REVIEW ARTICLE

The First Aid and Hospital Treatment of Gunshot and Blast Injuries

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SUMMARY

Background: When gunshot and blast injuries affect only a single person, first aid can always be delivered in conformity with the relevant guidelines. In contrast, when there is a dynamic casualty situation affecting many persons, such as after a terrorist attack, treatment may need to be focused on immediately life-threatening complications.

Methods: This review is based on pertinent publications retrieved by a selective search in Medline and on the authors' clinical experience.

Results: In a mass-casualty event, all initial measures are directed toward the survival of the greatest possible number of patients, in accordance with the concept of "tactical abbreviated surgical care." Typical complications such as airway obstruction, tension pneumothorax, and hemorrhage must be treated within the first 10 minutes. Patients with bleeding into body cavities or from the trunk must be given priority in transport; hemorrhage from the limbs can be adequately stabilized with a tourniquet. In-hospital care must often be oriented to the principles of "damage control surgery," with the highest priority assigned to the treatment of life-threatening conditions such as hemodynamic instability, penetrating wounds, or overt coagulopathy. The main considerations in initial surgical stabilization are control of bleeding, control of contamination and lavage, avoidance of further consequences of injury, and prevention of ischemia. Depending on the resources available, a transition can be made afterward to individualized treatment.

Conclusion: In mass-casualty events and special casualty situations, mortality can be lowered by treating immediately life-threatening complications as rapidly as possible. This includes the early identification of patients with life-threatening hemorrhage. Advance preparation for the management of a mass-casualty event is advisable so that the outcome can be as favorable as possible for all of the injured in special or tactical casualty situations.

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Gunshot and blast injuries are rare occurrences in Germany. They usually result from accidents involving guns, violent crime, careless handling of explosives, or industrial accidents. Because of the low incidence, there are no robust study data on these injuries in this country. Most publications on the outcome quality of the treatment of gunshot and blast injuries are, as one would expect, retrospective cohort studies (1–3).

The management and treatment of this class of injuries is resource-intensive and afflicted by complications (4, 5). If certain criteria are fulfilled or the clinical condition of the patients is critical, the therapeutic *modus operandi* according to the principles of damage control surgery (DCS), developed for the management of gunshot and blast injuries in the military context, can be recommended for the care of civilian victims (6, 7, e1). Treatment following DCS principles concentrates exclusively on survival and preservation of function, to minimize the additional (systemic) strain on the physiology of the severely injured persons (8, e2).

In the case of a mass injury event, a gun rampage, or a terror attack, departure from the standards of individual medical care may be required. There is a lack of uniform treatment recommendations in the sense of standards or guidelines for the prehospital or hospital treatment of gunshot and blast injuries, especially for major events.

Apart from the clinical trigger factors (*Box 1*) for the adoption of the DCS strategy, the tactical situation, the number of casualties, and shortage of resources, e.g., lack of material and personnel or technical problems, may require restriction of care procedures to maximize survival under exceptional conditions.

Specialist knowledge of typical injury patterns and treatment priorities after gunshot and blast trauma is essential so that all personnel in the rescue and care chain, from first aid to primary-care hospital, are equipped to act as needed. Our intention in publishing this article is to depict the status quo with regard to the prevailing accepted principles. In the absence of evidence-based studies, our recommendations for the treatment of gunshot and blast injuries are based on our personal experience and on the findings of recent publications identified by a selective Medline survey using relevant search terms.

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BOX 1

Trigger factors and indications for DCS*

- Persisting hemodynamic instability
- Multiple life-threatening/penetrating injuries
- Severe/hemorrhagic shock
- Injury severity score (ISS) >35
- Persisting acidosis (pH <7.2)
- Manifest coagulopathy
- Hypothermia (body temperature under 35 °C)
- Massive transfusion (>10 units PRBC)
- Shock room thoracotomy/laparotomy required
- Additional angioembolization required
- Shortage of resources or mass injury event

*Modified from Parker (e17) and Asensio (34); DCS, damage control surgery; PRBC, packed red blood cells

Initial Phase and Prehospital Care

Depending on the situation, civilians with no kind of protective clothing can have injuries of any part of the body (5). In the first 10 min after injury (the “platinum 10 minutes”), the victims are in danger of the typical, avoidable immediately life-threatening complications (*Figure*) (9). In addition, thoracoabdominal and proximal bleeding bears the highest potential for mortality and necessitates swift, targeted primary surgical care. Hemorrhage from these sites is responsible for most of the avoidable deaths from gunshot and blast injuries (10).

