# Massive Haemorrhage Control

6

Alia Yaqub and Peter Lax

- Understand the different types of major haemorrhage
- Know how to manage the different types of haemorrhage
- Understand when advanced techniques, such as REBOA and thoracotomy, might be used

**Case Discussion: Massive Haemorrhage in Civilian Settings**

*A known Intravenous Drug User has self-inflicted wounds to his left antecubital fossa and has bled significantly. Paramedics on scene have applied two tourniquets in an attempt to control the bleeding. They report the patient is pale, confused and sweaty. They will be in the Emergency Department (ED) in 5 minutes.*

*What should you do?*

*What are the steps in pre-hospital haemorrhage control?*

*What should the goals be in resuscitation?*

*When should pre-hospital or ED thoracotomy be considered?*

*When might resuscitative endovascular balloon occlusion of the aorta (REBOA) be considered?*

Returning to the original case, the patient will arrive shortly. Anticipate needing to give warmed blood quickly. This may require activation of the local massive transfusion pathway. Blood should be given to maintain a central pulse. Pre-hospital haemorrhage control should have included a failure of direct pressure, and a failure to stop the bleeding with a single tourniquet should lead to the application of a second. The aim of resuscitation should be definitive bleeding control. This is likely to be achieved operatively, but for now, the patient may need significant analgesia in order to tolerate the tourniquet. There is no role for thoracotomy or REBOA in this case.

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## Introduction

Advances in trauma care are often fuelled by conflict, and current understanding and treatment protocols for massive haemorrhage control are no different in this respect. As medicine advances and our understanding of pathophysiological mechanisms expands, treatments for trauma improve, resulting in increased survival. Several case review series have looked at death rates and mechanism of death on the Battlefield from World War 2, through the American experience in Vietnam and, more latterly, to operations in Iraq and Afghanistan. Overall mortality has decreased, from 30% in World War Two to 24% in Vietnam and under 10% in recent conflicts [1] (though the absolute accuracy of these figures has been somewhat disputed due to the methodology used) [2]. While medical advances have played a significant part in reducing in-hospital deaths, the reintroduction of simple and long-known techniques have seen a substantial decrease in the number of soldiers who have died of treatable haemorrhage. In Vietnam, half of the potentially treatable deaths were from limb wounds that were amenable to tourniquet use [3], but this rate fell to 13.5% in Iraq from 2001–2011 [4]. This is due primarily to the training of personnel in the use of massive haemorrhage control techniques, including the use of tourniquets, with subsequent feedback and reinforcement during the military operational medical pathway [4–7]. While deaths in warzones will show a more substantial component of blast and ballistic injuries, the basic principles of massive haemorrhage control and their importance remain the same in civilian practice. With terrorist incidents such as the bombings in Madrid in 2004 [8], Boston Marathon in 2013 [9, 10] and more recent major incidents in Paris [11, 12], military evidence is all the more relevant to civilian trauma care.

Studies and reports on massive haemorrhage in civilian settings [13] have shown a concerning picture. In one review, trauma haemorrhage was identified as the cause of 30–40% of all trauma deaths and 51% of early trauma deaths. A study from Texas into mortality from isolated extremity injury showed approximately half of these patients could have been saved by tourniquet use earlier in their care [14]. A Canadian retrospective review identified that 16% of trauma deaths might have been preventable if sources of bleeding were more aggressively sought and treated [15].

In common with military experience, massive haemorrhage represents the leading cause of potentially treatable trauma deaths in the civilian population. For treatment to be life-saving, it must be instigated as quickly as possible, often by people with minimal or basic medical training. There is also evidence linking duration and depth of hypovolaemic shock with worsening outcome [16–20]. Treating massive haemorrhage earlier may save lives; both at the immediate point of treatment and later by minimising the systemic effects of hypotensive shock, such as coagulopathy and multiorgan failure. The American College of Surgeons Stop the Bleed campaign [21] started in 2015. It highlights how a significant proportion of preventable deaths are from haemorrhage [22] and recognises that professional help will not arrive immediately. The campaign, therefore, aims to train bystanders to manage severe bleeding as quickly as possible using simple techniques. A study performed in 2018/19 into the efficacy of the Stop the Bleed teaching showed that this campaign, with a combination of lectures and hands-on skill workshops, improved knowledge and management in life-threatening bleeding scenarios [23].

This is not a phenomenon seen exclusively in the USA; in the UK, the 1999 Stephen Lawrence inquiry [24] appears to support this need for bystander education. It found the teenager (who was stabbed and bled to death at a bus stop) was dead before the ambulance crew arrived, but that there were bystanders present who could have intervened.

Haemorrhage control efforts can be broadly divided into two categories; temporary and definitive. Most of the methods covered in this chapter fall into the former group, and may buy the patient enough time to reach the latter. The use of pressure and tourniquets will be covered, as well as more advanced measures. As will be discussed, much of our current civilian practice comes from military evidence.

## What Is Massive Haemorrhage?

Confusingly, there is not a single universally accepted definition of massive haemorrhage in the literature. Definitions are hugely variable and range from absolute numbers such as 50% blood loss within three hours [25], six units of RBC's in 12 h, 50 units of blood components in 24 h [26], loss of more than one circulating volume within 24 h [27] or a sustained rate of >150 ml/min [25]. There is at least recognition in some publications that these definitions are problematic [26, 28]. In most cases, the criteria are both retrospective and heavily weighted towards hospital practice and the varyingly accurate assumption that blood and blood products will readily be at hand for transfusion. The reality from the previously mentioned data is that patients with massive haemorrhage will, in many cases, not survive the transfer to hospital from the scene of injury unless the source of their massive haemorrhage is at least temporarily addressed at the point of injury. Of the more practical definitions, an ongoing rate of blood loss of equal to or greater than 150 ml/min, or bleeding that leads to a heart rate of more than 110 beats/min or systolic blood pressure of less than 90 mmHg [28] are more useful. Massive haemorrhage may be difficult to define precisely, but to borrow a legal phrase, "I know it when I see it" [29].

## Sources of Massive Haemorrhage

### External Bleeding

The Advanced Trauma Life Support adage of "blood on the floor and four more" holds true [30]. Large amounts of external bleeding should be very obvious, and ongoing bleeding should be addressed as a priority. Patients may also lose massive amounts of blood into their pelvis or from long bone fractures (humerus and femur), and both long bone and pelvic fractures can be splinted to reduce both pain and bleeding. Bleeding into the chest and abdomen is much more challenging to treat in the pre-hospital setting; management is explored further under the non-compressible haemorrhage section (below) and the damage control surgery and interventional radiology sections of this textbook.

### Skin/Scalp Bleeding

Staples, sutures and/or adrenaline dressings (and occasionally devices such as the iTClamp [31, 32]) may be needed to stem bleeding from the scalp, as bandages may provide insufficient pressure when applied circumferentially around the head. The iTClamp is a device that opposes wound edges to encourage clots to form and arrest bleeding (see Videos 6.1–6.3). It has been used by military [33] and civilian [34] personnel in the USA in isolation or combination with other haemorrhage control methods. In common with other mass haemorrhage control strategies, its application can be rapidly learnt and then applied by those with minimal medical training. The iTClamp is now part of the Committee on Tactical Combat Casualty Care's recommendations for Tactical Field Care in combination with haemostatic dressings, as it can apply direct pressure without a practitioner remaining hands-on with the patient [35]. While the device looks painful to use, the patient (by definition) will have a significant wound to require it to be applied in the first place and so require good analgesia *a priori*. Surprisingly, when an assessment of pain was made during application on 26 volunteers, the average pain score on application on a 1–10 scale was self-reported as a mean of 2.0 ± 1.1. On removal, pain scores were 1.9 ± 1.5. The maximum scores on application and removal were 5.0 and 7.0 respectively, with a minimum score of 0 for both [36]. It is also safe in terms of tissue damage. One study demonstrates minimal tissue damage (needle holes only in 59/60 cadaveric and swine applications [37]). The iTClamp also outperforms the Combat Application Tourniquet (CAT) in terms of preservation of marksmanship skills in healthy volunteers on a target range [38]. This may be of relevance if used in tactical environments.

Video 6.1: iTClamp Application to live animal model **[External video link: https://www.youtube.com/watch?v=OGJyzxyLCMs]**

Video 6.2: iTClamp application to the scalp **[External video link: https://www.youtube.com/watch?v=EOvtQsDcEWo]**

Video 6.3: iTClamp self-application by healthy volunteers **[External video link: https://www.youtube.com/watch?v=18U1Jh7idHU]**

Other haemorrhage control methods from large skin edges include adrenaline-soaked dressings and application of sutures or staples for wound opposition. Adrenaline dressings manage bleeding by causing local vasospasm, and staples or sutures allow rapid skin opposition in bleeding wounds. Paramedics may carry staples; sutures are more often instituted by a doctor in the UK.

