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ORIGINAL ARTICLE

Terrorist attacks: common injuries and initial surgical management

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Abstract

Terrorism-related incidents and shootings that involve the use of war weapons and explosives are associated with gunshot and blast injuries. Despite the perceived threat of terrorism, these incidents and injuries are rare in Germany. For this reason, healthcare providers are unlikely to have a full understanding of the special aspects of managing these types of injuries. Until a clear and complete picture of the situation is available after a terrorist or shooter incident, tactical and strategic approaches to the clinical management of the injured must be tailored to circumstances that have the potential to overwhelm resources temporarily. Hospitals providing initial care must be aware that the first patients who are taken to medical facilities will present with uncontrollable bleeding from injuries to the trunk and body cavities. To improve the outcome of these patients in extremis, the aim of the index surgery is to stop the bleeding and control the contamination. Unlike damage control surgery, which is tailored to the patient's condition, tactical abbreviated surgical care (TASC) is first and foremost adapted to the overall situation. Once the patients are stabilised and all information on the situation is available, the surgical management and reconstruction of gunshot and blast injuries can follow the principles of damage control (DC) and definitive early total care (ETC). The purpose of this article is to provide an overview of the pathophysiology of gunshot and blast injuries, wound ballistics, and the approach and procedures of successful surgical management.

Keywords Blast injuries · TASC · Damage control surgery · Gunshot wounds · Terrorist attacks · Tactical surgery

Introduction

Life-threatening situations and law enforcement operations following terrorist incidents and shootings that involve the use of war weapons and explosives are associated with special injury patterns. Especially, perforating and penetrating junctional injuries (in the cervical, axillary or inguinal regions) and injuries to body cavities from projectiles, projectile fragments or other fragments lead to an increased number of patients with life-threatening bleeding that requires surgical management [1].

In addition, every incident has its own dynamic nature because of its particular time and situational context, the number of persons injured or otherwise affected, the direct or indirect involvement of hospitals depending on their proximity to the incident site, and the type of weapons employed.

Terrorist attacks such as those in Nice on 16 July 2016 and at Breitscheidplatz in Berlin on 19 December 2016 can lead to massive numbers of casualties and, because of the weapon used (i.e. trucks), can cause injuries that are common in traffic accidents and that are typically seen in everyday clinical practice. This article, however, focuses on the much rarer patterns that are associated with gunshot and blast injuries such as those seen in the attacks in Paris in 2015 and Las Vegas in 2017.

We only address basic facts and pathophysiological aspects that healthcare providers must understand to make

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informed decisions regarding the emergency medical treatment and initial care of patients. Other articles are available which focus on how to plan und perform the reconstruction of gunshot and blast injuries [2–4].

In this article, we briefly describe gunshot and blast injuries and provide examples of incidents and situations that caused these injuries to enable readers to prepare themselves appropriately for incidents and exercises.

Terrorist incidents: special scenario-related aspects

Tactical and strategic approaches to initial care

Maximising the number of survivors requires initial responses und care tailored to the scenario as well as priority-based treatment at all levels in the evacuation chain, and the optimum use of resources for the treatment of mass casualties under the conditions of a terrorist or shooter incident [5].

An analysis of past incidents revealed the high number of casualties with life-threatening bleeding from gunshot and blast injuries. As a result, efforts were undertaken to optimise the organisation of the evacuation chain in life-threatening situations and law enforcement operations to allow for.

- immediate bleeding control (if possible),
- the early identification of patients with life-threatening bleeding that cannot be controlled at the scene and
- the immediate transfer of these patients to nearby hospitals that provide initial treatment [5].

There are different approaches to the clinical management of patients in a mass-casualty incident. One approach that has already proved effective involves the appropriate sorting of the injured by a senior triage coordinator (CATEGORISING) and the setting of priorities by an emergency operational and medical coordinator (EOMC), who transfers patients to further care, e.g. surgical stabilisation, depending on the presence of life-threatening conditions and the patient's immediate need of treatment (PRIORITISING).

Tactical reasons may require that initial surgical management be reduced to essential care and focus on ensuring the survival of as many casualties as possible (tactical abbreviated surgical care—TASC) [6, 7].

The probability of survival of haemodynamically unstable patients (triage category 1++) can only be increased by rapid surgical bleeding control that is adapted to an operational environment.

Terrorist scenarios and casualty loads (mass-casualty terrorist incidents)

A rough analysis of some of the past terrorist attacks in Europe shows that these incidents varied in type, structure and sequence of events and, if war weapons were used, caused injuries similar to those seen in war settings [8].

Whereas, for example, the attacks in Istanbul in January 2016 and in Ansbach, Germany, in July 2016 involved the use of explosive devices in busy public places, the incident in Brussels in March 2016 actually consisted of a number of attacks that took place at different locations. In Madrid (March 2004) and London (July 2005 and September 2017), attacks occurred in enclosed spaces, i.e. bombs detonated in Madrid on the train line and in London at underground stations and in an underground train.

