North Atlantic Treaty Organization. *Emergency War Surgery NSATO Handbook 2010*. Washington, DC: Borden Institute. http://www.bordeninstitute.army.mil/other_pub/ews/EWS.ZIP. Accessed December 2014.

Roberts P, ed. *The British Military Surgery Pocket Book*. AC No. 12552. London, UK: HMSO; 2004.

Santry HP, Alam HB. Fluid resuscitation: past, present, and the future. *Shock*. 2010;33:229–241.

Willy C, Voelker HU, Steinmann R, Engelhardt M. Patterns of injury in a combat environment. 2007 update. *Chirurg*. 2008;79:66–76.

Trauma Anaesthesia 19

19.1 INTRODUCTION

Trauma anaesthetists are an essential part of the trauma team working in close collaboration with the surgeon. Trauma anaesthesia is involved in the entire chain of trauma care, from pre-hospital, to emergency room, often multiple operating room episodes, intensive care and pain management.

Trauma anaesthesia as a subspecialty of anaesthesiology requires broad experience in all modes of anaesthesia and a flexible approach to applying this knowledge. Strategies that work in elective cases may not be appropriate for trauma patients. The trauma anaesthetist participates in and contributes to the decision-making process during the initial resuscitation and provides resuscitation and anaesthesia in the perioperative setting.

Because of this comprehensive involvement and the frequent multiple surgeries for some severely injured, trauma anaesthetists may be a consistent asset throughout the entire treatment process.

19.2 PREPARATION FOR DAMAGE CONTROL

Damage control surgery (DCS) describes the strategy of limiting surgical intervention in haemodynamically compromised trauma patients by restricting procedures to early control of haemorrhage and contamination, and postponing the definitive anatomical repair until the patient is more stable.

19.2.1 Introduction

In this chapter we will cover the aspects of trauma anaesthesia related to damage control in trauma. Anaesthetic involvement in specific situations, such as head trauma, is dealt with in the other relevant chapters. Special skills are also described in those chapters.

19.2.2 Planning and Communicating

When the trauma patient enters the emergency room the trauma anaesthetist should take charge of the airway, optimize oxygenation and resuscitation, taking account in particular the patient's neurologic condition and temperature.

The trauma team should then decide the optimal process of care for that individual. Interventions in the emergency room (ER) should be limited to those that are essential for survival. Ensuring adequate venous access and perhaps an extra-large-bore IV cannula may make an important difference; an arterial line may not be worth the time. Together with the surgeon, the anaesthetist has an important role in initiation of diagnostics or surgery depending on the clinical condition.

The anaesthetist has a crucial role in optimizing the physiology to match the surgical strategies. Assessment of ongoing dynamic changes and reaction to treatment is an essential contribution to the decision-making process.

The planned strategy for resuscitation and surgery should be communicated closely between the surgeon, the anaesthetist and the team, coordinated by the trauma team leader.

19.3 DAMAGE CONTROL RESUSCITATION (DCR)

With the development of the concepts of DCS in the early 1990s, it became clear that anaesthetic strategies needed to adapt to special needs aiming at a comprehensive and multidisciplinary resuscitation approach. The non-surgical management needs to be maximally time efficient and

supportive in order to provide the best possible conditions for early surgical haemostasis[1]. The DCS and damage control anaesthesia combine together in the concept of 'damage control resuscitation' aiming to rapidly stop bleeding, restore blood volume, aggressively preventing and correcting coagulopathy, hypothermia and acidosis[2].

The five principal pillars of DCR are:

- Limit or omit fluid administration, early use of blood product.
- Monitor permissive hypotension.
- Target coagulopathy.
- Prevent and treat hypothermia.
- Facilitate early use of tranexamic acid where indicated.

The DCR aims to treat and prevent conditions which exacerbate haemorrhagic shock and the ensuing systemic inflammatory response. The DCR addresses the pathophysiologic consequences of tissue trauma and blood loss and reduces the risks of overly aggressive fluid resuscitation, while targeting correction of metabolic derangements and coagulopathy. The concept of limiting operative stress by delaying definitive repair until after control of haemorrhage and after the patients improves his or her physiology is supported by DCR. The importance of an early transfer to an intensive care unit (ICU) for subsequent normalization of microcirculation, correction of coagulopathy and re-warming are stressed. Therefore, patients in the damage control pathway can be expected to arrive in ICU in a critical and under-resuscitated state. Early and optimal flow of information about the situation and specific needs between the surgical, anaesthetic and ICU teams is key for optimal management. Therefore, trauma resuscitation requires prolonged multidisciplinary collaboration, starting in the pre-hospital setting and continuing through emergency departments and operating theatres to the ICU.

In most civilian trauma centres of the developed world, less than 10 per cent of the trauma workload qualifies for damage control strategy. Precise and early identification of these patients is of the essence as the overuse of this approach may lead to significant morbidity and hospital resource use. With early haemorrhage control and optimal resuscitation, some patients may rapidly improve their hemodynamic state. Therefore, even if initially considered for the DCR pathway, they might now be suitable for definitive care. Constant re-assessment is crucial and the role of the anaesthetist in providing continued information about the patient's hemodynamic and organ perfusion is key for joint decision making.

