

Explosions and Blast Injuries

The role of Forensic Medicine

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Why we need to know about types of Explosions and Blast injuries?

1. Terrorist activity in many parts of the world is associated with the use of a variety of explosive devices.
2. **Basic knowledge** for both Surgeons and pathologists.
3. **Surgeons and ER physicians:** triage and response is dependent on the nature of injuries.
4. **Pathologists:** in terrorist attacks with large numbers of victims **identification** is a priority in addition to **autopsies** to establish the cause of death.
5. **Reconstructing the circumstances:** Careful examination of the nature and distribution of injuries, and evidence collection help in reconstructing the circumstances. (both from the alive victims and deceased)

Types of Explosive Devices

- Terrorist bombs come in all shapes and sizes and with varying degrees of sophistication.
- Terrorists use bombs for different reasons against a variety of targets.
- Road Side, Rubbish, Broken down vehicles, Dead animals, Boxes, Unattended bags.
- Usually hidden and mistaken for a harmless object and some times accidentally activated by the victim (antihandling devices)

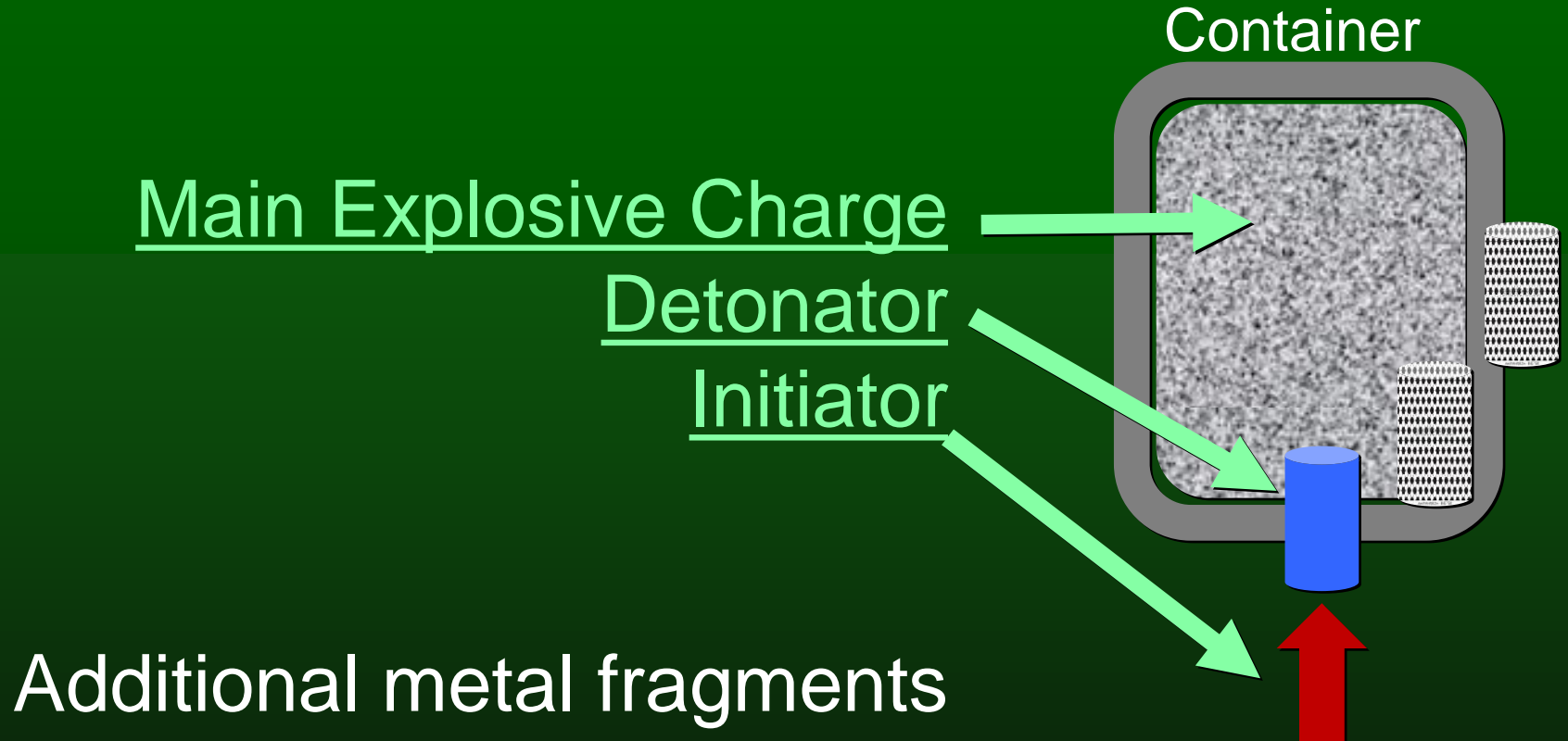
- 1) **Simple** unskillfully constructed homemade devices using “low-order” explosives . **Improvised Explosive Devices (IED)**
- 2) **Sophisticated** bombs using powerful military explosive materials “high-order” explosives. Remotely controlled detonators.