The November 2015 Paris attacks, which consisted of a series of attacks at different locations and involved a combination of bombings and shootings, had an even more detrimental effect as a result of the sequence and structure of events. These attacks presented one of the most complex medical and logistical challenges that an urban area had so far been confronted with.

Gunshot and blast injuries and the resultant thermal and mechanical injuries are known from past and present asymmetric military conflicts and wars as well as from terrorist attacks against the civilian population in crisis regions and are commonly seen in these incidents [9–11]. The military principles of initial emergency medical treatment and subsequent surgical stabilisation can be transferred to the civilian sector and provide the basis for an appropriate response to new and future scenarios.

Military personnel most commonly sustain injuries to the extremities since they wear personal protective equipment that protects the wearer's head, chest and abdomen. By contrast, the victims of civilian terrorist incidents do not have any protection and include persons from all age groups [5]. Apart from immediately life-threatening conditions such as tension pneumothorax, penetrating injuries and bleeding to junctional zones and injuries associated with bleeding into body cavities can have potentially fatal consequences for these patients [12–15].

Categories of casualties after terrorist incidents

Regardless of triage algorithms that are widely established and discussed, the surgical perspective divides victims of terrorist incidents into four basic categories (apart from those casualties who were killed immediately).

The following four categories can be distinguished at the scene of an incident:

1. Casualties who require an on-scene intervention for the management of an immediately life-threatening injury-related condition (e.g. bleeding control, airway management, needle decompression of the chest/finger thoracostomy, pericardiocentesis) and subsequent re-evaluation of haemodynamical stability.
2. Haemodynamically unstable casualties who, despite an on-scene intervention (see above) and/or local bleeding control (e.g. pressure dressing or tourniquet), can only survive if they are immediately transferred to an appropriate facility for rapid surgical bleeding control, which is subject to situational constraints.
3. Haemodynamically stable casualties who are at risk of haemodynamical instability and have injuries that are typically seen after terrorist incidents but are not immediately life threatening. These patients must be closely monitored and re-evaluated and, depending on the availability of resources, are rapidly transferred to an appropriate medical treatment facility.
4. Haemodynamically stable casualties who were not directly exposed to gunshots or an explosive force and sustained injuries associated with the circumstances of an incident. These patients are evaluated and are given a lower priority for transfer to a medical treatment facility.

If triage can be performed at the incident scene, it must be applied during the initial stage after an incident to identify patients who, despite an on-scene intervention, present with persistent bleeding into a body cavity and haemodynamic instability. In this critical setting, prehospital under-triage or over-triage would otherwise reduce the probability of survival of patients whose lives could be saved if they underwent rapid in-hospital surgery for bleeding control.

The only effective surgical and emergency medical approach to reducing overall mortality is, therefore, to rapidly identify casualties with junctional bleeding or bleeding into body cavities at the incident scene, to identify priorities for transfer, and to transport patients to appropriate surgical facilities [10, 16].

Priorities of clinical emergency care

A structured emergency care algorithm such as prehospital trauma life support (PHTLS®), uniform standardised treatment principles such as the ABCDE steps of advanced trauma life support (ATLS®), and the use of a standardised language for communicating vital signs and other essential information were reported to improve the quality of care and thus to reduce immediate mortality [17–20].

The appropriate use of a proximal tourniquet can adequately stop arterial bleeding from an extremity for up to 2 h without the risk of irreversible complications such as nerve paralysis and soft tissue damage [21]. Wound packing or tamponade (with or without a topical haemostatic agent) and direct pressure are usually insufficient to control bleeding in the inguinal and axillary areas. Bleeding into body cavities cannot be controlled at the scene of an incident or outside the hospital setting.

Patients who received prehospital care at the scene of an incident or during transport must be triaged at the hospital using a structured sorting procedure. The objective of initial in-hospital triage is to CATEGORISE patients, to PRIORITISE them for surgical procedures, to COORDINATE further patient management, and to IMPLEMENT the required procedures.

At the same time, patients who have been moved to triage or holding areas or who require close observation and nursing care after surgery must be re-evaluated dynamically and continuously.

Basic aspects of tactical and strategic approaches to surgical care (DCS versus TASC)

In modern trauma care, the management of patients along the principles of damage control surgery (DCS) has proved successful and can reduce mortality [22–26].

Improved prehospital care, short transport times and the provision of in-hospital care along DCS principles can be expected to improve the survival of patients with even complex injury patterns in a post-attack tactical situation [9, 13, 27].

This implies that an optimisation of prehospital care with a focus on the expedient transport of casualties leads to the rapid arrival of haemodynamically unstable patients at the hospital [5].

As a rule, the management of a single patient with multiple injuries along with the principles of DCS is limited to stop the bleeding and control the contamination of hollow viscus organs in the shortest possible time and to achieve the best possible functional outcome for the patient. The objective of this approach is to avoid additional adverse systemic effects of unnecessary surgical procedures and a further increase in the trauma load of a severely injured patient. This approach implies that patients receive the best possible care that is tailored to the individual patient.