## Facial Trauma

Harris et al. from London HEMS described a technique to manage massive maxillofacial bleeding in 2010 [39]. Several other pre-hospital care providers have since adopted this technique. It involves using a well-fitting cervical collar to splint the face, applying bite blocks between the maxilla and mandibular molars, as well as a nasal epistat in each nostril (Fig. 6.1). Given the significant association between significant maxillofacial injury and head injury, these patients are often intubated. The endotracheal tube also provides a degree of splinting [40]. This method and the anatomical sources of maxillofacial bleeding are more fully explored in the airway chapter of this textbook.

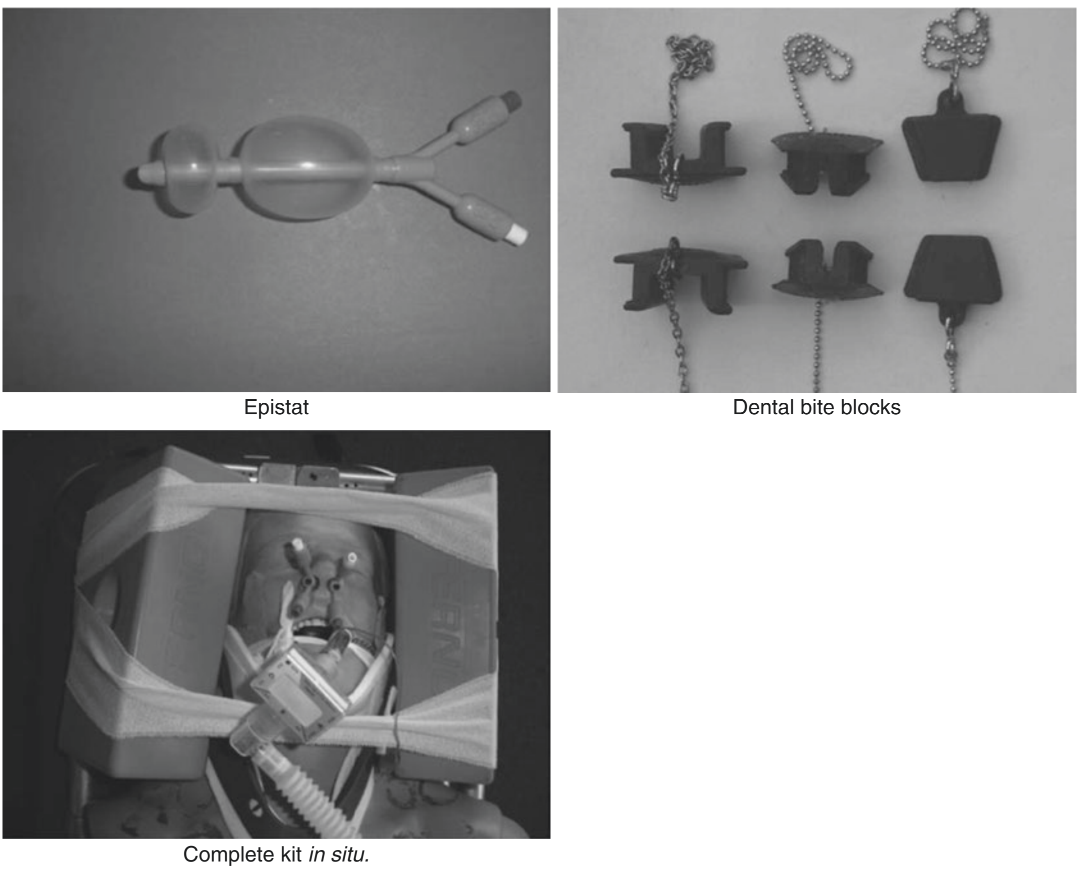


**Fig. 6.1** Kit for controlling massive maxillofacial haemorrhage (from Harris et al. [39])

## Pelvic Trauma

Bleeding from pelvic injuries can be catastrophic, either from bone edges, associated vascular damage or visceral injuries. Specifics of pelvic injuries are dealt with in the pelvic chapter, but in terms of massive haemorrhage control, the application of a pelvic binder is a haemorrhage control intervention. Their application is now a standard procedure for ambulance crew [41]. The Faculty of Pre-Hospital care made a consensus statement in 2012 reviewing the available evidence and supported their use and that of scoops rather than repeated log rolls [42]. Pelvic binders have been used in an effort to control pelvic haemorrhage for decades [40]. The reduction in pelvic volume is thought to create tamponade and reduce venous bleeding, while reduction and stabilisation of the fracture site is believed to minimise bone edge bleeding and protect against disruption of any initial clot formation [43]. A study examining the effects of pelvic binders published in 2017 showed they significantly reduced mortality and blood transfusion [44]. If a pelvic binder is not available, a simple sheet may be used to reduce the volume of the intra-pelvic cavity and subsequent bleeding into it [45].

Patient handling is now geared to reduce rotational movement with the aim of preserving clot. A patient with significant pelvic fractures found in a semi-prone position was previously log-rolled; such a patient would undergo 510 degrees of rotation rather than 170 degrees which can be achieved with a scoop stretcher [40].

## Treatment of Massive Haemorrhage

Massive haemorrhage largely falls into two categories in trauma—compressible and non-compressible. There is also an element of environmental interplay in pre-hospital care. What might be an anatomically compressible injury (e.g. a cut brachial artery) may be temporarily uncompressible based on the patient's location (e.g. arm caught in heavy machinery up to the axilla). Safety of personnel is the prime consideration (see scene safety chapter), so ensure that any dangers are addressed before starting treatment—e.g. machines that are still running may injure those who attempt a rescue. Some treatments are appropriate for haemorrhage in both pre- and in-hospital settings, such as tranexamic acid administration (TXA). The CRASH-2 trial [46] showed a 9% relative risk reduction in mortality in bleeding trauma patients, with the most benefit seen if TXA was given within the first hour of injury, but benefit still seen if administered within three hours of injury. This drug is now a standard medication given by paramedics and other pre-hospital clinicians in the UK [41]. Hypothermia is well-recognised to impair clotting and worsen bleeding, so patients should be kept as warm as possible. This may involve measures such as the removal of wet clothes and the use of blankets, as well as fluid/blood warmers. More detail is available in the circulation and haemostasis in trauma chapters.

## Compressible Haemorrhage

The prime example of compressible haemorrhage is an injury to a limb. The more distal the injury, the easier it is to deal with, especially if there is an arterial component. As wounds become more proximal, they become increasingly difficult to either compress or use a tourniquet. Injuries in the neck, axilla or groin are referred to as junctional haemorrhage. They are particularly problematic as they contain large vascular structures which may be quite deep, difficult to control, and are not readily amenable to tourniquet use.

**DDIT Escalation of Treatment**

- **Direct pressure**
  - Expose the bleeding site and apply direct pressure
- **Direct pressure (again)**
  - If bleeding is not immediately brought under control, quickly reassess that the pressure is applied to the correct site and re-apply. Avoid the temptation of repeated looks or swathes of dressings; remember

all bleeding is blood that is no longer carrying oxygen to vital organs. Once blood has left the body, it cannot be reinfused (at least in the pre-hospital environment).

- **Indirect pressure**
  - If direct pressure has failed to stop the bleeding, apply indirect pressure in addition to direct pressure. This is done over an artery proximal to the bleeding site and compresses the vessel against a bone. Either direct pressure in isolation or in combination with indirect pressure controls the bleeding in most cases.
- **Tourniquet**
  - If the bleeding is still not controlled, apply a tourniquet. The application time should be documented on the tourniquet and form part of the handover to the receiving team.

The escalation from direct pressure through the rest of the treatment pathway as needed must be rapid. If there is a high-volume ongoing blood loss, there is precious little time to arrest it. The progression through the process of assess—intervene—re-check—escalate has to be fast to preserve as much circulating volume as possible. Even if blood is immediately available for transfusion, transfused red blood cells do not function as well as the patient's own blood immediately after admission. How long blood products have been stored may also influence how well they work [47–49]. The best blood to be circulating in a patient's body is their own, so preserving as much of it as possible instead of replacing it should be the aim. Occasionally, an obvious catastrophic bleed will require tourniquet application from the outset (e.g. amputation, major artery transection). In these cases, it is appropriate to use a tourniquet as a first-line haemorrhage control method, as escalation and reassessment steps are unlikely to be effective without tourniquet use. During the time it would take to escalate as described above, the patient is still losing valuable blood. Once the patient is in a more controlled environment, it may be appropriate to de-escalate from tourniquet use when facilities are available to allow appropriate haemorrhage control (e.g. in an operating theatre or emergency department).