- Terminology:

- Under-car booby-trap devices
- Car bombs
- Culvert bombs
- Incendiary devices
- Firebombs
- Drogue bombs
- Letter-package devices
- Pipe bombs
- Nail bombs
- Mortar bombs.
- Suicide bombers

Improvised Explosive Devices (IED)

There are three main basic components



- العبوة التفجيرية الرئيسة
- الصاعق
- محفز التفجير

Key Components of an IED

Main Explosive Charge

- Is the main element of an explosive device.
- Can be from military or from commercial sources, or home made.
- Different forms such as a liquid, powder, gas or plastic.

High-Order

- TNT – trinitrotoluene
- Dynamite (nitroglycerin diatomaceous earth)
- ANFO ammonium nitrate and fuel oil).
- Semtex - a plastic, odorless, used in many terrorist bombings.
- Military explosives EDX C4 Plastic explosive

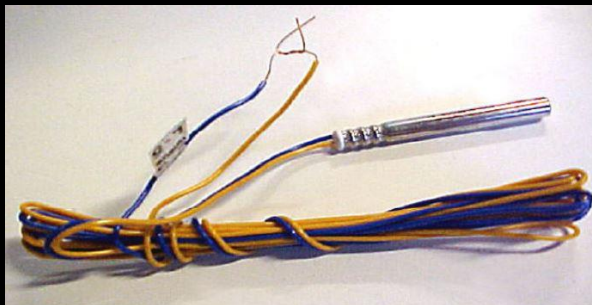
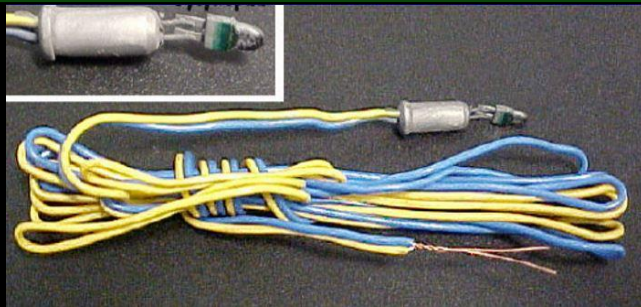
Low-Order

- Black and smokeless powders (It is a mixture of sulfur, charcoal, and potassium nitrate)
- Potassium chlorate and sugar

Key Components of an IED

Detonator

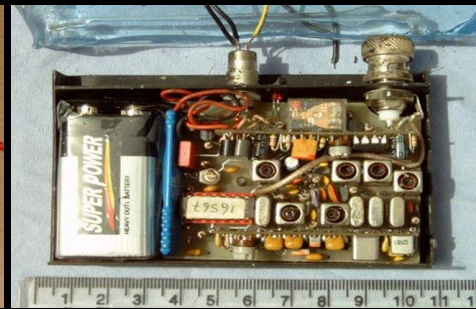
- Their purpose is to set off a small explosion which is strong enough to cause detonation of the main charge.
- Detonators can be in different sizes and shapes.
- The most common detonator is a cylindrical shape and may be with or without additional wires.
- Detonators are made from either aluminum or copper.
- Explosive: Lead Azide Lead Styphate Mercury Fulminate.
- Very sensitive to heat, friction, or shock



Key Components of an IED

Initiator

- It send an initial impulse to the detonators causing them to explode.
- Initiators can be any shape or size, including the original military factory made product, to an adapted toy or household electrical item.
- Initiators can be electronic, mechanical or chemical in construction, or a combination of all three.



**Slow burning fuse wire
cotton rope saturated
with potassium nitrate
or black powder**



**Detonating cord
Flexible cord filled with Explosive:
PETN (pentaerythritol tetranitrate)
Speed: 5 Kilometer per second**

Key Components of an IED

Container

- The explosive device container can be constructed to cause more damage to the target
- It can be made from different materials such as metal, plastic, wood, and others
- can be adapted to be able to hide the device.
- It protect the device from weather conditions

Key Components of an IED

Additional metal fragments

- The purpose of adding additional fragments or shrapnel is to increase casualties and the amount of damage to the target.
- They are either contained within the container or around its exterior.
- Small metal balls, screws, nails and scrap metal are usually used for that purpose.



Booby-Trap Devices

- A booby trap is a device or setup that is intended to kill, harm or surprise a person, unknowingly triggered by the presence or actions of the victim, i.e. opening a door, picking something up or switching something on, or moving a car.
- **Car Booby-Trap:** This small device, containing only a kilogram or so of plastic explosive, is attached magnetically to the underside of a motor vehicle, usually beneath the driver's seat area.
- A simple timer mechanism, such as a **wristwatch** or parking timer, is included in the device and this in turn is activated by a **mercury tilt switch** that operates once the vehicle is in motion.
- Used to eliminate specific targets, usually the **driver of the vehicle**, although occasionally other passengers are also killed or seriously injured.
- Amputation of the lower limbs are typically seen in such cases.