In mass-casualty incidents with a large number of severely injured patients and especially in mass-casualty terrorist events, the primary aim is to ensure the survival of as many patients as possible. Hospital resources may be temporarily overwhelmed in such situations. Healthcare providers may then have to depart from the principles of individualised medical care in an attempt to address the needs of all patients.

In this situation, in-hospital surgical care is subject to situational constraints and is initially reserved for patients with immediately life-threatening injuries and haemodynamically unstable patients. Functional outcome is only of secondary importance. To clarify the difference between the DC (O) S and the TASC concept, possible therapy decisions for different patients are listed in Table 1. It should be noted that these therapy suggestions are not generally applicable in these exceptional situations. They should be understood as an idea to manage this difficult situation.

Only if all healthcare providers and other relevant decision-makers understand and respect these principles and act according to them in a major incident, a successful joint response and the maximisation of the number of survivors can be achieved.

Blast and fragment injuries

High-order and low-order explosives

Blast injuries are caused by the detonation of explosives. Depending on their energy release and reaction velocity, explosives are categorised as high-order explosives (HEs) or low-order explosives (LEs).

They are further characterised based on their source (“manufactured” or “improvised” explosive devices). Whereas the military uses only manufactured explosive devices that are HE based, mass-produced and quality-tested weapons, improvised explosive devices (IEDs) may be composed of HEs, LEs or both depending on what is available [28]. This means that IEDs, when compared to manufactured explosive devices, produce effects that are difficult to predict as a result of the associated kinetics and dynamics of injury. In the case of an incomplete detonation, residues or material that was added to the device can, over time, cause systemic effects in patients. Metal objects such as nails or steel balls are often added to a device to increase the fragmentation effect.

The impact of explosion settings on injury patterns and numbers of casualties

Open-space versus closed-space explosions and suicide versus non-suicide attacks

Depending on the device used but also on the environment of detonation, explosives cause different patterns of injury. Whereas the wounding effect of explosives decreases exponentially with distance from the source in explosions that occur in open spaces, it can increase when explosions take place in confined spaces as a result of reflection and augmentation of pressures, protection against direct effects, and secondary fragmentation [29–31].

Suicide attacks are associated with a further exponential increase in fatalities and, for example, the incidence of amputations since the perpetrators themselves have the ability to adapt the circumstances (time, place and number of casualties) in such a way that they can achieve their perverted objectives [5].

Primary survivors who have no life-threatening injury-related condition (e.g. unconsciousness and airway obstruction, tension pneumothorax and pericardial tamponade) and no haemodynamically significant bleeding may have sustained extensive injuries with major systemic effects. Compared with penetrating injuries to the trunk, however, these

Table 1 TASC concept vs. DCS in a situation with limited resources because of a mass-casualty incident

Patient no	Diagnosis	Possible treatment after initial assessment	
		DCS	TASC
Applying the TASC concept in mass-casualty incidents with limited resources and limited OR capacity to one free OR			
1	Spleen rupture and haemodynamic unstable	Laparotomy, management according to intraoperative findings	Laparotomy, management according to intraoperative findings
2	Amputation of the lower limb and haemodynamic unstable	Operation with debridement amputation	Leaving the tourniquet in place, antiseptic moist dressing and calculated antibiosis, postponed operative intervention
3	Forearm fracture with dislocation and compromitted sensibility, no other injuries	Reposition and possibly external fixator	Reposition and immobilization e.g. with plaster, postponed operative intervention
4	Traumatic brain injury with intracranial bleeding and initial GCS 3	Neurosurgical intervention depending on the CT findings	Most likely no intervention to save other patients with intra-abdominal or intra-thoracic bleeding
5	Multiple soft tissue injuries caused by fragments and hearing loss left ear	Operative wound debridement and management according to intraoperative findings	Antiseptic moist dressing and calculated antibiosis, postponed operative intervention
6	Pneumothorax and fracture of the right femur	Chest tube insertion and external fixator right femur	Chest tube and immobilization right femur, postponed operative intervention

injuries are associated with delayed dynamics and a delayed clinical course.

Kinematics of explosions and blast waves

The detonation of an explosive results in the production of large amounts of combustion gases and a supersonic shock wave that spreads radially outwards. Using a change in optical refraction, high-speed videos of explosions show the shock wave as a distinct line which precedes the combustion gases and a cloud of debris and fragments. In other words, an initial high-velocity shock wave is followed by a blast wind. This sudden overpressure spreads radially [32].

The high-velocity shock wave can have direct effects on the autonomic nervous system and travels through the body. Energy is transferred at boundaries between different types of tissue as a result of changes in tissue characteristics.

When entering or passing through the body, the high-velocity shock wave and the subsequent changes in atmospheric pressure caused by the blast wind can lead to tissue damage as a result of tissue disruption and bleeding (e.g. within the lung parenchyma), and barotrauma (e.g. injuries to the tympanic membrane or perforations of hollow viscera) [33].

