Blast Injuries

Nick Colovos, MD, FACEP

Explosive devices have become the destructive agents of choice for many terrorists, primarily because the materials used to construct them are so easily accessible. During the 1990s, a number of bombing incidents diminished Americans' sense of security. In February 1993, the World Trade Center bombing in New York City killed 6 people and injured more than 1,000. In April 1995, a truck bomb exploded at the Murrah Federal Building in Oklahoma City, killing 168 people and injuring more than 750. In June 1996, the bombing of Khobar Towers in Dhahran, Saudi Arabia, killed 19 U.S. airmen. A year later, a bomb attack at Olympic Centennial Park in Atlanta was intended to harm not only bystanders but also the law enforcement officers who went to the scene after receiving a telephone call announcing the pending explosion. Similarly, in 1997, also in Atlanta, a secondary device was aimed at fire fighters, emergency medical services (EMS) personnel, and police officers called to bombings at a health care clinic and a nightclub.[1]

Disaster response personnel must understand the pathophysiology of injuries associated with explosions and must be prepared to assess and treat the people injured by them. The early presentation of victims can be deceiving, because the initial manifestations of significant injury can be subtle.

INJURY MECHANISMS OF A BLAST

Explosions cause injury through three principle mechanisms: primary blast injury, secondary injury, and tertiary injury. Primary blast injury is caused by the effect of the blast wave or pressure wave on the body. Secondary injury is the result of debris propelled by the blast wind of the explosion. These flying projectiles can produce both

penetrating and blunt trauma. Finally, tertiary injuries are caused by the displacement of the body by the blast winds into environmental objects. Regardless of the mechanism of explosion-related injury, the basic principles of trauma care still apply.

Blast waves are produced by the detonation of munitions, the firing of large caliber guns, and any type of explosion. These waves can be powerful enough to injure individuals exposed to them. The organs most vulnerable to this type of injury are the gas-filled organs, namely, the ear, the lungs, and the gastrointestinal tract.

An important concept that defines injury patterns is the medium in which the blast occurs. An underwater blast wave has particular lethality because water is incompressible compared with air. Therefore, a wave resulting from a blast occurring underwater travels farther and faster than a wave from a similar explosion on land. Hence, blast injuries in water occur at greater distances from the detonation point and are often more severe.

Another characteristic of blast waves is that they are indeed waves, traveling in a sinusoidal pattern. The injury patterns they produce are caused not only by the medium in which they travel but also the position of the victim's body in relation to the wave and any reflective/deflecting objects in the environment. For example, as a blast wave strikes a wall, it is reflected, subsequently magnifying the wave's energy. A person standing in front of the wall can be subjected to devastating forces. Similarly, the use of body armor may provide a false sense of security. Body armor does protect a person from shrapnel, but significant underlying blunt trauma may result from exposure to a wave blast coming from an explosion. (The advantages of body armor far outweigh this risk.) As the wave strikes the body of someone wearing armor, the energy is reflected against the inside of the body protection, producing injuries far greater than if no armor was worn at all.

Therefore, a person wearing body armor cannot be presumed to have been protected from explosion-related injury. Explosions in confined spaces have a similar effect. Injuries are magnified by the effect of reflective surfaces within a closed room.

Primary Blast Injury

Primary blast injury is caused by the direct effect of a blast wave created by an explosion. When an explosion occurs, gases expand suddenly and spherically from the center of the explosion. Because of the compressibility of air, this expansion of gases compresses the surrounding air, creating a high-pressure front. This blast wave travels outward at supersonic speeds of more than 900 mph.

Primary blast injury is the direct result of this dense wave striking the body. Bystanders feel the explosion as a sudden thump in their chest, which is the arrival of the pressure/blast wave. Under some circumstances, this force is magnified several thousand times, causing significant injury.

Primary blast injury has three primary mechanisms. The first is *spalling*, which occurs when the shock wave (blast wave) transfers from a dense medium (liquid) such as water to a less dense medium (gas) such as air. In an underwater explosion, for example, the shock wave travels in front of the detonation, reaches the surface, and reflects off the less dense air. This scenario is comparable to the effect of striking the outside of a rusty bucket with a hammer. The transfer of energy displaces rust from the inside of the bucket, even though the hammer did not strike it directly. During naval battles, depth charges are released into the water. It appears as if there are two explosions for each depth charge. The first is the spalling effect. It causes injury by the transfer of reflected blast wave energy through a body's' dense substrates (liver, muscle) into the less dense

material of the gastrointestinal tract and lungs. An upward explosion of water follows because of expanding gases caused by the detonation.[2]

The second mechanism of injury is the implosion of gas-filled spaces as the high pressure in the surrounding fluid or solid compresses them. Third, primary injuries are related to differences in tissue density, which affects rates of acceleration and deceleration. These differences result in shearing and tearing forces.

