

Anaesthesia considerations in penetrating trauma

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Editor's key points

- Bullets can travel a considerable distance through the body making the extent of injury from gunshot wounds (GSW) unpredictable.
- GSW to the chest, abdomen, and pelvis can cause extensive injury with potential for rapid haemodynamic deterioration.
- Penetrating neck injuries can progress rapidly to airway obstruction.

Trauma and penetrating injury, mostly in the form of assault and self-inflicted gunshot and stab wounds, is a major contributor to mortality and morbidity in the modern world, specifically among younger populations. While the prevalence of this form of injury is drastically lower in the UK and Europe in comparison with the USA, it is still common enough to necessitate practising anaesthetists to have a good understanding and working knowledge of the principles in treating victims with penetrating injury. This review article aims to cover basic principles of attending to penetrating trauma victims starting at the pre-hospital level and continuing into the emergency department (ED) and the operating theatre. We will highlight major issues with regard to airway control, severe bleeding treatment, and emergency scene and ED procedures. We also suggest a work flow for treating life-threatening penetrating injury and review the major controversies in this field. Our perspective is based on the experience and procedures used at the University of Washington's Harborview Medical Center, the only level 1 trauma centre covering the states of Washington, Alaska, Montana, Idaho, and Wyoming in the USA. This region contains almost 11 000 000 persons over a surface area of more than 2 700 000 km².

Keywords: anaesthesia, emergency service; trauma; wounds, gunshot; wounds, penetrating

Background

The World Health Organization estimates that traumatic injuries from traffic accidents, drowning, poisoning, falls, burns, and violence kill more than five million people worldwide annually, with millions more suffering from the consequences of injuries. Eight of the 15 leading causes of death for people aged 15–29 yr are violence or injury-related. Trauma is the second-most common single cause of death and represents 8% of all deaths worldwide. A large proportion of people surviving their injuries incur temporary or permanent disabilities. Trauma puts not only a burden onto the individual and the individual's family, but also creates a significant cost for society in the short- and long-term treatment of trauma victims, and also in the loss of productivity of these often young victims.¹

Penetrating injuries

Penetrating trauma is most commonly caused by assault or self-inflicted injuries with firearms or knives. Civilian penetrating injuries caused by gunshot wounds (GSW) and stab wounds are one of the leading causes of morbidity and mortality in the USA.

In 2010, homicide and suicide, the majority of which were firearms-related, were among the leading five causes of death in the 10–44 age group in the USA. There were 16 259

homicides in the USA, and of those, 11 078 were committed with firearms, a rate of 3.62 per 100 000 for firearm-related homicides based on the 2000 census population. An additional 19 392 deaths were self-inflicted firearm injuries and 858 deaths were caused by either unintended or undetermined causes of firearm discharge. In 2010, a total of 2598 people died in the USA from stabbing or cutting-related incidents, and of those, 1799 were considered homicides. The same year 53 738 non-fatal assaults with firearms and 131 338 non-fatal assaults with cutting or piercing instruments were treated in hospitals.²

In the UK, the number of homicides and firearm-related deaths and injuries is drastically lower. In 2011, there were 329 deaths from homicides, 31 caused by discharge of firearms and 114 deaths by assault with a sharp object.³ This translates to a rate of 0.56 per 100 000 for firearm-related homicides based on the 2001 census population and a total homicide-related rate of 0.19 per 100 000. The crime statistics from the office for national statistics reported a total of 6001 assaults with firearms in which the weapon was discharged in 2230 instances, resulting in 42 deaths and 1244 injuries.⁴

A study by Davies and colleagues looking at the trends in civilian firearm injuries and deaths in England and Wales between 1998 and 2007 showed a mean incidence rate of 0.53% for firearm injuries among trauma patients reaching

the hospital alive (487 patients). While the data set (The Trauma Audit and Research Network) only covers around 70% of trauma receiving hospitals in the UK and a large proportion of GSW fatalities die on scene, it is still clear that the ratios are much lower than those seen in the USA.⁵

Stab wounds are likewise significantly less common in the UK than in the USA but still remain a problem. In the years 2011–2, there were more than 12 326 cases of actual bodily harm and grievous bodily harm caused by sharp instruments.⁶ In a study by Crewdson and colleagues⁷ examining all penetrating injuries in London between 1991 and 2006, an annual increase of 23.2% was found in patients sustaining stabbing injuries and 11.0% for those sustaining GSW.

In Europe, about 2% of all trauma-related fatalities are caused by homicide, which amounted to an annual average of 4704 deaths between 2008 and 2010. Of those, 34% were due to sharp objects and 17% are due to firearm discharge. With regard to self-inflicted injuries, 57 614 deaths (25%) of all trauma-related fatalities were caused by suicide. Of those, 7% were due to firearm discharge and only 2% due to sharp objects.⁸

The direct and indirect economic implications of trauma, specifically penetrating injuries which usually affect young people, are enormous. According to the US Center for Disease Control and Prevention (CDC), the direct medical costs for more than 12 000 patients dying of assault-related GSW in 2005 were more than US \$60 million, while the cost for lost work and productivity was more than US \$18 billion. For hospitalized patients injured as a result of an assault by firearm, direct medical costs were estimated at more than US \$400 million. The cost of loss of work and productivity were estimated at US \$2.27 billion and a combined lifetime cost of US \$2.6 billion.⁹

In the UK, the mean hospital costs for adults over 18 yr of age suffering penetrating injuries between 2000 and 2005 was £7983, ranging between 6035 in patients with injury severity score (ISS) 9–25 to more than 16 000 in patients with ISS > 34.¹⁰

Penetrating traumatic injury, and trauma in general, is a burden to society with respect to the loss of life and the direct and indirect costs caused by these injuries, especially in the USA and to a lesser degree in the UK and Europe.

Pre-hospital treatment

‘The Golden Hour’ concept, coined by R. Adams Cowley, founder of the Maryland Institute of Emergency Medical Services is used regularly to characterize the importance of the time interval between incident and arrival at tertiary care centres. Cowley identified the importance of time from injury to arrival at the appropriate facility supplying definitive care as a key concept in the management of trauma patients.¹¹ During that first crucial hour after injury, many patients are being treated by emergency medical services (EMS) providers or in the emergency department (ED).

Civilian pre-hospital management varies with regard to staffing capabilities, times for evacuation, and distance to nearest

trauma centres. Regardless of the set-up, a crucial component is preparation. A pre-laid programme with policies for field treatment (or not to treat in the field), proper staff to be dispatched, evacuation routes, and decision schemes for transporting patients to the nearest hospitals vs nearest trauma centres must be in place.