Car Bombs

- Transporting, Concealing a bomb.
- Devastating container as a bomb.
- A car boot can be packed with a large quantity of explosive material and the vehicle driven to its intended target.
- Detonation by a simple timer mechanism
- Destruction of the car results in multiple secondary missiles radiating from the center of the explosion, which can cause death or serious injury.
- Difficult to recover forensic evidence such as fingerprints, fibers, or low copy number DNA relating to its occupants.

Culvert Bombs

- A culvert is a structure that allows water to flow under a road, railroad, trail
- Large quantities of homemade explosive, made from ammonium nitrate fertilizer and sugar, concealed in water culverts beneath country roads.
- The security forces would then be attracted to the scene, usually by an anonymous report of suspicious activity in the area.
- Terrorists, concealed at a vantage point some distance away, would detonate the device as the police or army patrol drove over the culvert.

Incendiary Devices

- These small devices, sometimes concealed in audio cassette cases, contain a small quantity of **low-order explosive**, a **detonator**, and a **simple timer** (such as a wristwatch)
- They are often left concealed in commercial premises and are intended to detonate when the premises have been emptied for the evening.
- **Their purpose is primarily to cause destruction of the building and its contents by the fire**, which is generated by detonation.

Firebombs

- Considerably larger than incendiary devices and consist of an **explosive device attached to a container of flammable liquid** such as petrol.
- The force of the explosion causes rupture of the container and the release of inflammable vapor which then ignites.
- The fire develops rapidly and may engulf buildings within seconds, resulting in death of the occupants.

Drogué Bombs

- Anti-vehicle grenade consisting of about 230 g of explosive packed into a can attached to a throwing handle.
- These homemade devices intended to be dropped or thrown from the upper floors of buildings or bridges at police or military vehicles passing below.
- Their construction included a hollow cylindrical copper core which melted on detonation and could penetrate the armor-plated roofs of these vehicles.

Letter-Package Devices

- Small explosive devices to be sent in the post to targeted individuals.
- The device is usually contained within a large padded envelope and detonation is usually achieved when the envelope is opened by an unsuspecting recipient.
- Injuries sustained in such circumstances are usually confined to the face and are often characterized by linear abrasions and lacerations radiating from a point in front of the face.

Pipe Bombs

- These are fairly simple improvised devices essentially consisting of a length of metal pipe filled with low-order explosive such as that decanted from fireworks or shotgun cartridges.
- A simple taper fuse is attached and, once lit, the device is thrown at the intended target.
- Fatalities have occurred in those inadvertently picking up the devices, or when the device explodes prematurely, whilst being thrown.
- The pattern of the injuries sustained in such cases is clearly important in determining the innocence or guilt of the casualty.

Nail Bombs

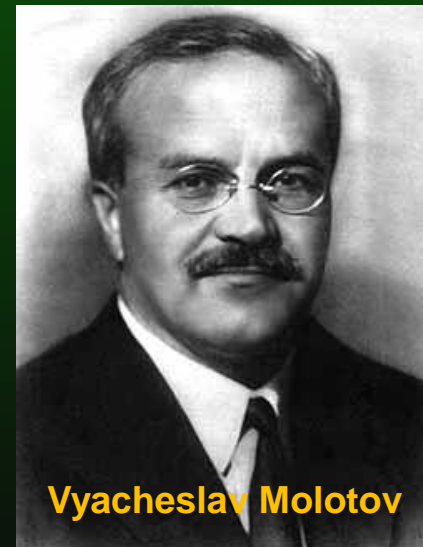
- These small devices were also intended to be thrown by hand at a target, possibly a member of the security forces or a group of rioters from an opposing faction.
- The construction involved a small explosive charge wrapped in corrugated cardboard and containing numerous long nails.
- Those close to the point of detonation could sustain serious or even fatal injuries due to being struck and pierced by the contents of the device.

Mortar Bombs

- These devices consist of metal cylinders packed with explosive and are designed to detonate on impact with their intended target.
- They are usually launched from firing tubes constructed on the back of an open lorry or a van fitted with a false roof.
- The advantage of this moving firing point is that it can be located relatively close to even a “protected” target and then abandoned, allowing the terrorists to make their escape before timed detonation occurs.
- The mortars may travel up to about 200m but are inherently inaccurate and frequently fail to detonate on impact.
- It is not unusual for such devices to miss their intended target such as a police station or military camp by a long way, and instead explode in an area populated by civilians.

Molotov cocktail

- The Molotov cocktail has been a favorite of guerillas and terrorists.
- It consists of a bottle full of gasoline and a rag which serves as a wick.
- The wick is lit and the bottle is thrown at the target.
- Various chemicals and acids may be added to this cocktail to increase its destructive potential.
- The name "Molotov cocktail" is nicknamed after V. M. Molotov, a foreign minister of the Soviet Union.