The organs most vulnerable to primary blast injury are those containing air. The body is able to respond to pressure change well if the change in pressure is slow. The ear uses the eustachian tube to equilibrate the pressures of the middle ear. Diving to the bottom of a pool induces a similar effect of pressure changes. The atmospheric pressure increases toward the bottom of the pool, squeezing the middle ear. A diver can open the eustachian tubes by holding his or her nose and blowing (performing a Valsalva maneuver), which relieves the pressure on the middle ear. Diving-induced increases in pressure are minimal (1 to 2 atmospheres above normal), yet they can cause profound discomfort to the middle ear if equalization does not occur. Similar venting is used by the lungs through the respiratory tree and by the gastrointestinal tract through expulsion of gases. Each of these mechanisms allows the body to equilibrate with the ambient atmospheric pressure.

An explosion that produces a pressure wave 1000 times the magnitude of the example above, traveling at supersonic speed, will impose tremendous damage when it strikes any body in its path. Hollow organs are disrupted by the rapid increase in atmospheric pressure. As the pressure wave strikes the body, it compresses the air-filled organs and collapses them. Gas-filled organs are like balloons filled with air. If they are

squeezed by applying hard pressure rapidly (as during the impact of a pressure wave), they will burst. The resulting force causes shearing of vascular beds, pulmonary contusions, pneumothorax, and gastrointestinal hemorrhage. In fact, the force of a pressure wave can be significant enough to force air into blood vessels, resulting in air emboli.

Secondary Blast Injuries

Secondary blast injuries (penetrating or blunt) result from debris acting as projectiles as the blast wave propels them. Since the blast wave travels at supersonic speeds, there is little chance that people in its path will be able to dodge the wave front or the debris it carries. Therefore, scene safety is vitally important. Since the energy of the blast wave dissipates with distance, it is important for responders and victims to move (or be moved) a safe distance away. This distance depends on the degree of threat.

Tertiary Blast Injuries

Tertiary injuries are the result of individuals being thrown by the blast wave and associated wind. The victim became a projectile. Injuries in this category vary depending on what the victim hits in the environment.

This category also includes "miscellaneous effects": burns from fire or radiation, crush injury associated with structural collapse, as well as smoke and carbon monoxide inhalation (which has particular importance if an explosion occurred in a closed space).

ASSESSMENT

The approach to the casualty with explosion-induced injury is the same as for any trauma victim, i.e., initiation of life support measures. Attention should be directed to the common life-threatening manifestations of thoracic and abdominal injuries. Pulmonary

manifestations include hemorrhage, barotrauma, and arterial air embolism; abdominal manifestations include hemorrhage and hollow organ rupture. Therapy is directed at the specific manifestations as well as avoiding iatrogenic injury.[3]

Signs and Symptoms

The initial assessment begins with the early recognition of potential injuries. Affected people may appear disoriented and confused, and they may have difficulty hearing because of eardrum rupture. The organ most sensitive to pressure change is the ear. The ear is designed with the specific purpose of collecting and amplifying pressure signals. Acoustic energy is converted to mechanical energy by displacement of the tympanic membrane (eardrum) into the middle ear. If the rise of energy is too rapid, the eardrum cannot accommodate the rapid pressure change and therefore ruptures. The threshold of tympanic rupture is approximately 5 pounds per square inch (PSI).

Fifty percent of people exposed to pressures above 15 PSI over atmospheric pressure will have eardrum rupture (Table 1). Therefore, not everyone exposed to a blast will present with ruptured eardrums, but those who do require special attention because further underlying injury may exist. Isolated eardrum perforation in survivors of explosions does not appear to be a marker of concealed pulmonary blast injury or of poor prognosis.[4] Thus, if an individual presents with isolated eardrum rupture, a chest film should be obtained and the patient admitted for 24 hours to rule out pulmonary injury. In a mass casualty event, persons who have sustained isolated eardrum perforation from explosions may be discharged from the emergency department after chest radiography and a brief observation period.