In this chapter we describe the strategy and the pathophysiology behind the three non-surgical pillars of DCR.

19.3.1 Limited Fluid Administration

Aggressive fluid resuscitation to restore normal circulatory function has long been the mainstay of the initial approach for haemorrhagic shock. In 2004, Moore et al. coined the term 'bloody vicious cycle', showing that crystalloid administration leads to a transient rise in blood pressure, followed by increased haemorrhage, which requires further fluid administration, leading to the sequence of hypotension, fluid bolus, re-bleeding and deeper hypotension. It is currently accepted that administration of high volumes of fluid before achieving definitive haemostasis increases the rate of bleeding by raising cardiac output, with increased blood pressure counteracting local vasoconstriction and reopening spontaneously clotted vessels. In addition to dilutional coagulopathy, large volumes of crystalloid fluids have deleterious effects on organ function, the endothelium and immunological and inflammatory mediators. All of these are associated with poor outcome. Recent studies have shown that high volumes of crystalloids increase reperfusion injury and leukocyte adhesion, resulting in an increased incidence of infectious complications and multiple organ failure (Table 19.1)[3].

During ongoing surgical bleeding, clear fluids should be limited to minimal amounts or even omitted until definitive control of haemorrhage has been achieved. Early use of blood and blood products in this critically bleeding group of trauma patients reduces crystalloid administration and is the mainstay of resuscitation in damage control. Some even recommend to limit the use of crystalloids in trauma-related haemorrhagic shock to a function of carrier of drugs and to keep lines open between blood product administrations. Preferred types of crystalloids are balanced solutions such as Ringer lactate solution or Plasmalyte 0.9%. Sodium chloride solution ('normal saline') can contribute to hyperchloraemic acidosis which may have an adverse effect on renal function. Synthetic colloids containing starches have shown to interfere with fibrin polymerization, coating of platelets, blocking of fibrinogen receptor (GPIIb-IIIa) and von-Willebrand type 1-like syndrome and cause coagulopathy (colloid-induced coagulopathy), increased bleeding and transfusion requirements. Starch solutions have also been associated with an increased risk of renal failure and increased mortality in the critically ill[4], although the discussion is still ongoing.

Consequences of Aggressive Crystalloid Resuscitation[3]

Respiratory	Capillary permeability
	Pulmonary oedema, which also results in acute lung injury (ALI)/acute respiratory distress syndrome (ARDS)
Gut	Intestinal permeability
	Bacterial translocation
	Paralytic ileus
	Abdominal compartment syndrome (ACS)
	Anastomotic dehiscence
Heart	Myocyte action potential
	Ventricular dysfunction
	Arrhythmia
	Membrane polarization
	Disruption of phosphorylation
	Cellular oedema
	Apoptysis
Blood	Dilution of coagulation factors
	Increased blood loss
	Counteracting vasoconstriction
	Oncotic pressure
Vessels	Catecholamine release
	Vascular resistance to catecholamines
Inflammatory Pathways	Activation of inflammation (TNFα, interleukins, SIRS)
	Early vasoplegia
Endothelium	Damage to endothelial integrity
	Capillary leak

Source: Adapted from Cotton BA, Guy JS, Morris JA, Jr., Abumrad NN, *Shock*, 26(2), 115–121, 2006; and Kozar RA, Peng Z, Zhang R, et al., *Anesth Analg*, 112(6), 1289–1295, 2011. With permission.

Limiting fluid administration raises the question of how to maintain blood pressure. The use of vasopressors for hemodynamic support during resuscitation after injury is controversial. While arginine vasopressin and phenylephrine have shown to provide some beneficial effects in patients with traumatic brain injury, lung contusion or in animal models with haemorrhagic shock[6], a prospective multicentre study on blunt trauma patients has shown an increased mortality in patients with early vasopressors use[7]. Therefore, hypovolemic shock should be treated primarily by volume replacement, but low doses of vasopressors might be useful to counteract the sympatholytic and cardiovascular depressant effect of anaesthetic agents.

In regard to the question around maintaini pressure, what blood pressure goal should b for during the acute resuscitation of bleeding patients?

19.3.2 Permissive Hypotension

Permissive hypotension is a strategy to reduce bl by limiting systolic pressure to the minimum nec maintain perfusion of vital organs. In massively l patients, raising blood pressure to normal level achieving surgical haemostasis has been shown to bleeding by displacing clot[5] formed during the attempt at primary haemostasis ('popping the cl strategy is not new, and was reported during Wo I, when Cannon stated that 'Haemorrhage in the shock may not have occurred to a marked degree blood pressure has been too low, and flow too s overcome the obstacle offered by the clot. If the p is raised before the surgeon is ready to check an ing that may take place, blood that is sorely need be lost'[4]. Although safe limits of blood pressure i of preservation of organ perfusion are unknown, blood pressure of 80 mm Hg, and in the case of co tant severe brain trauma, mean arterial pressure (M over 80 mm Hg are recommended. While there is r evidence for these limits, it is very clear that such lo sures should be maintained for the shortest possib in order to limit vital organ ischaemia. The impo of early surgical haemostasis and the need for th concept being applied as a whole has to be emphas