Direct pressure onto a bleeding site is a well-accepted first aid measure for most cuts, whether they fall into the definition of massive haemorrhage or not, as is the elevation of the bleeding site above the level of the heart. Direct and continuous pressure with a gauze pad or bandage may be sufficient in itself to stem bleeding, but it may take time to work. One problem often seen is repeated removal of dressings to check if bleeding has stopped. If clots start to form around the wound/dressing interface and then the dressing is removed, the bleeding will restart. For this reason, when a wound is first seen it can be helpful for hospital staff if a picture is taken before dressing if this will not delay treatment. Once a wound has been covered (if superficial) or packed (if deep) to stop bleeding, the dressings should not be taken down or swapped until the patient is in hospital, ideally in an operating theatre if the wounds are severe. If there is bleeding through the dressing, another dressing should be placed on top and the initial dressing left in place to avoid disrupting any clot. Pressure should be focused (where possible) on the specific point of the wound that is bleeding.

## Indirect Pressure

If direct pressure is insufficient, indirect pressure over a major pulse point (brachial or femoral artery) in addition to pressure over the wound may help to reduce bleeding. This is resource-intensive, as pressure now needs to be kept on two areas constantly. Simultaneously, other therapeutic interventions that are necessary are undertaken, and this may be impossible for a lone clinician. Indirect pressure may buy time to apply a haemostatic dressing or tourniquet if one is not immediately available. However, it is primarily a short-term temporising measure that is not practical for more extended periods.

Pressure on the aorta is the most extreme example of indirect pressure. There has been some simulation evidence suggesting that indirect pressure can be transmitted effectively to the aorta by two-handed or knee compression of the abdomen [50]. This method cannot currently be advocated for clinical use due to lack of evidence. However, it is a similar thought process for some devices such as the Abdominal Aortic and Junctional Tourniquet (AAJT) [51]. While initial data on healthy individuals for this device were compelling, further studies have failed to live up to the initial promise. The AAJT is less effective than other junctional devices and takes longer to apply [52, 53].

## Tourniquets

The final step in the DDIT pathway for managing compressible haemorrhage is the application of tourniquets. Tourniquets work by stopping the arterial blood flow to an injured limb, thereby minimising further blood loss. They have been used since the Middle Ages, with military use first documented in 1674 [54]. They have, at times, fallen out of favour [55] but are currently recognised to be life-saving for bleeding that is uncontrolled by direct pressure. Tourniquets form the last stage in major limb haemorrhage guidance for UK paramedics [41], and the National Institute for Clinical Excellence supports their use [56]. The Faculty of Pre-hospital Care advises that tourniquets are applied as rapidly as possible, directly against the skin, as distal as possible above the wound and tightly enough to arrest haemorrhage [57]. Combat Action Tourniquets (CAT) are the most widely used model [58] and are designed to allow application with one hand—this allows for self-application if necessary (Fig. 6.2). Although each brand has its own instructions, the broad principle is that they are strapped around the limb and pressure increased with a windlass, compressing a single artery against a single bone until bleeding is stemmed.

**Fig. 6.2** Combat Application Tourniquet with windlass tightened

Many devices, including the CAT, come with a place to write on the time of application. Whether or not this is the case, it is vital to document the application time and hand this over to the receiving team. Additional measures (such as a large "T" and the time of application written on the patients' forehead or another visible area) act as a reminder that a tourniquet has been applied. This is especially important in intubated or unconscious patients who may not complain of the pain due to the tourniquet and suffer ischaemic complications as a result. When properly applied to conscious patients, the resulting ischaemia causes pain in addition to the injury itself; the analgesia requirement is likely to be significant, requiring morphine, ketamine or some other potent analgesic. Tourniquets may be applied in the ED if bleeding cannot be managed in any other way, though pneumatic devices are preferred if available.

There is an ongoing debate about the role of tourniquets in the management of crush injury. Theoretically, there is some benefit in their use after crush to prevent reperfusion injury by stemming blood flow to the affected site and controlling the release of blood from ischaemic tissues back into the central circulation. Due to ongoing ischaemia, rhabdomyolysis and muscle damage, this returning blood may be cold, high in potassium and acidic. This may cause hypotension and arrhythmias, as seen in vascular surgery when clamps are taken off and limbs reperfuse [59, 60]. This concern has been raised with a similar phenomenon reported in knee replacement surgery [61]. In practical terms, pneumatic devices are more effective than windlass devices such as the CAT as they arrest blood flow at lower pressures [62] and cause less tissue damage, hence why they are preferred in hospital practice.

The evidence for the use of any tourniquets in traumatic crush injury is often low quality and contradictory. However, what relevant published literature there is agrees that fluid resuscitation and the avoidance of potassium-containing solutions are important in these patients [63–65]. In these cases, the potential for sudden cardiovascular deterioration should be anticipated when a casualty is released from a crush scenario. Although theoretically attractive, further study is needed before clear recommendations can be made for the routine use of tourniquets in traumatic crush injury. If there is an overt vascular injury that would necessitate tourniquet use in other circumstances, one should still be used. Research is still ongoing on how to best mitigate the ischaemic consequences of tourniquet use [66], but tourniquets are life-saving devices and should be used when necessary.

A key point on tourniquet use is that although these devices are easy to use, training is essential and should be as immersive as possible. Putting a device on a fake limb without any movement or resistance is a straightforward task; however, this does not adequately replicate how the task is achieved *in vivo*. Putting a tourniquet on an aggressive/combative/confused patient in the pre-hospital environment is very different from doing it in a warm, well-lit classroom. Practitioners should “train how they fight” and aim to stretch themselves while training with these devices and ensure familiarity with the particular model that their employer uses. This should increase efficacy and proficiency when they are needed for real.

Other concerns revolve around the length of time they can be applied. The general consensus is that after two hours there is a risk of permanent nerve damage and muscle or skin necrosis, and after six hours this extends to complete muscle damage that is likely to require amputation [67]. This data is primarily based on pneumatic tourniquet use in elective operating theatres. Patients who are hypovolaemic due to trauma, and have a non-pneumatic tourniquet applied, are at higher risk of complications. A battlefield study by Lakstein et al. [68] showed that the mean ischaemic time for tourniquet application without complications was 78 min. However, due to the heterogeneity of injuries it was difficult to demonstrate a minimum time before complications started. There is also uncertainty regarding whether the nature of tourniquet injuries is from direct pressure/compression or ischaemic damage of the nerve. Periodic loosening of tourniquets has been suggested to mitigate this damage; however, this will likely cause incremental bleeding and is therefore not generally advised in the first hour [69]. Once a tourniquet has been applied, the patient should be treated as a time-critical casualty and taken to hospital for immediate evaluation and treatment. Where the pre-hospital phase is prolonged (> 1–2 h), and after application of a direct pressure bandage to the bleeding wound, cautious tourniquet release (but leaving the tourniquet in place) is recommended.

The pain associated with correct tourniquet application has been previously mentioned, but another consideration may be the effects of pain or further resuscitation on the patient’s blood pressure. Tourniquets, when applied correctly, should obliterate a distal pulse. However, patients who have bled profusely may have lost distal pulses due to hypovolaemia before the tourniquet is applied. When an extremely painful stimulus such as application of a tourniquet or further resuscitation is given, if the tourniquet is not on tight enough and the blood pressure rises, bleeding may resume. If the tourniquet is maximally tightened and bleeding is still occurring, a second tourniquet may be applied to the same limb more proximally. This is more often required where there is more muscle to compress, typically in the upper leg.

### Haemostatic Dressings

In cases of severe haemorrhage, direct pressure can be combined with the use of haemostatic dressings such as Celox, Quik-Clot or Hem-Con. These dressings are impregnated bandages, pads or pellets (depending on the product used) that will increase clotting at the site of injury. In early zeolite-based dressings, such as first- and second-generation Quick-Clot products, this was achieved by absorbing water and concentrating the patients clotting factors at the wound site in an exothermic reaction. However, these were discontinued following reports of wound burns and tissue damage due to the heat created by the exothermic reaction [70–72].

