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the theoretical issues behind them and the practical implication of such modes of attack has never been higher.

See Also

Terrorism: Medico-legal Aspects; Suicide Bombing, Investigation

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Suicide Bombing, Investigation

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Introduction

Injuries or deaths from explosions due to bombing have generally only been occasionally encountered in clinical and forensic pathological practice. However, with the recent rise in militant terrorism, there has been an increase in the incidence of terrorist bombings, and the forensic pathologist or medical examiner is likely to be confronted with such cases.

Suicidal terrorism in one form or other has existed for years. It has been used by the Jewish sect of Zealots in Roman-occupied Judaea and by the Islamic Order of Assassins (hashashin) during the early Christian crusades. During World War II, the Japanese crashed explosive-laden warplanes on American ships, popularly known as "kamikaze" (divine wind). About 2000 of these suicide bombers rammed fully fueled fighter planes into more than 300 American ships in April 1945, in the Battle of Okinawa. About 5000 Americans were killed in those suicidal attacks. This has been the most costly naval battle in US history. More recently, suicidal bombing has been used increasingly to make a political statement e.g., on 21 May 1991, Rajiv Gandhi, former Prime Minister of India, and 16 others were killed by a female suicide bomber at Sriperumbudur, near Chennai.

In general, deaths by bombings can be classified as (1) suicidal, (2) homicidal, (3) accidental, and (4) suicidal-homicidal (terrorist).

In suicidal bombings, the main intention of the bomber is to kill himself or herself. The bomber takes care to choose an isolated spot, such as the interior of his/her own house, as he/she is not interested in injuring anyone else. Homicidal bombing is represented by cases where vehicles loaded with explosives are left at crowded places. Accidental explosions can occur in several situations such as bursting of gas tanks or when fire is kindled in areas where explosives are stored. Finally, suicidal-homicidal (terrorist) bombings are those where an individual either straps explosives on his/her body and detonates it in crowded places, or rams an explosive-laden vehicle into a crowd of people or into a building. An individual who straps explosives on his/her body may be referred to as a "strapped human bomb" (SHB). When he/she drives an explosive-laden vehicle into crowds, it is termed a "vehicular human bomb" (VHB).

This article focuses on suicidal and suicidal-homicidal (terrorist) bombings. Among these, it is usually the latter situation, which merits more public attention. However, investigative procedures at the scene of explosion as well as autopsy findings are comparable. While in suicidal bombings, circumstantial findings reveal much information (e.g., death of a single person, isolated spot chosen, previous history of suicidal intention, or earlier suicide attempts), it is the suicidal-homicidal bombing that stretches the forensic pathologist's and crime investigator's skills to its maximum. In such cases, the forensic pathologist or medical examiner, as well as other investigative authorities involved must identify: the actual suicidal bomber among the casualties, the type and source of explosive devices and ignition systems used, the affiliation of the suicidal bomber to a particular terrorist group, and several other similar questions. Above all, the forensic pathologist and investigator teams may be required to reconstruct the sequence of events.

Principles of the Design of Explosive Devices Used by Suicide-Homicide (Terrorist) Bombers

Explosives used by suicidal as well as suicidal-homicidal (terrorist) bombers are substances or devices capable of a sudden expansion of gas, which upon release of its potential energy creates a pressure wave. Based on the mechanism of energy release, explosives can be classified as chemical, mechanical, or nuclear. Chemical explosives, volatile or nonvolatile, decompose into gases upon detonation.

