

The Role of Radiology in Terror Injuries

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Key words: blast injury, stab wounds, postmortem, identification, computerized tomography

IMAJ 2002;4:564-567

Terrorist activity brought the horror of the battlefield into the city, inflicting war injury on children, women and old people. Until recently it seemed that terrorist attacks were confined to certain regions and were only rarely encountered in what was considered the more peaceful regions of the world. However, following the events of 11 September 2001, it has become evident that terrorist attacks could occur in the most unexpected places.

The Middle East has been an area of dispute for many decades. The conflict between Arabs and Jews in the Middle East has frequently resulted in trauma following terrorist acts. Despite the media coverage of our region as being subjected to war and terrorist attacks, they are by no means common. During the years 1992-93, blast injuries and stab wounds constituted about 3% each of hospitalized trauma patients in a large tertiary trauma center in Jerusalem. The majority of trauma patients in those years comprised victims of motor vehicle accidents and patients who sustained falls (35-38% each) (Hadassah Trauma Registry).

In recent years, radiology has played an important role in the workup of trauma patients in general, and of victims of terrorist attacks in particular. Radiologic examinations, including plain radiographs, computerized tomography, ultrasound and angiography, are used to assess the sites and extent of injuries. These examinations determine which patients will be triaged to immediate surgery and which will be followed conservatively, often using repeated radiologic examinations.

In this article, we explain the principles of blast injury and its radiologic appearances, describe the special characteristics of stab wounds as part of a terrorist attack, discuss methods of identification of disaster victims, and present our experience with postmortem CT scanning of trauma victims.

Blast injury

Mechanism of explosion

Detonation involves transformation of the explosive substance from the solid state to the gaseous state. This process creates a sphere of high pressure and high temperature - the blast wave - which expands rapidly. The pressure of the blast wave increases over a few microseconds to its maximum [Figure 1]. The rate of rise of pressure and the duration of overpressure determine the

severity of damage caused by the explosion. The size of the explosive charge determines the velocity of the blast wave and the duration of overpressure. A bigger explosion, caused by a bigger charge, will produce blast waves of greater velocity and longer duration. For example, detonation of a 50 pound charge of trinitrotoluene (TNT) creates an overpressure of 100 psi (pounds per square inch) above atmospheric pressure, lasting for 2 msec. A 4,000 lb charge would cause the same overpressure to last for about 10 msec [1,2].

The blast wave front, which initially travels at a speed of 8,000 m/sec, decreases in pressure and velocity exponentially as it advances away from the center of the explosion, until it reaches the velocity of sound. At this point, the explosion is heard. At the end of the decay of the pressure front, an underpressure is created. In an underwater explosion, the rate of decay is reduced, and therefore the lethal zone is greater, as compared with air explosion, for a given quantity of explosive [1]. Blast damage is amplified when the explosion occurs in a closed space, due to reflection of the blast wave [3].

The pressure variations produced by the blast wave are accompanied by transient winds (the "displacement wave"). High velocity winds can be produced even by small changes in pressure, due to the low density of air. An overpressure of 0.25 psi (much lower than the overpressure in a typical explosion) corresponds to a wind velocity of 125 mph, which is the velocity of a hurricane wind [2].

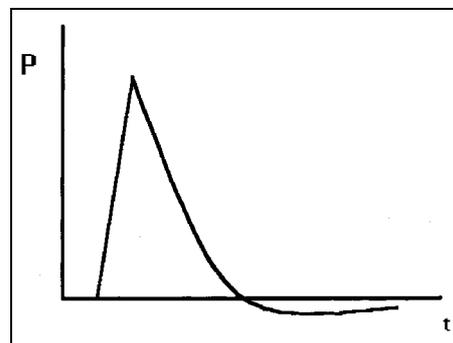


Figure 1. Pressure-time curve of the blast wave. The rate of rise of pressure and the duration of overpressure determine the severity of the explosion (P = pressure in psi, t = time in msec).