For those patients with life-threatening injuries, rapid evacuation and transport to definitive care is a key component. While there has been a lack of mortality benefits shown for shorter pre-hospital transport times for trauma patients as a whole, for a subset of patients, especially patients with penetrating injuries and those showing haemodynamic instability in the field, there is an advantage for shorter transport times^{12 13} and an increased mortality for prolonged on scene times.¹⁴ Where distances are great, as in parts of the USA, helicopter-based EMS systems provide a potentially lifesaving resource to expedite inter-hospital patient transport from a non-trauma centre to a trauma centre.^{15–17}

A ‘Guideline for field triage of injured patients’ published by the CDC has been in use in the USA since 1986. This guideline (last updated in 2011) aims to use an evidence-based medicine approach and provide criteria for transport destination. Physiological data, such as the Glasgow coma scale (GCS), systolic arterial pressure (SAP) and heart rate, anatomic injury data, and mechanism of injury, are used to help identify the need for treatment in a trauma centre. The guideline recommends the transport of any penetrating injury involving the torso, head, or neck to a trauma centre.¹⁸

Controversy exists concerning the effect on morbidity and mortality of advanced treatment done in the field, specifically airway management and fluid therapy. The success rates for successful field intubation by paramedic systems are well researched and range from 69% to 98%.^{19–21} However, even physician-staffed systems have a wide range of intubation success rates, ranging from 90% in systems with emergency medicine-certified physicians from different medical specialties to 100% when the emergency medicine-certified physicians were experienced anaesthetists.^{22–24} When analysing these studies, it becomes clear that the success rate of intubation, and ultimately the effect on mortality, depends primarily on the specific amount of airway training and expertise of the provider rather than their professional field.²⁵

A multitude of retrospective studies and a recent animal model for exsanguination conveyed no mortality benefits for field intubation in comparison with bag mask ventilation and in some cases even increased mortality attributed to prolonged scene time, oesophageal intubation, positive pressure ventilation, and more.^{26–29} However, none of these studies has properly controlled for experience of the paramedics in successfully performing tracheal intubation. At this point, there are not enough data to recommend against tracheal intubation in the field and it seems that proper airway management by a trained and experienced provider improves patient outcome.

In the UK, a very low percentage of trauma patients are intubated in the pre-hospital setting according to a 2007 report by the National Confidential Enquiry into Patient Outcome and Death (NCEPOD).³⁰ The report cited about 10% of all trauma

patient airway management examined by experts to be inadequate and recommended that any pre-hospital trauma patient intubation '... needs to be in the context of a physician-based pre-hospital care system'. The Association of Anaesthetists of Great Britain and Ireland (AAGBI) in its 2009 guidelines for pre-hospital anaesthesia reaffirms the statement that '... it should only be performed by appropriately trained and competent practitioners. ...'.³¹ We disagree with the earlier statement about physician-based systems because of the more than 99% success rate for pre-hospital intubation in the Seattle and King county area paramedic-based pre-hospital system (MEDIC 1).³² However, we agree that it is crucial to ensure proper training, experience, and continuing education of the pre-hospital personnel. While this may allow practitioners other than the experienced anaesthesia provider to manage airways in the field, it does require oversight and training by anaesthetists to provide a higher degree of expertise in airway management. The controlled environment of the operating theatre (OT) can be used to facilitate training of pre-hospital providers in airway management and expose them to an adequate number of procedures to gain critical experience.

Placement of i.v. lines and fluid resuscitation is a standard part of pre-hospital advanced life support (ALS). However, there are uncertainties whether the extended on-scene time to secure i.v. access and to initiate fluid therapy are beneficial.

Two recent large prospective studies showed completely differing outcomes regarding i.v. placement and pre-hospital fluid therapy effect on mortality. In one study done with more than 700 000 trauma patients, an increased mortality was found for penetrating trauma patients when receiving an i.v. line in the field [odds ratio 1.25, 95% confidence interval (CI) 1.08–1.45].³³

In another study including more than 1000 trauma patients in 10 level 1 trauma centres across the USA, pre-hospital fluid administration was associated with reduced mortality (hazards ratio 0.84, 95% CI 0.72–0.98).³⁴

Pre-hospital providers at the scene may have a better chance of securing i.v. access before substantial haemorrhage makes subsequent attempts at i.v. placement more challenging due to hypovolaemia and severe vasoconstriction. In 2013, Engels and colleagues found obtaining pre-hospital i.v. access was associated with longer EMS on-scene and pre-hospital times; 16.1 vs 11.4 min and 18.9 vs 16.5 min, respectively. Obtaining i.v. access in patients arriving to the ED without pre-hospital i.v. required 20.5 min for peripheral and 21.7 min for central line access.³⁵

The concept of 'hypotensive resuscitation' for patients with uncontrolled haemorrhage is based on the theory that overzealous fluid resuscitation, apart from further hindering the coagulation system, can potentially increase bleeding by interrupting delicate blood clots formed by the increased arterial pressure. Several studies have shown improved survival rates for trauma patients (general and penetrating injury) treated with a lower SAP goal before reaching the OT (90 and 70 mm Hg, respectively).^{36 37}

Modern civilian and military protocols for resuscitation of trauma patients call for the use of physiological data such as

consciousness level for patients with shock and the absence or presence of radial pulse to decide upon fluid therapy, rather than the targeting of set SAP goals. Our approach to the current conflicting evidence is to recommend securing i.v. access while *en route* to the hospital without delaying transport time, avoiding over-resuscitation of patients and using physiological goals for resuscitation instead of set arterial pressure goals until conclusive evidence shows otherwise.

In the UK, the National Institute for Health and Care Excellence (NICE) guidelines for pre-hospital fluid therapy in trauma patients published in 2004 underline the lack of solid evidence supporting pre-hospital fluid therapy, and recommend limiting this therapy to patients without a palpable radial pulse or central pulse for patients with penetrating torso injuries. Furthermore, it states that transport time should not be prolonged and any vascular access be instituted *en route*.³⁸

There is a lack of evidence showing mortality advantages in using pre-hospital ALS vs basic life support in urban trauma victims with some evidence suggesting higher mortality with the use of ALS,^{39 40} whether these findings are the result of longer on-scene or transport times to perform advanced procedures is unknown. This caveat might also not hold true for trauma in rural areas where transport times are much longer and haemodynamic changes are more significant by the time the patient arrives to the hospital. There are clearly more questions than answers with regard to scientific evidence for the utility of pre-hospital treatment, especially in urban setting where trauma centres are generally in close proximity.