Vyacheslav Molotov

Molotov cocktail

- The weapon is used by first soaking the rag in a flammable liquid immediately prior to using it, lighting the rag and throwing the bottle at the target.
- The bottle shatters on impact the liquid then spreads and ignites instantly, creating a large fireball.
- Fire can spread very quickly (up to 33 Meter per second)
- Temp of flame: Kerosene 990 Gasoline 1026 Methanol 1200
- Thickening agents include palm oil, laundry detergent, liquid dish soap some times added.
- **The explosion** is completely dependent on the fuel-air mixture within the bomb.
 - If **filled completely** with liquid will not explode upon impact, but will rather splash, and the liquid will catch fire more slowly.
 - If **filled with two-thirds** with flammable liquid, sealed, then a few minutes allowed for the air in the bottle to become fully impregnated with the fuel vapors.

Molotov cocktail – wick alternatives

- **Hypergolic mixtures** can be used A packet of sugar and potassium chlorate is taped to the outside of the bottle and sulfuric acid is added to the liquid inside. When the bottle breaks, the acid reacts with the sugar and chlorate to create a very hot flame that ignites the liquid.
- **Plastic bottles or containers** filled with fuels. Surrounded by loose paper that's set on fire and softens them eventually igniting the liquid inside. Plastic containers can burn completely and make identification difficult.

What happens during an explosion?

- 1) **Blast** is essentially an expanding hot sphere of gas generating from the high explosive contained within the bomb. Release tremendous amounts of energy.
- 2) **Temperature** of the explosive gases can rise to 3000 C.
- 3) **Pressures** of up to 150 000 atm can be generated. Human beings are endangered (6.805 atm) or above.
- 4) The destructive capacity of the blast is due to this pressure (known as blast loading). It dissipates rapidly into the surrounding medium causing in quick succession the following three phases:
 1. a positive pressure phase,
 2. a negative pressure phase (lasting about five to six times the duration of the positive pressure phase),
 3. the mass movement of wind (blast wind)



Size Does Matter



Explosives Lethal Blast Serious Injury
in Kg TNT-eq. Range (meters) Range (meters)

	Explosives in Kg TNT-eq.	Lethal Blast Range (meters)	Serious Injury Range (meters)
Suicide bomber	1– 5 kg	5 meters	10-30 meters
Compact car	227	30	450
Sedan	455	60	530
Passenger van	1,180 (~ OKC)	80	840
Panel truck	4,545 (~ Khobar)	91	1,150
Fuel truck	13,636 (~ Beirut)	140	1,980
Semi-trailer	27,273 kg	180	2,130