Patterns of injury caused by explosion

Explosion causes four patterns of injury [1,2]:

- *Primary injury* – caused by the blast wave itself.
- *Secondary injury* – caused by fragments propelled by the explosion. Not uncommonly in a terrorist attack, the explosive is combined with sharp objects such as nails and screws to enhance its damaging capability.
- *Tertiary injury* – caused by the blast wind from the explosion. The blast wind may cause falls or impaction against stationary objects.
- *Burns* – resulting from the intense heat caused by the explosion.

Mechanisms of blast injury

The blast wave damages living tissue by three mechanisms [1,2]:

- *Spalling* – which occurs at the interface between media of different densities when the shock wave passes from a high density to a lower density substance. This phenomenon is responsible for the throwing of droplets of fluid from the water surface to the air at air-water interfaces.
- *Implosion* – which occurs as the shock wave travels through an organ containing pockets of gas. At first, each pocket is compressed by the pressure of the surrounding fluid, but as the shock wave passes it expands very rapidly. The effect of this process is that of a miniature internal explosion, which can be extremely damaging if it occurs in a confined space.
- *Acceleration-deceleration* – The victim may be accelerated away from an explosion or impacted against a stationary object. When acceleration occurs, organs of different densities accelerate at a different rate relative to one another and may collide. The result may be a tear, for example when a mesentery is stretched beyond its elastic limits. Additional damage that may be lethal is caused by the sudden impact against a hard surface. This mechanism is significant in causing tertiary blast injuries, which are described below.
- Organs containing gas, such as the lung, the ear and the bowel, may be severely damaged by blast, while those containing fluid (urinary bladder, gallbladder) are essentially resistant to these mechanisms.

Blast injury to the lungs: mechanism and radiologic appearances

The susceptibility of the lungs to blast injury depends on the peak of overpressure and its duration. The lungs may be severely damaged with an overpressure of 50 psi lasting for more than 4 msec [1].

Spalling and implosion cause severe damage at the alveolar membranes, tearing them and joining alveolar spaces together. The alveolar spaces as well as the interstitium fill up with blood and edema fluid, due to pressure differentials between the blood vessels and the air-filled alveoli, as the shock wave passes. Acceleration causing the lung parenchyma to be sheared away from the vascular tree may result in alveolar-venous fistulas. Air is then forced into the pulmonary veins and may reach cerebral and coronary arteries. Mechanical ventilation and positive end-pressure ventilation should be avoided as long as possible in order to lower the risk of air embolism [1].

Chest radiographs are used to determine the severity of primary blast injury to the lung and to monitor its progression. The typical finding is bilateral patchy infiltrates in a "butterfly" distribution

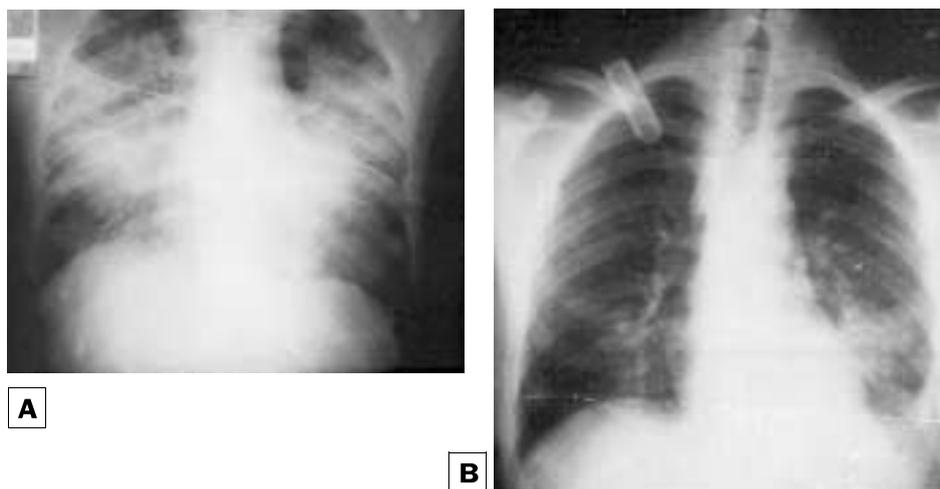


Figure 2. [A] Chest radiograph several hours following blast injury, showing typical bilateral patchy infiltrates in a "butterfly" distribution and widening of the mediastinum. [B] Four days later, most of the pulmonary findings have cleared up. The patient has also undergone a vascular bypass surgery due to a tear in the right subclavian artery.

