Terrorist attacks with explosive weapons: pattern of injuries and health constraints

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Abstract: Terrorist attacks are on the rise and aim to create vast damage and large numbers of injured people. Explosive weapons became the predominant ordnance for terror-related events and more countries have to deal with the aftermaths of bombing incidents. These attacks can create mass-casualty emergencies and trigger complex pattern of injuries. This paper utilises eligible secondary literature to review these patterns of injuries and discusses the constraints for health systems. It appears that fragments of explosive weapons trigger the highest number of injuries. Subsequently, the predominant injuries can be researched in penetrating trauma and complex bone fractures. Triage can be researched as a key-task after terror-related bombings to minimise mortality amongst survivors. A close collaboration of all involved health staff will be required to adapt to bombing events. Additional training for health staff might be needed to adapt to terror bombings and the civilian health structure might benefit from experienced military medical forces.

Keywords: terrorist attacks; terror-related events; explosive weapons; bombing events; bombing-incidents; pattern of injuries; terror-related events; mass casualty emergencies; emergency management; clinical management; emergency-triage.


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1 Introduction

Warfare significantly changed over the centuries and was always strongly linked to technological development. The shift from traditional fighting with bare fists, swords and sticks to highly developed long-range weapons took some hundreds of years. It was in the
beginning of the 19th century when black powder was replaced by stronger energetic materials and therefore opened the path for more destructive explosive weapons (Brehm, 2012).

Apparently, this evolution of new weapons was also available for potential terrorist events and previous research shows that since the late 1990s large terrorist attacks became a common event (Clark, 1998; Frykberg, 2002; Arnold et al., 2004). Previous studies mentioned that 88% from out of 93 reported terrorist attacks between 1991 and 2000 already used explosive weapons (Arnold et al., 2004). The National Counterterrorism Centre documented more than 14,000 terrorist-attacks throughout the world in 2007 which constitutes a 30% increase over 2006 (Champion et al., 2009). Recent terrorist attacks predominantly utilised the following methods of killing: suicide bombing, gunshots and explosions (Peleg et al., 2004). More powerful weapons trigger mass-casualty emergencies and the outcome appears to be more severe and complex compared to earlier years (Kluger et al., 2004). It seems that terrorist attacks aim to cause a sensation and to injure as many people as possible and subsequently, explosive weapons became one of the primary tools for terrorism (Kluger et al., 2004; Alfici, 2006; Frykberg, 2004). Since terrorism is not an endemic phenomenon but an epidemic, the management of terrorist attacks with explosive weapons constitutes a challenge for health facilities all over the world (Einav et al., 2004). It seems that physicians will have to treat more terror-related victims in the future (Peleg et al., 2004). Previous studies show that terror-related attacks cause injuries by: blast, penetrating shrapnel, burn injuries and gunshots (Einav et al., 2004). It appears that, especially, bombing-related injuries constitute a major challenge for the health system and the overall emergency management structures. Owing to the complexity and the unusual pattern of injuries, health systems might be overwhelmed by this challenge. Therefore, this paper discusses explosive devices which are characteristic for terror-related events, highlights the pattern of injuries caused by terrorist-related bombings and discusses the resulting challenges for health structures.

2 Methodology

This study utilises secondary data from the United Nations, publications from non-governmental humanitarian organisations and several peer-reviewed publications. Publications were researched via ScienceDirect, GoogleScholar and PubMed by the following keywords: explosive weapons, improvised explosive device, explosive weapons injury pattern, mass casualty emergencies, injury pattern of explosive weapons and injury pattern of terrorist attacks. Researched studies are based on past terror-related incidents when explosive weapons were the choice of ordnance. Selected studies discuss terrorist bombings in a civilian environment, which triggered mass casualty emergencies and several injuries related to the bombing incident. On the basis of this, 23 eligible peer-reviewed studies and additional other publications could be identified to discuss the consequences of terror-related bombings. Uncited information was drawn from the author’s professional experience as a disaster manager working in different countries of armed conflict.
3 Common types of explosive weapons

Explosive weapons include various types of models with different functional modes. They include anti-personnel mines, mortars, improvised explosive devices, grenades, rockets and missiles. Overall, they all share the common characteristic to cause injuries and death by blast, heat and fragmentation. They all use explosives as their primary mode of functioning.