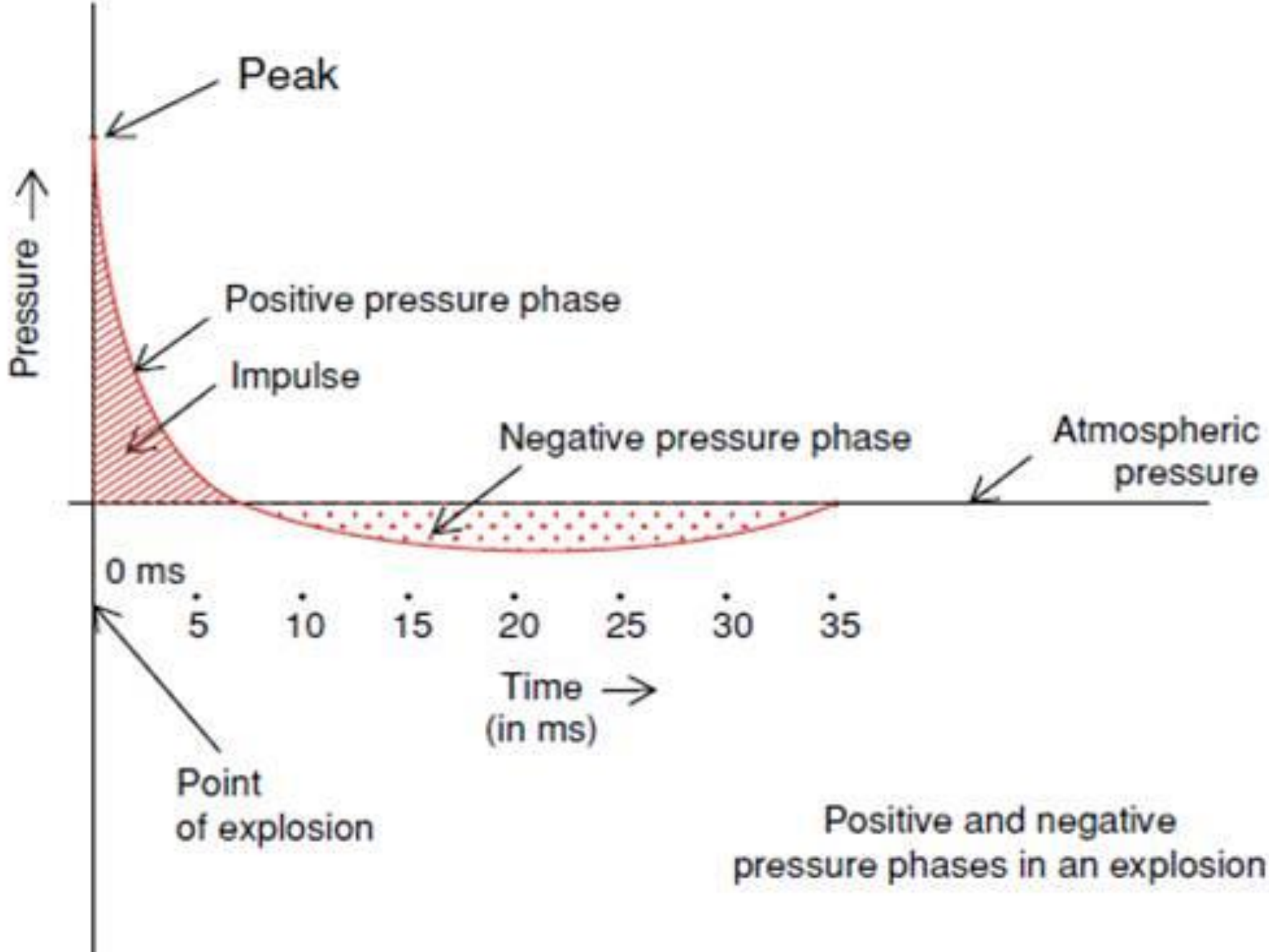


Illustration of blast wave, with steep pressure wave front



**Unique
to Blast**

PRIMARY

- Blast lung
- Eardrum rupture and middle ear
- Abdominal hemorrhage and perforation
- Eye rupture
- Non-impact, blast-induced mTBI?

SECONDARY

- Penetrating ballistic (fragmentation) or blunt injuries
- Eye penetration

TERTIARY

- Fracture and traumatic amputation
- Closed and open brain injury
- Blunt injuries
- Crush injuries

QUATERNARY

- Burns
- Injury or incapacitation from inhaled toxic fire gases

QUINARY

- Illnesses, injuries, or diseases caused by chemical, biological, or radiological substances (e.g., "dirty bombs")

*PSYCHOLOGICAL TRAUMA (including PTSD)

- * Added based on latest research suggesting a high risk of developing PTSD following a concussion

Effects of Explosion

Well-defined pattern of injury from

1. **Very close to the center** of the explosion: they are **blown to pieces** and scattered by the force of the explosion gases.
2. **Explosion flame**: Direct contact leads to **flame burns**. Exposure to the momentary heat radiation causes **flash” burns**.
3. **Shock wave** spreads concentrically from the blast center. This pressure wave is followed by a **post blast wind**, which also does damage. (Manifested principally as blast lung, bowel contusion, and tympanic membrane rupture)
4. **Flying missiles and fragments** propelled by the explosion.
5. **Injury resulting from displacement of the victim’s body** as a whole by the complex pressure loads imposed upon it.
6. **Falling debris and demolished buildings**. Producing direct blunt injuries, crushed injuries or traumatic asphyxia injuries.
7. **Fumes of Explosion**: Suffocation
8. **Secondary fire**: Burns and smoke inhalation.

Complete Disruption

- The victim may be literally blown to bits and the parts scattered over an area of 200m radius.
- This is relatively uncommon but may occur in current terrorist situations:
 1. someone is carrying a large bomb that explodes.
 2. victim is blown up by a landmine.
 3. suicide bombers who strap explosives to their bodies.
- When collected, washed, and examined, the identifiable remains are typically seen to comprise pieces of **scalp** and **skin**, **portions of spine**, **major limb joints**, and **lumps of muscle**.
- Usually most of the internal organs are missing.
- **Nonhuman tissue** is often found amongst the material submitted for examination and must be identified and discarded.

Explosive Injury

- Traumatic Amputation: In couple of meters of the explosion, parts of their limbs blown off and sustain severe smashing of other parts of the body, often with rupturing of the chest or abdominal cavities, but they usually remain sufficiently intact.
- Preferential Amputation: Explosive shock waves causes fractures and preferential amputation through the shafts rather than the joints of the long bones.
- Shrapnel Wounds from the effects of material propelled in all directions from the center of the explosion. Shrapnel deliberately placed around the device or in the terrorist situation, from fragments of a car filled with explosive.
- Debris Wounds from the surroundings (brick, plaster, and wood, varying from reasonably large fragments to dust). The larger the fragment, the deeper it will penetrate the body and the more lethal it is likely to be.

Explosive Injury

- The characteristic type of injury due to fragments propelled by an explosion is a triad of

1. Small bruises

2. Punctate abrasions

Bbruises and abrasions tend to be quite small, up to 1cm in diameter.

