

34 Conflict surgery

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BLAST INJURIES

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As already discussed, blast has become the predominant mechanism of injury in recent conflicts. Unfortunately, terrorist attacks within urban centres mean that these injuries are increasingly encountered within civilian practice. While explosives come in many forms and their effects vary as a result, fundamental principles underlie all blast events. An explosive may be defined as 'a substance that can be made to undergo a rapid chemical reaction that will transform a liquid or solid into gas, liberating a large amount of energy'. The explosive properties of such a material are determined by its chemical composition. Frederick Gerard Friedlander, 1917–2001, Austrian mathematician, lived and worked in the UK from 1934, at which time he was expelled. Low explosives react by a process called deflagration, where a flame passing through the material at a rate significantly slower than the speed of sound. They are made up of a combustible material and an accompanying oxidant. Low explosives include gunpowder, gasoline and pyrotechnics such as fireworks and flares. Low explosives more commonly cause burns than typical blast injuries and will not be discussed further. In contrast, high explosives degrade via detonation. Shock waves are passed through the material at supersonic speeds and the resultant energy is expelled at very high rates. High explosives include plastic explosive and trinitrotoluene (TNT). The input of a relatively small amount of energy results in the production of a very large volume of gas, at high speed and pressure. The outward expansion causes a wave of compressed air that moves away from the point of detonation at supersonic speeds and in a uniform sphere (within a free field). The change in surrounding pressure is described as the blast overpressure. Following detonation within a free field, there is a near instantaneous pressure rise, which falls exponentially. This is classically described by the Friedlander curve (Figure 34.4). This characteristic pressure peak is only seen during a truly free (almost theoretical) scenario. Enclosure of the blast or reflection of blast waves by people, vehicles or buildings is likely to change the overpressure profile such that high pressures may be sustained for longer periods and have a greater propensity to cause injury. For this reason, blasts within enclosed spaces are notable for causing a greater range and severity of injury. In addition to expanding gases, detonation of explosives may result in the expulsion of fragments. These fragments may be part of a device casing, separate material deliberately added with the intention of fragmentation or environmental material flung by the blast. Blast winds are generated by the displacement of surrounding air. The direction of these winds may change as the blast subsides.

Blast overpressure Quasi-instantaneous pressure rise Pressure Positive pressure phase Negative pressure phase Atmospheric pressure Time Figure 34.4 Theoretical blast overpressure changes within a free field.

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Ballistic injuries

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Terminal ballistics (or wound ballistics) describes the interaction between projectiles and target tissue. This interaction and subsequent transfer of energy cause injury. The kinetic energy of the bullet is related to the mass and velocity of the impacting projectile. Both the mass and velocity of military firearms may be considerably greater than those commonly seen in civilian trauma, leading to higher energies and more severe wounds. While the weapon and ammunition type may be a determinant in the potential injury caused, many other factors, including range, angle, clothing, armour and anatomical variation, will determine the actual wound pattern. Although an understanding of ballistic science may allow a surgeon to anticipate possible injuries, each should be evaluated and managed individually. In consideration of the damage done, tissue may be described by the areas of disruption caused by the projectile and the permanent and temporary wound cavity, which are illustrated in Figure 34.2. The permanent cavity is the localised area of definitive tissue injury caused by contact with the projectile. This area of cell necrosis is the result of direct contact, crushing and laceration of tissues in the path of the projectile. The size and trajectory of the projectile determines the cavity size. This type of cavity is the predominant wound effect of pistol bullets, which have relatively low energy. Higher energy projectiles, including military rifle and machine gun bullets, may be subject to greater degrees of deformation and tumbling as they travel through tissue. This increases the effective cross-sectional area of the projectile and may lead to a larger and less regular permanent wound cavity. In contrast, the temporary wound cavity is created by lateral displacement of tissue that has not been in direct contact with the bullet. The degree of damage in this area is dependent on the amount of energy transferred by the bullet and the material properties of the tissue itself. Individual tissues have an elastic strength that resists the stretching caused by a projectile. As the energy increases, the tissue is no longer able to rebound and, above certain thresholds, contusion, laceration and permanent damage may occur. Skin, muscle, lung and bowel wall tissues have good elastic strength and may rebound well following stretch, with minimal damage within the temporary wound cavity. In contrast, liver, brain and spleen have poor elasticity and are more likely to shatter when stretched. The incompressibility of fluids within hollow organs (bowel and bladder) means that they are vulnerable to stretch despite favourable properties of the tissue wall itself.