19.3.3 Targeting Coagulopathy

Early and aggressive administration of blood and products has shown to improve survival after tr related haemorrhagic shock[8]. Lost blood volume s be replaced by blood products aiming at near equal of packed red blood cells (PRBC): fresh frozen p (FFP): platelets[9,10]. Such regimens have demons improved outcome. Data suggest that plasma-resuscitation when compared to crystalloids is be preserving endothelial integrity. Administration e after haemorrhagic shock has anti-inflammatory erties and a potential glycocalyx-restoring capacity

Up to 30 per cent of injured patients present impaired coagulation on arrival at the care facility presence of trauma-related coagulopathy is a surr

marker of the extent and severity of tissue trauma and shock and correlates with mortality. Coagulation abnormalities related to severe trauma have several causal factors including consumption of clotting factors and platelets, dilution after administration of fluids and, fibrinolysis as well as hypothermia and acidosis. Early identification of patients with acute traumatic coagulopathy (ATC) is crucial for timely initiation of haemostatic resuscitation[12,13]. Early blood gases are a quick and helpful tool to identify patients in shock. Base deficit or lactate has shown to provide a reliable correlation with the need for massive transfusion and risk of death. A base deficit of >2 mmol/L correlates with class 2, and BD >6 mmol/L with class 3 shock according to the ATLS definition[14]. In the absence of timely laboratory assessment, in patients with evidence of impaired end-organ perfusion and extensive tissue trauma, initiation of haemostatic resuscitation may be indicated even before biologic or viscoelastic confirmation of ATC. Early administration of blood products raises logistic challenges. The implementation of a massive transfusion protocol (MTP) is recommended, which will allow the ready availability of blood products. Availability of a MTP has shown to be associated with a reduction of organ failure and improved 30-day survival after severe trauma[15]. The putative mechanism is potentially related to earlier transfusion of plasma and platelets.

While the optimal ratio of pRBC:FFP:platelets is unclear, haemostatic resuscitation is generally recommended initiated with a fixed ratio close to 1:1:1[16] followed by a switch, as early as possible, to goal-directed resuscitation guided by viscoelastic haemostatic assays[17] (VHAs) (see also Chapter 4).

Fibrinolysis is a key feature of the ATC. The CRASH-2 trial[18] showed a 30 per cent mortality reduction after the administration of tranexamic acid in trauma patients at risk of significant haemorrhage. A bolus of 1 g of tranexamic acid, followed by an infusion of 1 g over 8 hours, has become used within many MTPs. It should be given as early as possible to bleeding trauma patients; if treatment is not given until 3 hours or later after injury, it is less effective and could even be harmful. In major haemorrhage, fibrinogen reaches critically low values earlier than other coagulation factors or platelets. Replacement is generally necessary to maintain a plasma concentration of 150–200 mg/dL and its early use (in the form of cryoprecipitate or fibrinogen concentrate) has been integrated in many MTPs even though strong evidence supporting this is lacking. Further data are needed.

Despite the increased use of tranexamic acid, the gathering and validity of the data has been called into question in a major trauma centre environment. In addition, a recent study indicated that the majority of severely injured patients have a fibrinolysis shutdown, and therefore, tranexamic acid may have no effect[19].

Tranexamic acid is not widely used routinely outside of Europe, and its greatest use may be where increased clot lysis is shown to be present (e.g. using thrombo-elastography).

19.3.4 Prevent and Treat Hypothermia

Hypothermia below 35°C had a profound impact on surgical site infection rates after trauma laparotomy. Hypothermia also adversely affects coagulation as well as cardiac output and function in most bodily organs. Hypothermia and acidosis compromise thrombin generation kinetics via different mechanisms. Hypothermia primarily inhibits the initiation phase, whereas acidosis severely inhibits the propagation phase of thrombin generation. Similarly, hypothermia and acidosis affect fibrinogen metabolism differently. Hypothermia inhibits its fibrinogen synthesis, whereas acidosis accelerates fibrinogen degradation, leading to a potential deficit in fibrinogen availability. Thus, the specific steps related to hypothermia prevention and treatment are:

- Keep the operating room (OR) temperature warm (25°C or higher). Maintaining a warm OR on patient arrival helps keep patients warm.
- Have additional warming devices available, including a forced air device system, fluid warmers on the IV line, warm IV solutions, and warm blankets.
- Have a system to warm all solutions that are to be used in the surgical field.

19.3.5 Key Messages

- Assess arterial blood gases on every trauma patient to aid decision making.
- Before surgical control of haemorrhage:
  - Limit crystalloid fluid resuscitation.
  - Do not use synthetic colloids.
  - Commence blood products and goal-directed haemostatic resuscitation early.
  - Allow blood pressure to be below normal during early haemorrhage control.
- Arrange early transfer to ICU and effective multidisciplinary communication.