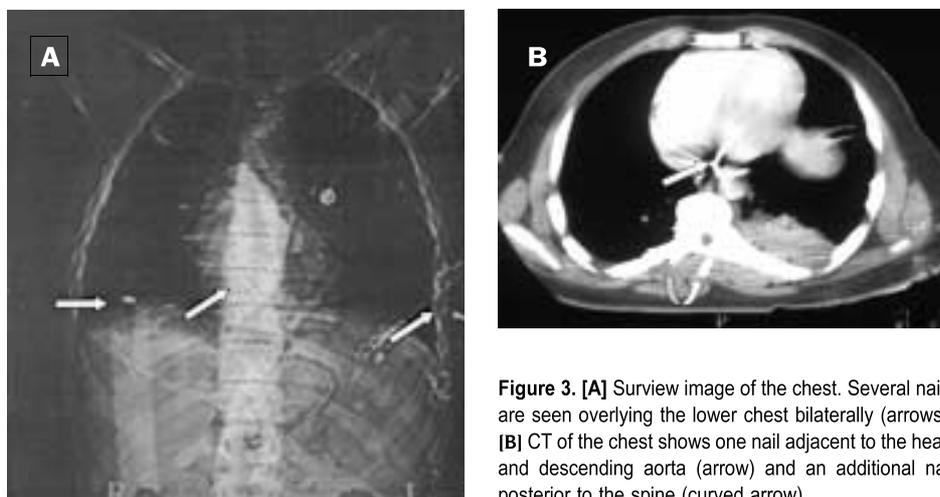


Figure 3. [A] Surview image of the chest. Several nails are seen overlying the lower chest bilaterally (arrows). [B] CT of the chest shows one nail adjacent to the heart and descending aorta (arrow) and an additional nail posterior to the spine (curved arrow).

[Figure 2]. The chest X-ray usually clears within 5–7 days. Chest X-rays are also helpful to determine the presence of impacted foreign bodies, which constitute the secondary blast injury. CT scans may be helpful in determining the exact location of a mediastinal foreign body [Figure 3].

Stab wounds

The year 1987 was the beginning of the uprising of the Palestinians living in the territories occupied by Israel and is known as the First Intifada. Knife stabbing was a frequently used lethal weapon during that period.

In 1996, Hanoch et al. [4] described a series of 154 people who were victims of knife stabbing during the Intifada years. This study showed that knife stabbing used in terrorist attacks against civilians has different characteristics to stabbing that occurs under criminal circumstances. The typical stabber was a young fanatic in a state of high tension. The victims were mostly Jews, aged 12–92 years. Because knife stabbing was intended to kill and not merely injure or frighten, the knives used were long kitchen or butcher knives, in contrast to the short-bladed spring knives typically used in criminal settings [4].

In these terrorist attacks the chest was the most common site of stabbing. In 46% of the victims the right posterior chest was the site of knife entry. This was explained by the assumption that the right-handed stabber usually approached the victim from behind. Internal organ injuries occurred in 56% of the victims, leading to a 25% mortality rate. This percentage far exceeds the published mortality data for stab wounds, which ranges between 0 and 4% [4].

Sometimes the knife was left embedded in the wound. Since the terrorists tend to use long knives, their blades may act as a tamponade and thus control hemorrhage. Therefore, it is recommended that the knife be removed cautiously, only under direct visual control, in the operating room. Chest radiographs have a role in determining the location of the blade of an embedded knife prior to its extraction [4] [Figure 4].



Figure 4. Chest radiograph showing a large butcher knife embedded in the right chest. The lateral radiograph (not shown) confirmed that the tip of the blade of the knife was adjacent to the spine.

