = Hospital Mutual Aid System
HMARS = Hospital Mutual Aid Radio System
ICS = Incident Command System
TM = tympanic membrane

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Abstract
Terrorist bombings continue to remain a risk for local jurisdictions, and retrospective data from the United States show that bombings occur in residential and business areas due to interpersonal violence without political motives. In the event of a mass-casualty bombing incident, prehospital care providers will have the responsibility for identifying and managing blast injuries unique to bombing victims. In a large-scale event, emergency medical services personnel should be required to provide prolonged medical care in the prehospital setting, and they will be able to deliver improved care with a better understanding of blast injuries and a concise algorithm for managing them. Blast injuries are categorized as primary, secondary, tertiary, and quaternary, and these injuries are related to the mechanism of injury from the blast event. After an initial evaluation, the emergency healthcare provider should consider following a universal algorithm to identify and treat blast injuries within these categories to prevent further morbidity or mortality in the prehospital setting.

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Introduction
The possibility of a bombing event in a major urban area remains a serious threat in most cities around the world. Given the complexity of the current geo-political climate, multiple groups view violence as a means either to promote instability or to bring attention to their causes. In addition, data from the United States show that often the bombings simply are motivated by interpersonal violence.[1] Many bombing victims initially receive medical care from a prehospital provider, and these healthcare professionals require appropriate knowledge about identifying and treating bomb-related injuries in the prehospital setting. Many articles have been written about the management of blast injuries in the hospital setting, and articles also have been written in the emergency medical services (EMS) literature about the management of specific types of blast injuries.[2–8] This paper will present a unified algorithm for the treatment of primary, secondary, tertiary, and quaternary blast injuries by prehospital providers.

Epidemiology of Bombing Events
A 20-year retrospective analysis of bombing events in the US identified 36,110 bombing incidents, 5,931 bomb-related injuries, and 699 bomb-related deaths occurred during the study period.[1] The etiology of a majority of the injuries and deaths was homicide rather than vandalism, protest, or extortion. Additionally, the injuries and deaths were due to bombs made from easily accessible materials such as fertilizers and firearms powder. Residential sites were the locations in which 31.5% of the injuries and 35.5% of deaths; commercial sites accounted for 29.3% of injuries and 10.6% of deaths.[1] These data indicate that bombing events are a serious concern. In addition, bombing incidents often are attempted with the intent to cause significant morbidity and mortality using common materials, and they are detonated in both local communities and business districts. Therefore, prehospital care providers in all jurisdictions should be prepared for bombing events and subsequent blast injuries.

Event	Hospital Data Injuries (*Total)	Deaths	EMS Patient Transports
Oklahoma City 1995	434 (592)	167	90 (20.7%)
Atlanta Olympics 1996	111	1	111 (100.0%)
WTC 9/11/2001	1,103 (7,250)	2,749	282 (25.5%)
Pentagon 9/11/2001	106	189	93 (87.7%)

Table 1—Emergency medical services transports for selected mass-casualty terrorism events in the US

After a bombing event, not all victims will interact with their local EMS system (Table 1). Many factors affect whether an ambulance will transport a patient to a local healthcare facility. Usually, the classic models of prehospital care triage, triage classifications, triage tags, flow points, and treatment areas only apply to a contained scene. Immediately after a bombing event, patients disperse from the scene, and the "walking wounded" arrive at healthcare facilities by private transportation or by foot. Approximately 25% of patients will be transported by the EMS system.[9] However, after the bombing event at the Atlanta Olympics in 1996, 100% of victims were transported by EMS because the mass gathering had prompted local officials to be prepared for a potential disaster, and local authorities had ambulances stationed at the event site. During the 11 September 2001 event at the Pentagon, the scene immediately was contained due to the high level of security at the facility, and the victims had few choices except ambulance transport for evacuation and treatment.[2–12]