Summary box 34.2 Ballistics

A B Figure 34.2 Diagram showing the permanent wound cavity (A) and the temporary wound cavity (B). This relatively large temporary cavity is more typical of a higher energy weapon. Internal ballistics – characterise the projectile within the weapon during firing External ballistics – characterise the projectile in free flight Terminal ballistics – characterise the projectile/tissue interaction

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Terminal ballistics – characterise the projectile/tissue interaction

CONSIDERATIONS

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International Humanitarian Law (IHL) regulates humanitarian issues during armed conflict. Modern IHL is derived from a variety of sources, notably the Geneva Conventions and their additional protocols, along with further specific regulations from the United Nations and The Hague Conventions. IHL provides medical personnel with rights in times of armed war, but also assigns duties to them surrounding the rights of protected personnel under their care. Importantly, medical personnel are bound by medical ethics and IHL to treat patients solely based on need and without regard for their nationality, race and class or their religious or political beliefs. Along with providing medical support to deployed forces, treatment is offered to both home nation and enemy combatants. The treatment of such patients may require a change in the approach to their definitive care. Evacuation of these Medical support roles may not be possible and the staged approach to care may need modification. Transfer to host nation medical facilities may be possible but dependent on local capability. This scenario may require an adaptation to clinical thinking. As an example, consider the ethical and logistical dilemma in performing revascularisation and orthoplastic procedures for a local patient in a country without rehabilitation facilities. Medical personnel and facilities are protected under IHL and should not be attacked. However, the nature of modern conflict is unconventional; guerrilla warfare and the inability of deployed forces to define the enemy combatant requires the security of facilities and personnel to be of the highest priority.

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Complex dismounted blast injury

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In contrast, the dismounted IED casualty may sustain a characteristic pattern of injuries, including lower limb amputation, pelvic fracture and genital, perineal and rectal injuries. The most common cause of death in such casualties is from exsanguination. Initial management is therefore focused upon control of bleeding with tourniquets and swift proximal vascular control. This group may in the future benefit from the judicious use of resuscitative endovascular balloon occlusion of the aorta (REBOA) as a bridge to definitive control. Role of REBOA in civilian trauma remains greatly contested and its use in military and austere settings may be complicated by long timelines entailing a prohibitively high burden of ischaemic injury. Following control of bleeding and DCR, management principles for complex dismounted blast injury include debridement and delayed reconstruction of soft tissues. Orthopaedic considerations include external fixation of pelvic injuries and the retention of maximal limb length for rehabilitation. High rates of rectal injuries require careful rectal examination with proctoscopy and early consideration of faecal diversion. Genitourinary injuries should be managed with careful catheterisation if possible (and consideration of suprapubic catheters) with exploration of scrotal wounds. - Complex dismounted blast injury

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- DCS was first described by Rotondo et al., although the idea of an abbreviated laparotomy for the unwell patient was not totally novel. The concepts of DCS were initially applied to complex trauma patients with combined vascular and visceral injuries. Improved outcomes were seen following DCS principles compared with conventional definitive surgery. The DCS approach is to restore physiology over anatomy and is typically divided into several phases: Phase 1. Recognition of injury severity and the need for damage control principles, both surgical and resuscitative. Features of phase 1 include rapid-sequence induction of anaesthesia and intubation, early rewarming and prompt movement to the operating theatre. Phase 2. Immediate laparotomy with rapid control of bleeding and contamination, abdominal packing and temporary wound closure. Phase 3. Movement to the intensive care unit (ICU) for ongoing resuscitation with normalisation of biochemical and physiological parameters. Phase 4. Re-exploration in the operating theatre to perform definitive repair of all injuries. Multiple procedures on multiple occasions may be required. Even at this stage, non-essential procedures may be truncated or delayed if physiology deteriorates. This may not be straightforward. While various physiological and biochemical markers of injury have been suggested, there is no validated threshold. Hypothermia, coagulopathy, acidosis, blood loss and anticipated operative time should all be considered (see Chapters 26 and 27). The benefits of a DCS approach to those patients who need it has been repeatedly shown, but liberal, and perhaps overzealous, use of DCS is unlikely to be beneficial to those who would tolerate definitive repair. DCS puts a heavy toll on theatre and ICU resources. In addition, multiple trips to theatre may increase the likelihood of morbidity, including abdominal wall hernias, fistulae and infection. Damage control resuscitation (DCR) should be concurrent with DCS. The principles of DCR include permissive hypotension, the avoidance of crystalloid with haemostatic resuscitation and the recognition and management of acute traumatic coagulopathy (ATC). The application of these principles to military patients is uncertain because of longer time lines. Prolonged periods of permissive hypotension are likely to be harmful, whereas haemostatic resuscitation and management of ATC is ineffective in the absence of haemorrhage control.
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DECISION MAKING WITHIN THE DEPLOYED ENVIRONMENT

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The damage control approach is vital in a proportion of war injuries, but thought must be given to available resources. Within a well-established role 3 unit, both DCS and definitive procedures are likely to be possible. Blood and blood products are also likely to be available and restocked regularly. In this mode of care. In contrast, decision making becomes more crucial within the austere environment. Theatre space, intensive care beds, - equipment and blood products may be limited. Long evacuation times may contraindicate permissive hypotension. Limited resources, such as blood, may need to be divided among casualties. Within a role 1 or role 2 facility, immediate evacuation may be undertaken in preference to more thorough stabilisation. Decision making of this nature is complex and difficult and requires practice in the context of simulation, exercises and courses. - DECISION MAKING WITHIN THE DEPLOYED ENVIRONMENT