Explosives can be classified as either high-explosive or low-explosive composition (Giannou et al., 2013). Low explosives cause less damage compared to high explosives and include guns and small bombs. High-explosive bombs usually follow a three-step explosive sequence (detonator, booster charge and main charge) and are mostly designed to break up into fragments (Giannou et al., 2013). Subsequently, common types of explosive weapons, used in terror-related incidents will be discussed.

3.1 Suicide bombing

Suicide bombs can cause large numbers of injured people due to the fact that suicide bombers can stay unnoticed until the last moment. With detonations inside of large groups of civilians these attacks trigger chaos and can generate a drastic change in everyday behaviour. Suicide bombers use various designs of bombs and can include vests, belts or modified cars (Ramasamy et al., 2010).

3.2 Thermobaric enhanced-blast explosive device

This type of explosive weapons uses atmospheric oxygen to produce a large detonation (Dorneanu, 2007). An initial explosion releases explosive substances in the air which is subsequently used to trigger a second explosion (DePalma et al., 2005). Due to the dispersion of explosive material in the air, the detonation can be vast and cover a large area.

3.3 Improvised explosive device (IED) or vehicle borne IED (VBIED)

An IED is a ‘homemade’ bomb which is constructed and used in a different way compared to conventional military ordnance. IEDs can be found in various designs, sizes and functional modes. However, they are always developed to cause “gross disruption and disintegration of the body” (Horrocks, 2001). It seems that IEDs are predominantly used by terrorists within various regions around the world (Champion et al., 2009). One of the major differences to conventional military design can be identified by the fragments of the explosive device. The fragments in conventional military design are created by a breakup of the case, but IEDs utilise additional objects to cause more damage to the surrounding (e.g., nails, glass, bolts or nuts) (Champion et al., 2009). Vehicle borne IEDs follow the same composition as an IED but are always mounted to vehicles (e.g., cars or motorbikes).
### 3.4 Dense inert metal explosives

Dense inert explosives are produced by mixing explosive material with small particles of an inert heavy material. Therefore, there is no need to generate fragments by the casing of the bomb since they are already attached to the explosive (Global Security, 2015). Explosions of this type of bombs are highly lethal and create a shower of small fragments.

### 4 Pattern of injuries

In principle, an explosive device is designed to create a blast (abrupt increase in atmospheric pressure) and fragmentation (Brown, 2013). The detonation of an explosive device can be visualised in three phases: the appearance of a positive and a negative shock wave, followed by blast wind (see Figure 1).

**Figure 1** Pressure phases of an explosion over time

![Pressure phases of an explosion over time](source: Drafted by Author)

The detonation of an explosive device can be understood as an exothermic reaction (the explosive charge gets converted into high-pressure gases) creating a sudden increase of pressure compared to atmospheric level (Giannou et al., 2013). The positive pressure wave is marked by a very high pressure which decreases very quickly over time. The negative pressure wave follows immediately after it and is marked by a lower pressure differential but lasts much longer. During the first phase it creates a vacuum (negative pressure) which can suck in air and objects; this phase seems to have even more destruction energy compared to the positive pressure wave (Giannou et al., 2013). The blast wind, created by the sudden expanded gases, travels immediately after the shock waves and creates additional overpressure (Ramasamy et al., 2011). The blast wind can reach up to 100 m/s and is therefore able to cause significant additional damage (Giannou et al., 2013; Champion et al., 2009).