ED and airway management

In the Harborview system, the ED's role in the penetrating trauma patient is primarily as a triage station and initial treatment area. Patients can arrive haemodynamically stable, unstable, or without signs of life. Depending on the patient's haemodynamic stability, further treatment, diagnostic tests, or immediate transport to the OT are indicated.

Upon arrival to the hospital, urgent securing of airway is indicated in unstable patients or those destined to the OT not already intubated. In the severely injured patient, loss of airway or breathing is the most immediate threat to life alongside massive haemorrhage. Thus, airway stabilization with adequate pulmonary mechanics remains the first priority of resuscitation.⁴¹

Airway management is tailored to the type of injury, the nature and degree of airway compromise, and the patient's haemodynamic and oxygenation status. An immediate assessment of the patient's airway in the context of injuries, overall condition, and potential for deterioration help determine if and when to proceed in securing the airway. Indications for intervening to secure the airway include: respiratory failure, apnoea, reduced level of consciousness (GCS \leq 8), rapid change of mental status, airway injury or impending airway compromise, high risk for aspiration, or 'trauma to the box', which includes all penetrating injuries to the abdomen or chest cavity. Since patients with penetrating injuries can rapidly decompensate, our institution asserts a low threshold for

securing a definitive airway in a time-sensitive fashion. Control of the airway and sedation can facilitate prompt resuscitative measures, thorough diagnostic injury workup, and, if warranted, emergent surgical intervention. If injuries are deemed non-threatening after complete workup, early tracheal intubation is a priority upon meeting the appropriate criteria.

With ballistic injuries, we consider 'trauma to the box' to include GSW with entrance wounds from the neck to the pelvis, especially when the bullet trajectory is not obvious. In the absence of an exit wound, bullets can travel a considerable distance within the body and bullets entering the abdomen can potentially cause injuries to the chest or neck. Bullets entering through the upper arm can also be found in the chest cavity. Thus, injury related to GSW is unpredictable and many trauma surgeons will proceed urgently to diagnostic laparotomy or thoracotomy.

In the context of traumatic brain injury, early airway intervention is critical in order to avoid secondary injuries caused by hypoxia and hypercarbia.

Penetrating facial or neck injuries require early attention as those can rapidly progress into complete airway obstruction, secondary to evolving oedema and anatomical distortion. As more time elapses from initial injury, increasing oedema, subcutaneous emphysema, blood, vomitus, and secretions further complicate securing the airway.

The ASA algorithm for management of difficult airways is a useful starting point for the trauma anaesthesiologist, whether in the ED or the OT.⁴² However, as the algorithm suggests, re-awakening a patient after difficulty in securing the airway is usually not an option; tracheal intubation must be achieved using conventional or surgical means. A surgical airway may be the first or the best option in certain conditions.⁴³

In general, rapid-sequence induction accompanied after pre-oxygenation with cricoid pressure and in-line cervical stabilization, followed by direct laryngoscopy (DL), is the safest and most effective approach.⁴⁴ It is especially appropriate in the emergency setting and in unconscious, combative, or hypoxaemic patients when the status of the spine is not known. Cervical spine precautions are unnecessary when the mechanism of injury does not suggest spine injury (e.g. GSW to the abdomen without falling).⁴⁵ Video laryngoscopy (VL) is an especially useful adjunct for patients with possible cervical spine injury or reduced mouth opening, but visualization can be obscured by blood or vomitus on the camera lens. There are several types of commercially available video laryngoscopes (e.g. Glidescopes, C-MAC), none of which has been proven to be better than DL in trauma settings. Some evidence exists that in ED patients (most of them trauma patients), VL intubation had higher success rate for first pass in patients with difficult airways.⁴⁶ Volunteers and non-trauma studies demonstrate improved glottic visualization, particularly in patients with difficult airways.⁴⁷ Awake fiberoptic intubation is often impeded by urgency, lack of cooperation, and difficult visualization due to vomitus, secretions, or blood in the airway.

If tracheal intubation is unsuccessful after three attempts, including one attempt by an airway expert, cricothyrotomy is warranted. Especially in penetrating neck injuries, expanding

haematoma can quickly distort anatomy and cause airway oedema from venous stasis, thus a surgical airway should not be delayed.

In recent decades, primary management of airway in the ED, both in the USA and in the UK and Europe, has been increasingly taken over by Emergency Physicians. While many of these physicians practising in Europe have anaesthesia training, the experience of US emergency medicine physicians in airway management is often limited. There have been concerns that success rates are lower and complications rates are higher when airway management is conducted by Emergency Physicians as opposed to anaesthetists.

A recent study by Bernhard and colleagues concluded that complications during the first 200 attempts for tracheal intubation performed by anaesthesia residents justify supervision by a specialist in the field or by a senior anaesthetist. Out of all residents, 52% reached the target of 200 intubations after 50.2 +/- 14.8 weeks. The success rate of 95% did not stabilize until after 150 intubations were performed.⁴⁸ Even these relatively low numbers are usually far above the number residents in emergency medicine in the USA will achieve during their training. However, there have been studies in the emergency medicine literature showing similar success and complications rates for emergency medicine physicians and anaesthesiologists in trauma patients requiring tracheal intubation.^{49 50} In the UK, criteria for trauma centre status include immediate availability of an experienced anaesthetist for airway management in trauma. Our institution requires the intubation of trauma patients in the ED to always be conducted by the anaesthesia team.

In conclusion, hospitals need to have protocols in place for airway management of trauma patients by the most appropriate provider and be able to guarantee the highest possible success rate.