Key Logistical Principles

Immediately after a bombing event, the local jurisdiction should implement an Incident Command System (ICS) to ensure the orderly management of a bombing scene. The ICS usually is directed by the fire department, and the Incident Command Center establishes four primary divisions: (1) operations; (2) planning; (3) logistics; and (4) administration.[13,14] At the site of the actual bombing, the most important operational principle is scene safety.[15] Prehospital providers and first-responders must be attentive to personal safety. In cooperation with police officials, paramedics and emergency medical technicians (EMTs) assess the scene for additional threats. These threats include secondary devices, falling debris, and delayed fires or explosions from infrastructure such as natural gas lines. If possible, paramedics and EMTs should attempt to memorize a few key details of the scene in order to provide greater information to the receiving facility and to help with further forensic or epidemiological studies. Information such as the extent of damage to structures near the patient, location of the patient at the scene relative to the blast device, and numbers of other individuals in the vicinity are useful by local officials.[16]

The on-scene transport officer, EMS dispatch services, and hospitals should coordinate the transport of patients among local hospitals within the vicinity of the bombing. Many jurisdictions have initiated a Hospital Mutual Aid System (HMAS) and an affiliated Hospital Mutual Aid Radio System (HMARS).[17] In the immediate aftermath of such an event, both HMAS and HMARS facilitate communications between multiple hospitals in an urban area to improve the flow of multiple patients through the local healthcare system. After many bombings, the hospitals closest to the attack receive most of the patients, and these facilities have to triage among both high-acuity and low-acuity patients.[18–20] For greater logistical efficacy, high-acuity patients are transported to the closest appropriate hospitals, and lower-acuity patients are taken to more distant hospitals. In addition to patients arriving by non-EMS means, ambulances frequently transport multiple patients to the same facility over a short period of time. Prehospital care providers may continue to bring patients to the same hospital because they: (1) want to achieve rapid transport times and return-to-scene times; (2) are instructed to take patients to the nearest facility; (3) are unable to use roads to other facilities; or (4) may not know the routes to outlying hospitals. Since the nearest facility is most likely to receive the majority of the EMS-transported patients for reasons listed above, and the largest portion of the self-transporters for similar reasons, the closest facility to the event must establish itself as a casualty collection point, and have plans to triage and secondarily transport patients to more distant facilities.

In EMS systems with Basic Life Support (BLS) and Advanced Life Support (ALS) care providers, efforts should be made to triage patients needing transport, but unlikely to need further advanced care to the BLS care providers. Due to the possibility of decompensation and worsening patient condition, BLS care providers should not be responsible for transporting patients who require or are likely to require advanced care. As much as resources will allow, these patients are better attended by ALS providers. One caveat may be situations with very short transport times and limited resources, but this must be determined on a case-by-case basis.

Medical Management of Bombing Injuries

The prehospital care of injuries due to bombings begins with fundamental resuscitation protocols, such as c-spine precautions, airway, breathing, and circulation. Because prehospital providers are knowledgeable about the management principles of general trauma victims, these principles will not be addressed in detail. Since injuries due to terrorist bombings often are multiple and complex,[21] this article focuses on a systematic management of the specific injuries related to bombing events. Blast injuries due to bombings can be classified into four types: (1) primary; (2) secondary; (3) tertiary; and (4) quaternary.[22] *Primary blast injury* occurs from the effects of the blast wave upon tissues, and the injuries are due to pressure differentials that cause a rupture at the surface of organs or membranes. In primary blast injuries, the body parts most often affected are the lungs, tympanic membranes, intestines, eyes, and brain. *Secondary blast injuries* are due to bomb fragments and objects within the bomb (nails, bolts, nuts) that cause bodily injuries, and these injuries usually are penetrating injuries to the soft tissues and the eyes. *Tertiary injuries* are due to the patient being displaced by the blast wind and hitting a fixed object, i.e., a wall or the ground; the person usually suffers soft tissue injuries, fractures, amputations, and head injuries. *Quaternary injuries* include