Disaster victim identification

In terrorist attacks with a large number of victims, identification of individual victims may be necessary and can be accomplished using several methods.

Visual recognition

Visual recognition of the victim is not always possible as bodies may be severely mutilated. Additionally, visual recognition may be inaccurate and lead to mis-identification. Therefore, a combination of methods is necessary to achieve accurate and reliable identification [6,7].

Personal effects

Description of personal effects such as clothing, jewelry and pocket contents can be used as circumstantial evidence, provided a detailed and reliable antemortem description of the same objects can be obtained for comparison. It should be borne in mind that loose objects may be mistakenly attributed to the wrong body [6].

Physical evidence

Physical evidence can be obtained from external or internal examination. Description of the physical features of a body should be undertaken by a police officer familiar with obtaining descriptions, together with a medical expert such as a forensic pathologist or medical examiner. The identification process will also normally determine the cause of death. Following removal of clothing, general features of the naked body should be described, including gender, color of the skin, and estimated age, height and build. Specific features, such as scars, moles, tattoos and abnormalities, are often unique and may be extremely important. If antemortem fingerprints are available and if postmortem fingerprints can be obtained, it is possible to make an accurate identification [6,7].

Internal examination, i.e., an autopsy, may be necessary if the victim's identity or the cause of death cannot be determined by the external examination. Specimen and tissue samples may be obtained during the course of the autopsy. Blood or body fluids may be examined for traces of alcohol, drugs or carbon monoxide, and tissue samples may be examined in specialized (toxicology, pathology and serology) laboratories. Medical findings that may assist with identification include signs of previous fractures or surgery, missing organs (e.g., kidney or uterus), or implants [6].

The teeth and jaws are examined by a forensic dental expert as part of the general autopsy. Dental evidence is often so accurate that it may be the sole method used to identify an individual [6,7].

Genetic identification techniques complement other methods for identification of disaster victims and are particularly useful when a body has been severely mutilated. An individual's genetic data are identical in all of his or her cells and remain constant also after death. Genetic analysis can link the victims to members of their family and can aid in the matching of body parts [6,7].

X-rays are an important adjunct for both dental and internal examinations. X-rays can be used to estimate the victims' age, since changes in the skeleton occur with increasing age. They can also aid in determining the gender of the victim (for example, the shape of

the pelvic bones is different in men and women). X-rays may demonstrate that prior surgery has taken place, for example coronary artery bypass or valve replacement in the chest, laminectomy in the spine, or hip replacement surgery. Furthermore, X-rays can reveal unique identification information, such as old fractures and congenital dislocation of the hip. When prior X-rays are available, unique antemortem features such as the shape and size of the facial sinuses, the curvatures of scoliosis, the sutures and vascular grooves of the skull, and arthrotic changes can be matched with postmortem X-rays.

Postmortem CT

Postmortem CT, which has been in use for the past decade to determine the cause of death, can also be used for disaster victim identification. X-rays (as well as postmortem CT) are extremely effective for identifying and locating evidential material, such as bullets and bomb fragments [6,7].

Autopsy rates have declined worldwide but have become particularly rare in Israel. This is because the Jewish religion prohibits interference with the corpse and delaying burial of the deceased. Most Jewish families, therefore, withhold their permission for autopsy of their next of kin. Moslem and Christian families in Israel are also reluctant to agree to this examination. An alternative postmortem examination was therefore sought. In many cases, postmortem CT may help define the cause of death [Figure 5].

The role of postmortem CT as an alternative to autopsy was examined in a study carried out at the Hadassah University Hospital in Jerusalem during 1992 [8]. Thirteen trauma victims underwent total body CT scanning within 6 hours of death, followed by conventional autopsy under court order. In 12 additional cases, only postmortem CT was performed. Of the 127 pathologic findings in the bodies subjected to the two procedures, 44.9% were diagnosed by both conventional autopsy and postmortem CT, 29.9% were revealed by autopsy alone, and 25.2% were found only by postmortem CT. Postmortem CT was superior to autopsy in revealing bone injuries and air in body cavities, while at autopsy more soft tissue pathologies were found. In total, postmortem CT demonstrated 70.5% of all pathologic findings and autopsy revealed 74.8% [8].