In order to conduct a more effective investigation of a bombing incident, the forensic pathologist should at least be familiar with the basic design of bombs used by terrorists. Devices are generally concealed within an article of clothing worn close to the body such as a vest, belt, or jacket. Most bombing devices used by different terrorist organizations worldwide are mainly constructed based on similar principles, although there may be subtle differences. In general, such bombing devices consist of a simple push-button toggle switch for the ignition of the charge and the electric circuit is completed by using a simple battery. These ignition devices are relatively small in order to reduce the chances of discovery. The main explosive charge may consist of a military-grade plasticized explosive or homemade explosive mixtures. Most often used as the latter are chemical explosives such as 2,4,6-trinitrotoluene (TNT), black powder (potassium nitrate, sulfur, charcoal), liquid gasoline, or natural gas. The potential energy release of chemical explosives depends on the rate of decomposition, which in turn is determined by the chemical compounds used for the explosive; for example black powder has a lower rate of decomposition than TNT, which detonates at much higher speeds. Dispersed fragmentation is the mechanism primarily intended to kill persons in the vicinity of the explosion epicenter. Small metal objects, such as nails, screws, balls, or bearings, also form an integral part of the explosive device. With the blast wave (a radially propagating shock wave resulting from the explosion), these "missiles" scatter all over the surrounding environment and act like a spray of bullets. Many devices have a backup trigger system, such as an electronic timer, pager, or booby-trap type switch. If the attacker is killed, apprehended, or has to abort the attack by any other reason, a secondary trigger system then provides an alternative ignition.

Scene Investigation

In explosion-related fatalities, it is important to conduct inquiry by a team consisting of police investigators, bomb experts, and forensic pathologists. A terrorist attack should be initially suspected in each case of suicide involving explosives.

Apart from death scene investigation, autopsy findings, and technical reconstruction of the explosive device, and the analysis of explosive residues using gas chromatography–mass spectrometry, scanning electron microscopy, and stereomicroscopy, the history of the victim may give additional hints about the the mode of death – suicide or homicide without a terrorist background. The determination whether the manner of death is suicide, homicide, or accident in such cases can present a difficult task to the investigative authorities, especially within the first ten hours following the incident.

It is usually the intention of a terrorist bomber to cause as many casualties as possible, so a crowded place – confined or open space – is normally chosen for detonation of the explosive. Thus, the scene of suicide-homicide bombing is usually characterized by massive destruction (Figure 1). It must be kept in mind that when an initial attack has occurred, it may be followed by a (sometimes even more) powerful follow-on attack shortly thereafter, a tactic utilized in the terrorist bombing which killed over 200 in Bali, Indonesia in 2002. This second attack is timed to inflict the maximum number of casualties against the responding police, fire and emergency medical

Figure 1 Scene of suicidal-homicidal bombing with three victims lying on the floor in a totally destroyed courtroom. Massive destruction of walls, ceiling, and windows as well as debris scattered all over the floor. Bloodstains can be seen on the walls in the lower parts. Courtesy of Professor B. Madea, Institute of Legal Medicine, University of Bonn, Germany.

Figure 2 Posterior view of a bombing victim with deep lacerations and interspersed foreign body fragments on neck (A) and occiput (B). Courtesy of Professor F. Longauer, Institute of Legal Medicine, Pavol-Jozef-Šafárik-University, Košice, Slovak Republic.

service (EMS) responders, and gathering crowds. Thus, while EMS responders may arrive at the scene immediately to rescue the surviving injured persons, all other responding personnel and vehicles should stay clear of the immediate attack site. Gathering crowds and media personnel should be kept clear of the site. The crime scene investigators must try to locate the debris furthest from the object bombed. An inner cordon should then be placed at one-and-a-half times this distance, and an outer cordon at some convenient distance outside of that. The area between the inner and outer cordon is used by police teams, members of emergency services, press, etc., while the area inside the inner cordon can only be visited by the bomb scene manager, exhibits officers, and the members of the forensic pathologist's team.

As mentioned above, dispersed fragmentation is the primary killing mechanism in individual suicide bombing attacks. Fragmented components of the explosive device such as nails, or other smaller metal pieces, must therefore be looked for at the scene and on the outside as well as inside the bombing victims' bodies. This will be occasionally helpful in identifying a particular terrorist group, or a particular explosives manufacturer or dealer.