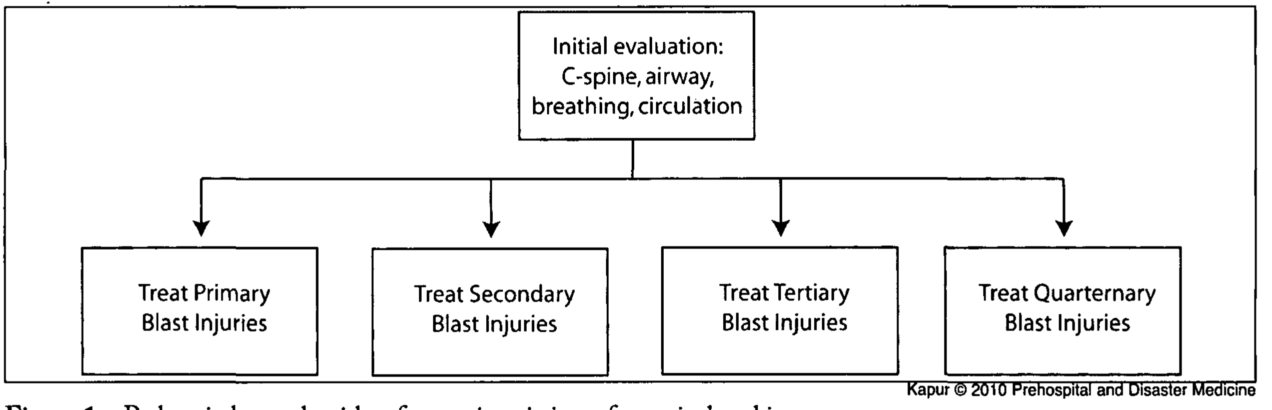

Figure 1—Prehospital care algorithm for treating victims of terrorist bombing events

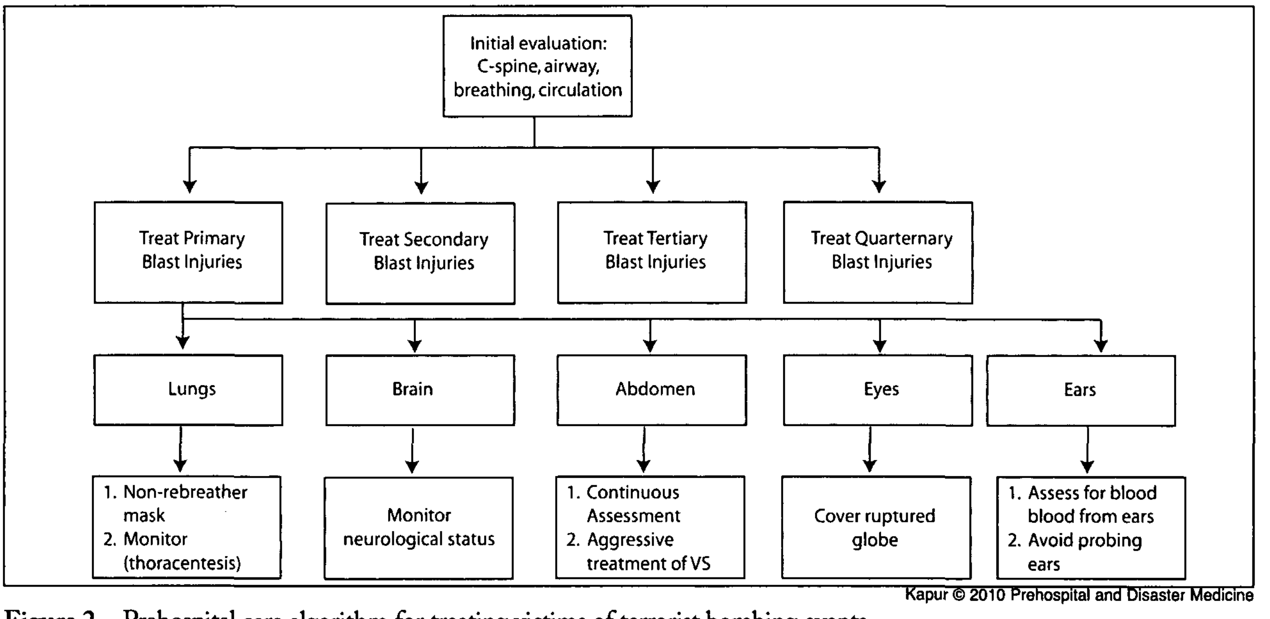

Figure 2—Prehospital care algorithm for treating victims of terrorist bombing events

any injuries due to delayed causes such as crush injuries from building collapse or burns from secondary fires. Quaternary injuries also include deterioration of chronic medical conditions such as exacerbations of asthma, angina, or hyperglycemia.[15]