Regardless of these fundamental aspects, the detonation of explosives causes five categories of injuries, which are illustrated in Fig. 1 and described in detail in Table 2.

'Combined thermal and mechanical injuries' can be used as a scientific term for these injury categories [34].

Gunshot injuries

Wound ballistics and wounding effects

As a rule, the behaviour of a projectile or a projectile fragment is determined by the physics of trajectories. The stability of a projectile along its trajectory (or flight path) depends on its shape, velocity, centre of gravity, aerodynamic characteristics and deflection.

The extent of damage to the target is influenced by a number of factors, e.g. the kinetic energy of a projectile when it

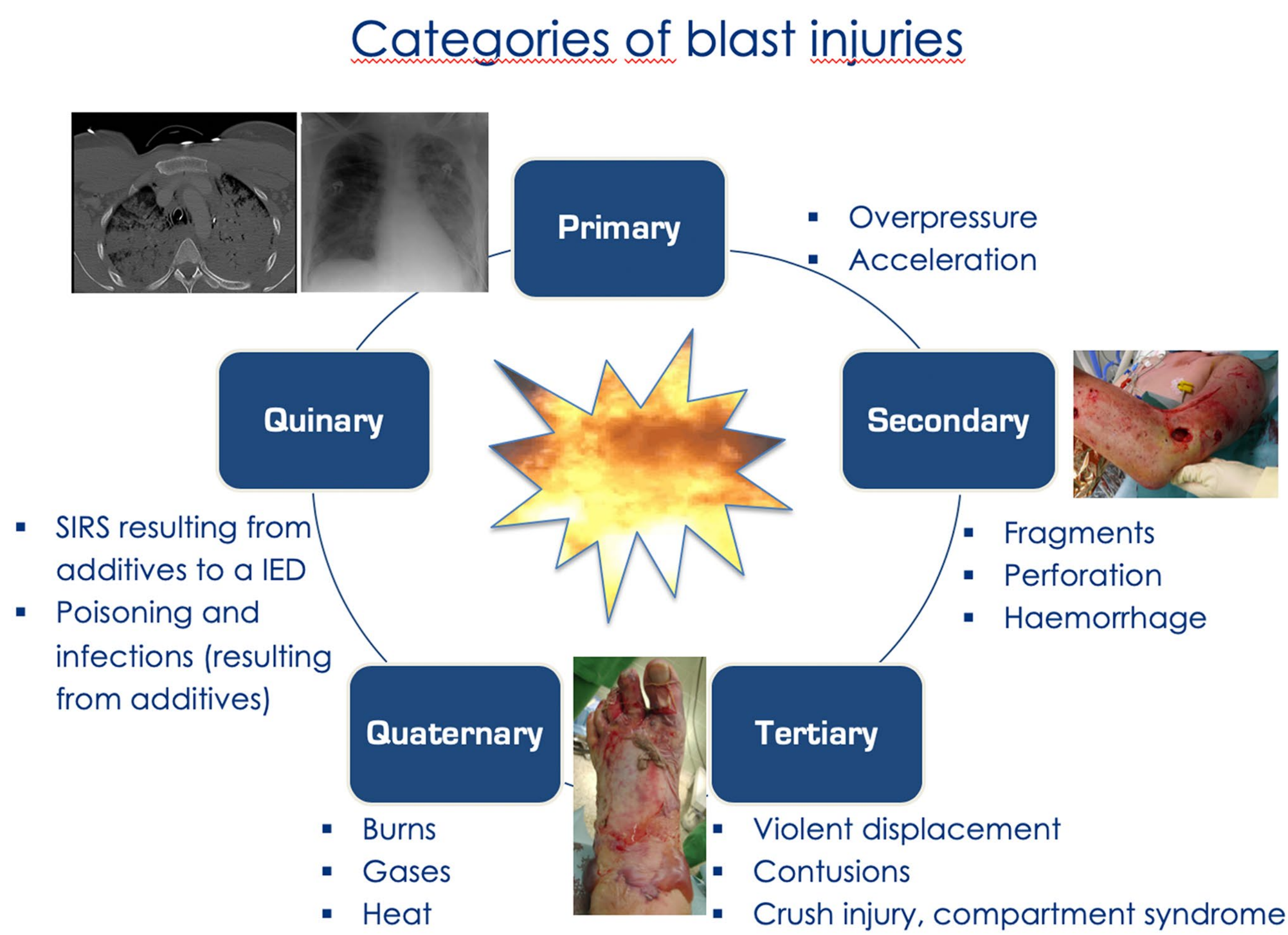

Fig. 1 Categories of blast injuries (*SIRS* systemic inflammatory response syndrome)