As with the location of burn injuries and splinter penetration (Figure 2), the location of damage to clothing is helpful in establishing the body posture of a victim (or the attacker) at the time of the explosion. In addition, in suicidal bombings involving just one person (the suicidal), the pattern of bloodstains at the scene of explosion gives additional hints towards the reconstruction of events.

It must be remembered that the scene of bombing may still contain undetonated explosives. Until the arrival of the bomb squad, no object should be touched as it may contain unexploded devices. Potential concealment areas for bombs include parked vehicles at the scene of bombing.

Autopsy Findings

Explosions in confined spaces are associated with more and a higher extent of severe injuries and a higher mortality rate compared with explosions that occur in open spaces, because the blast wave reflects back from the walls and the ceilings of buildings. It is usually impossible to draw any realistic conclusions from injuries sustained by the victims concerning the size of the explosive charge. Proof of air embolism is essential when the body surface is intact since air embolism is a major cause of death in blast victims. If the autopsy is not performed within a few hours after death, the differentiation between air and decomposition gases should be made with the pyrogallol test.

Gross Pathology

Appearance of external injuries based on the definition of blast injuries Instantly with the explosion, compression of air in front of the pressure wave that heats and accelerates air leads to a sudden increase in atmospheric pressue (overpressure) and temperature transmitted into the surrounding environment creating the blast wave.

According to their etiology, injuries caused by explosions are traditionally classified into four categories: primary, secondary, tertiary, and quaternary blast injuries (Table 1).

Primary blast injuries Injuries directly inflicted on the human body by the sudden increase in air pressure after an explosion are referred to as primary blast injuries and involve almost exclusively gas-containing internal organs such as the lungs, middle ear, and gastrointestinal tract, the organs most vulnerable to overpressure. Primary blast injuries on the external surface of the body are: scattered dermal abrasions and contusions, gross lacerations of the skin (Figure 3) that may be interspersed with foreign body material, mutilations or amputations of limbs, opening of body cavities (Figure 4), decapitation, near-total disruption of the body (Figure 5), or even complete body destruction. Primary blast injuries are estimated to contribute to 86% of fatal injuries in explosion victims.

Secondary blast injuries Secondary blast injuries result from blast-energized bomb fragments and other displaced objects at the site of explosion such as glass, casing, and masonry causing splinter-induced penetrating trauma.

Tertiary blast injuries Tertiary blast injuries occur when the body is accelerated from the blast wave initially and is then abruptly decelerated on rigid objects, thus resulting in a combination of blunt force and penetrating trauma.

Quaternary blast injuries Quaternary blast injuries are defined as those derived due to the collapse of a

Table 1 Classification of blast injuries caused by explosions according to etiology and types of injury

Category	*Etiology*	*Type of injury*
Primary blast injuries	(Direct) blast wave exposure	Disruption of the body, traumatic amputation, gaping lacerations of the skin, rupture of gas-containing organs (e.g., ear, lungs, gastrointestinal tract), perforation of hollow organs
Secondary blast injuries	Blast-energized bomb fragments and other debris (shrapnel)	Penetrating trauma
Tertiary blast injuries	Abrupt deceleration of the body on rigid objects following acceleration due to (indirect) blast wave effect	Blunt force trauma, penetrating trauma
Quaternary blast injuries	Collapse of a building or falling down of parts of a building where the explosion took place	Miscellaneous; for the most part blunt force trauma

Figure 3 Gross laceration of the skin due to the suicidal explosion of an industrial explosive (Gelamindonarit) with superficial abrasions and bruising seen adjacent to the wound's margin.

Figure 4 Opening of the abdominal body cavity following the (probably accidental) explosion of a homemade pipe bomb containing black powder. Note peppering, bruising, and abrasions seen on and adjacent to the wound's margin.