19.4 DAMAGE CONTROL SURGERY

19.4.1 Anaesthetic Procedures

Being able to predict situations is a key skill for the trauma anaesthetist and is derived from extensive experience. The anaesthetist should be able to predict how the patient physiology will evolve over a short period of time, and his or her response to treatment. The anaesthetist should anticipate the treatment the patient will receive and the route the patient will need to take to get to a stable state.

19.4.1.1 AIRWAY

In order to be able to correct hypoxia, manage CO_2, protect the airway and facilitate interventions most severe trauma patients will require intubation. Anaesthetists who deal with airway management on a daily basis are probably the best group to perform this task, but if other groups are to perform this they should be trained to perform it to the same standards and quality. Intubation in patients with possible neck trauma is a recognized difficult airway management situation. There are difficult airway algorithms available to assist decision making for situations. An oral tube may be impossible, a laryngeal mask not suitable and a surgical airway the only and fastest option. This decision needs to be made before the patient decompensates, and skill and experience are required to make the decision in a timely manner. The anaesthetist may need to rely on his or her own skills rather than wait for another individual. The skill of establishing a surgical airway needs to be taught and practised to be retained.

19.4.1.2 BREATHING

Mechanical ventilation is a life-saving treatment but also has increased dangers for trauma patients. Trauma patients are at increased risk of volume and barotrauma and acute respiratory distress syndrome (ARDS) from mechanical ventilation, referred to as ventilator induced lung injury (VILI). The injured lung is more susceptible to maldistribution of pressure between healthy and injured parts, leading to collapse in some areas with overdistension in others even at lower tidal volumes. The anaesthetist needs to apply judicious amounts of positive end-expiratory pressure (PEEP) and a ventilation strategy aimed at minimizing overdistension of the lung.

Damage to the thoracic wall and to the lung increase the risks of pneumothorax, air embolism and VILI adding to the original acute lung injury. During ventilation the anaesthetist needs to be aware of these potential complications and the options for treatment.

While ventilating the patient the anaesthetist also needs to take into account associated injuries and the influence of ventilation on injury. For example PEEP, $PaCO_2$ and PaO_2 are important in traumatic brain injury treatment strategies. The PEEP may reduce blood pressure, especially in the presence of hypovolaemia. Furthermore, PEEP at high levels (>12 mm Hg) may increase intracranial pressure (ICP). Nevertheless, it has also been demonstrated that in brain-injured patients during mechanical ventilation, the application of moderate levels of PEEP (up to 8 cm H_2O) provided protection against the occurrence of lung injury, probably by restoring lung volume and reducing lung heterogeneity – that is atelectasis, airway closure and tidal expiratory flow limitation. Mean arterial pressure (MAP) and ICP monitoring and prevention of hypoxia are essential for prevention of secondary brain injury. $PaCO_2$ also affects ICP, and the aim is to achieve normocarbia ($PaCO_2$ 35–45 mm Hg). Hypocarbia increases cerebral vasoconstriction, leading to decreased cerebral blood flow (CBF), which may decrease ICP but also cause ischaemia. Decreasing $PaCO_2$ (by hyperventilating the patient) is a treatment strategy that should be limited to short duration management of critically raised ICP (e.g. en route to an intervention for reducing the ICP, e.g. surgery). Hypercarbia increases CBF by vasodilatation and increases ICP in severe brain injury with the risk of decreasing cerebral perfusion pressure and causing or worsening secondary brain injury.

19.4.1.3 CIRCULATION

Control of exsanguinating bleeding has taken priority over the airway breathing circulation changing the ABC mnemonic to C (control of catastrophic bleeding)-A-B-C, certainly in the pre-hospital and military settings.

19.4.1.4 VASCULAR ACCESS

Vascular access is required for the administration of resuscitation drugs and blood transfusion. The ATLS approach calls for two large-bore intravenous (i.v.) cannulas. The rationale is not to put twice as much volume in (permissive hypotension) but to have redundancy and availability when required. With a second i.v. you can have a separate access for medication that cannot be mixed and as backup if you have a dysfunctional line.

If one of the i.v.s is a small-calibre one there is the option to change it to a larger one using a wire Seldinger technique that will allow exchange for a rapid infusion catheter. Another way to gain better i.v. access is to apply a tourniquet above the small catheter, infuse 60 mL of i.v. fluid and insert a larger-bore i.v. catheter above the small catheter in the now distended vein.

If the need for a rapid infusor system is foreseen, a 14-gauge (at least) catheter will be needed to allow high flow (500–800 mL/min). The i.v. lines used for the rapid infusor should not have one-way valves such as in use in the ICU and only high-flow three-way stopcocks if you really need them. Medication should have a separate line from the high-flow system. A central venous line allows multiple ports, central venous pressure measurement and high flow fluid administration as well as venous blood gas measurements. A central venous line allows early intravenous feeding.

The larger the bore of the i.v. cannula, the greater the flow (Figure 19.1).