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Environmental effects

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As already alluded to, the shockwave of blast overpressure is modified by an enclosed or partially enclosed space. Environmental variations may make marked differences to injury rates and clinical presentations following blast. Higher rates of blast lung and TM rupture are seen following enclosed blast (in which both the casualty and blast are enclosed). In contrast, secondary blast injuries may be lower in number as more people are protected from energised fragments. Tertiary injury is difficult to predict based on blast characteristics but a higher proportion of blunt injuries have been seen following enclosed blast. A distinct pattern of injury has been described following underbody blast against military vehicles. Underbody blast casualties have a greater range of injuries and are overall more severely injured. In addition to blunt injury sustained from displacement within the vehicle, the effect of blast is manifested by propagation of the shockwave through a solid, with both upwards deformation of the floor and a rapid upwards acceleration of the whole vehicle and subsequent deceleration following impact with the ground. The solid blast injury burden includes severe foot and ankle and pelvic injuries. Mortality from underbody blast is most commonly caused by head injury and non-compressible torso haemorrhage, including aortic disruption and liver laceration. Environmental effects

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INFECTION

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Battlefield wounds are by their very nature grossly contaminated and the treatment and prevention of infection is one of the basic functions of war surgery. Wounds sustained during warfare are high-energy wounds with large areas of devitalised tissue. This is particularly the case for dismounted blast injuries - where there is massive disruption of tissue planes with soil and debris forced into the zones of injury (Figure 34.6). Wounding agents are all non-sterile and highly likely to be contaminated by bacteria. Both large-calibre ballistic wounds and blast wounds may contain dirty clothing or contaminated fragments. Multiple steps in casualty evacuation and substantial delays before treatment may allow progression of contamination to clinically significant infection. Specific organism patterns will depend on endemic flora, but commonly seen bacteria include: Gram-positive cocci, including staphylococci, streptococci and enterococci; Gram-negative rods, including *Escherichia coli*, *Proteus* and *Klebsiella*; *Pseudomonas*, *Enterobacter*, *Acinetobacter* and *Serratia* are common nosocomial pathogens that are usually expected among casualties following long periods of hospitalisation; *Salmonella*, *Shigella* and *Vibrio* should be suspected in cases of bacterial dysentery. Fungal infection, including *Candida*, should be considered in casualties hospitalised for prolonged periods, those who are malnourished or immunosuppressed or those who have received broad-spectrum antibiotics, adrenocortical steroids or parenteral nutrition. Techniques to reduce the infectious burden are part of every aspect of war surgery. At the point of wounding, sterile dressings should be applied. Antibiotics, if available, should be administered if evacuation and further treatment are likely to be delayed. Empirical antibiotic therapy should be commenced or continued following movement to a medical facility. The mainstay of treatment is prompt surgical control of the infectious cause with adequate debridement of non-viable tissue and drainage of infective material. Extensive irrigation should be employed to remove dead tissue and foreign bodies. High-pressure wound lavage has been shown to increase bacterial propagation into soft tissue and is not indicated. With few exceptions (such as facial wounds), closure of contaminated war wounds should not be performed at the time of first operation. The open wound should be left with clean, moist dressings. Negative pressure wound therapy should be considered for larger wounds. Antibiotic therapy should be tailored to specific wounds with the empirical antibiotic choice dependent on the injured body region or cavity. Microbial culture will aid the guidance wounds should be considered tetanus prone and appropriate tetanus prophylaxis administered. Clinical experience and judgement are essential in the assessment of war wounds. Adequate exposure, often with extension of the wound, is mandated to ensure debridement of all devitalised tissue. Serial operations may be required. Early consideration should be given to soft-tissue coverage. The skin is often remarkably resilient to injury and conservative debridement of it may facilitate more successful reconstruction.

(b) (c) Figure 34.6 Blast injuries including bilateral lower limb amputation (a), buttock and thigh soft tissue injury (b) and complex hind foot injury (c). The need for extensive debridement is

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Improvised explosive devices

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The characteristic weapon of modern warfare has been the IED, which was the leading cause of death among coalition 22 troops during conflicts in Iraq and Afghanistan. devices may range from rudimentary homemade explosives to sophisticated devices containing high explosives. Within this broad range of devices are further categories including road side explosives and blast mines, suicide bombers and explosive formed projectiles (EFPs). EFPs are a particular form of device with a deformable plate on the uppermost surface. The detonation of the device and expansion of the explosive products deforms this plate into a missile shape, while simultaneously accelerating it upwards to very high velocities. Alternatively, copper plates may melt to create a high-speed molten jet (a shaped charge). Upon contact with a target (typically a vehicle), the missile impacts the hull of the vehicle with a degree of penetration dependent on the device and vehicle armour. Huge amounts of kinetic energy are dispersed through the vehicle and occupants. Injuries may be caused by both direct impact of the deforming hull and gross upwards acceleration followed by downwards deceleration of the whole vehicle. Improvised explosive devices