Each product works using different mechanisms. These include direct activation of intrinsic clotting pathways (e.g. kaolin-based third-generation Quik-Clot) or attracting red blood cells into a bandage and creating an adherent seal over the wound (chitosan-based dressings such as HemCon/ChitoFlex/ChitoGauze/Celox). More recent iterations of haemostatic dressings (e.g. the modified rapid deployment haemostat) work on multiple complex mechanisms involving platelet activation, coagulation cascade activation, local vasoconstriction and agglutination of red blood cells, all mediated by fully acetylated poly-N-acetyl-glucosamine [73]. While there are numerous animal studies of these agents, there is little human trial data on differences in effectiveness *between* various products. One concern that is often brought up in chitosan-based dressings is the risk of allergic reaction in patients who are sensitive to shellfish (chitosan is a shellfish polysaccharide derivative). These dressings have specifically been tested on shellfish-sensitive patients and found to be safe [74, 75]. Most of these studies show that haemostatic dressings are effective in clinical use. Due to the widespread use by various military forces of Celox, HemCon and Quik-clot, it is unlikely that other products in this class will be able to break into the market [76]. Other novel sealants may be useful in different circumstances (e.g. FloSeal (gelatin granules and human thrombin) or fibrin sealants in surgery).

Future advances in the use of expanding haemostatic foams are focusing on minimising infection whilst optimising compression by using foam impregnated with iodine [77].

### Junctional Haemorrhage

These are areas of bleeding such as the neck, axilla or groin where the torso joins the extremities, and tourniquets cannot be easily applied. A ten-year retrospective US battlefield study showed that 17.5% of potentially preventable deaths were due to junctional haemorrhage [4]. Treating and preventing injuries in these areas is problematic for many reasons. There are a large number of vascular structures, but these are in areas where both tourniquets and direct pressure are difficult to apply and maintain, especially in military or other tactical settings.

From a military protection and prevention viewpoint, these areas are also challenging. Increasing the amount of protective body armour around the groin, axilla, or neck reduces the range of movement and can significantly limit mobility. Increasing protection but reducing speed and agility may result in an easier target for the enemy and unwittingly increase the risk of death or injury [78, 79].

The principles of direct pressure with haemostatic dressings are the same for treating junctional haemorrhage. These may be harder to perform successfully, but there are few options for managing bleeding in this area in the pre-hospital environment. Once in hospital, rapid transfer to theatre and control of proximal vessels in the chest or abdomen may be required.

Specific devices for junctional compression are in development and early deployment, such as the Combat Ready Clamp (CRoC), the SAM Junctional Tourniquet (SAM-JT), Junctional Emergency Tool and the previously mentioned AJTT [80]. While there is not a large amount of empirical trial data for the use of these devices, cadaveric studies and isolated case reports show they do have some merit. It is also worth looking at qualitative data from users. If the device is impractical to use *in vivo*, it is largely irrelevant how well it performs in perfect conditions in the manufacturers' lab. When end-users have trialled various devices, the CRoC and SAM-JT were preferred over the JETT and AJTT by US Army medics during training [81]. Feedback from actual battlefield use is equally poor for the AJTT, with units reporting it was "easily broken" and the CRoC was "bulky, heavy and takes too much time to apply" [80]. The AAJT is also contraindicated in penetrating abdominal trauma, so it does not appear to be a device that would be as useful as its manufacturers may hope in the population for which it was designed.

Some devices use haemostatic agents in an applicator for deep narrow track junctional wounds where compression may be difficult or impossible (such as the XStat [82, 83]). The XStat has been trialled favourably against Combat Gauze in animal models of haemorrhage [84], has a good safety profile during *in vivo* use in hospital [85] and has been incorporated into the Tactical Combat Casualty Care guidelines [86]. It is a syringe-like device that contains multiple compressed chitosan-covered cellulose sponges that can be injected into sites of junctional haemorrhage and secured with ordinary bandages [45]. The previously mentioned iTClamp has been successfully evaluated in animal models for use in conjunction with haemostatic agents for junctional haemorrhage [87] and has made its way into ToCCC guidelines [33, 35].

A few pre-hospital teams can also offer resuscitative balloon occlusion of the aorta (REBOA) in select cases. REBOA may be used to stop life-threatening junctional, pelvic or abdominal bleeding where other measures have failed. More and more teams can offer this within the hospital, and there may be a role for this in far-forward military surgical units as a damage control measure in the field, during transfer to higher levels of care or as part of initial damage control resuscitation [88–91]. The femoral artery is cannulated via a Seldinger technique, a balloon passed and subsequently inflated to occlude the aorta to arrest catastrophic bleeding (e.g. into a fractured pelvis) until a more definitive solution is offered. More on REBOA can be found in the dedicated chapter.

## Non-compressible Haemorrhage: Torso

Other than rapid transfer to a hospital with as delicate handling as possible, there is little that can be done pre-hospital in this group. The mainstay of treatment is transfer to a surgical facility, where surgery or interventional radiology can be performed, depending on injuries and local set up.

Persistent major haemorrhage in the chest may require a thoracotomy to stop the bleeding and is discussed in the traumatic cardiac arrest chapter. Surgical intervention for abdominal bleeding is not an option in the pre-hospital phase. This is for several reasons, but principally because of the complex surgical manoeuvres to access major vascular structures in the abdomen and the high number of structures that could be injured a priori or iatrogenically. This means that haemorrhage control by laparotomy is a technique that cannot be readily taught to non-surgeons. To facilitate operative management of abdominal haemorrhage, rapid transfer to an operating theatre is necessary. Many pre-surgical adjuncts have been suggested for the management of patients with non-compressible torso haemorrhage (NCTH) in an attempt to reduce the high morbidity and mortality in this group [92]. An American study suggested that the mortality of these patients can be up to 44% [93].

Trials are ongoing, with treatments such as expanding polyurethane foam being suggested for use in intra-abdominal non-compressible haemorrhage before surgery [94, 95]. Such foam expands and becomes solid, occluding bleeding points but risking localised pressure necrosis and subsequent surgical complications such as adhesions. These potential complications may, however, be an acceptable alternative to exsanguination.

Other treatments which have been investigated include:

- Gas insufflation to tamponade bleeding vessels (shown to be effective in animal models [45]).
- Lyophilised and freeze-dried blood products such as thrombosomes. There was some initially good animal safety data and encouraging phase 1 trial data for thrombocytopaenic patients [96–98]. This would have massive logistical advantages over using conventional platelets as they are stable at room temperature for 24–36 months and can be stockpiled and rehydrated quickly. However, further studies are needed (Phase 2 trials of thrombosomes are ongoing). With the extremely limited data currently available, the use of lyophilised platelets in lab-based animal trauma models have shown either decreased [99] or no [100] haemostatic ability.
- Nanoscale injectable therapies—polymers that encourage activated platelets to aggregate and decrease blood loss. Preliminary animal data is mostly positive, but they have a narrow therapeutic window. There exists some concern over the potential for pulmonary infarcts when post-mortem studies of test rats were performed [101–103].
- Other injectable therapies (such as polySTAT [104, 105]) improve fibrin clot cross-linking in rat models. While this decreases blood loss, due to the polymer's size, it is excreted slowly, with up to 7% of the polymer retained in the kidneys a week after administration [106].
- Occlusion of the descending aorta (REBOA) may also be used as a last-ditch attempt to stem bleeding that would otherwise prove fatal, but this comes with high morbidity and mortality as the balloon would have to be inflated in zone 1 or 2 [45] (see REBOA Chapter for further information).

## Fluid Management

The circulation and trauma-induced coagulopathy chapters give a more thorough discussion on the theoretical basis, evidence and management of fluids in trauma. Below is a brief summary of current UK guidance. Pre-hospital teams are advised by the National Institute of Clinical Excellence to resuscitate patients in aliquots of 250 ml to a radial pulse in patients bleeding from blunt injuries and to achieve a central pulse in those with penetrating wounds [107].

International guidance advises aiming for a systolic blood pressure of 80–89 mmHg in patients without concomitant head injury [108].

Some pre-hospital services can give blood; since 2012 this has been possible in UK civilian services [40] though the vast majority of services carry crystalloid as a first-line fluid. Either may be used to achieve the outcome measures suggested by NICE. Those able to are advised to obtain intravenous access regardless of whether or not fluid is to be administered pre-hospital, [41] as it may be harder to achieve later. Pre-hospital blood transfusion improves patient physiology at the time of arrival to ED [109]. It makes clear physiological sense to replace what is lost with the same substance, rather than a crystalloid with neither oxygen-carrying capability nor coagulation factors, where this option is available. The currently running RePHILL trial in the UK is looking to provide evidence for the efficacy of pre-hospital blood in trauma patients [110], though realistically even an equivocal outcome is unlikely to decrease the trend of pre-hospital transfusion, as it is becoming an accepted (and anticipated) standard of care.