19.4.2 Monitoring

Besides the standard anaesthesia monitoring, a five-leads electrocardiogram (ECG) in case of thoracic injury is advisable. Blunt cardiac injury can be detected by changes in ECG and treated with supportive therapy. Ventilation should be monitored with pulse oximetry for adequate oxygenation and end-tidal (ET) CO_2 for assuring adequate respiratory minute volume. The $ETCO_2$ further informs us about cardiac output decreasing in the case of circulatory collapse.

An arterial line provides the opportunity for beat-to-beat blood pressure monitoring, blood sampling and physiological status, but should not delay time to surgery or intervention. Arterial line insertion is first attempted peripherally (radial or brachial or dorsal foot arteries), secondarily moving proximally (femoral or axillary arteria) in difficult situations with massive bleeding.

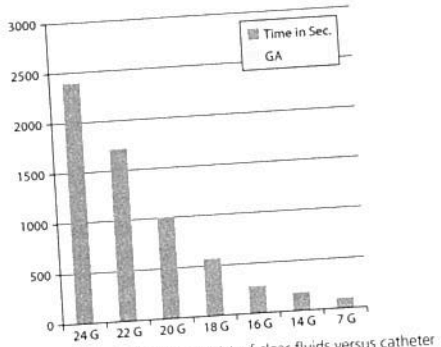

Figure 19.1 Time in seconds to infuse 1 L of clear fluids versus catheter gauge.

In the OR, in due time and according to the clinical condition, hemodynamic status can be evaluated by accessing cardiac output. The purpose is to evaluate the status of the blood volume and cardiac function in order to secure normovolaemia and perfusion, meanwhile avoiding hypo- as well as hypervolaemia. In the early dramatic phase of damage control resuscitation (DCR) using pulse, BP, pulse oximetry and $ETCO_2$ can be the only possibilities, but when more control is achieved hemodynamic monitoring can be intensified according to the clinical condition.

Haemodynamic monitoring is a means of checking cardiac output and performing volume estimation:

- Pulse and BP.
- Central venous pressure or central venous saturation ($S_{cv}O_2$) accessed via a central line.
- Transthoracic or transoesophageal echocardiogram – focus assessed transthoracic echocardiography (FATE).
- Mixed venous oxygen saturation via pulmonary artery catheter (rarely indicated in damage control).
- Minimally invasive cardiac output estimation via arterial line.

Monitoring of a bispectral index (BIS) may prevent awareness during trauma anaesthesia, although BIS responses to ketamine administration are atypical and can be paradoxical.

Monitoring urine output may give some indication of the volume status. Due consideration should be given to insertion of a urine catheter in the case of suspected urethra injury.

Temperature monitoring is essential in trauma management. Intraoperative normothermia is an important quality performance measure for patients undergoing surgery as it should be in trauma management.

19.5 ANAESTHESIA INDUCTION IN HYPOVOLAEMIC SHOCK

19.5.1 Introduction

Anaesthetizing a severely injured patient requires a thorough knowledge of the medications used and their altered pharmacokinetics and pharmacodynamics in the hypovolemic, acidotic and hypothermia trauma patient. The principal goal of anaesthesia for trauma patients is to provide analgesia, unconsciousness and amnesia and eventually muscle relaxation without further deteriorating the deranged physiology and hemodynamic situation. In traumatic brain injury, systolic blood pressure <90 mm Hg and PaO_2 <60 mm Hg are independently associated with increased morbidity and mortality.

The pharmacokinetics (absorption, distribution, metabolism and elimination) change significantly with hypovolemic shock. The severely injured patient is in a condition of increased sympathetic tone in attempts to redistribute the circulation to brain and heart. In shock, the body becomes the equivalent of a single compartment model, a blood-brain circuit, at the expense of the perfusion of gut, liver, kidneys and muscles. Intravenous drugs will be almost instantaneously distributed to heart and brain, resulting in more rapid-onset, higher brain concentrations and more profound effects. Further, many anaesthesia induction agents show a high protein binding. Hence, in hypovolemic shock and especially after fluid resuscitation, reduced plasma protein binding leads to increased availability of free drug with higher effect site concentration and concomitantly increased adverse haemodynamic effects.

Anaerobic metabolism and metabolic acidosis will alter the distribution of ionizable drugs, leading to enhanced brain concentration. Furthermore, in shock, hepatic and renal blood flow is markedly decreased, impairing the intrinsic metabolic capacity leading ultimately to an increase in the free fraction of drugs and prolonged action. Drugs with a high hepatic extraction rate, such as propofol, ketamine, and morphine and synthetic opioids, will show a prolonged duration of action.

19.5.2 Drugs for Anaesthesia Induction

The effect site equilibration constant, cited as t½Keo, represents the time necessary for the administered drug to reach an appropriate anaesthetic concentration in the brain. The longer the t½Keo of a drug, the higher the initial plasma concentration needed to achieve a rapid anaesthetic concentration. Hence, intravenous anaesthetic agents with the shortest t½Keo are generally best suited for a rapid induction in the severely injured, hypovolaemic patient (Table 19.2).