It has been shown that care quality can be improved and immediate overall mortality reduced by following structured trauma care algorithms and uniform, standardized treatment principles (ABCDE algorithm,

prehospital trauma life support [PHTLS], advanced trauma life support [ATLS]) together with communication of essential information and vital parameters using a uniform vocabulary (e3, 11).

Persons with life-threatening hemorrhage at proximal sites (axilla and groin) or in the body cavities must be identified as soon as possible.

In the short term (1 to 2 hours), bleeding from arteries of the extremities can be controlled adequately by means of a tourniquet (C-ABCDE). Bleeding from the groin or armpit is usually not sufficiently checked by wound packing or tamponade (with or without a hemostatic) and local pressure.

Active bleeding in the body cavities cannot be brought under control at the place of injury or before admission to hospital. Only swift, logistically optimized transport to a facility equipped for surgical hemostasis can reduce mortality.

Hospital treatment

When a number of patients with gunshot or blast injuries are admitted to hospital at the same time, an experienced physician, ideally one trained in rescue, catastrophe, and tactical medicine, must decide how and in what order to proceed.

In mass injury events, the priority is survival of as many victims as possible. Such an event leads to a temporary shortage of hospital resources, and in this phase individual medicine is not an option. All efforts have to be focused on treatment of the immediately life-threatening injuries (DCS together with damage-control orthopedics [DCO] and damage-control resuscitation [DCR]).

The beginning and end of this critical phase of medical care must be clearly defined and communicated and thus constitute a dynamic process (e4).

Management according to DCS principles

Management according to DCS principles should be initiated when the so-called clinical or situation-dependent trigger factors are present (*Box 1*).

The basic principles and goals of DCS are summarized in *Box 2*. All efforts are directed towards stabilization of the pathophysiology and avoidance or treatment of the lethal triad (acidosis, coagulopathy, hypothermia).

Simple, rapid procedures are required. Surgery to control bleeding is restricted to a minimum in order to prevent complications from organ dysfunction or protracted shock and avoid further contamination. Familiarity with the pathophysiology of gunshot and blast injuries is crucial to decision-making in such a scenario.

Pathophysiology of blast injuries

Explosive materials are divided according to the amount of energy released and the speed of the reaction into high order explosives and low order explosives. In addition, manufactured devices are distinguished from improvised explosive devices (IED) (e5). Small metal

FIGURE

Triad of immediately life-threatening complications following gunshot and blast injuries

objects (nails, ball bearings) are often added to IED to increase fragmentation.

The injury pattern depends on the device used and the location. In an open space the effect decreases exponentially with increasing distance from the point of detonation, but in an enclosed area the transmitted energy is potentiated by reflection of pressure waves (4, 12, 13). Independent of these fundamental physical principles, detonation of explosives causes five types of injuries, classified as shown in *Table 1*.

The wound ballistics of gunshot injuries

Internal ballistics, external ballistics, and target ballistics are the key terms describing the function of guns up to the moment when the projectile exits the barrel. Detailed presentation of these concepts is outside the scope of this review. Medical interest is primarily in the effect of the projectile on its target, i.e., the wound ballistics. A multitude of factors determine exactly what happens. The factors listed in *Box 3* are decisive for the amount of energy transmitted from projectile to tissues and the damage caused.

Weapons of identical type and caliber, and also metal fragments, can cause different wounds at different distances depending on the kinetic energy on impact and the specific energy transmission to the tissues.

Treatment of typical injuries

Blast or gunshot injuries of body cavities

Penetrating thoracoabdominal injuries have a high lethal potential (14). The survival of victims of such injuries depends on swift surgical control of bleeding (12). Visible perforating foreign bodies are initially left in place because they may exert a tamponading effect. Abdominal stab wounds perforate the peritoneum in 60 to 75% of cases, but the figure for gunshot injuries is 95%, and owing to the wound ballistics of the projectile the injury patterns are complex and challenging, both diagnostically and therapeutically (15).

Explosives have by far the highest destructive potential. In the trunk, immediate direct damage to hollow or parenchymatous organs is accompanied by primary perfusion damage of the lung parenchyma and the organs. The possible delayed consequences, sometimes not arising until days later, are acute post-traumatic lung failure (acute respiratory distress syndrome [ARDS] or blast lung) and secondary ischemic bowel perforations.