Figure 5 Explosive-induced trauma of the upper posterior part of the trunk with decapitation and gaping lacerations of the superior parts of both thoracic cavities in a suicidal-homicidal bombing victim who was located in the immediate vicinity to the epicenter of the explosive device consisting of TNT.

Figure 6 Superficial flash burn injuries upon the skin of the anterior side of the lower parts of the trunk and more severe burns of the superior parts of the body deriving from local ignition of clothing following an accidental gas explosion.

building or parts of a building where the explosion took place.

Burns Superficial flash burn injuries, together with singeing of head hair and eyebrows, derive from the enormous heat generated by the explosion (direct burns). More severe burns usually represent indirect burns that derive from local ignition of clothing. They can be differentiated from burns that result from a secondary fire at the scene of explosion by their restriction to areas of clothing of the victim (Figure 6). The clothes of the victims are possibly torn for the most part (Figure 7), depending mainly on the vicinity of the victim to the epicenter of explosion (the loss of clothing may also take place simply due to ignition). The location of burn injuries and splinter penetration is helpful in determining the body posture of a victim (or the attacker) at the time of the explosion.

Internal injuries Since, as explained above, external injuries inflicted on the human body by explosions are mediated by miscellaneous underlying mechanisms, victims usually suffer from a combination of primary-blast effects to gas-containing organs, blunt-force injuries, penetrating trauma, and burns.

Internal injuries in explosion-related fatalities comprise perforation of hollow organs, such as the ear, gastrointestinal tract, and urinary bladder, in the absence of penetrating cranial or abdominal trauma. The gut may be torn off from the mesenterium.

Figure 7 Suicidal-homicidal bombing. The perpetrator is lying in a lateral position within glass, casing, and masonry displaced by the explosion. Clothing is torn off and lacerations and tissue loss of the limbs are seen. Courtesy of Professor B. Madea, Institute of Legal Medicine, University of Bonn, Germany.

Solid abdominal organs, such as the liver, kidneys, spleen, and pancreas, less frequently incur injury in the form of contusions or lacerations. In general, damage to the liver and spleen is only seen when the abdominal wall has been opened by the blast wave or secondary to penetrating trauma.

In the lungs, unilateral or bilateral pneumothorax may be seen. Usually, the lungs show severe overdistension. Grossly visible lesions of the lungs are circumscribed or more confluent petechiae as well as contusion zones seen under the pleural surfaces or within the parenchyma on cut sections through the organ. These contusions may be focal, multifocal, or diffuse and are most often seen shining through the pleural surfaces adjacent to the diaphragm, medially next to the heart, and especially corresponding to protruding parts of the rib cage. Where fire fumes were inhaled, deposits of soot particles will be seen in the trachea and bronchi. Edema, mucosal bleeding, and patchy or vesicular detachment of the mucosa in the nose, mouth, pharynx, larynx, trachea, and bronchi are often indicative of an inhalation of hot gases. The nasopharynx, larynx, and trachea, comprising the upper respiratory tract, are usually involved in blast injury. Emphysematous bullae under the mucosa of the upper respiratory tract are another frequent finding in blast victims (Figure 8).

Cardiac contusions, grossly manifesting as hemorrhages in the form of petechiae and hemorrhages are commonly located in the epicardium along the posterior surface of the heart next to the diaphragm and in the endocardium of the left ventricle. Myocardial ischemia may be caused by air emboli in survivors.