Table 19.2 Effects of Anaesthetic Induction Agents

Induction Agent	Effector Site Equilibration (t½Keo)	Haemodynamic Effects	Comments
Propofol	≤20 min	↓ HR unchanged (↑) ↓ Cardiac output ↓ Blood pressure ↓ Laryngeal reflexes Vagotonic	Poorly suited for rapid induction in haemodynamic compromise Potential increase in intracranial pressure outweighed maintenance of haemodynamics
Ketamine	±2 min	↑ Heart rate ↑ Cardiac output ↑ Blood pressure Sympathomimetic	Minimal dose adjustment needed in hypovolaemic shock
Etomidate	±2.5 min	↓ Cardiac output ↓ Blood pressure ↓ Steroid synthesis ↓ Heart rate ↓ Inotropy ↓ Laryngeal reflexes	Possible adrenocortical suppression
Thiopental	±1.5 min	↓ Vasodilatation	Dose reduction required, ideally <3 mg/kg
Benzodiazepines	±9 min	↓ Cardiac output ↓ SVR ↓ Sympathetic tone	Time to reach effector site is slow

Commonly used anaesthetic drugs have a direct depressant effect on the cardiovascular system, inhibit compensatory mechanisms and carry a high risk to further deteriorate the haemodynamic status of trauma patients. Subsequent positive pressure ventilation will impair venous return and contribute to further haemodynamic impairment. Recognition of masked hypovolemia and an accurate estimation of its extent are crucial in the choice of type and dose of anaesthetic drugs.

For induction of general anaesthesia, the most commonly used drugs include ketamine, thiopental, etomidate, midazolam and propofol. For the choice of the most suited induction agent, the patient's physiology, comorbidities and the anaesthetist's experience should be taken into consideration. All anaesthetic induction agents can be vasodepressors and have potential to cause hypotension. The skill and experience of the anaesthetist are the most important determinants for a good outcome. Short-term use of a vasopressor can reverse vasodepressor effects but it must be emphasized that continued need for vasopressors in the trauma patient population is associated with poor outcomes.

19.5.2.1 PROPOFOL

Propofol has a long t1/2Keo of up to 20 minutes, indicating that for rapid induction a higher initial dose is required. However, in shocked patients, propofol shows an increased end-organ sensitivity (e.g. lower C50) and a slower intercompartmental clearance. Haemorrhagic shock has shown shift of the concentration/effect relationship to the left, demonstrating a 2.7-fold decrease in the effect site concentration required to achieve 50 per cent of the maximal effect in the BIS scale. In shock, potency of propofol is increased, and the dose required to reach effect site concentration is 5.4-fold reduced. Therefore, rapid induction can be performed with propofol, but a high dose is required in patients exhibiting increased organ sensitivity. This, in view of the important concomitant negative effects on haemodynamics, makes propofol a poor choice for the trauma setting, but if used, dose reduction to approximately one-third is highly recommended.

19.5.2.2 KETAMINE

Ketamine is a highly lipid-soluble drug. At a physiologic pH, almost 50 per cent is dissociated and only 12 per cent is bound to plasma proteins. This ensures a rapid blood-brain equilibration and fast clinical onset.

Ketamine is the least likely agent to cause cardiovascular depressant effects. Its direct negative inotrope effect is counteracted by a stimulatory effect on the cardiovascular system, probably by a centrally mediated sympathetic response and inhibition of noradrenaline re-uptake. In the severely shocked patient with a state of catecholamine exhaustion or resistance to further catecholamine effect, the direct effects of ketamine on myocardial depression may outweigh the indirect sympathetic effects and haemodynamic collapse may still occur. A reduction of the induction dose to 0.25 to 0.5 mg/kg i.v. may be indicated. Ketamine has further shown to provide anti-inflammatory proprieties; however its clinical impact in trauma patients remains to be determined. Ketamine has reportedly both raised and lowered intracranial pressure. In traumatic brain injury, the cerebral autoregulation is impaired and the CBF is directly depending on the cerebral perfusion pressure. Maintenance of hemodynamic stability may therefore outweigh potential risks. Further, ketamine reduces cerebral oxygen consumption' and the cerebral vasodilatation as observed in spontaneously breathing patients may be reduced by controlled ventilation.

19.5.2.3 ETOMIDATE

Haemorrhagic shock produces minimal changes in the pharmacokinetics and pharmacodynamics of etomidate. Etomidate preserves the pressor response to intubation, and shock affects only minimally its ability to reach the effector site rapidly. Its central and peripheral volumes are only lightly decreased in acute hypovolemia, increasing its blood levels by about 20 per cent. Therefore, unlike as with other hypnotics, only minimal adjustments in induction dose are required to achieve the same drug effect in haemorrhagic shock. As compared to propofol, no increased drug sensitivity had been demonstrated for etomidate. These points provide etomidate with a good safety profile as an induction agent in trauma patients.

However, in many countries etomidate was withdrawn after the CORTICUS study, which showed that in septic patients even a single dose may suppress the corticoadrenal axis for up to 67 hours. In the non-septic trauma patients, suppression of steroid synthesis does not seem to be associated with worse outcome as increased on mortality or prolonged length of stay.