As with algorithms for trauma and cardiac patients, an algorithm for victims of bombing events will help to ensure that specific injury patterns will be evaluated and treated in a step-wise manner and that important injuries will not be missed. This paper advocates a prehospital care algorithm based on the current nomenclature for bombing injuries: (1) primary injuries; (2) secondary injuries; (3) tertiary injuries; and (4) quaternary injuries (Figure 1).

Primary Blast Injuries

After initial stabilization of the patient, the prehospital provider evaluates and treats primary blast injuries (Figure 2). The lungs and abdomen are the two systems at highest risk of serious injury from primary blast. The lungs can be injured severely in a bombing event, and prompt assessment and treatment of primary blast lung injuries is important in the prehospital setting. Blast lung injury (BLI) can be complicated by hemothoraces or pneumothoraces. Clinical signs and symptoms of BLI include dyspnea, chest pain, hemoptysis, hypoxia, and/or wheezing.[6] There is a higher incidence of BLI associated with skull fractures, penetrating injuries to the torso or head, burns greater than 10% total body surface area (TBSA), and an explosion inside of a confined space. Initial management includes the administration of supplemental oxygen via non-rebreather mask (NRB) and continuous pulmonary function monitoring using pulse oximetry. If the patient's pulmonary status deteriorates, endotracheal intubation may be necessary. If positive pressure ventilation is required, special consideration must be given to the fact that BLI places the patient at high risk of air embolism. Due to pulmonary or vascular tearing, the possibility of an air embolism may increase with positive pressure ventilation. Air enters the injured vasculature and can lead to tachycardia, hypoxia, and hypoperfusion.[23] Treatment of an air embolism in the field is supportive. The patient is placed in Trendelenburg and left lateral decubitus position to help trap any air in the apex of the heart. In addition, if the patient develops a tension pneumothorax, the patient will require needle thoracentesis decompression. The prehospital provider must administer intravenous (IV) fluids conservatively to avoid exacerbating blast lung injury or inducing pulmonary edema.

Some studies have shown that the kinetic energy of the blast wave transferred to the central nervous systems caus-