3. Irregular puncture lacerations.

Lacerations, vary between 1 and 3cm in diameter, may contain small fragments of metal or wood derived from the bomb or its container.

Background of dust tattooing and a dusky purple discoloration of the exposed skin.

Flying-Missile Injury

- **Beyond a few meters** serious injury and death result from the impact of larger separate fragments (usually of metal). The spraying injuries disappear.
- The **penetrating force** of this relatively small explosion fragment is very high.
- These fragments can penetrate the soft tissues of the body **quite deeply**, even traversing bone, their momentum being obtained not from their mass but from their velocity.

Injury from Falling Buildings

- Victims inside or adjacent to a building demolished by an explosion are buried under the rubble.
- Could be the only effects of the explosion on the victim.
- Two main forms:
 - a) **Impact injuries**: serious or fatal wounds from the collapse of heavy structural components.
 - b) **Traumatic asphyxia** due to pressure of rubble on chest.
- **Impact injuries**: When removed from the rubble the body and its clothing are soiled by dust from brick, cement, or plaster, and the extent and nature of the injuries are only revealed when the clothing has been removed and the body thoroughly washed.
- **Traumatic asphyxia**: the signs are usually quite clear: purple discoloration of the upper parts of the body with petechial hemorrhages in the skin and conjunctivae and perhaps some congestive hemorrhage from the nose and ears.

Flame Burns

- **Contact with the momentary flame:** The temperature of the explosive gases can **rise to 3000 degree C.**
- **Individuals close to the center of the explosion** usually sustain severe disruptive injuries and the burns are a minor component.
- **Outside momentary flame range:** burned by the radiant heat but the effects decrease rapidly from the center of the explosion.
- **Secondary fire:** usually produce sever burns. Combination of inflammable materials into the device. Result of disruption of a source of flammable material.

- Severe burns may lead to:
 - **difficulties in identification.**
 - **obliteration of surface injuries.**

Flash Burns

- The ignition is associated with a momentary flash of very high temperature.
- Victims exposed to the flash have their outer clothing burned off and sustain extensive uniform-thickness cutaneous burns.
- Tight clothing such as a bra, underwear, and footwear may protect the underlying skin

Blast Injuries

- An explosion is associated with a narrow wave of very high pressure, which expands concentrically from the center of the explosion and briefly engulfs every object or person in its path.
- The pressure is exceptionally high at the front of the wave but decreases toward its rear and becomes a slight negative pressure, or partial vacuum, before the wave is complete.
- The total duration of the shock wave is brief; the pressure component lasts perhaps 5ms for a relatively modest explosive device whilst the negative suction component may be 30ms.
- The blast wave can knock a person down, move objects, and demolish buildings – these effects are usually due to the impact of the sudden pressure wavefront.

Blast Lung

Hypotheses of Blast Lung

- damage to epithelial surfaces within the lungs as a result of a stress wave passing **through the parenchyma** and encountering interfaces of different density
- transmission of pressure pulses and subsequent flow of blood **from the great vessels** of the abdomen to the pulmonary vessels leading to rupture of pulmonary capillaries
- compression and subsequent violent re-expansion of small **air spaces in the lungs** as a result of the passage of the shock wave.

Blast Lung

Findings

- Widespread alveolar damage
- Tears in the visceral pleura
- Pulmonary hemorrhage,
- Atelectasis,
- Pneumothorax, hemothorax, pneumomediastinum
- Traumatic lung cysts.
- Air emboli are common, which can be due to traumatic alveolar–venous fistulae.
- Subcutaneous emphysema and chest wall damage, including injuries to the ribs.

Blast Lung

Macroscopically

- areas of blotchy purple-black areas of sub-pleural hemorrhage.
- Usually these are scattered at random but occasionally may be seen as parallel bands of bruising related to the overlying ribs.
- Sectioning the lungs reveals more discrete areas of hemorrhage scattered in the tissue often with a tendency to be more central than peripheral.
- The rest of the tissue is patchily edematous.
- The overall weight of the damaged lung is increased due to both hemorrhage and edema.

Blast Lung

Microscopically

- Intra-alveolar hemorrhage within intact alveoli with larger areas of surrounding hemorrhage.
- Disruption of alveolar walls.
- Hemorrhage extends into the bronchioles and there is a variable amount of edema fluid in the alveoli.
- Emphysematous dilatation of some of the alveolar ducts may be identified.
- In patients who survive, the changes are modified by infiltration with a neutrophilic inflammatory reaction and often by the development of adult respiratory distress syndrome (ARDS).

Blast Lung

Diagnosis:

- Primary blast injuries to the lungs are rarely of major significance in civilian casualties from terrorist bombs.
- To be injured by blast, one has to be in the immediate vicinity of the explosion (within a few meters), and at such a range, the victim is likely to die at the scene from other injuries.
- Also it must be borne in mind that not all lung injury is due to blast. Sometimes the lungs are bruised by direct blows on the chest by bomb fragments and debris.