Four categories can be used to classify the pattern of injuries of explosive devices: primary effects, secondary effects, tertiary effects and quaternary effects (DePalma et al., 2005; Champion et al., 2009). Primary and secondary injuries happen in the phase of the positive pressure wave, tertiary injuries during the phase of the blast wind and quaternary
injuries can be reported as health constraints apart from the three categories but still linked to the explosion. Table 1 displays an overview of the four categories.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Description</th>
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<tbody>
<tr>
<td>Primary</td>
<td>Injuries caused by barotrauma (the high pressure from the first blast wave)</td>
</tr>
<tr>
<td>Secondary</td>
<td>Injuries caused by diverse fragments (in the phase of the first and the second blast wave)</td>
</tr>
<tr>
<td>Tertiary</td>
<td>Injuries caused by the blast wind (displacement of the body and collapsing of buildings)</td>
</tr>
<tr>
<td>Quaternary</td>
<td>Other explosion-related injuries apart from the three classifications. Moreover, the aggravation and complication of already existing medical condition by the explosion</td>
</tr>
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</table>

Source: Drafted by Author

4.1 Primary injuries

Primary injuries are triggered by the positive and the negative overpressure waves immediately after the detonation (injuries are caused by barotrauma) (Mäkitie and Pihlajamäki, 2006). Owing to the high and low pressure relative to atmospheric pressure, air-containing organs are the most affected body parts (e.g., ears and lungs) (Cernak et al., 1999). Typical injuries caused by blast overpressure include: cyanosis, eardrum hyperaemia, bleeding outside the body, an increase of the heart rate and a fall of the mean arterial pressure (Cernak et al., 1999). The degree of the injury can be directly linked to the extend and the duration of the first pressure wave (Frykberg, 2002). Other studies also mention the pulmonary, gastrointestinal and auditory systems as one of the most affected body parts (Wolf et al., 2009). Moreover, the blast wave can cause ischaemic complications, triggered by serious pulmonary injuries (e.g., arterial air emboli) (Wolf et al., 2009).

4.2 Secondary injuries

Secondary injuries are marked by penetrating wounds, caused by bomb casing fragments (pieces of the explosive weapons) or sudden accelerated objects by the overpressure (Champion et al., 2009). Moreover, some bombs might contain additional material to increase the damage (e.g., bolts or nails). Any body part can be affected by these flying projectiles and secondary injuries are understood as the leading cause of death and injury (DePalma et al., 2005). Fragments can cause penetrating traumas and direct fractures to the bone structure (Ramasamy et al., 2011). Moreover, they can trigger huge cavities to the body and according to the speed of the projectile it will remain in the body or create an exit hole. Previous studies show that it is easier to treat victims when the projectile still remains in the body; furthermore, these patients are more likely not to need surgical reconstruction (Rose et al., 1988). Bone fractures can also be triggered by high energised fragments passing the body in close proximity; due to the high pressure these fragments exert on the human body (Rose et al., 1988).
4.3 Tertiary

Tertiary injuries are triggered by the blast wind, which follows the positive and the negative pressure wave (Mayo and Kluger, 2006). Tertiary injuries are mainly caused as a result of individuals being thrown by the blast wind; and the impact with other objects (Frykberg, 2002; Rose et al., 1988). Moreover, tertiary injuries can be caused by fragmentation of buildings and other objects (e.g., cars). Every part of the body can be affected and the pattern of injuries can vary widely. Different types of fractures, crash injuries (due to collapsing buildings), amputations and entrapments can occur (Mayo and Kluger, 2006). Blunt traumas and open or closed brain injuries are other common reported tertiary injuries (DePalma et al., 2005).

4.4 Quaternary

Quaternary injuries are marked by other explosion-related injuries, illnesses or diseases (Champion et al., 2009). These types of injuries are separated from the causes of primary, secondary and tertiary mechanisms. Quaternary injuries include the aggravation of existing medical conditions due to the bombing incident. One of the most common patterns of injuries is burns from resulting fires after the explosion (Mayo and Kluger, 2006; Harrison et al., 2010). More quaternary pattern of injuries can be researched in inhalation injuries (e.g., toxic gas), asthma, general breathing problems from dust or injuries caused by environmental contamination (Champion et al., 2009).

The appearance of the different injury classifications over the duration of an explosion are summarised in Figure 2.

Figure 2  The appearance of pattern of injuries during an explosion

Source:  Drafted by Author

5 Health constraints

Explosive weapons are designed to cause damage by blast and fragmentation. Two major health constraints can be identified: the appearance of a mass-casualty emergency and
unusual and extraordinary injury patterns (Aharonson-Daniel et al., 2006). Subsequently, the constraints for health systems will be discussed.