Hypovolaemia and bleeding are, until proven otherwise, the most likely reasons for hypotension in the penetrating injury victim. Tension pneumothorax or massive haemothorax can cause haemodynamic instability, while direct cardiac injury or underlying medical cardiac conditions are less common. A tension pneumothorax or haemothorax can be quickly diagnosed in the ED and treated with the placement of a chest tube. Small-bore needles, frequently used in the field for chest decompression, are often clogged with blood from a combined haemopneumothorax within seconds and are not very useful in the setting of thoracic trauma. Patients who are haemodynamically unstable due to ongoing haemorrhage should be expeditiously transported to the OT or angiography suite to achieve proper haemostasis. If a decision has been made to intervene surgically, attempts to stabilize or resuscitate in the ED will only delay definitive surgical control of the bleeding. Prolonged ED times for severely injured trauma patients have been shown to increase mortality.⁵¹ Quick airway control, chest drain insertion, and initiation of blood transfusion can be performed before transport to the OT. More time-consuming procedures, such as placement of central lines or arterial lines, should not be allowed to delay transfer. In our practice, the ultimate treatment to stabilize

the bleeding penetrating trauma patient is source control of the bleeding in the OT by the surgeon. While angio-embolization of bleeding vessels is an increasingly used option for haemodynamically unstable blunt trauma patients, especially those with suspected or proven pelvic injury, its utility in the context of penetrating injury is much lower.^{52 53}

In contrast, the haemodynamically stable patient poses several diagnostic and therapeutic dilemmas for the trauma team and the ED. There are several algorithms and protocols targeting the more common types of injuries such as abdominal stab wounds. An example is the Western Trauma Association algorithm for managing patients with anterior abdominal stab wounds, which has been validated in prospective studies.^{54 55} A majority of these patients would not meet criteria for laparotomy or laparoscopy, with management being limited to wound exploration utilizing local anaesthetics while remaining in the ED. These patients generally will not require further anaesthetist involvement after the initial phase of management.

For patients suffering penetrating injuries without pulse or cardiac output, or on the verge of hypovolaemic arrest, ED thoracotomy is a viable option. This technique entails a lateral thoracotomy, cross-clamping the descending aorta, and manual cardiac massage if needed. This manoeuvre enables perfusion of coronary and cerebral vessels. The surgeon tries to locate and control the more distal source of bleeding while vigorous blood transfusion and resuscitation is performed by the anaesthetist. However, mortality rates of this technique are extremely high, around 90% for penetrating injuries with better results for patients with direct cardiac injury.^{56 57} Experimental measures such as extracorporeal life support and rapid deep hypothermia are being tested in laboratory settings but have yet to find their way into clinical use.⁵⁸

OT setting and bleeding control

Having a designated OT for major urgent trauma cases, whether blunt or penetrating, is central to successful, efficient treatment of trauma patients. Ideally, such a room is located in close proximity to the ED to reduce transport time. Given infrastructure limitations, maintaining a designated major trauma OT is rarely an option outside dedicated trauma centres. A large enough OT with the requisite staff and equipment close at hand (generally in a large theatre suite) should be designated as the emergency major trauma theatre in such cases. The standard set-up for a trauma OT must include an anaesthetic machine, basic and advanced airway management equipment including video laryngoscope, equipment for establishing arterial and central venous cannulation, a rapid infusion system, fluid warmer, emergency drugs for resuscitation, and an ultrasound machine. Transoesophageal echocardiography (TOE) can be of immense value in trauma anaesthesia if the necessary expertise is available and access to an appropriate machine with a TOE probe is highly recommended.

Allocating roles and responsibilities within the theatre anaesthesia team is essential for effective working and should be done ahead of time and preferably within the framework of departmental guidelines. An example for such a layout of staff and

equipment used in our level 1 trauma centre is given in Figure 1 and brief description of procedures and roles in Figure 2.

Priorities for treatment of intubated, unstable patients arriving emergently to the OT include (re)confirmation of the tracheal tube placement and securing proper intravascular access. Surgical start time and haemorrhage control should not be delayed for placement of arterial or central lines which can be done during surgery.

Until haemorrhage is controlled and cardiovascular stability achieved, the authors avoid the use of volatile anaesthetics due to their vasodilatory effects and prefer using ketamine with low doses of midazolam and fentanyl as haemodynamically tolerated by the patient.

A rapid infusion system should be connected to the largest i.v. catheter available and the fluid warmer to an alternative catheter as a second line. For expected massive blood transfusion, a large-bore (at least 6 Fr) central venous catheter can be placed in the internal jugular or subclavian vein. Alternatively, existing smaller peripheral venous catheters can be replaced by a 7 Fr rapid infusion catheter over a guide wire, such as the Arrow[®] RIC[®] rapid infusion catheter exchange set. Arterial line placement is useful for monitoring and drawing blood for laboratory tests, but should not take priority over appropriate i.v. access. Once an arterial catheter is placed, baseline investigations, which include arterial blood gas, lactate, baseline electrolytes, coagulation screen, and haematocrit, are sent. Aggressive rewarming efforts are achieved with active underbody warmer units, in conjunction with fluid warmers, warm blanket, and if needed an increased room temperature. Regarding ventilation, lung protective strategies are preferred if adequate oxygenation and ventilation are attainable.

Patients requiring significant volume resuscitation at this point are usually beyond the amount of blood loss that can be compensated with crystalloid or colloid infusion.

The issue of what, when, and how much blood products to give the exsanguinating patient has been a matter of lively debate over the last decade. Much experience has been gained from recent military campaigns in Iraq and Afghanistan and has impacted on civilian trauma care. A body of evidence now exists which shows mortality and morbidity benefits for early, aggressive treatment with whole blood or red blood cell (RBC) concentrate, fresh-frozen plasma (FFP), and platelets (PLT) in a ratio similar to that of whole blood, often described as 1:1:1 ratio.^{59–61}

There is, however, an ongoing controversy regarding the utility of arbitrary FFP and RBC infusion according to pre-set quotas. There is evidence that 'goal-directed therapy' using viscoelastic coagulation test (TEG[®] or ROTEM[®]) is efficient and leads to reduced use of blood products, higher levels of fibrinogen, and is associated with better outcomes.^{62–65} The Latest European guidelines for treating severe bleeding in trauma recommend using viscoelastic tests for coagulation monitoring but other than initiating early treatment is unable to strongly recommend for or against using a pre-set ratio.⁶⁶ It is worthwhile mentioning that a number of part of publications not favouring pre-set quotas were conducted on blunt trauma victims. It is unclear how applicable the results are for penetrating trauma victims.