Blast Injuries, Ears

- Bruising and/or rupture of the tympanic membrane
- Damage to Eustachian tube, Ossicles chain, Organ of Corti within the cochlea.
- Most victims who survive an explosion may initially complain of deafness associated with tinnitus but usually recover if the ossicles have not been damaged.

Blast Injuries, Gastrointestinal

- hemorrhage into the peritoneum and bowel wall especially in the lower small intestines or the cecum where gas content is greater.
- Perforation of the bowel is uncommon but has been reported especially at the ileocecal junction.
- Retroperitoneal hemorrhage,
- Injuries to solid organs.

Blast Injuries, Cardiovascular

- Myocardial contusion,
- Myocardial laceration,
- Coronary artery air embolism, and hemorrhage.

Blast Injuries, central nervous system

- concussion
- various forms of intracerebral hemorrhage.
- Retinal Hemorrhage

Clinical Issues

Clinical Issues

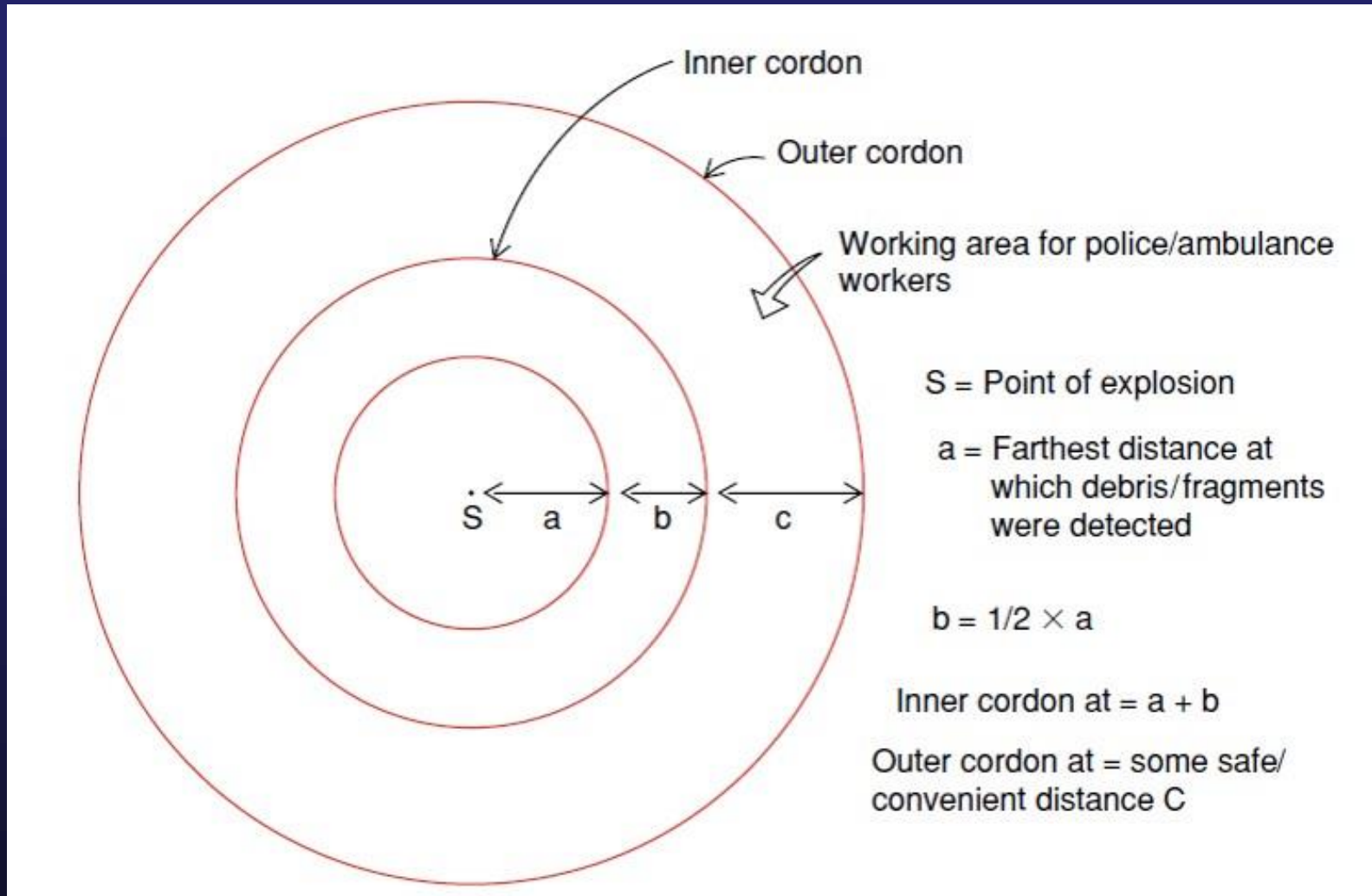
- 1) The predominant post explosion injuries among survivors involve standard penetrating and blunt trauma.
- 2) Clinical signs of blast-related abdominal injuries can be initially silent until signs of acute abdomen or sepsis are advanced.
- 3) Blast lung is the most common fatal injury among initial survivors.
- 4) Primary blast lung and blast abdomen are associated with a high mortality rate.
- 5) Auditory system injuries and concussions easily overlooked.
- 6) Isolated tympanic membrane rupture is not a marker of morbidity
- 7) The symptoms of mild traumatic brain injury and posttraumatic stress disorder are linked.
- 8) Traumatic amputation of any limb is a marker for multi-system injuries.