5.1 Constraints for emergency management

Terrorist attacks with explosive weapons can provoke a large number of injured people and therefore constitute a challenge for the civilian emergency management systems and hospitals (Born et al., 2007; Frykberg, 2002). Furthermore, these types of incidents are usually rare and healthcare facilities with their responsible physicians might not be adequately trained to respond to these out of proportion demands (Frykberg, 2002). Previous studies already highlighted the importance to train health-staff (e.g., surgeons and nurses) in the extraordinary demands of mass-casualty emergencies (Lennquist, 2005; Born et al., 2007). However, it remains difficult to predict the dimension of future attacks and therefore adapt specific preparation trainings.

Bombing events trigger a specific arrival manner to hospitals and normally, patients are received in groups (Peleg et al., 2004). Moreover, terror events have shown that victims, arriving at hospitals, display unique and different pattern of injuries (Aharonson-Daniel et al., 2006). Groups of injured people are marked by a random distribution of gender and age, since the bombings appear mostly in large clusters of people. Moreover, previous studies discovered a clinical dilemma in treating blast victims suffering from a blast lung and burns at the same time; blast lungs require fluid restriction while burns demand for fluid administration (Aharonson-Daniel et al., 2006).

Every mass-casualty emergency will display the need to select priority patients according to the injury and the chance of surviving; the concept of ‘triage’ (Jenkins et al., 2008). Triage in mass-casualty emergencies constitutes a serious challenge for emergency management systems. Because of the large number of injured people the emergency system is overwhelmed and it becomes difficult to identify the small number of patients who are suitable for further treatment. In case of bombing events it seems profitable to perform triage outside emergency rooms of hospitals to spare the medical resources for the victims with the highest needs (Frykberg, 2004). Furthermore, triage can only be implemented effectively when the person in charge has a proper understanding of the pattern of injuries (Born et al., 2007). Experienced trauma surgeons might be most suitable to be the leading triage officers (Frykberg, 2004). However, most of the triage officers might not be adequately educated for incidents with explosive weapons due to the fact that these events do not occur on a daily basis. Picking the appropriate persons in advance, remains a crucial task to provide better treatment for the wounded.

Hospitals might benefit to install a triage area before the entrance of the building to perform an additional selection of patients. Additionally, this area opens the possibility to perform decontamination procedures. Moreover, the need for intubation on arrival at the hospital will be much higher compared to other emergencies, due to the fact that patients require a quick evacuation and space can be reserved to perform necessary actions.

There is a strong correlation between the type of bombing and the emerging needs at the hospital infrastructure. Therefore, information gathering in advance seems to be a crucial task; indoor explosions will for example lead to a higher number of blast injuries (primary injuries) compared to outdoor explosion or a large number of patients with burns will demand for a higher number of fluid infusions.
5.2 Complexity of injuries

The second major health constraint can be found in the complexity of injuries caused by explosive weapons. It can be recognised that explosive-weapon-injuries require specific trauma surgery and adequate long-term post-operative medical care. Victims of bombing events generally consume more hospital resources and have an extended stay in intensive care units compared to other emergency patients (Moyes, 2009).

Previous studies show that the majority of explosive weapons victims suffer from general and complex fractures (Handicap International, 2015). It can be recognised that most of these secondary patterns of injuries are caused by fragments. Multiple trauma, amputations and penetrating injuries (by fragments) are the leading cause of death after bombing incidents. The highest number of casualties appears in the primary blast of the event and survivors are therefore most affected by secondary and tertiary pattern of injuries.

An initial check of victims should include an examination of the tympanic membranes (DePalma et al., 2005). If the membrane is ruptured it can be assumed that the victim was exposed to serious blast force and should be forwarded to further examination. Further examination should include radiography of the chest and observation for at least 8 h, due to the fact that primary blast injuries can be delayed (DePalma et al., 2005). Lung injuries might also be delayed or overseen in the primary medical check and can be identified by permanent monitoring of the patient (e.g., by pulse oximetry or similar patient monitoring systems).