Criteria for a pre-hospital thoracotomy are essentially the same as an ED thoracotomy provided the appropriate skill-mix is present on scene; if there is a penetrating injury that may be causing cardiac tamponade and the patient has been in cardiac arrest for less than ten minutes [111–114] it may be appropriate. This approach can occasionally also be used to manage life-threatening pulmonary haemorrhage, though with fewer survivors. Further information can be found in the chapter on traumatic cardiac arrest. The Resus Council advise that a thoracotomy be considered in any penetrating trauma arrest with wounds from the nipple to the epigastrium [115]. There is no such guidance for arrests in blunt trauma. The Faculty of Pre-Hospital Care [116] state that any such intervention must be performed within ten minutes of the loss of cardiac output. This is a very narrow timeframe for such measures and makes intervention within the required time difficult without appropriate skills on scene (as opposed to transferring to a hospital within the timelines). Survival rates beyond this time are virtually zero. Specifically, it should be pointed out that a resuscitative thoracotomy is for the treatment of penetrating thoracic trauma, or injuries that may involve the thorax (e.g. epigastric stab wound that traverses the diaphragm). It is not a treatment for hypovolaemia caused by non-thoracic injuries which are otherwise amenable to direct control (e.g. limb haemorrhage). While compression of the descending aorta may arrest blood supply to a bleeding pelvis or leg, tourniquets or other strategies outlined above will do the same. The cornerstone of treatment in these peri-arrest patients is aggressive filling with blood products along with source control, initially with a tourniquet then definitively in an operating theatre. A recent systematic review has suggested a role for this intervention in some instances of isolated, non-compressible abdominal trauma with signs of life (pulse or recent arrest in a PEA rhythm) [117]. However, it excluded pre-hospital thoracotomies and reported a significant increase in morbidity and mortality in polytrauma patients compared to isolated injuries. These data need to be interpreted cautiously as interventions such as REBOA, interventional radiology and improvements in haemostatic resuscitation may mean that while thoracotomy for abdominal trauma was previously seen as a last-ditch effort, the adoption of newer, less invasive treatments may improve survival in this group without the need for thoracotomy. There are individual and organisational learning curves in adopting any new treatment, so the indications for resuscitative thoracotomy may become fewer still as these treatments mature.

## Conclusion

Massive haemorrhage can be fatal. The treatment may be simple; direct pressure is often sufficient, but occasionally a more sophisticated approach is required. Any pre-hospital or ED technique may only be temporising. Still, it may allow the patient to survive until a more definitive procedure is possible and should not delay transfer to definitive care. Competence in massive haemorrhage control is an essential skill for all staff involved in providing trauma care, whether in hospital or pre-hospital. While pre-hospital clinicians are more likely to encounter patients with injuries requiring these interventions, patients may self-present with catastrophic injuries at emergency departments or clinics. The majority of skills are easily teachable for the most part and require little in the way of medical knowledge. This is best demonstrated by the proliferation and success of programmes such as the “Stop the bleed” campaign [21] and Public Access and Tourniquet Training Study [118] in the USA, and may potentially save many lives. These courses are both effective and well regarded by attendees [119] but do require top-up training to maintain competence. The dramatic drop in patients who died of treatable injuries in military theatres of operations is also another testament to the importance, practicality and ease of learning of how to implement these vital skills in trauma care [120] outside of the direct supervision of medical personnel. The number of devices and treatments available and in development for the treatment of massive haemorrhage is increasing. Hopefully, it will decrease the number of preventable deaths from junctional and non-compressible haemorrhage further still.

While several dramatic interventions come under the umbrella of massive haemorrhage control, there are diminishing returns in success rates for increasingly invasive procedures. There is a great deal of debate and many publications, courses and simulations dedicated to these interventions in this population. However, increased attention to improving the application of more rudimentary haemorrhage control methods may obviate the need for some of them. By acting early enough and aggressively enough with haemorrhage control and minimising scene times, patients may never require interventions such as REBOA or a resuscitative thoracotomy. Some injuries and circumstances may require these interventions promptly; however, they are the minority of cases rather than the majority and should only be undertaken when there is a realistic prospect of patient benefit [121].

**Questions and Answers**

**What are the two major types of haemorrhage?**

*Answer: compressible and non-compressible*

**What bleeding might be halted by tourniquet application?**

*Answer: limb/extremity bleeding*

**What is the initial treatment of any bleeding?**

*Answer: direct pressure*

**What is the maximum timescale in which thoracotomy could be considered?**

*Answer: within 10 minutes of arrest*

**What location of bleeding might REBOA manage?**

*Answer: junctional, pelvic or abdominal*

## References


1. Gawande A. Casualties of war — military care for the wounded from Iraq and Afghanistan. N Engl J Med. 2004 Dec 9;351(24):2471–5.
2. Holcomb JB, Stansbury LG, Champion HR, Wade C, Bellamy RF. Understanding combat casualty care statistics. J Trauma. 2006 Feb;60(2):397–401.
3. Bellamy R. Combat trauma overview. In: Bellamy R, Zajtchuk R, editors. Anesthesia and perioperative care of the combat casualty. Borden Institute; 1995. [cited 2020 May 8]. p. 1–42. [Internet] Available from https://www.cs.amedd.army.mil/borden/bookDetail.aspx?ID=3ebfb1fd-2292-4555-9883-80f69fb70df4&pageTitle=Anesthesia%20and%20Perioperative%20Care%20of%20the%20Combat%20Casualty
4. Eastridge BJ, Mabry RL, Seguin P, Cantrell J, Tops T, Uribe P, et al. Death on the battlefield (2001–2011): implications for the future of combat casualty care. J Trauma Acute Care Surg. 2012 Dec;73:S431–7.
5. Hodgetts TJ, Mahoney PF, Russell MQ, Byers M. ABC to <C> ABC: redefining the military trauma paradigm. Emerg Med J. 2006 Oct;23(10):745–6.
6. Cordts PR, Brosch LA, Holcomb JB. Now and then: combat casualty care policies for operation Iraqi freedom and operation enduring freedom compared with those of Vietnam. J Trauma. 2008;64(2 Suppl):S14–20. discussion S20
7. Kotwal RS, Montgomery HR, Kotwal BM, Champion HR, Butler FK, Mabry RL, et al. Eliminating preventable death on the battlefield. Arch Surg. 2011 Dec 1;146(12):1350–8.
8. de Ceballos JPG, Turégano-Fuentes F, Perez-Diaz D, Sanz-Sanchez M, Martin-Llorente C, Guerrero-Sanz J. 11 March 2004: the terrorist bomb explosions in Madrid, Spain – an analysis of the logistics, injuries sustained and clinical management of casualties treated at the closest hospital. Crit Care. 2005;9(1):104–11.
9. D'Andrea SM, Goralnick E, Kayden SR. 2013 Boston Marathon bombings: overview of an emergency department response to a mass casualty incident. Disaster Med Public Health Prep. 2013 Apr;7(2):118–21.
10. Collaborative TBTCC. Boston Marathon bombings: an after-action review. J Trauma Acute Care Surg. 2014 Sep;77(3):501–3.
11. Service Médical du RAID. Tactical emergency medicine: lessons from Paris marauding terrorist attack. Crit Care. 2016 Feb 13;20(1):37.
12. Hirsch M, Carli P, Nizard R, Riou B, Baroudjian B, Baubet T, et al. The medical response to multisite terrorist attacks in Paris. Lancet. 2015 Dec;386(10012):2535–8.
13. Sauaia A, Moore FA, Moore EE, Moser KS, Brennan R, Read RA, et al. Epidemiology of trauma deaths: a reassessment. J Trauma. 1995 Feb;38(2):185–93.
14. Dorlac WC, DeBakey ME, Holcomb JB, Fagan SP, Kwong KL, Dorlac GR, et al. Mortality from isolated civilian penetrating extremity injury. J Trauma. 2005 Jul;59(1):217–22.
15. Tien HC, Spencer F, Tremblay LN, Rizoli SB, Brenneman FD. Preventable deaths from hemorrhage at a level I Canadian trauma center. J Trauma. 2007 Jan;62(1):142–6.
16. Mitra B, Cameron PA, Mori A, Fitzgerald M. Acute coagulopathy and early deaths post major trauma. Injury. 2012 Jan;43(1):22–5.
17. Jones AE, Aborn LS, Kline JA. Severity of emergency department hypotension predicts adverse hospital outcome. Shock. 2004 Nov;22(5):410–4.
18. MacLeod JBA, Lynn M, McKenney MG, Cohn SM, Murtha M. Early coagulopathy predicts mortality in trauma. J Trauma. 2003 Jul;55(1):39–44.
19. Davenport RA, Brohi K. Cause of trauma-induced coagulopathy. Curr Opin Anaesthesiol. 2016 Apr;29(2):212–9.
20. Neeki MM, Dong F, Toy J, Vaezazizi R, Powell J, Wong D, et al. Tranexamic acid in civilian trauma Care in the California Prehospital Antifibrinolytic Therapy Study. West J Emerg Med. 2018 Nov;19(6):977–86.
21. Stop The Bleed [Internet]. Stop the bleeding coalition. [cited 2019 Aug 26]. Available from https://stopthebleedingcoalition.org/
22. Curry N, Hopewell S, Dorée C, Hyde C, Brohi K, Stanworth S. The acute management of trauma hemorrhage: a systematic review of randomised controlled trials. Crit Care. 2011;15(2):R92.
23. Zwislewski A, Nanassy AD, Meyer LK, Scantling D, Jankowski MA, Blinstrub G, et al. Practice makes perfect: the impact of stop the bleed training on