In perforating thoracic trauma, airtight closure of the entry wound without drain insertion is contraindicated, as life-threatening tension pneumothorax may result (e6). Drainage constitutes adequate treatment in 85% of perforating thoracic injuries (e7). In the event of heavy or persistent bleeding (>1500 mL initially, 500 mL/h, or >250 mL/h for >4 h), surgical intervention is recommended (e8). An overview of DCS techniques is provided in *Box 4*.

Combined thoracoabdominal injuries are complex and associated with high mortality. A median laparotomy is created for exploration. In the event of

BOX 2

Goals of initial DCS stabilization

- Stop the bleeding
- Containment of contamination and lavage
- Prevention of further injuries/increased complications
- Ischemia prophylaxis, preservation of perfusion (or reperfusion)

DCS, damage control surgery

continuing instability, exclusion of an intra-abdominal cause, and exclusion of tension pneumothorax or hemopneumothorax, transdiaphragmatic pericardial windowing is recommended (16).

Perforating abdominal injuries are generally treated by means of emergency median laparotomy. In rare selected cases nonsurgical treatment may be preferred, with intervention later if needed. Hemodynamic instability, evisceration, and peritonitis are indications for laparotomy (17).

The DCS procedures to contain bleeding and contamination in abdominal injuries are listed in *Table 2*. DCS often includes a laparostomy to avoid formation of an abdominal compartment. Revision or “second-look” surgery should take place 24 to 72 hours later (18). Penetrating trauma frequently involves the small and large bowel (e9).

After the bowel, the liver—the largest parenchymatous organ of the body—is the organ most often affected by perforating injuries, although the damage is seldom severe. Compression and application of local hemostatic agents can be primarily definitive. Resection is necessary in only 5% of liver injuries, and complex injuries are even rarer, accounting for only 2% of cases (e7).

Damage to the spleen, particularly in gunshot injuries or after blast trauma, rapidly becomes a significant hemodynamic problem. The basic decision—whether or not the spleen can be preserved—depends on the severity of injury and the patient’s hemodynamic situation. In the DCS scenario the spleen is removed. It is essential to administer the necessary vaccinations and booster injections in the course of further treatment.

Perforating injuries of the pancreas are very rare. After containment of bleeding, the further treatment depends on whether the duct system is injured (e10). While parenchymal injuries should be drained, the options for treatment of duct injuries include interventions such as endoscopic retrograde cholangiopancreatography (ERCP), with insertion of a stent if required, and surgery ranging from debridement to resection. Primarily complex resections (head of pancreas) are associated with a poorer prognosis and represent the surgical solution of last resort (19).

TABLE 1

Classification of blast injuries

Blast injury	Mechanism	Possible injuries
Primary	Barotrauma from pressure or shock wave, caused by fluctuations of atmospheric pressure in the blast wave	Eardrum rupture, injury of air-filled hollow organs ("blast lung", bowel, etc.), air embolism, dissection and avulsion of soft tissues (12, 35, 36)
Secondary	Fragmentation effect: owing to their shape and their eccentric rotation, fragments travelling outward from the detonation site can produce a wound cavity 20 to 25 times larger than the fragments themselves and bring about local tissue pressure of up to 6.89 bar (e14, e18, 37).	Cause of most injuries and deaths (23): – Perforating injuries throughout the body, cavitation effect of fragments with resulting increased wound size, contusions
Tertiary	Collapsing buildings, impact trauma, burial; being thrown against solid objects by the blast wave also falls in this category.	After secondary injuries, tertiary injuries are the type found most frequently among primary survivors: – Predominantly blunt injuries over the whole body, compartment syndrome, crush syndrome, traumatic asphyxia, fractures, amputations, organ damage; in the case of collapsing buildings, entrapment and entombment are responsible for a higher number of primary deaths and higher overall mortality (4, 38)
Quaternary	Burns, inhalation trauma, exacerbation of pre-existing diseases	Burns and inhalation trauma, caused by heat or chemicals, decompensation, e.g., of pulmonary and cardiovascular diseases, complications of anticoagulant treatment
Quinary	Infectious, chemical, or radioactive additives to the explosives; not yet completely explained	Hyperinflammatory states at the initial stage of treatment (4, 39)

If abdominal arteries are injured, in the extreme case (DCS) the celiac trunk, mesenteric artery, or internal iliac artery (unilaterally) can be ligated. Damage to the superior mesenteric artery or the renal artery, however, requires reconstruction (e11).