Impaling objects in the body appear frequently after bombing incidents and should never be removed onsite. Victims have to be transported with the object to the emergency department and the removal should be conducted in operating theatres. However, objects can be reduced, cut or bent to facilitate the transport of patients.

Owing to the complexity of blast injuries it would benefit surgical teams around the world to regularly meet and discuss specific patient cases. Surgical teams in countries of peace are normally not trained for the treatment of bombing injuries and by sharing the knowledge and experience of everybody, the treatment for patients might be improved. Moreover, not only surgical methods must be adapted to the new pattern of injuries but also post-operative-care, nursing, physiotherapy and radiology (Giannou et al., 2013).

6 Conclusion

It appears that fragments of explosive weapons are causing the highest number of injuries. Fragments can travel over hundreds of metres and can be found in various implementations (especially when IEDs are used). Although the danger of shock waves and the blast wind is obvious, current studies repeatedly report fragments as the highest risk factor of explosive weapons.

Owing to the increase of terrorist attacks with explosive weapons it seems important for civilian healthcare facilities to gain a deeper understanding of blast injuries. Explosive weapons can trigger complex pattern of injuries which are above the everyday complexity. A close collaboration of all involved health staff (especially trauma surgeons and nurses) will be needed to tailor appropriate answers to these challenges.

Triage constitutes a significant task to increase the number of survivors after terrorist-related bombings. It seems that more training is needed to avoid over- and
under-triage after bombing incidents. Moreover, hospital management structures will have to remain flexible and adaptable to treat this unusual pattern of injuries. Blast injuries can be complicated to treat and sometimes their consequences are delayed and diagnoses might be missed.

The civilian health system might benefit from already existing structures which are trained to deal with terror-related incidents. One possibility could be a closer collaboration with military medical forces. It seems that these forces are well trained for terror-induced mass-casualty events; even when they deal with them as infrequently as the civilian sector. Training and ongoing planning for the worst cases might allow civilian health structures to cope better with terror-related incidents.

6.1 Recommendations

Past bombing incidents in Europe displayed that the hospitals were able to manage the arriving casualties. Most victims of such incidents die on the spot and survivors predominantly displayed treatable wounds. A survey of fatal explosion injuries in Finland from 1985 to 2004 displayed that after explosions, in this time period, 10 persons died at the scene and only three persons could be transported alive to the hospital (Mäkitie and Pihlajamäki, 2006). A similar distribution was researched for explosions caused by homemade bombs. Eight persons died at the scene and also only three persons could be transported to the hospital alive (Mäkitie and Pihlajamäki, 2006). Also the recent incident of the November 2015 Paris attacks displayed that the majority of victims died on the spot and fewer people were transported to the emergency departments. During this attack, 130 people were killed, 368 people injured and 80 persons transported to hospitals (BBC Europe, 2015). Moreover, French hospitals reported that they were able to treat the emerging wounds, but struggled with the high number of casualties (Marcus, 2015). It seems that most of the European hospitals are prepared to treat complex penetrating trauma and blast injuries.

Owing to the nature of bombing incidents the number of casualties on the spot appears to be vast. For example, the 2004 Madrid train bombings displayed 191 killed victims and more than 1800 injured people (BBC Europe, 2004). Therefore, emergency management structures still need to be reviewed critically. Because high numbers of casualties can arise, it remains unsure if the local emergency personnel are able to handle this situation.

This paper highlights that European hospitals seem to possess the capacity to handle bombing incidents and no specific preparation is necessary in the future. However, at the same time this review recommends that emergency management organisations should review their triage capacities and the preparedness of their staff in performing mass casualty management. It seems that at this point, improvement can be achieved not in the hospitals, but by the performance on the spot. This improvement however, lies on the shoulders of emergency personnel and paramedics, who might not be experienced and trained enough to perform triage for several 100 victims. Mass casualty management is difficult to train because of the high investment to prepare such authentic situations and might not be possible frequently. However, considering the findings of this review, a focus on triage training will benefit in future incidents and might reduce over- and under-triage after bombing incidents.
Terrorist attacks with explosive weapons

References