Clinical Issues

- 9) Air embolism is common, and can present as stroke, MI, acute abdomen, blindness, or deafness.
- 10) Compartment syndrome, rhabdomyolysis, and acute renal failure are associated with structural collapse, prolonged extrication, severe burns, and some poisonings.
- 11) Consider the possibility of exposure to inhaled toxins and poisonings (e.g., CO, CN)
- 12) Wounds can be grossly contaminated. Consider delayed primary closure and assess tetanus status.
- 13) Ensure close follow-up of wounds, head injuries, eye, ear, and stress-related complaints.
- 14) Communications and instructions may need to be written.

Investigations

Sketch of explosion site with inner and outer cordons marked



The area inside the inner cordon may only be visited by officers, and the members of the forensic team.

An outer cordon is placed outside. The area between the inner and outer cordon is used by police teams, emergency services, press, etc.

Investigations of Deaths Following a Bomb Explosion

- Following a terrorist bomb there may be many fatalities and the forensic pathologist dealing with such cases may have to start a predetermined mass disaster plan for dealing with large numbers of bodies.

The main problems are:

- identification of the victims
- confirming the number of victims
- ascertaining the causes of death
- determining the circumstances of death
- the retrieval of forensic evidence.

Circumstances of Death

- Reconstructing the circumstances of death can be the most rewarding aspect of autopsies on explosion victims. As with other deaths involving terrorist groups, it is not unusual for an explosion to be followed by rumors and allegations, which the pathologist can often confirm or disprove.
- When a bomb **goes off prematurely** – perhaps whilst being manufactured, loaded into a car, or primed – and a terrorist is killed, it may be alleged that the deceased was an innocent passer-by.
- When a bomb **goes off whilst being transported** by car, it might be said that a terrorist blown out of the vehicle was a pedestrian.
- When a bomb **goes off inside a building**, some of the dead may be terrorists planting the bomb whilst others are uninvolved innocent victims.
- **It is thus essential, if possible, to demonstrate the relative positions of the victims and bomb.**

Circumstances of Death

- Must compare the injuries: their **severity, distribution, and pattern**. Interpretation rests on two factors.
- **First, explosive force declines rapidly with distance** and only those victims very near to the source are badly mutilated.
- **Second, the force is highly directional** and it is often possible to determine the position of the device in relation to the deceased – thus an explosion at ground level injures the legs of those nearby more than other parts of their bodies. Similarly, the legs especially show severe mangling injuries when an under-car booby trap device explodes.
- An intelligence assessment of this kind is often invaluable in the investigation; however, unless the significance of the features is readily apparent, **this kind of evidence should be used with care in court**.
- Unusual things can happen, **bizarre wounds can occur**, and a particular pattern of injuries sometimes proves misleading.

Retrieval of Forensic Evidence

Fragments recovered from the bodies of explosion victims have important forensic significance.

- Determine the particular characteristics of the explosive device and thus implicate a specific terrorist organization.
- link components recovered from bodies with similar items seized by the security forces in searches and raids on suspected terrorists.
- X-raying bodies prior to autopsy will assist in the identification and recovery of shrapnel from bodies.
- **Recovery of fragments** from soft tissue can be extremely tedious and occasionally it may be worthwhile excising the tissue and subjecting it to digestion. Trypsin or meat tenderizer can be used to facilitate this.

Suicide Bombers

- The majority of suicide bomb attacks are of two types:
 1. **an individual, with explosives strapped to his/her body**, detonates the device amongst a crowd of civilians or close to a targeted individual
 2. **vehicle, packed with explosives**, is driven by the bomber into a specific location such as accommodation being used by civilians or military personnel.

Suicide Bombers - Individual

- The body of an individual strapped with explosives is invariably completely disrupted by the blast. Typically most of the trunk is blown away but remarkably the head and lower limbs remain relatively intact and are usually found some distance away from the center of the explosion.

Suicide Bombers - Car

- The suicide car bomber, usually because of the large size of the device, is completely disrupted and little of the body may be recovered.
- The parts that are collected are usually the fairly obvious portions of the body such as a segment of spine, perhaps a foot, and pieces of scalp and skin. The internal organs are rarely recovered.