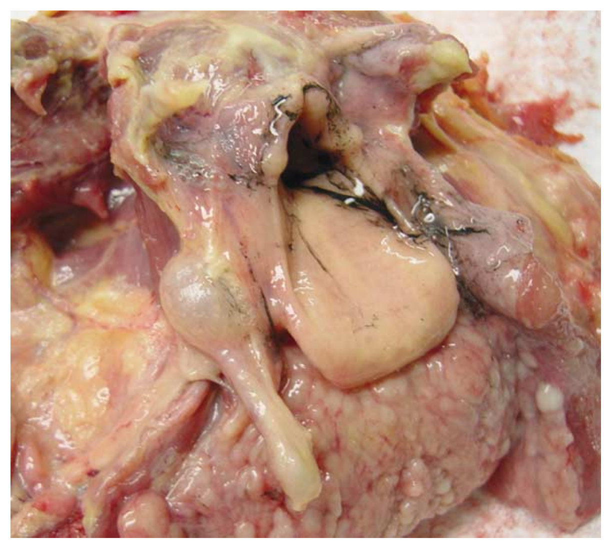

Figure 8 Emphysematous bullae under the mucosa of the pharynx and larynx and aspiration of soot upon the mucosa of the epiglottis and larynx in an explosion-related fatality.

The brain may undergo direct injury, such as cerebral contusion, or indirect injury such as cerebral infarction from air emboli in those victims who survive the incident.

Histopathology of Blast Lung Injury

Of the gas-containing organs, the lung is the most susceptible to primary blast effects and the extent

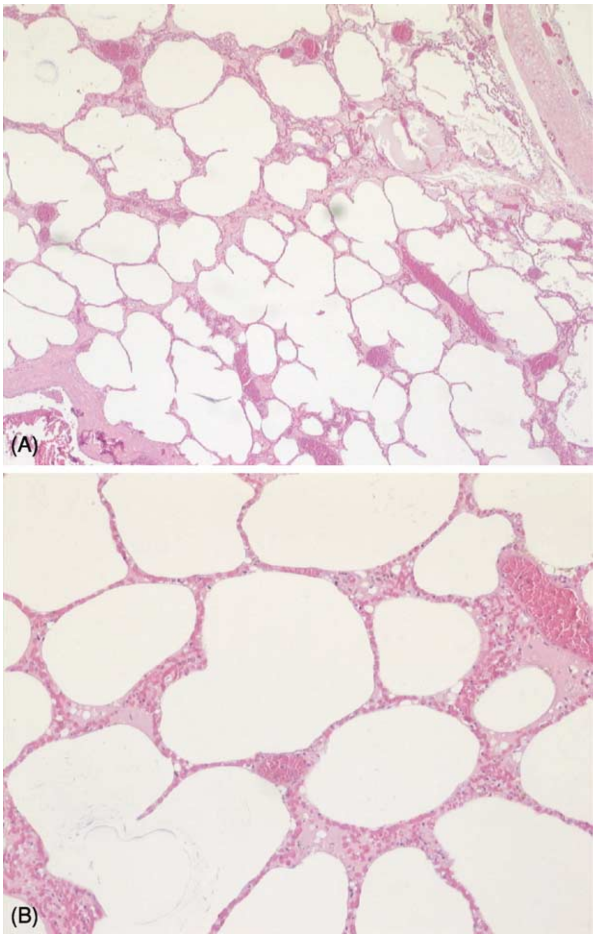

Figure 9 Blast lung injury. (A) Panoramic view of severe alveolar overdistension, enlargement of alveolar spaces, ruptures, and thinning of alveolar septae (×25). (B) Close-up view of ruptures and thinning of alveolar septae (×100).

of lung injury is the decisive parameter defining mortality in victims of explosions who survive in the first place. Alveolar ruptures, thinning of alveolar septae, and enlargement of alveolar spaces (Figure 9) as well as circumscribed subpleural, intraalveolar, and perivascular hemorrhages, the latter showing a cufflike pattern in the interstitial spaces around larger and smaller pulmonary vessels (Figure 10), are the main histopathologic findings in blast lung injury. Aspiration of soot is often seen in the bronchi. In addition, venous air embolism, bone marrow embolism, and pulmonary fat embolism are frequent findings. Leukostasis, an intense alveolar and interstitial edema, as well as interstitial inflammatory infiltrates can be observed in blast victims who survived the incident for a few hours.