hemorrhage control knowledge, wound packing, and tourniquet application in the workplace. Injury. 2019 Apr;50(4):864–8.
24. McPherson SW, Cook T, Sentamu J, Stone R. The Stephen Lawrence enquiry. Report of an inquiry. [Internet]. United Kingdom: The Stationery Office Ltd; 1999 Feb [cited 2020 May 15]. Available from https://webarchive.nationalarchives.gov.uk/20130814142658/http://www.archive.official-documents.co.uk/document/cm42/4262/4262.htm
25. Greater Glasgow and Clyde NHS Trust. Management of major Haemorrhage [Internet]. [cited 2020 May 8]. Available from https://handbook.ggcmedicines.org.uk/guidelines/resuscitation-and-anaphylaxis/management-of-major-haemorrhage/
26. ASA Committee on Blood Management. Massive transfusion protocol (MTP) For Hemorrhagic Shock [Internet]. American Society of Anesthesiologists; 2018 [cited 2020 May 9]. Available from https://www.asahq.org/search-results#q=MASSIVE%20TRANSFUSION%20PROTOCOL%20(MTP)%20FOR%20HEMORRHAGIC%20SHOCK&sort=relevancy
27. Norfolk D. United Kingdom blood services. Handbook of transfusion medicine. London: HMSO; 2013.
28. Hunt BJ, Allard S, Keeling D, Norfolk D, Stanworth SJ, Pendry K. A practical guideline for the haematological management of major haemorrhage. Br J Haematol. 2015;170(6):788–803.
29. I know it when I see it. In: Wikipedia [Internet]. 2020 [cited 2020 May 8]. Available from https://en.wikipedia.org/w/index.php?title=I_know_it_when_I_see_it&oldid=946560466
30. American College of Surgeons, Committee on Trauma. Advanced trauma life support: student course manual. 10th ed. Chicago, IL: American College of Surgeons; 2018.
31. Tan ECTH, Peters JH, Mckee JL, Edwards MJR. The iTClamp in the management of pre-hospital haemorrhage. Injury. 2016 May;47(5):1012–5.
32. Mckee JL, Mckee IA, Ball CG, Tan E, Moloff A, McBeth P, et al. The iTClamp in the treatment of pre-hospital craniomaxillofacial injury: a case series study. J Inj Violence Res. 2019 Jan;11(1):29–34.
33. Butler FK, Giebner S. Committee on tactical combat casualty care meeting: San Antonio, TX 5-6 September 2018 meeting minutes. J Spec Oper Med. 2019 Spring;19(1):136–45.
34. Life-Saving Hemorrhage Control by Tactical Police Using Tourniquets and the iTClamp [Internet]. JEMS. 2016 [cited 2020 May 21]. Available from https://www.jems.com/2016/12/22/life-saving-hemorrhage-control-by-tactical-police-using-tourniquets-and-the-iTClamp/
35. Committee on Tactical Combat Casualty Care. Tactical combat casualty care guidelines for medical personnel 1st August 2019.pdf [Internet]. 2019 [cited 2020 May 21]. Available from shorturl.at/bxBO5
36. McKee J, McKee I, Ball C, McBeth P, Bennett B, Filips D, et al. Subjective pain scores with the application and removal of the iTClamp in healthy volunteers. Can J Surg. 2017 Jun 1;60(3):S5–43.
37. Mckee JL, Lakshminarasimhan P, Atkinson I, LaPorta AJ, Kirkpatrick AW. Evaluation of skin damage from accidental removal of a hemostatic wound clamp (the iTClamp). Prehospital Disaster Med. 2017 Dec;32(6):651–6.
38. LaPorta A, Kirkpatrick AW, Mckee JL, Roberts DJ, Tien H, Beckett A, et al. Randomised controlled trial comparing marksmanship following application of a tourniquet or haemostatic clamp in healthy volunteers. BMJ Mil Health. 2017 Jun 1;163(3):177–83.
39. Harris T, Rice S, Watts B, Davies G. The emergency control of traumatic maxillofacial haemorrhage. Eur J Emerg Med. 2010 Aug;17(4):230–3.
40. Lockey DJ, Weaver AE, Davies GE. Practical translation of hemorrhage control techniques to the civilian trauma scene. Transfusion (Paris). 2013 Jan;53(Suppl 1):17S–22S.
41. Brown SN, Kumar D, James C, Mark J, Association of Ambulance Chief Executives (Great Britain), Joint Royal Colleges Ambulance Liaison Committee, et al. JRCALC clinical guidelines 2019 [Internet]. 2019 [cited 2020 May 15]. Available from https://search.ebscohost.com/login.aspx?direct=true&scope=site&db=nlebk&db=nlabk&AN=2293957
42. Scott I, Porter K, Laird C, Bloch M, Greaves I. The pre-hospital management of pelvic fractures: initial consensus statement. J Paramed Pract. 2014;6(5):248–52.
43. Chesser TJS, Cross AM, Ward AJ. The use of pelvic binders in the emergent management of potential pelvic trauma. Injury. 2012 Jun;43(6):667–9.
44. Hsu S-D, Chen C-J, Chou Y-C, Wang S-H, Chan D-C. Effect of early pelvic binder use in the emergency management of suspected pelvic trauma: a retrospective cohort study. Int J Environ Res Public Health. 2017;14(10):1217.
45. van Oostendorp SE, Tan ECTH, Geeraedts LMG. Pre-hospital control of life-threatening truncal and junctional haemorrhage is the ultimate challenge in optimising trauma care; a review of treatment options and their applicability in the civilian trauma setting. Scand J Trauma Resusc Emerg Med. 2016 Sep 13;24(1):110.
46. CRASH-2 Trial Collaborators. 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.
47. Heddle NM, Cook RJ, Arnold DM, Liu Y, Barty R, Crowther MA, et al. Effect of short-term vs. long-term blood storage on mortality after transfusion. N Engl J Med. 2016 Nov 17;375(20):1937–45.
48. Sowers N, Froese P, Erdogan M, Green R. Impact of the age of stored blood on trauma patient mortality: a systematic review. Can J Surg. 2015 Oct 1;58(5):335–42.