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Introduction

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The treatment of war wounds is as ancient as warfare itself. The Edwin Smith papyrus has been dated to 1600 BC and is the oldest known treatise on trauma surgery and anatomy. The history of battlefield surgery is the history of surgical advancement and the importance of the medical lessons learned from war have long been recognised. While almost every conflict has served to increase our knowledge of the treatment of war injuries, and many individuals have played significant parts in the development of war surgery, Dominique Jean Larrey is considered by many to be the first modern military surgeon. Larrey, a French battlefield surgeon and favourite of Napoleon, devised some of the first systems of triage and casualty care that still form the fundamentals of modern military medicine. These systems must be in place in order to overcome the difficulties and logistical challenges of providing medical care to a battlefield.

He who wishes to be a surgeon must first go to war. Hippocrates (c. 460–377 BC)

Learning objectives

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To understand and appreciate: Fundamental differences of war surgery • Injury patterns of modern warfare • Learning objectives

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MANAGEMENT OF GUNSHOT WOUNDS

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The management of gunshot wounds in a conflict setting may differ from that in civilian practice. The typical low-energy wounds caused by pistols are sometimes managed conservatively in civilian trauma centres with adequate wound care, cleaning and antibiotics. Military wounds are associated with higher energies, higher rates of infection and more severe injury. The extent of these injuries, including the size of the wound cavities, may not be adequately assessed without thorough surgical examination (Figure 34.3). As such, most penetrating wounds in the military setting are explored under anaesthetic. The extent and capacity for recovery of the temporary wound cavity may not be appreciated at the time of the first operation. A damage control approach should be adopted if the physiology of the patient dictates it. An interval period may also allow for adequate appreciation of the permanent wound cavity, along with the response of the surrounding structures and demarcation of non-viable tissue.

(b) Figure 34.3 Entry wound to the right shoulder (a) with the wound extended in order to assess it adequately (b) .

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While haemorrhage control prior to the need for massive transfusion is ideal, this is often not the case. The degree of injury and associated massive blood loss associated with war injuries may necessitate large-volume transfusion. The use of crystalloids to resuscitate exsanguinating patients is strongly discouraged, but the optimal ratio of blood products has not yet been ascertained. Massive transfusion protocols exist within most deployed units. The use of such a protocol in a UK role 3 facility , along with aggressive resuscitation and use of blood products, has been associated with improved trauma 18 outcomes. The success of such a protocol is highly dependent on a steady stream of blood products and reflects the sophisticated transfusion infrastructure that should be woven into a deployed capability . Blood transfusion is increasingly administered in a more forward location (within both role 1 and role 2 environments) with limited volumes of blood transported to the point of w ounding by aeromedical response teams. Future resuscitativ strategies are under much scrutiny . The use of whole blood (and the possibility of ‘walking blood banks’) may be combined with alternatives to conventional blood components, which can join adequate oxygen carriage with positive or neutral e ff ects 19 on patient coagulation. MASSIVE TRANSFUSION

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MEDICAL EVACUATION

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Medical evacuation refers to the movement and en route care of casualties within a conflict zone. The evacuation may be the initial movement from a battlefield or between other more sophisticated echelons of care, up to and including repatriation to a home nation. Aeromedical evacuation using either fixed or rotary wing - aircraft has had a major impact on evacuation timelines. Certain considerations must be made prior to and during aeromedical evacuation: /uni25CF the patient should be sufficiently stabilised for the anticipated mode and duration of travel; /uni25CF the patient's airway and breathing are adequate for movement; /uni25CF intravenous access, surgical drains, urinary catheters and any other tubes should be firmly secured; - /uni25CF patients at high risk for thoracic barotrauma should be considered for prophylactic chest tube placement before prolonged aeromedical evacuation; - /uni25CF blankets and/or warmers should cover the patient securely to mitigate against hypothermia. The capability of different evacuation platforms may vary - from highly sophisticated mobile critical care units to the simple transportation of casualties by non-medical personnel. These capabilities, along with the timelines and distances involved in casualty movement, should be major considerations for the planning of medical support operations. The 'golden hour' is an oft-quoted principle in trauma medicine and refers to the initial time period following injury during which a life is most likely lost or saved. Although the origins and applicability of the term are disputed, the principle is ubiquitously understood. Within the military setting, death is certainly seen to occur most commonly within the prehospital environment and within a short period after injury, with better outcomes seen after rapid transport to surgical care. Improvement in outcomes from severe deployed trauma may rely upon either the shortening of time to damage control care or lengthening of the 'golden hour'. Shortening of timelines may be achieved with change in transport systems or deployment of surgical teams further 'forward', or even the use of telemedical technology to utilise remote expertise. Lengthening of the golden hour may perhaps be achieved by the use of novel prehospital haemorrhage control techniques or an 5-8 increase in the availability of prehospital blood products. MEDICAL EVACUATION

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The term 'role' is used to designate the tiers of medical support that integrate into a modern military operation. An appreciation of the capabilities and limitations of these roles is essential to improving the care of casualties at each stage. Different nations and forces will have medical support configured with some variability but, overall, systems are similar in order to ensure that the basic treatment, supply and evacuation needs that are essential for a military operation are available.