19.5.2.4 THIOPENTAL

Thiopental exhibits several desirable properties in the shocked patient as a short t1/2 Keo (1.5 min) and a tendency to preserve autonomic responsiveness as a reflex tachycardia or the pressor response to laryngoscopy. However, its usefulness in the setting of hypovolemic shock is compromised by the important negative inotropy and arteriolar vasodilation, leading to severe hypotension in shocked patients. Doses must therefore be carefully adapted to values if possible below a range of 3 mg/kg.

19.5.2.5 MIDAZOLAM

Midazolam in induction dose has shown to significantly decrease plasma norepinephrine concentration and alters baroreflex control of the heart rate. It also causes reduction of systemic vascular resistance and left ventricular stroke work index. Hence, in hypovolemic patients, it may further decrease blood pressure and prevent compensatory tachycardia. Additionally, midazolam is highly protein bound, inhibiting a rapid entry into the brain effector site. The half-life for closure of its imidazol-ring, which enhances lipid solubility and brain entry, is long (10 min), making this agent of little value for rapid sequence induction (RSI).

There is no hard outcome evidence supporting one agent over the other, but whatever agent is chosen, induction doses must be adapted to the patient's physiology, and most often reduced. Many use a combination of induction drugs combining their different effects. Normalization of haemodynamic parameters with aggressive fluid resuscitation prior to induction has not proven to completely reverse the increase in induction drug potency.

Maintenance of anaesthesia during damage control procedures in the haemodynamically compromised patient requires a careful choice and titration of drugs. Perioperative awareness is well recognized during emergency anaesthesia, often as a consequence of dose reduction. A comparison of patients treated by ketamine induction and maintenance with volatiles versus no maintenance drug showed a perioperative awareness rate of 11 per cent versus 43 per cent. The choice of the optimal maintenance drug is influenced by the patient's physiology and his or her injury profile. For traumatic brain injury and trauma to the spinal cord, intravenous anaesthesia as with propofol is recommended, while as in other settings inhalational anaesthesia might be more suited. A BIS measure might be a valuable help in preventing awareness in the severely shocked patient with altered dose requirements.

19.6 BATTLEFIELD ANAESTHESIA

Battlefield anaesthesia is both an anaesthetic as well as an operational problem (see also Chapter 18). It is not an exclusive medical problem. It occurs in an environment that both provides the platform from which you treat and influences the decision making.

Battlefield anaesthesia presents many challenges, including the need to maintain airway control, hypothermia of the casualty, restricted drug availability, lack of supplementary oxygen and the possible requirement for prolonged post-operative mechanical ventilation. Mass casualty situations are also a constant possibility in the military arena. Surgery requires both adequate analgesia and anaesthesia. No single agent can provide both an appropriate level of anaesthesia and analgesia, hence a combination of drugs and techniques is required. The choices of anaesthetic are narrowed in austere conditions; these are limited to general anaesthesia (either intravenous or inhalational), regional anaesthesia or none at all. For surgical exploration of body cavities, general anaesthesia is most frequently chosen, while a regional anaesthetic may be more appropriate for injuries of the extremities or perineum. In the field, RSI is the norm, using fast-acting hypnotic and neuromuscular blocking agents to facilitate rapid airway control. In the absence or limitation of supplemental oxygen supplies, RSI becomes even more crucial as pre-oxygenation of the patient's lungs is often not possible. There are several RSI cocktails used in the pre-hospital setting, most using a combination of induction agent paralyzing agent and analgesia. Sedation, amnesia and analgesia can then be maintained with intravenous agents such as ketamine, benzodiazepines and opiates.

For long procedures or surgical sites involving the abdomen or thorax, a combination anaesthetic that includes an inhalation agent such as isoflurane may be used. British surgical teams use a portable 'tri-service apparatus' that does not require a compressed gas source, and they have gained much experience with this technique of field anaesthesia. This 'draw-over' type of vaporizer is currently also in use by several other countries in austere settings. The draw-over configuration places the ventilator distal to the vaporizer, entraining ambient air and vapour across the vaporizer in the same manner as the spontaneously breathing patient.

Regional anaesthesia remains an important option in battlefield anaesthesia, as it provides both patient comfort and surgical analgesia, while maintaining patient consciousness and spontaneous ventilation. With the relatively large number of extremity wounds in modern conflicts, and certainly in the mass casualty setting with a limited anaesthesia capability, regional aesthetic techniques should not be overlooked. Continuous infusion nerve blocks provide excellent analgesia for post-operative casualties during evacuation.

19.6.1 Damage Control Anaesthesia in the Military Setting

Anaesthesia for 'damage control' procedures and major cavity injury is really a fusion of continuing resuscitation and critical care. This requires optimization of haemodynamic status, re-warming of the casualty and pain relief. One of the biggest challenges will be reversing the hypothermia that is almost universal in haemorrhagic patients in these conditions. As well as warming all intravenous fluids and ventilator circuits, an active re-warming device will be required. If a return to the operating theatre for more definitive surgery is not planned in the forward location, critical care must be maintained throughout the aeromedical evacuation.