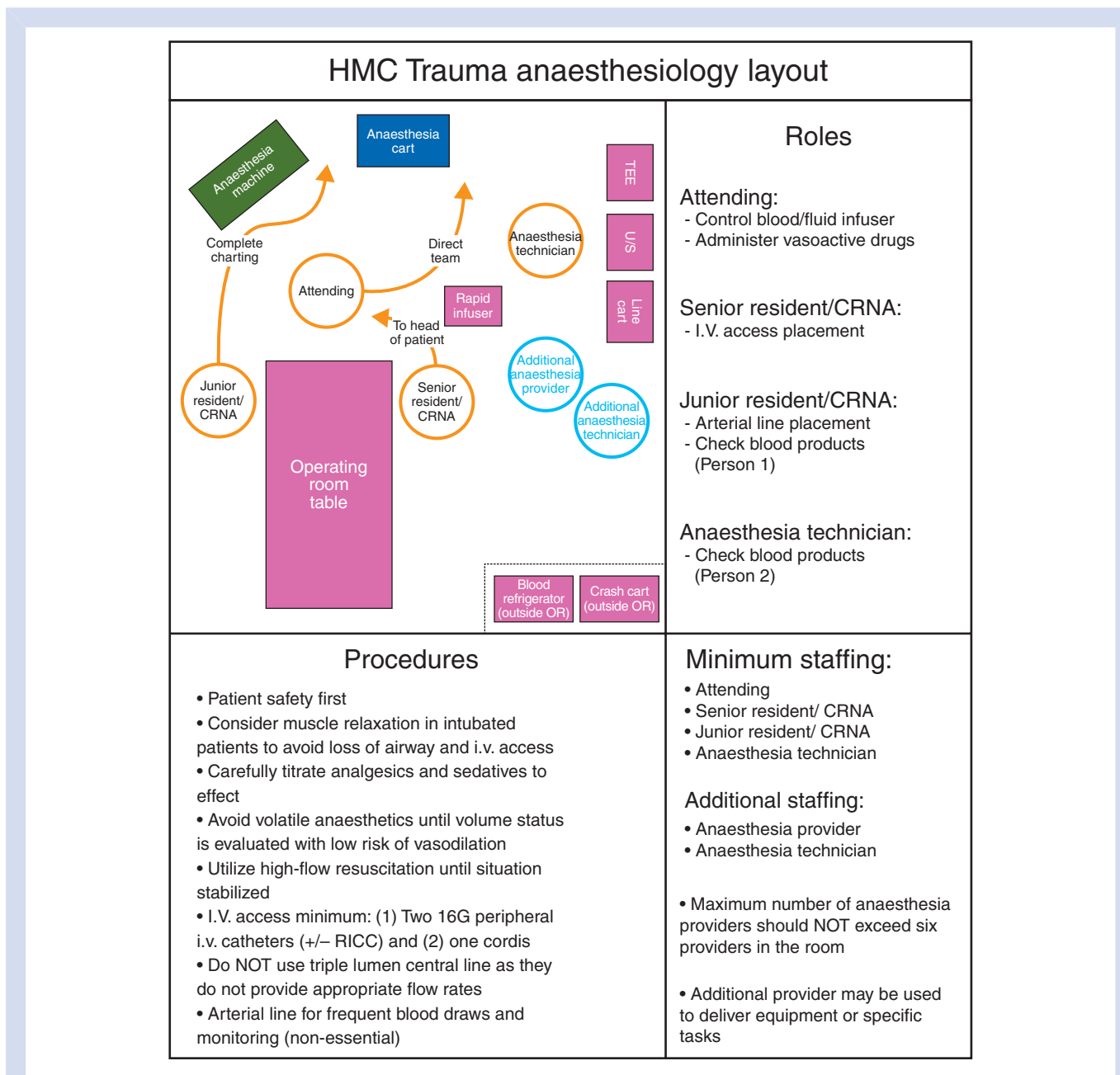


Fig 1 Harborview Medical Center anaesthesiology team layout for the management of major trauma. HMC, Harborview Medical Center; CRNA, Certified Registered Nurse Anaesthetist.

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There is also evidence, mainly from Austria and Germany, that using coagulation factor concentrates instead of FFP is effective and avoids some of the risks associated with using large amounts of human blood products.⁶⁷⁻⁶⁹ In the USA, these concentrates are indicated for use in reversal of vitamin K antagonist in acutely bleeding patients and given their high cost compared with FFP and paucity of evidence in trauma patients are not usually used in massive bleeding trauma patients. Activated Factor VII is likewise not usually used due to lack of high-quality studies showing utility, specifically in penetrating injury.^{70 71}

When activated, massive transfusion protocols consisting of fixed ratios of blood products can help guide resuscitative efforts

in the event of massive blood transfusion. In resuscitation from life-threatening haemorrhage, uncross-matched blood products are used until patient-specific products are available. In most cases, this set of blood products consists of 4-6 units of RBC, 4-6 units of FFP, and one pooled unit of PLT, mimicking a total of 2-3 litre of whole blood volume. Tranexamic acid, an antifibrinolytic agent, has also been shown in a randomized controlled trial (CRASH-2) to improve mortality when given to bleeding patients within 3 h of injury.^{72 73}

In patients with uncontrolled haemorrhage, permissive hypotension with SAP ~70-80 mm Hg or a mean arterial pressure of ~50 mm Hg should be considered until the source of

HMC trauma anaesthesiology guidelines

1. Crash room setup

- Machine check
- Emergency drugs
- Fluid warmer
- Central venous catheter kit (e.g. Cordis)
- Airway equipment
- Rapid infusion system (e.g. Belmont)
- Arterial line setup

2. Identify patient

3. Check existing intravenous access

- Replace i.v. tubing with HMC tubing
- Consider replacing 20/18G i.v. with 7 Fr rapid infusion catheter (RIC)
- Connect Belmont to largest bore i.v.
- Connect fluid warmer to second i.v.

4. ASA standard monitoring

5. Induction

- Rapid sequence induction (\pm manual In-line stabilization)
- Avoid potent vasodilators (e.g. propofol, volatile agents) until haemorrhage controlled and/or resuscitation achieved)
- Confirm pre-existing ETT (auscultation + E'_{CO_2})

6. Maintenance/management

- Send baseline labs (e.g. arterial blood gas, emergency haemorrhage panel)
- Give antibiotics
- Consider 1:1 RBC:FFP transfusion ratio (paediatric: 10 ml kg⁻¹)
- Consider early platelet transfusion
- Minimize crystalloid infusion
- SBP 80 (MAP ~50) during uncontrolled haemorrhage
- Normalize BP and perfusion after control of bleeding
- Activate 'Massive transfusion protocol (MTP)' as indicated
- Avoid and treat hypothermia
- Tranexamic acid if <3 h since injury (1 g/10 min followed by 1 g/q8 h)
- Monitor and maintain serum calcium
- Monitor and maintain serum glucose
- SBP 90–100 (or higher) if associated with closed head injury
- Consider lung protective ventilation strategies (6 ml kg⁻¹ x ideal body weight)

Fig 2 Harborview Medical Center (HMC) anaesthesiology guidelines for the management of major trauma.

bleeding is controlled. If the penetrating injuries are associated with head injury or suspected medical co-morbidities, arterial pressures may be maintained at a higher level (SAP 90–100 mm Hg). Serum calcium must be checked regularly and supplemented, especially during a massive blood transfusion. To maintain perfusion pressure, a vasopressor such as a norepinephrine infusion or vasopressin either as bolus or continuous infusion may also be used. Upon control of haemorrhage, arterial pressure is normalized.