Table 2 Categories of blast injuries

Category	Mechanism	Possible types of injuries
Categories of blast injuries		
Primary	Pressure wave (barotrauma) Changes in atmospheric pressure caused by the blast wave Initial high-velocity shock wave followed by blast wind	Most commonly affected are air-filled organs such as the middle ear, the lungs, and the hollow abdominal viscera. Air embolism can occur as well [30, 33, 35] Although isolated injuries to the extremities are rare, the blast wave can lead to fractures, complete or incomplete amputations, and soft tissue avulsion injuries. In their analysis of limb amputations by an explosive blast, Hull and Cooper described how pressure changes spread in compartments along the fascia. They found that, as a result of this mechanism of injury, lower extremity amputations often occurred at the level of the tibial tuberosity. The high mortality rate associated with primary amputations—only 9 of 52 victims survived in the study by Hull and Cooper—demonstrates the high level of energy released and the effects on air-filled organs [36]
Secondary	Effects of fragments and fragmentation Predominantly penetrating injuries caused by fragments that are spread from the centre of detonation Fragments are propelled from the centre of explosion at a velocity of up to 1800 m/s. Despite a rapid loss of velocity, they can create wound cavities that are 20 to 25 times larger than their own size and can cause local pressures of 6.89 bar as a result of their shape and behaviour in flight (cavity effect) [14, 15]	Secondary blast effects account for the majority of injuries and deaths [33] They cause severe bone injuries and devastating concomitant soft tissue injuries. Especially in the case of suicide attacks, there is the risk of the implantation of foreign bone fragments, which induce an immune response to allogenic bone tissue, and the risk of the transmission of infectious diseases [37, 38] Similar to projectile components, fragments can cause penetrating injuries that, if associated with haemodynamically significant bleeding into body cavities, can develop into life-threatening conditions requiring rapid surgical bleeding control. Whether fragments are primary fragments (those that are part of the weapon) or secondary fragments (those that became airborne as a result of the explosion) plays only a minor role in determining the extent of injury, which primarily depends on the distance from the centre of explosion as well as on the number, size and form of fragments
Tertiary	Structural collapse, violent displacement and entrapment These injuries are caused by structural collapse and fragmentation of buildings and vehicles or result from people being hit by objects (e.g. major parts of vehicles) that were accelerated by the blast wave They also result from individuals being thrown against solid objects by the blast wind	These injuries can be blunt or penetrating. They include traumatic asphyxia, open and closed fractures, amputations involving the extremities, compartment syndrome and crush syndrome. The underlying mechanism can also lead to blunt injuries to organs Tertiary blast injuries are the second most common injuries in primary survivors following secondary blast effects. In the case of collapsing buildings and entrapment, the number of deaths is higher than that caused by secondary blast injuries, which are otherwise the leading cause of death [29, 33, 39]
Quaternary	Effects of heat and chemical substances	Quaternary blast injuries include burns and inhalation injuries caused by heat or chemical substances They encompass exacerbations or complications of existing conditions such as those that might be seen in patients receiving anticoagulants, patients with pulmonary or cardiovascular diseases, or women who are pregnant [33] In the past, quaternary injuries were all injuries not categorised as primary, secondary or tertiary injuries. A fifth category has recently been added to the categorisation of blast injuries
Quinary	Infectious, chemical or radioactive additives to explosive devices. The underlying mechanisms are not yet completely understood	These contaminated explosive devices ("dirty bombs") can cause a hyperinflammatory state at the initial stage of treatment [29, 40]

enters the tissue, the angle of impact and the type of tissue. Wounding (wound ballistics) is always multifactorial [41, 42].

Ballistics is the study of all processes concerning projectiles that are fired from a firearm. It is divided into the following areas:

- *Internal ballistics* the study of processes that occur in the chamber and barrel when a projectile is fired
- *Intermediate ballistics* the study of processes at the muzzle
- *External ballistics* the study of processes during the flight of a projectile
- *Terminal or wound ballistics* the study of effects of projectiles in the target or tissue

Since the acceleration of a projectile is a process that only takes place inside a firearm, the kinetic energy of a projectile at the time when it leaves the muzzle depends on the power of the propellant in the cartridge, the mass of the projectile, and the length, type and shape of the barrel. Once the projectile has exited the muzzle, its energy decreases.

By contrast, the stability of a projectile and its trajectory increases with distance from the muzzle. A projectile behaves like a spinning top. The rotation of a projectile, the associated torque, the aerodynamic characteristics of a projectile and air resistance contribute to stabilising a projectile during its flight.

This effect increases with the amount of energy that a projectile has. Depending on the energy of the projectile used, the same firearms and cartridges can cause different injuries at different distances. The velocity and kinetic energy of projectiles as well as trajectory stability decrease with increasing distance.

Effects of low-velocity and high-velocity projectiles

High-velocity projectiles have a high level of kinetic energy as a result of their mass and their velocity when they exit the muzzle. High-velocity projectiles with thin jackets deform and fragment more easily, especially on impact with stable tissues.

When they hit bone, impulse transmission and hydraulic effects can lead to the complete shattering of bone. Extensive lacerations are caused to organs with high density (e.g. liver, kidney) as a result of the lateral displacement of tissue around the projectile (cavity effect), intimal flaps are not uncommon in high-velocity gunshots in close proximity to the vasculature and should be investigated for.