Role 1 medical support provides for routine primary health care, specialised first aid, triage, resuscitation and stabilisation. It is integrated within a small unit. The capabilities of role 1 care will depend greatly on the size of the unit and the training of the personnel within it.

Role 2 provides an intermediate capability for the reception and triage of casualties, as well as being able to perform resuscitation and treatment of shock to a higher technical level than role 1. It is prepared to provide evacuation from role 1 facilities. It has capability for damage control surgery (DCS) and may include a limited holding facility for the short-term holding of casualties until they can return to duty or be evacuated.

Role 3 medical support is deployed hospital care and the elements required to support it. This includes a mission-tailored variety of clinical specialties, including primary surgery and diagnostic support. In recent conflicts role 3 facilities grew and evolved into sophisticated hard-built hospitals.

Summary box 34.1 Medical support roles

Role 4 provides care that cannot be deployed to the area of operations or is too time-consuming to be conducted there. It is normally provided in the country of origin or an allied nation depending on the location of deployment and time-lines of transfer. It is important to appreciate that these roles are highly variable both within and between different nations. The size and scale of the operations as a whole, along with predictions of both civilian and military medical requirements, will dictate the structure of the medical support.

R1- unit-level medical care including first aid and primary health care
R2 - intermediate unit for resuscitation, damage control and stabilisation
R3 - deployed hospital care with multispecialty capability
R4 - definitive hospital care within the home or allied nation

MEDICAL SUPPORT ROLES

The term 'role' is used to designate the tiers of medical support that integrate into a modern military operation. An appreciation of the capabilities and limitations of these roles is essential to improving the care of casualties at each stage. Different nations and forces will have medical support configured with some variability but, overall, systems are similar in order to ensure that the basic treatment, supply and evacuation needs that are essential for a military operation are available.

Role 1 medical support provides for routine primary health care, specialised first aid, triage, resuscitation and stabilisation. It is integrated within a small unit. The capabilities of role 1 care will depend greatly on the size of the unit and the training of the personnel within it.

Role 2 provides an intermediate capability for the reception and triage of casualties, as

well as being able to perform resuscitation and treatment of shock to a higher technical level than role 1. It is prepared to provide evacuation from role 1 facilities. It has capability for damage control surgery (DCS) and may include a limited holding facility for the short-term holding of casualties until they can return to duty or be evacuated. /uni25CF Role 3 medical support is deployed hospital care and the elements required to support it. This includes a mission- tailored variety of clinical specialties, including primary surgery and diagnostic support. In recent conflicts role 3 facilities grew and evolved into sophisticated hard-built hospitals. Summary box 34.1 Medical support roles /uni25CF /uni25CF /uni25CF /uni25CF care that cannot be deployed to the area of operations or is too time-consuming to be conducted there. It is normally provided in the country of origin or an allied nation depending on the location of deployment and time-lines of transfer. It is important to appreciate that these roles are highly variable both within and between different nations. The size and - scale of the operations as a whole, along with predictions of both civilian and military medical requirements, will dictate the structure of the medical support.

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PRINCIPLES OF WAR SURGERY

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Battlefield death occurs early (or immediately) because of devastating central nervous system injury and haemorrhage, or - - - late because of infection. Some of the injuries causing immediate death (including brain, heart and great vessel injury) are 11 non-survivable and may only be managed with prevention. Treatment of haemorrhage is therefore the mainstay of military trauma medicine. Bleeding should be recognised 12 and managed from the point of wounding. Tourniquets are indicated for the control of catastrophic extremity bleeding. Non-compressible torso haemorrhage carries a poor prognosis, although it may be amenable to methods of endovascular 14 control not yet commonly used. A damage control approach to surgery must be employed to stop bleeding, to remove necrotic tissue and foreign material and to reduce contamination. In addition to life-saving surgery, procedures to salvage limbs, including revascularisation 10 (or temporary shunting) and fasciotomy, should be considered early, when physiology allows.

gunshot wounds and explosions among US personnel. Gunshot (% of total Explosion (% of injuries) total injuries) US Civil War 91 9 First World War 65 35 Second World War 27 73 Korean War 31 69 Vietnamese War 35 65 Iraq/Afghanistan War 19 81 10 Adapted from Owens et al .