Conclusion

There is a paucity of trauma anaesthesia-related research and many studies are performed by other specialities such as emergency medicine and surgery, often without any input by

anaesthetists. Often, similar studies show different, if not completely opposite, results. There exists considerable variation and heterogeneity in traumatic injury and delivery of trauma care which confounds such clinical studies. Small differences along the treatment pathway, such as airway training of paramedics, distance to the trauma centre, equipment, staffing in the hospital, and the experience of provider, can dramatically change patient outcome. More high-quality research is needed to direct evidence-based trauma care and to improve overall patient outcomes.

Gunshot and stabbing injuries, while much less common in the UK than in the USA, can present as a challenging problem when encountered by the anaesthetist. Coherent, structured plans of treatment should be developed and rehearsed in advance. While the anaesthesia techniques and skills used to

treat these patients are identical to the ones providing anaesthesia to scheduled surgical patients, there are significant differences and challenges. Patients undergoing elective surgery are typically medically optimized, have undergone a pre-anaesthesia evaluation, are fasted, and may experience a limited amount of blood loss during the surgery. The trauma patient on the other hand, especially in the context of penetrating injuries, may already arrive exsanguinating and in profound haemorrhagic shock. This fact alone puts many anaesthetists out of their comfort zone as it requires a much different, much quicker, and sometime improvised approach to the patient. Most trauma patients arrive without much warning and leave little time for preparation. Surgery may need to be started to control bleeding without proper i.v. access or monitoring. A preoperative evaluation or information about medical conditions may be unavailable. Airway management poses challenges as it is often performed in a less controlled environment than the OT, in unstable patients with blood or vomit in the airway, and with reduced tolerance to apnoea. In order to avoid detrimental hypotension, the usual anaesthetic drugs should be avoided or used cautiously with reduced dosages. Blood transfusion may need to be initiated without having laboratory data or even knowing the amount of the actual blood loss. Furthermore, limited time, resources, and equipment are very common when performing trauma anaesthesia.

Nevertheless, anaesthetists have extensive experience and unique skills in managing even the most difficult airways, placing peripheral and central i.v. access, and managing the haemodynamics of bleeding patients, more so than any other medical speciality.

For these reasons, anaesthetists should play a fundamental role in any trauma setting using the team approach to trauma care. While early surgical intervention is required for most unstable trauma patients with penetrating injuries, so is the expertise of the anaesthetist to stabilize the airway and haemodynamics of such patients before operation, intra-operatively, and after operation. Furthermore, the anaesthetist can provide continuity of care as the perioperative provider involved in the care of the trauma patient at the scene, in the ED, through the OT, into the intensive care unit and in the later phase of pain management.

Authors' contributions

N.S.: primary draft, data collecting, revision, and final manuscript preparation. R.V.C.: primary draft, data collecting, revision, and final manuscript preparation. A.G.: data collecting, revision, and final manuscript preparation.

Declaration of interest

None declared.

References

- Peden M, McGee K, Sharma G. *The Injury Chart Book: A Graphical Overview of the Global Burden of Injuries*. Geneva: World Health Organization, 2002
- Centers for Disease Control and Prevention. Injury prevention and control: data and statistics, 2010. Available from <http://www.cdc.gov/injury/wisqars/LeadingCauses.html> (accessed 4 November 2013)
- UK National Statistics Publication Hub. Injury and poisoning mortality in England and Wales, 2011. Available from http://www.statistics.gov.uk/hub/release-calendar/index.html?newquery=*%&uday=0&umonth=0&uyear=0&title=Injury+and+poisoning+mortality+in+England+and+Wales&pagetype=calendar-entry&lday=&lmonth=&lyear= (accessed 4 November 2013)
- Office for National Statistics. *Statistical Bulletin: Crime in England and Wales—Quarterly First Release*, March 2012. Available from http://www.ons.gov.uk/ons/dcp171778_273169.pdf (accessed 4 November 2013)
- Davies MJ, Wells C, Squires PA. Civilian firearm injury and death in England and Wales. *Emerg Med J* 2012; **29**: 10–4
- Office for National Statistics. *Statistical Bulletin: Crime in England and Wales, Year Ending June*, 2013. Available from http://www.ons.gov.uk/ons/dcp171778_331209.pdf (accessed 4 November 2013)
- Crewdson K, Lockey D, Weaver A, Davies GE. Is the prevalence of deliberate penetrating trauma increasing in London? Experiences of an urban pre-hospital trauma service. *Injury* 2009; **40**: 560–3
- European Association for Injury Prevention and Safety Promotion (EuroSafe). *Injuries in the European Union: Summary of Injury Statistics for the years 2008–2010*. Amsterdam, 2013
- Centers for Disease Control and Prevention. Data and Statistics: Cost of Injury Reports. Available from <http://wisqars.cdc.gov:8080/costT/> (accessed 4 November 2013)
- Christensen MC, Nielsen TG, Ridley S, Lecky FE, Morris S. Outcomes and costs of penetrating trauma injury in England and Wales. *Injury* 2008; **39**: 1013–25
- National Association of Emergency Medical Technicians. *PHTLS: Basic & Advanced Prehospital Trauma Life Support*, 6th Edn. St Louis, MO: Mosby, 2007
- Swaroop M, Straus DC, Agubuzu O, Esposito TJ, Schermer CR, Crandall ML. Pre-hospital transport times and survival for hypotensive patients with penetrating thoracic trauma. *J Emerg Trauma Shock* 2013; **6**: 16–20
- McCoy CE, Menchine M, Sampson S, Anderson C, Kahn C. Emergency medical services out-of-hospital scene and transport times and their association with mortality in trauma patients presenting to an urban Level 1 trauma center. *Ann Emerg Med* 2013; **61**: 167–74
- Funder KS, Petersen JA, Steinmetz J. On-scene time and outcome after penetrating trauma: an observational study. *Emerg Med J* 2011; **28**: 797–801
- Stephen HT. Controversy in prehospital care: air medical response. *Emerg Med Pract* 2005; **7**: 1–26
- Galvagno SM Jr, Thomas S, Stephens C, et al. Helicopter emergency medical services for adults with major trauma. *Cochrane Database Syst Rev* 2013; **3**: CD009928
- Andruszkow H, Lefering R, Frink M, et al. Survival benefit of helicopter emergency medical services compared to ground emergency medical services in traumatized patients. *Crit Care Advance Access* published on June 21, 2013, doi:10.1186/cc12796
- Centers for Disease Control and Prevention. *Guidelines for Field Triage of Injured Patients*. Available from <http://www.cdc.gov/mmwr/preview/mmwrhtml/rr6101a1.htm> (accessed 4 November 2013)
- Cobas MA, De la Peña MA, Manning R, Candiotti K, Varon AJ. Prehospital intubations and mortality: a level 1 trauma center perspective. *Anesth Analg* 2009; **109**: 489–93
- Colwell CB, Cusick JM, Hawkes AP, et al.; Denver Metro Airway Study Group. A prospective multicenter evaluation of prehospital airway management performance in a large metropolitan region. *Prehosp Emerg Care* 2009; **13**: 304–10