Postmortem CT has several advantages over autopsy. It is a rapid test, lasting about 20 minutes, and uses conventional CT scanners that were state of the art at the time the study took place. The use of spiral and multislice CT scanners, which are the current state-of-the-art scanners, has shortened the duration of postmortem CT even further. In postmortem CT there is no direct contact with the remains of the deceased, and thus the possible risk of contracting a contagious disease is avoided. In the above-mentioned study, some of the scans were performed while the corpse was still in the body bag [8]. The printed hard copies of the CT examination could serve as indisputable evidence if the case comes to court. But most importantly, from the religious point of view, postmortem CT does not disrupt the body and is readily accepted by the families of the deceased.

Although postmortem CT probably cannot replace conventional autopsy, it may be used when a postmortem examination is necessary but permission for autopsy is refused. It may shed light

on the cause of death in trauma patients. It could also aid in determining whether death was preventable, and thus helps to improve the care of similar cases that may be encountered in the future.

Summary

Although one might think that nothing could be further apart than "terror" and "medicine," in reality, medicine is intimately involved in the rescuing of those who are injured in terrorist attacks and in identifying and determining the cause of death in those who do not survive.

Radiology has an important role in the workup of trauma patients in general, and in patients injured during the course of a terrorist attack in particular. Radiologic examinations determine the location and severity of injuries and are used to follow injured patients, particularly when complications occur. Conventional X-rays and CT scans are useful to detect the presence of foreign bodies, such as bullets, shrapnel and nails, which are often combined with the explosive charge in suicide bombings. Both can also be used for postmortem examinations.

Although biologic, chemical and radiologic warfare constitute a real threat for the future, it is essential that we be familiar with the more "conventional" forms of terror that we face today.

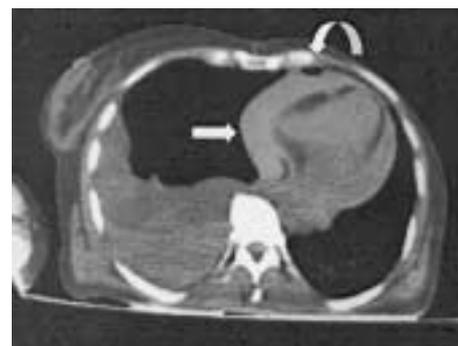


Figure 5. Postmortem CT of a 53 year old woman with a stab wound in the chest. The knife was extracted at the site of the attack. The mediastinal window shows a large hemothorax (straight arrow). Note the air bubble where the knife had entered the pericardium (curved arrow). There is also a large right hemothorax displacing the mediastinum to the left.

References

1. Mellor SG. The pathogenesis of blast injury and its management. *Br J Hosp Med* 1988;39(6):536-9.
2. Stapczynski JS. Blast injuries. *Ann Emerg Med* 1982;11:687-94.
3. Kluger Y, Soffer D, Sorkine P, Aladgem D. Blast injury: detonation and injury pattern. *Harefuah* 1997;132(8):591-3 (Hebrew).
4. Hanoch J, Feigin E, Pikarsky A, Kugel C, Rivkind A. Stab wounds associated with terrorist activities in Israel. *JAMA* 1996;276(5):388-90.
5. Yellin A, Golan M, Klein E, Avigad I, Rosenman J, Lieberman Y. Penetrating thoracic wounds caused by plastic bullets. *J Thorac Cardiovasc Surg* 1992;103:381-5.
6. Disaster victim identification. <http://www.interpol.int/Public/DisasterVictim/Guide/chapitre3.asp>
7. Robb N. 229 people, 15 000 body parts: pathologists help solve Swissair 111's grisly puzzles. *Can Med Assoc J* 1999;160(2):241-3.
8. Donchin Y, Rivkind AI, Bar-Ziv J, Hiss J, Almog J, Drescher M. Utility of postmortem computed tomography in trauma victims. *J Trauma* 1994;37(4):552-6.

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