49. Anand T, Ramnanan R, Skinner R, Martin M. Impact of massive transfusion and aging blood in acute trauma. Am Surg. 2016 Oct;82(10):957–9.
50. Douma MJ, O'Dochartaigh D, Brindley PG. Optimisation of indirect pressure in order to temporise life-threatening haemorrhage: a simulation study. Injury. 2016 Sep;47(9):1903–7.
51. Taylor DM, Coleman M, Parker PJ. The evaluation of an abdominal aortic tourniquet for the control of pelvic and lower limb hemorrhage. Mil Med. 2013 Nov;178(11):1196–201.
52. Smith S, White J, Wanis KN, Beckett A, McAlister VC, Hilsden R. The effectiveness of junctional tourniquets: a systematic review and meta-analysis. J Trauma Acute Care Surg. 2019 Mar;86(3):532–9.
53. Bonanno AM, Hoops HE, Graham T, Davis BL, McCully BH, Wilson LN, et al. Efficacy of the abdominal aortic junctional tourniquet-torso plate in a lethal model of noncompressible torso hemorrhage. J Spec Oper Med. 2018 Winter;18(4):106–10.
54. Welling DR, McKay PL, Rasmussen TE, Rich NM. A brief history of the tourniquet. J Vasc Surg. 2012 Jan;55(1):286–90.
55. Hawk AJ. How hemorrhage control became common sense. J Trauma Acute Care Surg. 2018;85:S13–7.
56. NICE. NICE Quality Standard 166: Trauma [Internet]. National Institute for Health and Clinical Excellence; 2018 [cited 2020 Jan 12]. Available from https://www.nice.org.uk/guidance/qs166/resources/trauma-pdf-75545603800261
57. Faculty of Pre-Hospital Care, Royal College of Surgeons of Edinburgh. Position Statement on the application of Tourniquets [Internet]. RCSEd; 2017 [cited 2020 May 15]. Available from https://fphc.rcsed.ac.uk/my-fphc/resources/position-statements
58. Beaucreux C, Vivien B, Miles E, Ausset S, Pasquier P. Application of tourniquet in civilian trauma: systematic review of the literature. Anaesth Crit Care Pain Med. 2018 Dec;37(6):597–606.
59. Yang B, Fung A, Pac-Soo C, Ma D. Vascular surgery-related organ injury and protective strategies: update and future prospects. Br J Anaesth. 2016;117(suppl_2):ii32–43.
60. Katseni K, Chalkias A, Kotsis T, Dafnios N, Arapoglou V, Kaparos G, et al. The Effect of Perioperative Ischemia and Reperfusion on Multiorgan Dysfunction following Abdominal Aortic Aneurysm Repair. BioMed Res Int [Internet]. 2015 [cited 2020 May 21];2015. Available from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4698535/
61. Iwama H, Kaneko T, Ohmizo H, Furuta S, Ohmori S, Watanabe K. Circulatory, respiratory and metabolic changes after thigh tourniquet release in combined epidural-propofol anaesthesia with preservation of spontaneous respiration. Anaesthesia. 2002 Jun;57(6):588–92.
62. TLai. Emergency tourniquet | Military and Pre-Hospital [Internet]. tourniquets.org. 2017 [cited 2020 May 21]. Available from https://tourniquets.org/military-and-pre-hospital-tourniquets/
63. Schwartz DS, Weisner Z, Badar J. Immediate lower extremity tourniquet application to delay onset of reperfusion injury after prolonged crush injury. Prehosp Emerg Care. 2015;19(4):544–7.
64. Sever MS, Vanholder R. Management of Crush Victims in mass disasters: highlights from recently published recommendations. Clin J Am Soc Nephrol. 2013 Feb 1;8(2):328–35.
65. Managing the Toxic Chemical Release that Occurs During a Crush Injury [Internet]. JEMS. 2018 [cited 2020 May 21]. Available from https://www.jems.com/2018/10/22/managing-the-toxic-chemical-release-that-occurs-during-a-crush-injury/
66. Percival TJ, Rasmussen TE. Reperfusion strategies in the management of extremity vascular injury with ischaemia. Br J Surg. 2012;99(S1):66–74.
67. Lee C, Porter KM. Tourniquet use in the civilian pre-hospital setting. Emerg Med J. 2007 Aug;24(8):584–7.
68. Lakstein D, Blumenfeld A, Sokolov T, Lin G, Bssorai R, Lynn M, et al. Tourniquets for hemorrhage control on the battlefield: a 4-year accumulated experience. J Trauma Acute Care Surg. 2003 May;54(5):S221.
69. Clifford CC. Treating traumatic bleeding in a combat setting. Mil Med. 2004;169(12 Suppl):8–10. 4
70. Cox ED, Schreiber MA, McManus J, Wade CE, Holcomb JB. New hemostatic agents in the combat setting. Transfusion (Paris). 2009 Dec;49:248S–55S.
71. McManus J, Hurtado T, Pusateri A, Knoop KJ. A case series describing thermal injury resulting from zeolite use for hemorrhage control in combat operations. Prehosp Emerg Care. 2007 Mar;11(1):67–71.
72. Wright JK, Kalns J, Wolf EA, Traweek F, Schwarz S, Loeffler CK, et al. Thermal injury resulting from application of a granular mineral hemostatic agent. J Trauma. 2004 Aug;57(2):224–30.
73. Smith AH, Laird C, Porter K, Bloch M. Haemostatic dressings in pre-hospital care. Emerg Med J. 2013 Oct 1;30(10):784–9.
74. Waibel KH, Haney B, Moore M, Whisman B, Gomez R. Safety of chitosan bandages in shellfish allergic patients. Mil Med. 2011 Oct;176(10):1153–6.
75. Bennett BL, Littlejohn L. Review of new topical hemostatic dressings for combat casualty care. Mil Med. 2014 May 1;179(5):497–514.
76. Welch M, Barratt J, Peters A, Wright C. Systematic review of pre-hospital haemostatic dressings. J R Army Med Corps. 2019 Feb;166(3):194–200.
77. Landsman TL, Touchet T, Hasan SM, Smith C, Russell B, Rivera J, et al. A shape memory foam composite with enhanced fluid uptake and bactericidal properties as a hemostatic agent. Acta Biomater. 2017;47:91–9.
78. Kollock RO, Hale D, Vogelpohl R, Kremer L, Horner J, Cox C, et al. The influence of body armor on balance and movement quality. Int J Exerc Sci. 2018 Jun 1;11(1):648–56.