- 21 Warner KJ, Sharrar SR, Copass MK, Bulger EM. Prehospital management of the difficult airway: a prospective cohort study. *J Emerg Med* 2009; **36**: 257–65
- 22 Timmermann A, Russo SG, Eich C, et al. The out-of-hospital esophageal and endobronchial intubations performed by emergency physicians. *Anesth Analg* 2007; **104**: 619–23
- 23 Timmermann A, Eich C, Russo SG, et al. Prehospital airway management: a prospective evaluation of anesthesia trained emergency physicians. *Resuscitation* 2006; **70**: 179–85
- 24 Helm M, Hossfeld B, Schafer S, Hoitz J, Lampl L. Factors influencing emergency intubation in the pre-hospital setting. A multicenter study in German Helicopter Emergency Medical Service. *Br J Anaesth* 2006; **96**: 67–71
- 25 Davis DP, Koprovicz KM, Newgard CD, et al. The relationship between out-of-hospital airway management and outcome among trauma patients with Glasgow Coma Scale Scores of 8 or less. *Prehosp Emerg Care* 2011; **15**: 184–92
- 26 Stockinger ZT, McSwain NE Jr. Prehospital endotracheal intubation for trauma does not improve survival over bag-valve-mask ventilation. *J Trauma* 2004; **56**: 531–6
- 27 Taghavi S, Jayarajan SN, Khoche S, et al. Examining prehospital intubation for penetrating trauma in a swine hemorrhagic shock model. *J Trauma Acute Care Surg* 2013; **74**: 1246–51
- 28 Shafi S, Gentilello L. Pre-hospital endotracheal intubation and positive pressure ventilation is associated with hypotension and decreased survival in hypovolemic trauma patients: an analysis of the National Trauma Data Bank. *J Trauma* 2005; **59**: 1140–5
- 29 Eckstein M, Chan L, Schneir A, Palmer R. Effect of prehospital advanced life support on outcomes of major trauma patients. *J Trauma* 2000; **48**: 643–8
- 30 Trauma: who cares? National Confidential Enquiry into Patient Outcome and Death, 2007. Available from http://www.ncepod.org.uk/2007report2/Downloads/SIP_report.pdf (accessed 4 November 2013)
- 31 AAGBI Safety Guidelines—Prehospital Anaesthesia. The Association of Anaesthetists of Great Britain and Ireland. February 2009. Available from http://www.aagbi.org/sites/default/files/prehospital_glossy09.pdf (accessed 4 November 2013)
- 32 Prekker ME, Kwok H, Shin J, Carlborn D, Grabinsky A, Rea TD. The process of prehospital airway management: challenges and solutions during paramedic endotracheal intubation. *Crit Care Med* Advance Access published on February 28, 2014, doi:10.1097/CCM.0000000000000213
- 33 Haut ER, Kalish BT, Cotton BA, et al. Prehospital intravenous fluid administration is associated with higher mortality in trauma patients: a National Trauma Data Bank analysis. *Ann Surg* 2011; **253**: 371–7
- 34 Hampton DA, Fabricant LJ, Differding J, et al. PROMMTT Study Group. Prehospital intravenous fluid is associated with increased survival in trauma patients. *J Trauma Acute Care Surg* 2013; **75**(1 Suppl. 1): S9–15
- 35 Engels PT, Passos E, Beckett AN, Doyle JD, Tien HC. IV access in bleeding trauma patients: a performance review. *Injury* 2014; **45**: 77–82
- 36 Bickell WH, Wall MJ Jr, Pepe PE, et al. Immediate versus delayed fluid resuscitation for hypotensive patients with penetrating torso injuries. *N Engl J Med* 1994; **331**: 1105–9
- 37 Dutton RP, Mackenzie CF, Scalea TM. Hypotensive resuscitation during active hemorrhage: impact on in-hospital mortality. *J Trauma* 2002; **52**: 1141–6
- 38 Pre-hospital initiation of fluid replacement therapy in trauma. National Institute for Clinical Excellence, January 2004. Available from <http://www.nice.org.uk/nicemedia/live/11526/32820/32820.pdf> (accessed 4 November 2013)
- 39 Isenberg DL, Bissell R. Does advanced life support provide benefits to patients?: A literature review. *Prehosp Disaster Med* 2005; **20**: 265–70
- 40 Stiell IG, Nesbitt LP, Pickett W, et al. OPALS Study Group. The OPALS Major Trauma Study: impact of advanced life-support on survival and morbidity. *Can Med Assoc J* 2008; **178**: 1141–52
- 41 American College of Surgeons. *ATLS Manual*, 9th Edn. Chicago, USA: American College of Surgeons, 2012
- 42 Ferson D, Chi TL. Developments in general airway management. *Thorac Surg Clin* 2005; **15**: 39–53
- 43 Wilson WC. Trauma: airway management, ASA difficult airway algorithm modified for trauma—and five common trauma intubation scenarios. *ASA Newsletter* 2005; **69**: 9–18
- 44 Shearer VE, Giesecke AH. Airway management for patients with penetrating neck trauma: a retrospective study. *Anesth Analg* 1993; **77**: 1135–8
- 45 Scannell G, Waxman K, Tominaga G, et al. Orotracheal intubation in trauma patients with cervical fractures. *Arch Surg* 1993; **128**: 903–5
- 46 Mosier JM, Stolz U, Chiu S, Sakles JC. Difficult airway management in the emergency department: GlideScope videolaryngoscopy compared to direct laryngoscopy. *J Emerg Med* 2012; **42**: 629–34
- 47 Griesdale DE, Liu D, McKinney J, Choi PT. Glidescope videolaryngoscopy versus direct laryngoscopy for endotracheal intubation: a systematic review and meta-analysis. *Can J Anaesth* 2012; **59**: 41–52
- 48 Bernhard M, Mohr S, Weigand MA, Martin E, Walther A. Developing the skill of endotracheal intubation: implication for emergency medicine. *Acta Anaesthesiol Scand* 2012; **56**: 164–71
- 49 Bushra JS, McNeil B, Wald DA, Schwell A, Karras DJ. A comparison of trauma intubations managed by anesthesiologists and emergency physicians. *Acad Emerg Med* 2004; **11**: 66–70
- 50 Varga S, Shupp JW, Maher D, Tuznik I, Sava JA. Trauma airway management: transition from anesthesia to emergency medicine. *J Emerg Med* 2013; **44**: 1190–5
- 51 Ono Y, Yokoyama H, Matsumoto A, Kumada Y, Shinohara K, Tase C. Is preoperative period associated with severity and unexpected death of injured patients needing emergency trauma surgery? *J Anesth Advance Access* published on October 20, 2013, doi:10.1007/s00540-013-1727-0
- 52 Van Waes OJ, Cheriex KC, Navsaria PH, van Riet PA, Nicol AJ, Vermeulen J. Management of penetrating neck injuries. *Br J Surg* 2012; **99**(Suppl. 1): 149–54
- 53 Atar E, Griton I, Bachar GN, Bartal G, Kluger Y, Belenky A. Embolization of transected vertebral arteries in unstable trauma patients. *Emerg Radiol* 2005; **11**: 291–4
- 54 Biffl WL, Kaups KL, Cothren CC, et al. Management of patients with anterior abdominal stab wounds: a Western Trauma Association multicenter trial. *J Trauma* 2009; **66**: 1294–301
- 55 Biffl WL, Kaups KL, Pham TN, et al. Validating the Western Trauma Association algorithm for managing patients with anterior abdominal stab wounds: a Western Trauma Association multicenter trial. *J Trauma* 2011; **71**: 1494–502
- 56 Capote A, Michael A, Almodovar J, Chan P, Skinner R, Martin M. Emergency department thoracotomy: too little, too much, or too late. *Am Surg* 2013; **79**: 982–6
- 57 Burlew CC, Moore EE, Moore FA, et al. Western Trauma Association critical decisions in trauma: resuscitative thoracotomy. *J Trauma Acute Care Surg* 2012; **73**: 1359–63
- 58 Tisherman SA. Salvage techniques in traumatic cardiac arrest: thoracotomy, extracorporeal life support, and therapeutic hypothermia. *Curr Opin Crit Care* 2013; **19**: 594–8