As a rule, the pathophysiological effects of projectiles depend on the energy that is actually transferred to tissues. This energy transfer is determined by interactions between specific projectile characteristics and tissue types.

The extent of damage and wounding effects mainly depend on the following factors:

1. type and design of the projectile
2. distance/velocity at impact
3. tumbling/trajectory stability
4. projectile caliber and weight
5. type of tissue affected by the projectile
6. deceleration/transfer of energy to tissue

Knowledge of the physics of projectile trajectories and the kinetic energy of (projectile) fragments contributes to a better understanding of wounding caused by interactions between an object that enters tissue and the tissue that is struck by an object.

Basic principles of the initial management of gunshot and blast injuries

Management of soft tissue injuries

Regardless of the extent of injury, all wounds should be explored and debrided, and necrotic tissue should be removed as soon as possible. These injuries should be treated with thorough and careful irrigation that avoids further damage.

During primary aggressive debridement, functionally important structures such as nerves, tendons and blood vessels should be identified and preserved [12, 15, 43–46].

If possible, foreign bodies that are easily accessible or are accessible without the risk of further massive soft tissue trauma should be removed.

Especially at the stage of initial treatment, the removal of all embedded foreign bodies should be postponed with a view to reducing operation times and minimising further soft tissue damage.

As a rule, these wounds should not be closed primarily. Tetanus prophylaxis is required. In the post-primary phase, swabs and cultures should be obtained regularly for assessing and documenting wound contamination. As a result of the growing importance of multidrug-resistant micro-organisms, antibiotics should be given only if bone is involved or if there are local and systemic signs of inflammation. In addition, antibiotic therapy should be guided by microbiological results [44, 46].

Ideally, subsequent re-debridement during second-look operations should be performed daily or at least every 48 h and should be repeated until the wound is completely clean and there is no evidence of infection.

Open wound treatment of large defects is recommended in patients with blast injuries and facilitates wound re-evaluation.

In recent years, temporary closure, for example using negative-pressure wound therapy (with or without the intermittent instillation of an antiseptic solution), which involves the continuous or intermittent application of subatmospheric pressure, has become a reliable method for the protection and cleansing of wounds and the promotion of granulation tissue formation [47, 48].

Likewise, good results have been reported for the topical application of antimicrobial products such as polyhexamethylene biguanide (polyhexanide, PHMB) in combination with modern dressings for the local management of wounds, which are often infected with multidrug-resistant organisms [49–51].

Synthetic skin substitutes are also useful in the complex treatment of non-infected soft tissue defects that contain no pockets. They can help prepare the wound bed, avoid infection, and prepare the transplantation of skin grafts. Sufficient removal of exudate, however, must be ensured [52].

In the reconstructive phase, different types of flaps can be used to cover defects. In general, free distant flaps must be distinguished from local flaps. Flap selection is based on the size and site of the defect to be covered [53–56].

Burn injuries

Burns, whether alone or in combination with other trauma, are sustained by 5–10% of patients with blast injuries [57–59].

Apart from the administration of analgesia and fluids, escharotomy is an indispensable initial surgical measure in the early management of at least two thirds of circumferential burns (IIa degree and higher) and is performed in an attempt to lessen constriction and improve perfusion.

Likewise, fasciotomy should also be performed as soon as possible in patients suspected of having muscle compartment syndrome caused by possible concomitant injuries.

Perfusion of the affected areas must be assessed regularly.

Vascular injuries

Since tourniquets are today widely used for bleeding control in the prehospital treatment of casualties, growing numbers of primary survivors arrive at hospitals. As a result, the management of vascular injuries has become increasingly important to surgeons [6, 60, 61].

Once an arterial injury has been diagnosed by clinical examination and, if possible, by a Doppler-duplex ultrasound examination and once the decision to perform a limb salvage procedure has been made, the further management of the patient is based on the principles of DCS, i.e. surgical control of bleeding, rapid restoration of perfusion of the affected limb, if necessary with insertion of a shunt, and prevention of compartment syndrome [62, 63].

As long as one patent vessel guarantees blood supply to the lower arm or lower leg, other injured vessels can be ligated in view to controlling the bleeding.

The ligation of central vessels of the upper arm and thigh should be avoided when limb salvage is attempted [61, 64, 65].

The most commonly injured junctional zone or proximal extremity vessels are the carotid artery, the subclavian artery, the axillary artery, the iliac artery and the femoral artery. The carotid artery can be accessed more easily than the subclavian artery. Access to and compression of the subclavian artery are more complex and may even require division of the clavicle, temporary bleeding control can be achieved by inserting and tamponading with a Foley's catheter in the bullet tract. A transabdominal or extraperitoneal approach can be used to access the iliac vessels. Once access has been gained, bleeding is controlled by compression. The vascular segments proximal and distal to the site of injury are exposed for further management. In this setting, ligation and shunting are the primary damage control manoeuvres for managing defects that are larger than 2 cm. In the hemodynamically stable, not actively bleeding patient, endovascular procedures may be a treatment option.