Under DCS conditions, every intra-abdominal vein except the portal vein can be ligated. Nevertheless, depending on the circumstances one should attempt reconstruction of high-caliber veins.

A penetrating injury of the intraperitoneal portion of the bladder should be surgically closed prior to catheter drainage. In the case of extraperitoneal bladder injuries, catheter drainage suffices. Exceptions are extraperitoneal injury of the bladder neck or perforation by objects such as foreign bodies or bone fragments, e.g., from complex pelvic fractures, that remain inside the bladder (e12).

Injuries to proximal blood vessels

The proximal blood vessels most frequently injured are the carotid artery, the subclavian artery, and the iliac artery or femoral artery. While access to the carotid artery is uncomplicated, compression of and access to the subclavian artery are more complex and may even necessitate division of the clavicle.

Access to the pelvic vascular axis can be achieved by the transabdominal or extraperitoneal route. The basic principles are control of bleeding by compression and exposure of the vessel proximal and distal to the site of injury with encircling of the vessel, and then treatment of the wound. In the context of DCS, ligation and the shunt procedure are the primary options for bridging defects of more than 2 cm. Interventional procedures for endovascular hemostasis have become standard in the absence of DCS trigger factors.

Vascular injuries of the extremities

Peripheral vascular injuries and ischemia are treated by control of bleeding, restoration of perfusion by means of locally inserted shunts, vascular bypasses, and/or fasciotomy following an ischemic event (20, 21).

If the goal is preservation of the limb, ligation of central vessels of the upper arm or thigh is contraindicated. Definitive vascular reconstruction should be achieved as swiftly as possible, ideally within 2 hours of shunt insertion. Use of an autologous vein, ideally the great saphenous vein, is recommended for vascular reconstruction after fracture stabilization (20–23). Opinions differ regarding the timing of reconstruction, so the decision should depend on the patient's overall status; fasciotomy is mandatory in the case of ligation (e13, 24).

Fractures of the extremities

Fractures of large tubular bones in the extremities are stabilized in the correct axial alignment by immobilization with an external fixator, extension, or a plaster cast. This repositions large fracture surfaces and

BOX 3

Factors influencing the energy transfer to tissues in gunshot injuries

- Type/construction of projectile
- Distance/impact velocity
- Stability of projectile in flight
- Projectile caliber and weight
- Tissue properties

contains local bleeding. Furthermore, correct axial alignment of the fractures results in relaxation or relief of the local nerves. This prevents late complications of peripheral perfusion or motor and sensory function.

Perforating soft-tissue injuries and contusions

The most frequently occurring type of injury is penetration by projectiles or fragments (25, e14). The goal is swift control of contamination to prevent secondary infection. The initial treatment comprises local irrigation with an antiseptic agent (e.g., 0.04% polyhexanide) and application of a colorless, nonadhesive antiseptic dressing. As soon as possible, depending on the situation, soft-tissue defects are then decontaminated by two rinses with large quantities of fluid and obviously avital areas of tissue are surgically debrided.

In the case of open fractures, urgent systemic antibiotics (aerobic and anaerobic spectrum, e.g., a second-generation cephalosporin with metronidazole) is indicated. Tetanus prophylaxis is mandatory.

Retrieval of embedded foreign bodies is left until later so as to minimize operating time and to avoid further soft-tissue damage. Primary wound closure is counterproductive—open treatment is the method of choice for gunshot and blast injuries of the extremities, including re-evaluation.

Following surgical revision, temporary wound coverings can be applied, e.g., negative-pressure wound therapy dressings or topical antiseptic wound gels. These have shown good results for multiresistant pathogens with regard to local cleansing and prevention of recontamination (e15, 26, 27). In the postprimary phase, local contamination is documented by microbiological examination of material harvested using swabs. Specific antibiotics are given as required (25, 26).

Burns

Up to 40% of victims of blast injuries suffer burns, either alone or in combination with other injuries. If the burns (degree IIa or worse) extend around more than two thirds of the circumference, immediate escharotomy is indicated, accompanied by fasciotomy if there is clinical suspicion of muscular compartment syndrome (e16, 28).