79. Dempsey PC, Handcock PJ, Rehrer NJ. Impact of police body Armour and equipment on mobility. Appl Ergon. 2013 Nov;44(6):957–61.
80. Kotwal RS, Butler FK, Gross KR, Kheirabadi BS, Baer DG, Dubick MA, et al. Management of junctional hemorrhage in tactical combat casualty care: TCCC guidelines proposed change 13-03. J Spec Oper Med. 2013;13(4):85–93.
81. Kragh JF, Parsons DL, Kotwal RS, Kheirabadi BS, Aden JK, Gerhardt RT, et al. Testing of junctional tourniquets by military medics to control simulated groin hemorrhage. J Spec Oper Med. 2014;14(3):58–63.
82. Mueller GR, Pineda TJ, Xie HX, Teach JS, Barofsky AD, Schmid JR, et al. A novel sponge-based wound stasis dressing to treat lethal non-compressible hemorrhage. J Trauma Acute Care Surg. 2012 Aug;73(2 Suppl 1):S134–9.
83. National Institute for Health Research. XStat® Hemostatic Device for non-compressible junctional haemorrhage. Technol Alert. 2015 Jun;2.
84. Rall JM, Cox JM. Evaluation of Xstat and Combat Gauze in a Swine Model of Lethal Junctional Hemorrhage in Coagulopathic Swine [Internet]. 59th Medical Wing San Antonio United States; 2017 Mar [cited 2020 May 9]. Report No.: 17130. Available from https://apps.dtic.mil/docs/citations/AD1037122
85. Warriner Z, Lam L, Matsushima K, Benjamin E, Strumwasser A, Demetriades D, et al. Initial evaluation of the efficacy and safety of in-hospital expandable hemostatic minisponge use in penetrating trauma. J Trauma Acute Care Surg. 2019 Mar;86(3):424–30.
86. Sims K, Montgomery HR, Dituro P, Kheirabadi BS, Butler FK. Management of external hemorrhage in tactical combat casualty care: the adjunctive use of XStat™ compressed hemostatic sponges: TCCC guidelines change 15-03. J Spec Oper Med. 2016;16(1):19–28.
87. Stuart SM, Zarow G, Walchak A, McLean J, Roszko P. Pilot study of a novel swine model for controlling junctional hemorrhage using the iTClamp in conjunction with hemostatic agents. Mil Med. 2019;184(Supplement_1):367–73.
88. Glaser JJ, Fischer AD, Shackelford SA, Butler F, Rasmussen TE. A contemporary report on US military guidelines for the use of whole blood and resuscitative endovascular balloon occlusion of the aorta. J Trauma Acute Care Surg. 2019;87(1S):S22–7.
89. de Schoutheete JC, Fourneau I, Waroquier F, De Cupere L, O'Connor M, Van Cleynenbreugel K, et al. Three cases of resuscitative endovascular balloon occlusion of the aorta (REBOA) in austere pre-hospital environment—technical and methodological aspects. World J Emerg Surg. 2018 Nov 21;13(1):54.
90. Rees P, Waller B, Buckley AM, Doran C, Bland S, Scott T, et al. REBOA at role 2 afloat: resuscitative endovascular balloon occlusion of the aorta as a bridge to damage control surgery in the military maritime setting. BMJ Mil Health. 2018 May 1;164(2):72–6.
91. Reva VA, Hörer TM, Makhnovskiy AI, Sokhranov MV, Samokhvalov IM, DuBose JJ. Field and en route resuscitative endovascular occlusion of the aorta: a feasible military reality? J Trauma Acute Care Surg. 2017;83(1 Suppl 1):S170–6.
92. Rappold JF, Bochicchio GV. Surgical adjuncts to non-compressible torso hemorrhage as tools for patient blood management. Transfusion (Paris). 2016;56(Suppl 2):S203–7.
93. Kisat M, Morrison JJ, Hashmi ZG, Efron DT, Rasmussen TE, Haider AH. Epidemiology and outcomes of non-compressible torso hemorrhage. J Surg Res. 2013 Sep;184(1):414–21.
94. REVIVE: reducing exsanguination via in-vivo expandable foam – no study results posted – ClinicalTrials.gov [Internet]. [cited 2020 May 9]. Available from https://clinicaltrials.gov/ct2/show/results/NCT02880163
95. Chang JC, Holloway BC, Zamisch M, Hepburn MJ, Ling GSF. ResQFoam for the treatment of non-compressible hemorrhage on the front line. Mil Med. 2015 Sep;180(9):932–3.
96. Fitzpatrick GM, Cliff R, Tandon N. Thrombosomes: a platelet-derived hemostatic agent for control of non-compressible hemorrhage: lyophilized PDHA for hemorrhage control. Transfusion (Paris). 2013 Jan;53:100S–6S.
97. Thrombosomes (Lyophilized Platelets) Appear Safe in Phase 1 Trial [Internet]. [cited 2020 May 15]. Available from https://transfusionnews.com/2019/10/24/thrombosomes-lyophilized-platelets-appear-safe-in-phase-1-trial/
98. Hawksworth JS, Elster EA, Fryer D, Sheppard F, Morthole V, Krishnamurthy G, et al. Evaluation of lyophilised platelets as an infusible hemostatic agent in experimental non-compressible hemorrhage in swine. J Thromb Haemost. 2009;7(10):1663–71.
99. Inaba K, Barmparas G, Rhee P, Branco B, Fitzpatrick M, Okoye O, et al. Dried platelets in a swine model of liver injury. Shock. 2014 May;41(5):429–34.
100. Macko AR, Crossland RF, Cap AP, Fryer DM, Mitchell TA, Pusateri AE, et al. Control of severe intra-abdominal hemorrhage with an infusible platelet-derived hemostatic agent in a nonhuman primate (rhesus macaque) model. J Trauma Acute Care Surg. 2016 Apr;80(4):617–24.
101. Lashof-Sullivan MM, Shoffstall E, Atkins KT, Keane N, Bir C, VandeVord P, et al. Intravenously administered nanoparticles increase survival following blast trauma. Proc Natl Acad Sci. 2014 Jul 15;111(28):10293–8.
102. Shoffstall AJ, Everhart LM, Varley ME, Soehnlen ES, Shick AM, Ustin JS, et al. Tuning ligand density on intravenous hemostatic nanoparticles dramatically increases survival following blunt trauma. Biomacromolecules. 2013 Aug 12;14(8):2790–7.

103. Bertram JP, Williams CA, Robinson R, Segal SS, Flynn NT, Lavik EB. Intravenous hemostat: nanotechnology to halt bleeding. Sci Transl Med. 2009 Dec 16;1(11):11ra22.
104. Peng HT. Hemostatic agents for pre-hospital hemorrhage control: a narrative review. Mil Med Res. 2020 Mar 25;7(1):13.
105. Klein MK, Tsihlis ND, Pritts TA, Kibbe MR. Emerging therapies for prehospital control of hemorrhage. J Surg Res. 2020 Apr;248:182–90.
106. Chan LW, Wang X, Wei H, Pozzo LD, White NJ, Pun SH. A synthetic fibrin cross-linking polymer for modulating clot properties and inducing hemostasis. Sci Transl Med. 2015 Mar 4;7(277):277ra29.
107. Major haemorrhaging in the pre-hospital setting – NICE Pathways [Internet]. [cited 2020 May 15]. Available from https://pathways.nice.org.uk/pathways/trauma#path=view%3A/pathways/trauma/major-haemorrhaging-in-the-pre-hospital-setting.xml&content=view-node%3Anodes-circulatory-access-and-fluid-replacement
108. Spahn DR, Bouillon B, Cerny V, Duranteau J, Filipescu D, Hunt BJ, et al. The European guideline on management of major bleeding and coagulopathy following trauma: fifth edition. Crit Care. 2019 Mar 27;23(1):98.
109. Lyon RM, de Sausmarez E, McWhirter E, Wareham G, Nelson M, Matthies A, et al. Pre-hospital transfusion of packed red blood cells in 147 patients from a UK helicopter emergency medical service. Scand J Trauma Resusc Emerg Med. 2017 Feb 14;25(1):12.
110. RePHILL – University of Birmingham [Internet]. [cited 2020 May 21]. Available from https://www.birmingham.ac.uk/research/bctu/trials/portfolio-v/Rephill/index.aspx
111. Wise D, Davies G, Coats T, Lockey D, Hyde J, Good A. Emergency thoracotomy: 'how to do it'. Emerg Med J. 2005 Jan 1;22(1):22–4.
112. Lockey DJ, Lyon RM, Davies GE. Development of a simple algorithm to guide the effective management of traumatic cardiac arrest. Resuscitation. 2013 Jun;84(6):738–42.
113. Sherren PB, Reid C, Habig K, Burns BJ. Algorithm for the resuscitation of traumatic cardiac arrest patients in a physician-staffed helicopter emergency medical service. Crit Care Lond Engl. 2013 Mar 12;17(2):308.
114. Burlew CC, Moore EE, Moore FA, Coimbra R, McIntyre RC, Davis JW, et al. Western trauma association critical decisions in trauma: resuscitative thoracotomy. J Trauma Acute Care Surg. 2012 Dec;73(6):1359–63.
115. Deakin CD, Brown S, Jewkes F, Lockey D, Lyon RM, Moore F, et al. Pre-hospital resuscitation guidelines [Internet]. www.resus.org.uk. 2015 [cited 2020 May 20]. Available from https://www.resus.org.uk/resuscitation-guidelines/prehospital-resuscitation/
116. Leech C, Porter K, Steyn R, Laird C, Virgo I, Bowman R, et al. The pre-hospital management of life-threatening chest injuries: a consensus statement. Trauma. 2017;19(1):54–62.
117. Hughes M, Perkins Z. Outcomes following resuscitative thoracotomy for abdominal exsanguination, a systematic review. Scand J Trauma Resusc Emerg Med. 2020 Feb 6;28(1):9.
118. Goralnick E, Chaudhary MA, McCarty JC, Caterson EJ, Goldberg SA, Herrera-Escobar JP, et al. Effectiveness of instructional interventions for hemorrhage control readiness for laypersons in the public access and tourniquet training study (PATTS). JAMA Surg. 2018 Sep;153(9):791–9.
119. Zhao KL, Herrenkohl M, Paulsen M, Bulger EM, Vavilala MS, Moore M, et al. Learners' perspectives on stop the bleed: a course to improve survival during mass casualty events. Trauma Surg Acute Care Open. 2019 Jul 1;4(1):e000331.
120. Butler FK. Two decades of saving lives on the battlefield: tactical combat casualty care turns 20. Mil Med. 2017 Mar 1;182(3–4):e1563–8.
121. John HJ. Hinds on crack the chest-get crucified [Internet]. 2015 Jul 4 [cited 2020 May 20]. Available from https://emcrit.org/emcrit/john-hinds-on-crack-the-chest-get-crucified/
122. Cothren CC, Moore EE, Hedegaard HB, Meng K. Epidemiology of urban trauma deaths: a comprehensive reassessment 10 years later. World J Surg. 2007 Jul;31(7):1507–11.
123. Kauvar DS, Lefering R, Wade CE. Impact of hemorrhage on trauma outcome: an overview of epidemiology, clinical presentations, and therapeutic considerations. J Trauma. 2006 Jun;60(6 Suppl):S3–11.
124. Kauvar DS, Wade CE. The epidemiology and modern management of traumatic hemorrhage: US and international perspectives. Crit Care. 2005;9(Suppl 5):S1–9.