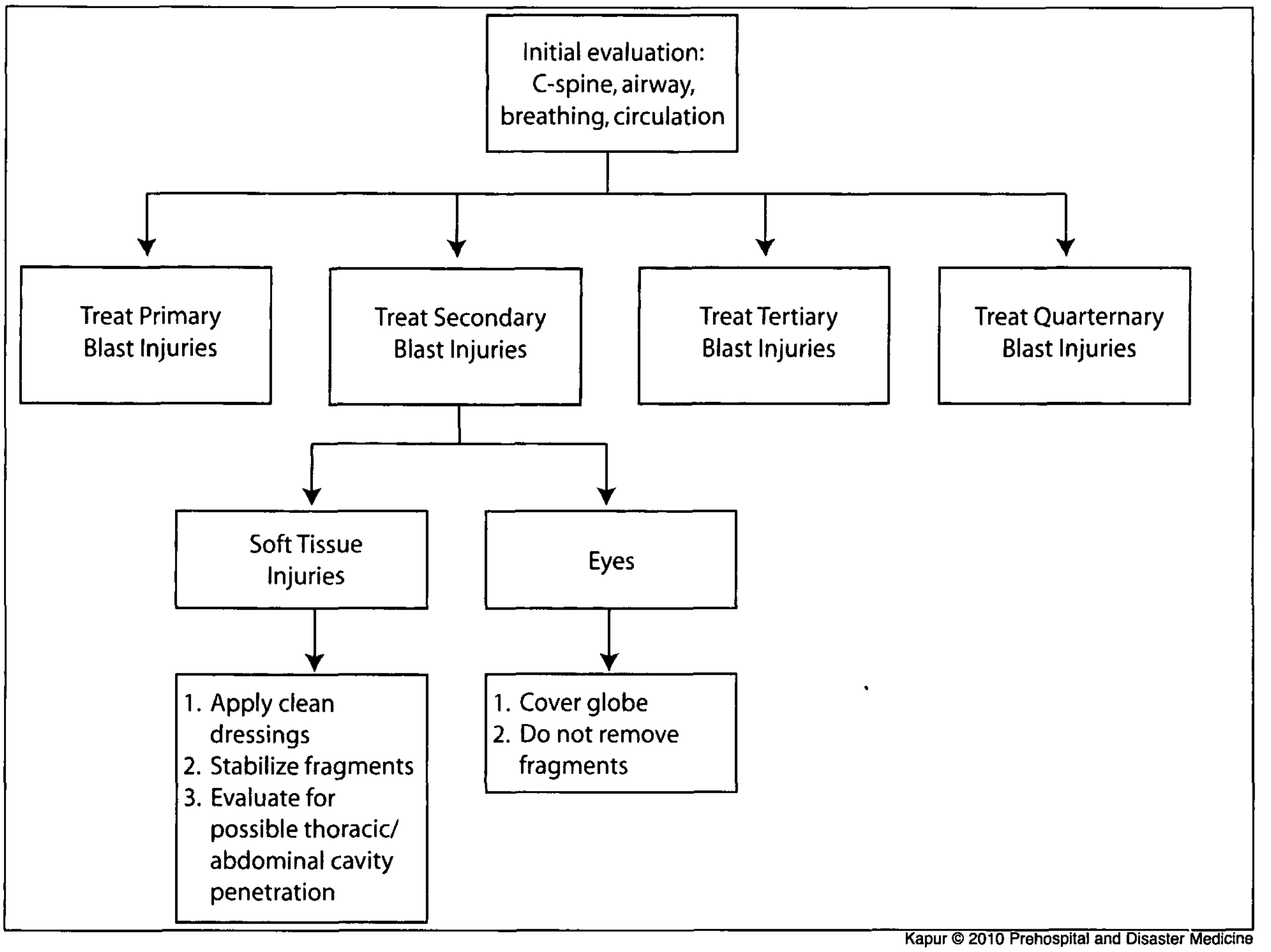

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Figure 3—Treatment algorithm for secondary injuries in bombing victims

es axonal injury and traumatic brain injury (TBI).[24,25] Monitoring of neurological status using the Glasgow Coma Scale (GCS) is important, and if the patient's neurological status deteriorates due to the impact of primary blast injury upon the brain, the patient may need to be intubated for airway control and assisted ventilation.

Primary blast injuries to the abdomen most often occur within the colon, and the blast wave can cause either hemorrhages or perforations of the bowel.[24] Abdominal injuries also can include solid organ lacerations. Patients with abdominal injuries may have clinical signs and symptoms that include nausea, vomiting, hematemesis, abdominal pain, and/or hypovolemia; on physical examination the patient may have focal or diffuse abdominal tenderness, rebound tenderness, guarding, and/or diminished bowel sounds.[26] If there are any signs of abdominal injury, abnormalities of vital signs must be treated aggressively, nothing is given by mouth, and serial abdominal examinations are performed. In situations in which patients have significant lung injury with concomitant injuries including the abdomen, a conservative fluid strategy that allows for permissive hypotension is best to protect the breathing status. Fluids are given to maintain the systolic blood pressure between 90–100 mmHg.[27]

Blast waves may cause ruptured globes, and if there is evidence of an eye injury, the eye is covered with a hard shield for protection. The tympanic membrane (TM) is easily damaged by primary blast mechanisms, and evidence of injury to the TM may indicate further damage to internal organs.[5,7] The prehospital provider evaluates and documents whether blood or fluid is coming from either ear, and probing of the ear is avoided.