Bone injuries

Regardless of the cause and severity of injury, the reduction, immobilisation and fixation of fractures and dislocations play a key role in the treatment of extremity injuries and help reduce pain, improve perfusion, and prevent further damage. This also applies to blast injuries to the extremities.

In the primary in-hospital phase, either definitive treatment or appropriate temporary treatment, which is more commonly used in patients with gunshot or blast injuries, is provided in accordance with the principles of damage control orthopaedic surgery (DCOS) and must be adapted to the presenting bone injury or dislocation and concomitant injuries.

Injuries to body cavities

Penetrating thoraco-abdominal injuries are associated with a high risk of mortality [66]. The survival of patients with this injury pattern depends on rapid surgical bleeding control [31]. Visible penetrating foreign bodies are left in place until they are removed under controlled conditions since they can have a tamponading effect. Peritoneal penetration occurs in 60–75% of abdominal stab injuries and in more than 95% of abdominal gunshot injuries, which cause complex injury patterns that are difficult to diagnose and to treat as a result of wound ballistics [67].

Explosive devices again have the greatest potential to inflict devastating injuries to the trunk. They cause not only direct damage to hollow or parenchymatous organs as a result of secondary and tertiary blast effects, but also primary perfusion damage to lung parenchyma and organs. Acute post-traumatic lung injury (ARDS) or blast lung as well as secondary ischaemic bowel perforations can occur, sometimes after a delay of several days [33].

In penetrating thoracic injuries, the entrance wound must not be sealed in an airtight manner unless a chest tube has been inserted. Otherwise, a life-threatening tension pneumothorax can result [68]. The placement of a drain alone can appropriately manage 85% of penetrating thoracic injuries [69]. Indications for surgical intervention are blood loss of more than 1500 mL upon initial insertion of a tube, 500 mL of bleeding within the first hour after insertion, and continued blood loss of more than 250 mL for three consecutive hours [70]. Combined thoraco-abdominal injuries are complex and are associated with high mortality [71]. In doubt which cavity to open first, the recommendation is to enter first the abdomen, since there is a higher probability that the bleeding origins from there. Due to the negative pressure in the chest, blood is often sucked into the chest cavity in case of concomitant diaphragm injuries which can pose a diagnostic challenge. If patients continue to be unstable and if a causative abdominal injury, a tension pneumothorax or a haemothorax have been excluded, a transdiaphragmatic pericardial window procedure is recommended [72].

Penetrating abdominal injuries are treated by midline emergency laparotomy or, in rare cases e.g. with isolated liver injuries and haemodynamic stable patients, by selective non-operative management with a delayed intervention. Haemodynamic instability, evisceration and peritonitis are indications for laparotomy [73].

Bowel injuries are clipped and dropped in the setting of damage control surgery, creation of a possible stoma in severe colonic injuries is left for the relook operation and not done in the index operation. A revision procedure or second-look operation should be performed after 48–72 h [74], meanwhile the abdomen is temporarily closed with an abdominal vacuum dressing (laparostoma), which can be easily and quickly reopened in ICU in case of symptoms or suspicion of an abdominal compartment syndrome.

In extreme cases (DCS), abdominal arterial injuries can be managed by ligation of the coeliac trunk or the inferior mesenteric artery, or (unilateral) ligation of the internal iliac artery. By contrast, injuries to the superior mesenteric artery and the renal artery require reconstruction [75]. With the exception of the portal vein and the suprarenal vena cava, all intra-abdominal veins can be ligated in the DCS setting. Nevertheless, large-calibre vein reconstruction should be attempted depending on the circumstances.

Treatment and care of ambulatory patients after a blast incident

Depending on the distance to the incident scene, a medical facility must assume that the first patients who arrive at the hospital are injured and uninjured survivors who self-refer to a hospital in an uncoordinated and unplanned manner. These survivors must be triaged and must receive care and treatment in such a way that the management of further patients is not adversely affected. In this situation, one of the main objectives of triaging self-referred victims is to distinguish between uninjured and injured walk-in patients.

Based on initial triage at the incident site, the next patients who arrive at the hospital likely are unstable patients with life-threatening bleeding or another life-threatening condition. The third group of victims likely are patients who were initially assessed as haemodynamically stable and show injury patterns that are commonly seen in this type of incidents. By this time point, initial organisational measures that were taken to activate the hospital emergency response plan should ensure the availability of resources [76].

The management of ambulatory patients can be a challenge since, especially after explosions, injuries may not be clinically apparent. A number of algorithms have been established to ensure a structured approach. Figure 2 shows an algorithm that is based on Ritenour and Baskin [35]

Implications for clinical practice

The treatment of gunshot and blast injuries continues to be a challenge. Since terrorist attacks occur in civilian settings worldwide, the management of gunshot and blast injuries is no longer confined to the military environment. For this reason, an understanding of these injuries and the principles of management is essential for both military and civilian physicians and surgeons. From a medical perspective, the focus is on the management of immediately life-threatening conditions and the control of bleeding and contamination as soon as the required resources are available. All injured or otherwise affected victims must be re-evaluated continuously and dynamically for changes in their condition and for their need for treatment (Fig. 3).