Table 1. Selected Pressure Effects of Explosions*

Pressure (pounds per square inch)	Effect
5	Possible tympanic membrane rupture
15	50% incidence of tympanic membrane rupture
30	Possible lung injury
40	Concrete shatters
75	50% incidence of lung injury
100	Possible fatal injuries
200	Death more likely than not

*Adapted from Kizer KW. Dysbarism. In Tintinalli JE, Kelen GD, Stapyczynski JS (eds). *Emergency Medicine: A Comprehensive Study Guide*, 5th edition. New York, McGraw-Hill, 2000, p 1276.

A careful examination may reveal ruptured tympanic membranes (eardrums) or hypopharyngeal petechial hemorrhages. These early findings should alert the rescuer to the fact that the victim sustained a significant exposure to a blast wave. Hence, underlying injuries to the pulmonary and gastrointestinal tract should be suspected and a through clinical examination should be performed.

Pulmonary

Disorientation and confusion may be the result of head injury, but if these symptoms coincide with tympanic membrane rupture, air embolism may be present. In addition, medical personnel should observe victims for shortness of breath, chest tightness, and hemoptysis (bloody cough). Each of these complaints is related to blunt trauma of the chest caused by the blast wave. Pulmonary contusions are delayed in their development and may not be evident for several hours. “Blast lung” may not present for 48 hours. Hence, it is important to obtain a chest film on all persons suspected of blast wave exposure, along with observation for at least 24 hours. There are no laboratory studies that offer any diagnostic help. An arterial blood gas measurement may be helpful in the diagnosis if hypoxia is present.

Gastrointestinal

Gastrointestinal injuries are much more difficult to identify, so clinical suspicion must be entertained. Early signs of gastrointestinal injury include decreased bowel sounds, abdominal tenderness, and rectal bleeding. Early radiographs of the abdomen may reveal free air under the diaphragm or air in the lumen of the intestine. These findings indicate significant abdominal injury. Their emergence may be delayed for several days.

TREATMENT

Regardless of the mechanism of explosion-related injury, the basic principles of trauma care still apply. As with any trauma patient, cervical immobilization and attention to life support measures should be implemented. A thorough history and examination can yield diagnostic clues of underlying injuries. Tympanic membrane rupture and hypopharyngeal hemorrhages require only conservative management. Neither of these carries any increase in morbidity. However, because they can be indicators of exposure to a significant pressure wave, further evaluation is required.

The most important aspect of care is airway management. Respiratory distress requires the use of supplemental oxygen. Progressive deterioration of a patient’s respiratory status may be an indicator of pulmonary barotrauma, pneumothorax, or air emboli. The caregiver should also consider whether there has been exposure to a toxic gas (carbon monoxide). Pneumothorax and air emboli require prompt diagnosis, as they can be lethal in minutes if untreated. Treatment for pneumothorax consists of supplemental oxygen and needle decompression of the chest if tension occurs. If air embolism is suspected, the patient should be placed in a prone position with the left side

down, the back at a 45-degree angle to the ground, and the head slightly lower than the feet. This allows the emboli to stay in the arms and legs, avoiding the vessels to the head. Air embolism is treated with a hyperbaric chamber, which compresses the air bubbles, making them smaller and more easily absorbed by the body. Positive pressure ventilation must be avoided because it worsens each of these conditions.

CONCLUSION

An accurate history and clinical examination can be in valuable in identifying subtle clues to the ominous pathology of blast injury.

References:

1. Domestic Preparedness
2. Virtual Navy Hospital Emergency War Surgery NATO Handbook: Part I: Types of Wounds and Injuries: Chapter V: Blast Injuries: http://www.vnh.org/EWSurg/ch05/05TreatmentofBl.html.
3. Argyros GJ. Management of primary blast injury. *Toxicology* 1997;121(1):105-115.
4. Leibovici D, Gofrit ON, Shapira SC. Eardrum perforation in explosion survivors: is it a marker of pulmonary blast injury? *Ann Emerg Med* 1999;34(2):168-172.
5. Kizer KW. Dysbarism. In Tintinalli JE, Kelen GD, Stapyczynski JS (eds). *Emergency Medicine: A Comprehensive Study Guide*, 5th edition. New York, McGraw-Hill, 2000, p 1276.