Secondary Blast Injuries

Secondary blast injuries are more common than are primary blast injuries, and the projectiles may cause either blunt or penetrating trauma.[8] Exposed areas of the body are at most risk to injury, including the eyes, thorax, and abdomen (Figure 3). The prehospital provider must identify each of the patient's soft tissue injuries and apply hemorrhage control techniques. The care provider also should keep in mind that even small puncture wounds may have been caused by debris that have resulted in penetrating trauma of the thorax or abdomen. Unless the base of these injuries can be clearly identified, they are presumed to be penetrating injuries, and evaluation and monitoring of potential thoracic or abdominal injuries is recommended.

Impaled fragments are not to be removed because their movement may precipitate increased bleeding. Bodily areas with soft tissue injuries are covered with clean dressings and impaled fragments are stabilized for transport.[22] In situations in which impalement prevents patient extrication, the prehospital provider stabilizes the patient's site of injury and

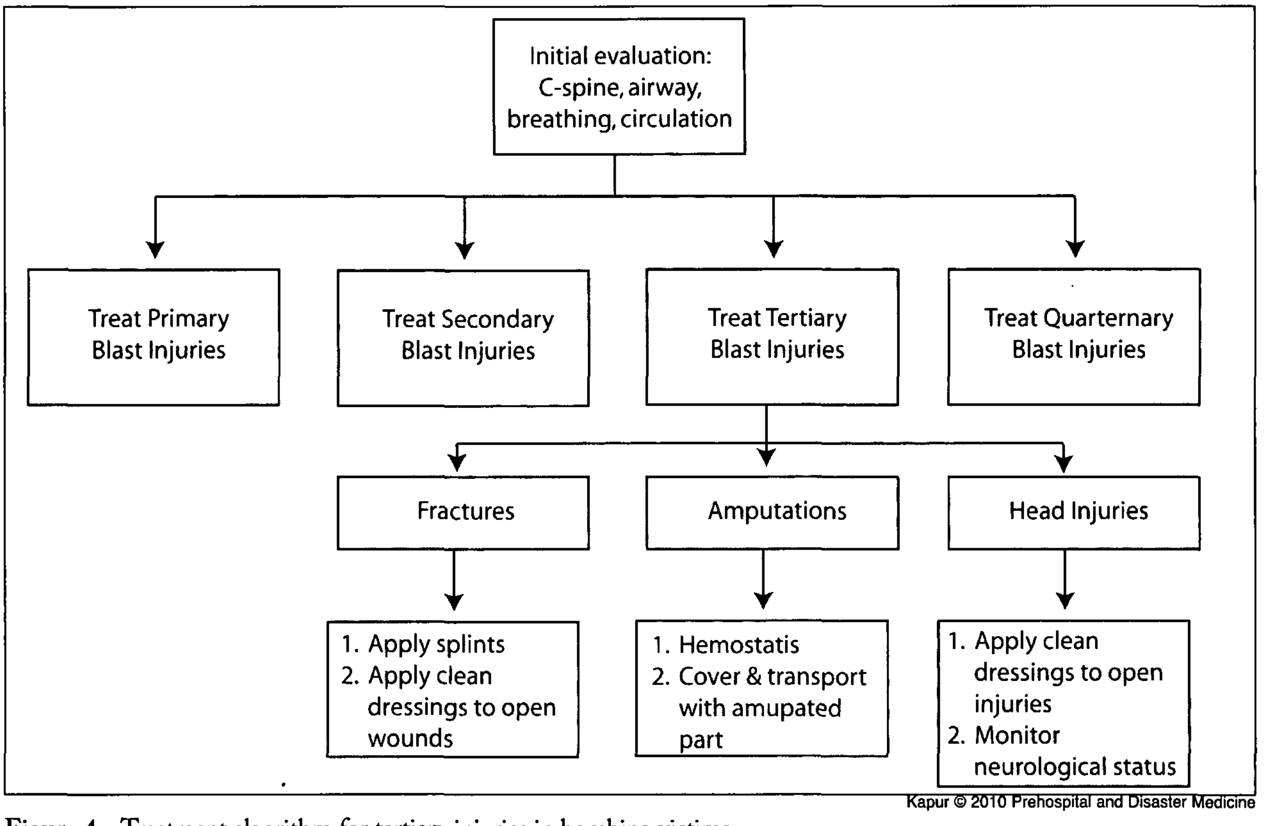

Figure 4—Treatment algorithm for tertiary injuries in bombing victims

awaits further help to free the debris and patient together. If the patient becomes hypovolemic due to excess blood loss or internal injuries, administration of IV fluids are required.

Secondary blast injuries can cause complex trauma to the eye and surrounding peri-orbital structures.[28] As with primary blast eye injuries, eye injuries due to bomb fragments are covered with a protective shield, and the eye is not manipulated. Fragments in the globe are left in place.

Tertiary Blast Injuries

The impact of the body's displacement due to blast waves may cause tertiary blast injuries. When the patient's body strikes against solid objects or lands on the ground, the patient may incur soft tissue injuries, fractures, amputations, or head injuries (Figure 4). Prehospital care providers evaluate for bone deformities and ask patients to identify specific areas of pain. These injuries are splinted and stabilized for transport, and all open wounds are covered with clean dressings. When an amputation has occurred, if possible, the amputated