- 59 Holcomb JB, Jenkins D, Rhee P. Damage control resuscitation: directly addressing the early coagulopathy of trauma. *J Trauma* 2007; **62**: 307–10
- 60 Zink KA, Sambasivan CN, Holcomb JB, Chisholm G, Schreiber MA. A high ratio of plasma and platelets to packed red blood cells in the first 6 hours of massive transfusion improves outcomes in a large multicenter study. *Am J Surg* 2009; **197**: 565–70
- 61 Holcomb JB, del Junco DJ, Fox EE, et al. The prospective, observational, multicenter, major trauma transfusion (PROMMTT) study: comparative effectiveness of a time-varying treatment with competing risks. *JAMA Surg* 2013; **148**: 127–36
- 62 Scalea TM, Bochicchio KM, Lumpkins K. Early aggressive use of fresh frozen plasma does not improve outcome in critically injured trauma patients. *Ann Surg* 2008; **248**: 578–84
- 63 Nascimento B, Callum J, Tien H, et al. Effect of a fixed-ratio (1:1:1) transfusion protocol versus laboratory-results-guided transfusion in patients with severe trauma: a randomized feasibility trial. *Can Med Assoc J* 2013; **185**: E583–9
- 64 Kozek-Langenecker S, Sørensen B, Hess JR, Spahn DR. Clinical effectiveness of fresh frozen plasma compared with fibrinogen concentrate: a systematic review. *Crit Care* 2011; **15**: R239
- 65 Rourke C, Curry N, Khan S, et al. Fibrinogen levels during trauma hemorrhage, response to replacement therapy, and association with patient outcomes. *J Thromb Haemost* 2012; **10**: 1342–51
- 66 Spahn DR, Bouillon B, Cerny V, et al. Management of bleeding and coagulopathy following major trauma: an updated European guideline. *Crit Care* 2013; **17**: R76
- 67 Schochl H, Nienaber U, Maegele M, et al. Transfusion in trauma: thromboelastometry-guided coagulation factor concentrate-based therapy versus standard fresh frozen plasma-based therapy. *Crit Care* 2011; **15**: R83
- 68 Nienaber U, Innerhofer P, Westermann I. The impact of fresh frozen plasma vs coagulation factor concentrates on morbidity and mortality in trauma associated haemorrhage and massive transfusion. *Injury* 2011; **42**: 697–701
- 69 Innerhofer P, Westermann I, Tauber H, et al. The exclusive use of coagulation factor concentrates enables reversal of coagulopathy and decreases transfusion rates in patients with major blunt trauma. *Injury* 2013; **44**: 209–16
- 70 Boffard KD, Riou B, Warren B, et al. Recombinant factor VIIa as adjunctive therapy for bleeding control in severely injured trauma patients: two parallel randomized, placebo-controlled, double blind clinical trials. *J Trauma* 2005; **59**: 8–15
- 71 Hauser CJ, Boffard K, Dutton R, et al. Results of the CONTROL trial: efficacy and safety of recombinant factor VIIa within a massive transfusion protocol in a civilian level I trauma center. *J Trauma* 2010; **69**: 489–500
- 72 CRASH-2 Trial Collaborators, Shakur H, Roberts I 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**: 23–32
- 73 CRASH-2 Collaborators, Roberts I, Shakur H, et al. The importance of early treatment with tranexamic acid in bleeding trauma patients: an exploratory analysis of the CRASH-2 randomised controlled trial. *Lancet* 2011; **377**: 1096–101

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