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Primary blast injury

Primary blast injury

Primary blast injuries result from the overpressure and are, as such, unique to blast. The effect of blast overpressure is most marked at the interface between air and tissue or liquid. Tympanic membrane (TM) rupture is the most common primary blast injury. Patients may be asymptomatic or have a degree of transient hearing loss and otorrhoea. Previously, the presence of TM rupture was used as a marker for other occult blast injuries. This has been challenged recently by findings that show TM injury is not ubiquitous in the presence of more severe primary blast injury. The blast environment and orientation of the ear canal to the shockwave are likely to determine the chance of injury. researched blast phenomenon. The exact mechanism of blast lung remains contested but it depends on the propagation of energy from the shockwave into the lung tissue, where it causes disruption. Proposed mechanisms of injury include spalling (disruption of tissues at air-liquid interfaces), implosion (compression and re-expansion of air-filled structures) and rapid acceleration of tissues of different densities. Large animal models have demonstrated that the level of injury is related to the rate of chest wall displacement, rather than the maximal depth of deflection. The severity of injury is dependent on the strength of the blast, the range from detonation and the surrounding environment. Those working closely with explosives may wear personal armour that assists in decoupling the effect of the primary blast. Current examples of such armour tend to be cumbersome. More common varieties of torso body armour provide protection against penetrating injury but probably do little to mitigate the effects of primary blast. The pathophysiology of blast lung includes both immediate and delayed responses. There is an immediate bradycardia and apnoea of variable length, which is likely to be a vagally mediated reflex. The lung injury itself is typified by alveolar capillary rupture with subsequent intrapulmonary bleeding and oedema. The extent of this injury is proportional to the blast exposure and may range from microscopic petechial injury to areas of frank haemorrhage. While rarely seen in isolation, primary blast may leave little external evidence of injury since the skin itself is rarely affected. Clinical features of blast lung include progressive hypoxia, which may not be apparent at the time of injury and is related to the inflammatory response to intrapulmonary haemorrhage and worsening oedema. Other structural lung injuries are associated with primary blast, although the prediction of these injuries by blast conditions is not consistent and is likely to be complicated by tertiary impact. Pneumothoraces may occur as a result of pleural rupture in the absence of penetrating injury. Injury to the larger vessels may lead to haemothoraces and the formation of alveolar-venous or bronchovenous fistulae. Air embolism due to such fistulae may cause acute hypoxia with cardiovascular collapse and is a leading cause of death in those who do not survive until treatment. The diagnosis of blast lung is clinical with findings of hypoxia following blast exposure. Typical 'bat-wing' pulmonary infiltrates are seen on the chest radiograph and computed tomography may discriminate these injuries from the more peripheral contusions seen in blunt trauma. Imaging may be useful in detecting associated structural lung injuries. Treatment of blast lung is largely supportive. Mechanical ventilation may be required but consideration should be given to the possibility of air embolism and pneumothorax that may be exacerbated. Some

centres advocate the use of prophylactic bilateral pleural decompression, although there is little evidence to suggest an effect on outcomes. Patients with significant blast lung injury are highly likely to have sustained other blast-related injuries and any management plan should consider their overall condition.

TABLE 34.3 Classification of blast injuries.

Classification	Injury type	Examples
Primary blast	Overpressure	Tympanic membrane injury, blast lung, intestinal blast injury
Secondary blast	Penetrating/	All penetrating injuries fragmentation
Tertiary blast	Blunt	Blunt and crush injuries, traumatic amputation
Quaternary blast	Miscellaneous	Burns, inhalation injury
Effect of device	Radiation	sickness, additions infection

incidence of abdominal injury due to air blast has not been extensively examined, although a recent review of multiple incidents, including a variety of blast conditions, showed that abdominal injury is not common – seen in around 3% of incidents. Damage is dependent on coupling of the blast overpressure and the shockwave to a stress wave that travels through the abdomen. The effect of shockwave dispersal is most marked at tissue–air interfaces. As such, the hollow organs are those most commonly injured. The caecum is probably most sensitive to intestinal blast injury. Conversely, the small bowel and its extensive mesentery may be more susceptible to large shear waves causing mesenteric tearing. The presentation of primary blast injury to the bowel may be delayed relative to the acute onset of blast lung. Abdominal symptoms may be absent initially with progression to pain and frank peritonitis, should perforation and contamination occur. Given the lack of external injury, indications for operative intervention are largely clinical, as with conventional blunt abdominal trauma. The patient should be assessed anaesthetically with particular consideration to the effect of anaesthesia and ventilation on any concomitant blast lung injury. The most common operative finding of intestinal blast is subserosal haemorrhage. Tearing of the mucosal surface with bleeding into the lumen of the tract may occur following repeated exposure to relatively lower blast overpressures. As in blunt injury, there is a propensity for mural haematomas to progress to perforation as a result of tissue necrosis. Full-thickness injuries to the bowel with immediate perforation can occur with a greater exposure to blast overpressure. The surgical management of blast bowel injury is that of any penetrating and blunt trauma, with primary repair or resection as indicated. Surgical judgement is essential regarding the findings of non-perforated but contused bowel. A damage control approach to such injuries may allow for repeat assessment later, but in a physiologically well patient, in whom a relook would not be justified, the surgeon must decide to resect a segment or risk future progression of these lesions to perforation. The solid organs are more resistant to primary blast. Parenchymal disruption due to the shockwave has been described at very high levels of overpressure, although the experimental data for these injuries are sparse. Injury, with subsequent bleeding, may result from rapid distractions of organ attachments and mesenteries. These blast conditions are more likely to be encountered in enclosed conditions and differentiation of primary from tertiary injuries is difficult. Primary blast injury