body part is salvaged, covered, and transported back with the patient. Partial amputations are not completed in the field. The patient's hemorrhage is controlled, and the exposed limb also is covered. When bleeding is difficult to control after standard hemorrhage control measures, prehospital care providers can consider the use of a tourniquet.[29,30] A tourniquet is best applied with a large blood pressure cuff inflated to >200 mmHg as necessary to control arterial bleeding for as short a time as possible.

Both open and closed head injuries are possible due to tertiary blast effects, and the patient is evaluated for any signs of head injuries such as hematomas or lacerations. Open head wounds are covered with clean dressings, and brisk scalp lacerations require compression dressings. If evidence of head injuries is present, the patient's neurological status requires close monitoring.

Quaternary Blast Injuries

Quaternary injuries are all medical consequences that occur after the initial impact of the explosion. These injuries may include burns from secondary fires, crush injuries from falling debris, or exacerbations of a patient's chronic diseases (Figure 5).[31] Especially if there has been some delay response, prehospital providers may have to address these quaternary medical issues. Burns are covered with clean dressings, and IV fluids are started for burns that cover large body surface areas. Prehospital providers identify limbs that have experienced crush injuries, and severe crush injuries are treated with IV fluids to help minimize the complications from rhabdomyolyis.

Patients with underlying asthma, coronary artery disease, or diabetes may experience exacerbations or complications from these diseases. Prehospital providers determine the patient's medical history and address specific quaternary complications. The providers monitor the patient's chronic diseases and are prepared to administer specific medications per protocol such as albuterol for asthmatic wheezing or nitroglycerin for chest pain.

Summary

Bombing events have the potential to cause large numbers of casualties, and the medical interventions of prehospital providers can minimize the morbidity and mortality due to these incidents. Using key logistical principals of patient