19.6.2 Battlefield Analgesia

Relief of pain is an important consideration for both the wounded and the military caregiver. Provision of effective analgesia is humane but also attenuates the adverse pathophysiological responses to pain, and is likely to aid evacuation from the battlefield and maintain morale. Analgesia may be given at self- and buddy-aid levels; protocols to guide medical and paramedical staff in the provision of safe and effective analgesia are available.

Analgesia methods used in recent conflicts include:

- Simple non-pharmacological.
- Reassurance.
- Splinting of fractures.
- Cooling of burns.
- Oral analgesics.
  - Non-steroidal anti-inflammatory drugs.
  - Paracetamol.
- Nerve blocks and infiltration of local anaesthesia.
- Intramuscular and intravenous opiates.
- Fentanyl lollipops.
- Methods under development – intranasal, ketamine, fentanyl and inhalation analgesics (e.g. methoxyflurane inhalation).

REFERENCES

1. Moore FA, McKinley BA, Moore EE: The next generation in shock resuscitation. *Lancet*. 2004;363(9425):1988–1996.
2. Holcomb JB, Jenkins D, Rhee P, et al. Damage control resuscitation: directly addressing the early coagulopathy of trauma. *J Trauma*. 2007;62(2):307–310.
3. Kasotakis G, Sideris A, Yang Y, et al. Inflammation, host response to injury. I: Aggressive early crystalloid resuscitation adversely affects outcomes in adult blunt trauma patients: an analysis of the Glue Grant database. *J Trauma Acute Care Surg*. 2013;74(5):1215–1221; discussion 1221–1222.
4. Cannon WB. The preventive treatment of wound shock. *J Am Med Assoc* 1918; 70: 618–21.
5. Zarychanski R, Abou-Setta AM, Turgeon AF, et al. Association of hydroxyethyl starch administration with mortality and acute kidney injury in critically ill patients requiring volume resuscitation: a systematic review and meta-analysis. *JAMA*. 2013;309(7):678–688.
6. Stadlbauer KH, Wagner-Berger HG, Raedler C, et al. Vasopressin, but not fluid resuscitation, enhances survival in a liver trauma model with uncontrolled and otherwise lethal hemorrhagic shock in pigs. *Anesthesiology*. 2003;98(3):699–704.
7. Sperry JL, Minei JP, Frankel HL, et al. Early use of vasopressors after injury: caution before constriction. *J Trauma*. 2008;64(1):9–14.
8. Spahn DR, Bouillon B, Cerny V, et al. Management of bleeding and coagulopathy following major trauma: an updated European guideline. *Crit Care*. 2013;17(2):R76.
9. Gunter OL, Jr., Au BK, Isbell JM, Mowery NT, Young PP, Cotton BA. Optimising outcomes in damage control resuscitation: identifying blood product ratios associated with improved survival. *J Trauma*. 2007;65(3):527–534.
10. Holcomb JB, Wade CE, Michalek JE, et al. Increased plasma and platelet to red blood cell ratios improves outcome in 466 massively transfused civilian trauma patients. *Ann Surg*. 2008;248(3):447–458.
11. Kozar RA, Peng Z, Zhang R, et al. Plasma restoration of endothelial glycocalyx in a rodent model of hemorrhagic shock. *Anesth Analg*. 2011;112(6):1289–1295.

12. Brohi K, Singh J, Heron M, Coats T. Acute traumatic coagulopathy. *J Trauma*. 2003;54(6):1127–1130.
13. Brohi K, Cohen MJ, Ganter MT, et al. Acute traumatic coagulopathy: initiated by hypoperfusion: modulated through the protein C pathway? *Ann Surg*. 2007;245(5):812–818.
14. Mutschler M, Nienaber U, Brockamp T, et al. Renaissance of base deficit for the initial assessment of trauma patients: a base deficit-based classification for hypovolemic shock developed on data from 16,305 patients derived from the TraumaRegister DGU®. *Crit Care*. 2013;17(2):R42.
15. Cotton BA, Au BK, Nunez TC, Gunter OL, Robertson AM, Young PP. Predefined massive transfusion protocols are associated with a reduction in organ failure and postinjury complications. *J Trauma*. 2009;66(1):41–48; discussion 48–49.
16. Hess JR, Holcomb JB, Hoyt DB. Damage control resuscitation: the need for specific blood products to treat the coagulopathy of trauma. *Transfusion*. 2006;46(5):685–6.
17. Stensballe J, Ostrowski ST, Johansson P. Viscoelastic guide to resuscitation. *Curr Opin Anesthesiol*. 2014;27:212–218.
18. Shakur H, Roberts I, Bautista R, et al. Effects of tranexamic acid on death, vascular occlusive events, and blood transfusion in trauma patients with significant haemorrhage (CRASH-2): a randomised, placebo-controlled trial. *Lancet*. 2010;376(9734):23–32.
19. Moore HB, Moore EE, Gonzales E, et al. Hyperfibrinolysis, physiologic fibrinolysis, and fibrinolysis shutdown: the spectrum of post injury fibrinolysis and relevance to antifibrinolytic therapy. *J Trauma Acute Care Surg*. 2014;77(6):811–817.