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SURGERY

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Modern warfare has changed over recent decades. The causes of injury are particular to the individual conflict, nation and 9 armed service. Historically , penetrating trauma was predominately sustained by combat infantry , whereas naval and air personnel sustained more blunt injuries (Table 34.1). Improvements in trauma scoring systems and the development of a concise system for the recording of injuries and casualty care have increased the ability of modern armed services to analyse the injury patterns of their deployed personnel. A cohort analysis of combat injuries incurred by US forces showed significant differences in injury patterns sustained in the most recent Afghanistan and Iraq conflicts compared with those sustained in the Second World War and the Korean and Vietnamese Wars. Head and neck injuries were far more common in recent conflict whereas thoracic and extremity injuries were less so. This is probably because of the increased use of body armour and similar personnel protective equipment in more recent conflicts. The mechanism of injury has also changed. Although ballistic injuries remain an important contributor to battlefield trauma, injuries due to explosions (which include improvised explosive devices [IEDs], landmines, mortars, grenades and rockets) have become increasingly common and are now the predominant mode of wounding and fatality . The relative proportions of injuries caused by explosive and ballistic weapons are shown in Table 34.2 . The emergence of explosive patterns of injury is due to the increasing use of IEDs within conflicts. IEDs have been the signature weapon within operations in Afghanistan and Iraq; however, their use has not been limited to these regions. The relative low cost, ease of production and widespread expertise means that IEDs are likely to play significant roles in most contemporary and future conflicts.

TABLE 34.1 Historical causes of injury among US service personnel. Service Mechanism Infantry Armoured Sea (%) Air (%) (%) (%) Ballistic 90 50 25 5 Blunt 2-3 5 10 50 Blast 2-3 5 10 <10 Thermal 2-3 25 30 25 Combined <5 15 25 10 9 Adapted from Champion et al .

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Secondary blast injury

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Secondary blast injury refers to the effect of fragments that are accelerated away from the device following detonation. Sources of fragments include: the casing of the device; purposefully placed fragments within the device; these may include nails, bolts or ball bearings and are embedded within the device or adherent to the exterior; nearby objects including glass and stones; biological material including bone may be expelled, particularly following a suicide bomb or antipersonnel mine attack. Shrapnel is often used to describe explosive fragments, although the term is more strictly applied to a specific form of artillery shell. The energy of a primary blast wave disperses quickly in proportion to the distance from the blast; it is subject to the inverse cube law. As such, only those within a reasonably small radius of the blast are affected. Conversely, the velocity and wounding potential of an energised fragment are subject to the inverse square law. Secondary blast injuries may occur at long range from the detonation. Fragments may be accelerated up to very high velocities. As with ballistics, injuries are dependent on the range and energy of the fragment. In contrast to bullet wounds, the variability of fragments produces a wide range of wounds and no two wounds will be the same (Figure 34.5). The irregular surfaces of fragments cause complex patterns of yaw and tumble. Both permanent and temporary wound cavities may be unpredictable and irregular. The management of fragment wounds is similar to ballistic and conventional penetrating trauma. Wounds should be adequately debrided. Fragment wounds should be considered dirty and principles of septic surgery applied. Where possible, serial debridement and delayed primary closure should be attempted. The fragments should be removed at the time of surgery if easily accessible. Other indications for early removal include fragments within joint spaces or adjacent to structures with danger of erosion and further injuries. Late indications for fragment removal include ongoing sepsis, pain or lack of function.

Large anterior fragmentation injury. Figure 34.5

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Tertiary blast injury

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Tertiary blast injury is the result of gross movement of person -nel, objects or infrastructure by blast wind. Tertiary injury is variety of injuries to all organ systems. Traumatic amputation is typically included within this category , although primary blast and the shattering or 'brisance' effect on bone may play a part. Tertiary blast injury

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WEAPON EFFECTS Ballistics

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- The ability to manage conflict injuries relies on an understanding of the underlying mechanism of wounding, which is likely to be different from that in civilian trauma. As stated, while ballistic injuries are no longer the most common cause of battlefield injury, firearms remain a common element in all conflict. Civilian trauma practice, depending on local firearm laws, may well encompass a significant volume of gunshot wounds, although patterns of injury with war wounds may well differ as a result of the weapons used. An understanding of the mechanism of ballistic wounding is required to treat these wounds effectively. The earliest recorded depiction of a firearm is from 1326, but firearms became ubiquitous on the battlefield during the 17th century. Ballistic weapons all work with the same principles – an explosion is used to propel a projectile along and out of a straight tube – but have evolved considerably from rudimentary cannons to sophisticated modern-day firearms. The explosive force within a modern firearm comes from propellant encased within a cartridge. The basic design of a cartridge is shown in Figure 34.1. Internal ballistics describes the characteristics of a projectile while inside the weapon. The hammer mechanism strikes a primer at the base of the cartridge, which ignites the propellant. Hot gas produced by the explosion expands and forces the bullet away from the cartridge and along the barrel. Spiral grooves, or rifling, impart spin on the bullet, which aids accuracy and stabilisation.