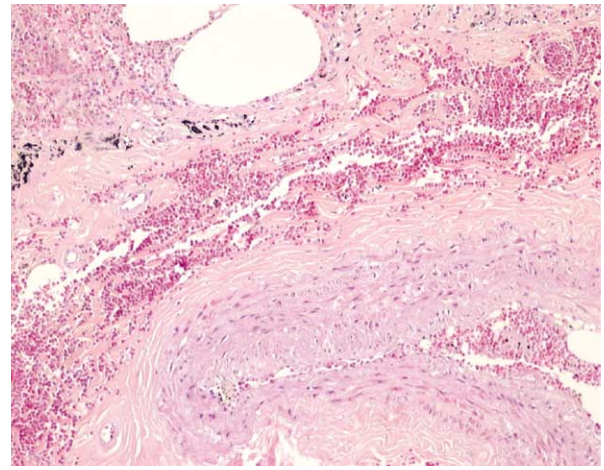

Figure 10 Interstitial perivascular hemorrhage showing a cufflike pattern around a larger pulmonary in human blast lung injury (×25).

Recovery of Evidence from the Body

Before undertaking the autopsy, it is essential to radiograph the whole body. This can reveal several radio-opaque and radiolucent bomb parts. Radio-opaque parts usually recovered from within the body include various metallic missiles, portions of trigger mechanisms, such as screws, wires, gears, springs, and batteries. Wires may be among the most important evidences to recover, because they can often indicate the specific manufacturer. Removal of this evidence is most essential; this can sometimes be so intricately lodged in the tissue that it may even require tissue maceration.

Radiolucent material may include fragments of the explosive wrapper, fragments of paraffin-coated paper (explosive cover), and other elements such as cloth, wood, cardboard, plastic, etc., used to conceal the bomb.

It is essential to radiograph the survivors also, since some explosive device fragments may be lodged in their bodies. If they are operated on surgically, and some surgical specimen such as a badly mutilated limb is removed, it should also be radiographed for similar reasons. The examination of survivors should be undertaken at the earliest stage possible by individuals with forensic medical training. Finally, after all fragments have been removed, it is recommended to carry out radiography again in order to ensure that the fragments have been completely removed.

Traces of explosives (burnt and unburnt) may be adhering to the body and should be recovered using a suitable solvent. Isopropranol is usually employed to recover explosive residues, but methanol and ethanol can also be used. In some countries, certain special substances known as “taggants” are required by law to be added to all explosives. These taggants are small magnetic or fluorescent chips, which contain color-coded information. These taggants do not burn with the explosive, but are scattered at the scene. These can be recovered by a magnet (if they are magnetic), or by fluorescence. They can provide information regarding the manufacturer of the explosive, the year, month, and day of the manufacture, and also the batch number of the explosive.

Identification

In multiple deaths, identification of the deceased is an important task and even more important is to identify the person responsible for the attack. Usually, the body of the suicide bomber will be the worst damaged or perhaps completely disrupted. If isolated limbs are recovered, an unusually high concentration of explosive residues on hands would indicate that the person handled explosives. DNA sticking to clothes, belts, etc., may help reveal the identity of the suicide bomber. Rajiv Gandhi was assassinated by an LTTE (Liberation Tigers of Tamil Eelam) female bomber called Dhanu. In this case, the Special Investigation Team visited the scene of crime where they found parts of Dhanu’s dress, strips of the vest, and the belt-bomb she wore with pieces of flesh attached, two toggle switches, wires used in the bomb, and a half-burnt 9-V battery. DNA profiling of the pieces of flesh found at the spot was done, as also that found sticking to the belt. The flesh piece attached to the belt matched with the portion of the woman’s body found. That established convincingly the theory of the assassin being a human bomb.

See Also

Crime-scene Investigation and Examination: Collection and Chain of Evidence; Recovery of Human Remains; **Mass Disasters:** Principles of Identification; **Terrorism:** Medico-legal Aspects; Nuclear and Biological; **War Crimes:** Pathological Investigation

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