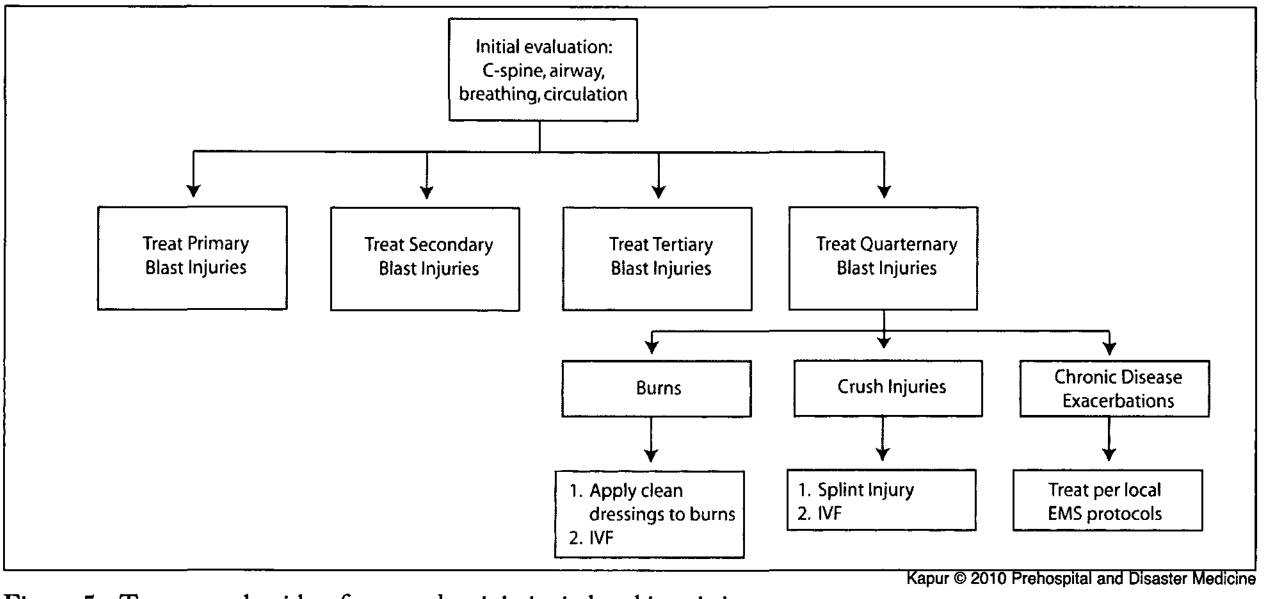

Figure 5—Treatment algorithm for secondary injuries in bombing victims

movement and anticipating the surge at the closest facility, deterioration of definitive patient care can be avoided. The appropriate prehospital algorithm for the management of blast injuries may assist providers in administering efficacious treatment in a timely manner. The most appropriate algorithm provides an organized approach for evaluating and treating primary, secondary, tertiary, and quaternary blast injuries to make sure critical injuries are not missed.

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Editorial Comments—Prehospital Care Algorithm for Blast Injuries due to Bombing Incidents

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This timely article by Kapur *et al* serves to remind us of the potential strain on existing emergency medical services likely to follow domestic bombing incidents. The authors have constructed straightforward patient care flow diagrams to guide prehospital personnel during the period of delay that invariably follows a mass-casualty incident. While the triage of such patients is not specifically addressed, the need for prehospital care focused on injuries unique to blast is useful.

The authors note the value of including details of the bombing scene in their report to the receiving hospital. In this era of digital photography and ubiquity of mobile telephones, pictures from the disaster setting could effectively accomplish this purpose. Air embolism as a consequence of primary blast injury is mentioned with the usual concerns and precautions. The incidence of this complication is unknown. It is often fatal and there is little that can be done in the field. The conditions for its development certainly attend primary blast effect. If suspected, the use of airway techniques, even bag-valve-mask ventilation, which tend to raise airway pressure must be used advisedly and only as a last resort. This caveat also applies to the primary blast victim with head injury where field endotracheal intubation is currently being questioned.

Secondary blast injuries are far more common, as cited by the authors. Entrapment with hypovolemia and hypotension indicate the need for intravenous fluids, but also for the release of the entrapped patient as a life-saving measure; amputation at the scene may be warranted under such circumstances. In instances where extremity bleeding is profuse and cannot be controlled with pressure, recent military experience has confirmed the life-saving worth of the tourniquet. There are now commercially available tourniquets that are easy to apply and more effective than the blood pressure cuff recommended by the authors. Such devices should be standard equipment on emergency vehicles and their use guided by informed medical direction, on or off-line. Lastly, the lethal consequences of crush injury seldom surface in the field, yet inexorably lead to renal failure and deaths in significant numbers. Early and brisk fluid therapy by whatever means possible is an important field measure, especially when delays are anticipated.