Bullet Propellant Casing Primer Figure 34.1 Diagram of basic cartridge structure.

Advances in firearm design have served predominantly to improve accuracy, reliability and rate of fire. Ammunition is normally held within a magazine or belt that loads directly into the chamber of the weapon. The loading mechanism determines the rate of fire. In a semiautomatic or fully automatic system, the recoil forces of the spent cartridge eject the cartridge while resetting the chamber and accepting a new cartridge from the magazine, such that the process may be repeated rapidly. Shotguns utilise a similar mechanism except that a collection of smaller projectiles – ‘shot’ – are expelled rather than a single bullet. These smaller projectiles disperse away from one another after leaving the barrel. The degree of dispersal is dependent on the relative length of the barrel. External ballistics describe the characteristics of a projectile in free flight. It may be influenced by ammunition type and ambient conditions. Ammunition differs widely with the most pronounced difference between pistol and rifle ammunition. Rifles are expected to be accurate at ranges up to and beyond 1000 metres, while pistols are intended for far shorter ranges. Rifle cartridges are longer and typically have a greater proportion of propellant to projectile. The characteristics of ammunition that determine wound effects are the size or calibre (which describes the internal diameter of the weapon barrel) and the material components

of the bullet: /uni25CF Full metal jacket ammunition has an outer coating of harder metal around a softer core. This reduces break down of the bullet along the barrel and improves accuracy , reliability and target penetration. /uni25CF Soft tip and hollow point ammunition have a degree of exposed lead that flattens and deforms on impact. These bullets have less penetrating ability but rapidly transfer en ergy to the impacted tissue and cause large wounds. WEAPON EFFECTS Ballistics

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- ○ The ability to manage conflict injuries relies on an under - standing of the underlying mechanism of wounding, which - is likely to be di ff erent from that in civilian trauma. As stated, while ballistic injuries are no longer the most common cause of battlefield injur y , firearms remain a common element in all conflict. Civilian trauma practice, depending on local firearm laws, may well encompass a significant volume of gunshot wounds, although patterns of injury with war wounds may well di ff er as a result of the weapons used. An understanding of the mechanism of ballistic wounding is required to treat these wounds e ff ectively . The earliest recorded depiction of a firearm is from 1326, but firearms became ubiquitous on the battlefield during the 20 seventeenth century . Ballistic weapons all work with the same principles – an explosion is used to propel a projectile along and out of a straight tube – but have evolved considerably from rudimentary cannons to sophisticated modern-day firearms. The explosive force within a modern firearm comes from pro - pellant encased within a cartridge. The basic design of a car - tridge is shown in Figure 34.1 . - Internal ballistics describes the characteristics of a projec - tile while inside the weapon. The hammer mechanism strikes a primer at the base of the cartridge, which ignites the propel - lant. Hot gas produced by the explosion expands and forces the bullet away from the cartridge and along the bar rel. Spiral grooves, or rifling, impart spin on the bullet, which aids accu - e racy and stabilisation.

Bullet Propellant Casing Primer Figure 34.1 Diagram of basic cartridge structure.

advances in firearm design have served predominantly to improve accuracy , reliability and rate of fire. Ammunition is normally held within a magazine or belt that loads directly into the chamber of the weapon. The loading mechanism determines the rate of fire. In a semiautomatic or fully auto matic system, the recoil forces of the spent cartridge eject the cartridge while resetting the chamber and accepting a new cartridge from the magazine, such that the process may be repeated rapidly . Shotguns utilise a similar mec hanism except that a collec tion of smaller projectiles – ‘shot’ – are expelled rather than a single bullet. These smaller projectiles disperse away from one another after leaving the barrel. T he degree of dispersal is dependent on the relative length of the barrel. External ballistics describe the characteristics of a projec tile in free flight. It may be influenced by ammunition type and ambient conditions. Ammunition di ff ers widely with the most pronounced di ff erence between pistol and rifle ammunition. Rifles are expected to be accurate at ranges up to and beyond 1000 metres, while pistols are intended f or far shorter ranges. Rifle cartridges are longer and typically have a greater propor tion of propellant to projectile. The characteristics of ammuni tion that determine wound e ff ects are the size or calibre (which describes the internal diameter of the weapon barrel) and the material components of the bullet: /uni25CF Full metal jacket ammunition has an outer coating of harder metal around a softer core. This reduces break down of the bullet along the barrel and improves accuracy , reliability and target penetration. /uni25CF Soft tip and hollow point ammunition have a degree of

exposed lead that flattens and deforms on impact. These bullets have less penetrating ability but rapidly transfer energy to the impacted tissue and cause large wounds.