For an efficient organisation of care for as many victims as possible after a terrorist incident, healthcare providers must have a fundamental understanding of the operational (and strategic) principles of all those involved in the response to the incident, they must reckon with a situation in which resources are initially overwhelmed, and they must adapt their tactical response procedures inside the hospital accordingly.

New algorithms and treatment approaches can be established, or existing treatment strategies can be improved on

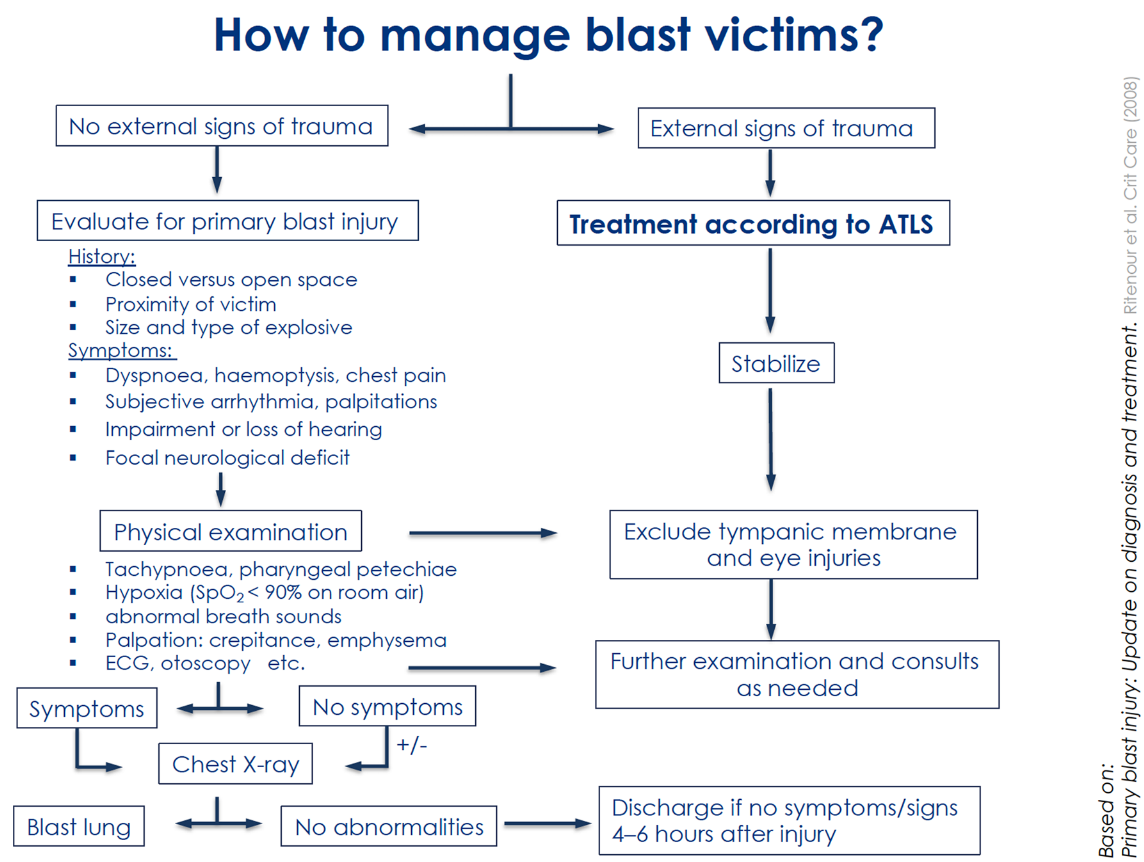

Fig. 2 Algorithm based on Ritenour and Baskin [24] for the management of blast victims

Fig. 3 Basic principles and main goals of the initial management of gunshot and blast injuries

- Consistent therapy of the deadly triad.
- STOP the BLEEDING.
- Tourniquets can save lives but may cause amputations.
- The extent of damage is usually greater than the wounds
- Blast wounds are "developing wounds". A second look is obligate.
- Consequent debridement within bounds
- Extensive wound irrigation - quantity, not pressure, is crucial!
- Blast wounds should not be closed primarily, because of the obligate contamination.
- Negative-pressure wound therapy has become a reliable method in treatment of blast wounds.
- The patients must be re-evaluated continuously and dynamically.

the basis of trauma registries and scientific analyses to take into account changes in the threat situation and complex trauma mechanisms.

Compliance with ethical standards

Conflict of interest DB, EK, CG and GA are instructors of the TDSC course. AF and BF are directors of the TDSC course. DB, AF, BF and GA developed the TDSC course concept. MM confirms that there is no conflict of interest.

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