The patient is first washed with warm disinfectant solution (hypothermia!), then the burns are superficially debrided (removal of all loose shreds of skin and blisters) and dressed with colorless antiseptic gel (e.g., polyhexanide nitrocellulose wound gel [polyhexamethylene biguanide, PHMB]) and sterile nonadhesive gauze (e16, 28).

Compartment syndrome and fasciotomy

In compartment syndrome, which may be caused, for example, by fracture, hemorrhage, crush injury, or ischemia–reperfusion, the perfusion of the affected part of the extremity is restricted by elevated pressure in the compartment concerned. If compartment syndrome is clinically suspected, therapeutic fasciotomy must be

BOX 4

DCTS techniques*

- Swift emergency thoracotomy via anterolateral standard route (fifth intercostal space)
- Nonanatomical lung resections using a stapler
- "En masse" lobectomy/pneumonectomy
- All-layer closure of thoracic wall musculature
- Temporary thoracic packing in presence of diffuse bleeding
- Vascular interventions (ligatures/shunts, replacement)
- Temporary patch closure of thoracic wall defects

Goal: Operating time 60 to max. 90 min

*Modified from Garcia et al. (40); DCTS, damage control thoracic surgery

carried out as soon as possible (29–31). Urgent indications for fasciotomy include injury or ligation of arteries or veins in the extremities, long transport times before revascularization, crush injury, and the slightest suspicion of imminent compartment formation prior to transfer (20, 21, 23, e13).

Amputations

The difficult decision whether to preserve or amputate a limb can sometimes be postponed following adequate initial immobilization (fixator) and restoration of perfusion (e.g., shunt insertion). On the principle "life before limb," however, an extremity may have to be sacrificed for the sake of stabilizing the patient as swiftly as possible.

TABLE 2

DCS techniques in abdominal injuries

Injury	Measure
Massive bleeding	Aortic clamping
Bleeding from large vessels	Ligature/bypass
Injury to liver parenchyma	Packing/compression
Bowel lesions	Staple closure/stoma/no anastomoses
Injuries to arteries	Shunt
Injuries to veins	Ligature
Urinary bladder injury	Catheter/drainage
Pancreas injury	Drainage
Peritoneal contamination	Lavage + laparostomy
Abdominal compartment	Laparostomy
Visceral swelling	Laparostomy

Goal: Operating time 60 to max. 90 min

DCS, Damage control surgery

If emergency amputation is necessary, the previously postulated guillotine technique should not be used. Rather, a debridement amputation should be carried out as far distal as possible and the wound should not be closed. Complete wound closure ensues a few days later under controlled conditions (21, 32, 33).

Goals of further treatment

Once the situation has been contained and the overall extent of damage is known, priority-oriented further treatment of all casualties can begin. It may be possible to return to individual medical care. Depending on the resources at hand, the casualties must be (re)distributed to the available institutions so that individualized surgical treatment can be carried out for as many of the victims as possible, or definitive treatment commenced.

The goal of the subsequent phase of restitution and stabilization is to continue and optimize the treatment that has been instituted. Measures to this end include:

- Restoration of euvoemia
- Normalization of ventilation parameters with correction of the acid–base balance
- Optimization of perfusion and oxygenation in the periphery
- Rewarming of the patient
- Specific measures to optimize coagulation, adapted to the status

At an appropriate time, all objects and materials potentially relevant to investigation of the event, particularly projectiles, fragments, and clothing, should be put aside for forensic analysis.

Conflict of interest statement

The authors declare that no conflict of interest exists.

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KEY MESSAGES

- The leading cause of death in gunshot and blast injuries is hemodynamically significant bleeding.
- Mortality can be reduced only by immediate emergency medical treatment of avoidable causes of death (tension pneumothorax, airway obstruction, bleeding from the extremities) and swift surgical control of hemodynamically significant bleeding from proximal vessels or in body cavities.
- Operative treatment follows the principles of damage control surgery (DCS). In special situations and if resources are severely limited, management concentrates on the procedures of tactical abbreviated surgical care (TASC).
- DCS focuses on surgical stabilization. Immediate treatment is restricted to life-saving procedures, with further necessary interventions ensuing over the following 24 to 72 hours.
- TASC is carried out with special regard to the availability of resources according to the DCS criteria.

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Supplementary material

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