Review

The epidemiology and modern management of traumatic hemorrhage: US and international perspectives

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Abstract

Trauma is a worldwide problem, with severe and wide ranging consequences for individuals and society as a whole. Hemorrhage is a major contributor to the dilemma of traumatic injury and its care. In this article we describe the international epidemiology of traumatic injury, its causes and its consequences, and closely examine the role played by hemorrhage in producing traumatic morbidity and mortality. Emphasis is placed on defining situations in which traditional methods of hemorrhage control often fail. We then outline and discuss modern principles in the management of traumatic hemorrhage and explore developing changes in these areas. We conclude with a discussion of outcome measures for the injured patient within the context of the epidemiology of traumatic injury.

Introduction

Although it is often thought of as being composed of individual events, traumatic injury is a pandemic disease – one that affects every nation in the world without regard for economic development, racial or religious predominance, or political ideology. The disease is acute in onset but often results in chronic, debilitating health problems that have effects beyond the individual victims. There are identifiable broad trends in the epidemiology of trauma within individual countries and regions, but injury has an impact in every community regardless of demographics [1]. Traumatic hemorrhage accounts for much of the wide ranging international impact of injury, causing a large proportion of deaths and creating great morbidity in the injured.

Epidemiology

Every individual in the world is at risk for traumatic injury. The etiologies of injury are as diverse as the lifestyles and socioeconomic backgrounds of its victims, ranging from interpersonal violence and terrorism to motor vehicle crashes and occupational accidents. Worldwide, an estimated 5 million people died as a result of injury in 2000, with a mortality rate of 83 per 100,000 of the population. Injury represented 9% of worldwide deaths and 12% of the burden of disease [2]. More than 90% of injury-related fatalities occur in low- and middle-income nations. The highest mortality rates from injury occur in the less wealthy nations in Eastern Europe, with the lowest rates in North America, Western Europe, China, Japan, and Australia [2]. Globally, road traffic injuries result in 1.2 million deaths per year, with an additional 20–50 million injuries. They rank as the 11th leading cause of death overall, accounting for 2.1% of all deaths worldwide and 25% of injury-related deaths [2]. The majority of traffic injuries and fatalities occur in low- to middle-income nations, with some of the highest fatality rates found in European nations [3]. Violence is a large contributor to injury-related fatality as well, with 1.6 million deaths worldwide in 2000, representing 16% of mortality from injury [2]. It is by far the leading cause of death among those aged 15–44 years and is much more prevalent in low- to middle-income countries [4]. Self-inflicted violence represents 16% of injury-related mortality worldwide, with falls and burns accounting for 6% and 5%, respectively [2].

In the USA in 2001, where more than 10% of residents suffered nonfatal injuries, trauma was the third leading cause of death overall and was the leading cause of death among those aged 1–44 years. There were 161,269 deaths from injury in 2002, for an overall rate of 56 per 100,000 residents. Death from injury in the USA results in more years of potential life lost before the age of 75 years than any other cause, accounting for 23% of lost years and illustrating the unequal burden of trauma on young people [5]. In Europe, trauma disproportionately affects the young as well. For example, nearly 40% of the injured in the German trauma registry for 2002 were aged between 20 and 39 years, with the greatest incidence occurring in persons aged between 20 and 24 years.

ATLS = Advanced Trauma Life Support; ICU = intensive care unit; MOF = multiple organ failure; RBC = red blood cell.

Unintentional injuries account for the majority of trauma in all age groups in the USA. Falls are the leading cause of nonfatal injury in all age groups apart from those aged 15–24 years, and motor vehicle accidents cause the most deaths from injury in all groups apart from infants and the elderly. Although unintentional trauma predominates, homicide is the second leading cause of death in US residents aged 15–34 years, and these fatal injuries result primarily from the use of firearms. In 2002 firearms caused 30,242 deaths for a rate of 10.5 per 100,000 residents. Across all age groups, firearm suicide and homicide were the third and fifth leading causes of overall injury or death, respectively, in 2002 [5]. Firearms cause a smaller proportion of traumatic injury in Europe than in the USA, and this is reflected in lower rates of penetrating trauma. In the USA the rate of penetrating trauma is around 20%, whereas in Germany the rate is less than 5%.

Costs

Trauma carries with it a great price that is paid at all levels of society – by individuals, families, communities, and nations. The burden of traumatic injury ranges from the significant financial costs of modern trauma care to the emotional distress of having a loved one, especially a young individual, become critically injured or die. The financial costs of road traffic injuries alone can amount to up to 2% of a nation's gross national product [3]. The US Centers for Disease Control and Prevention estimated that, in 2000, US$117 billion was spent on injury-attributable medical care, amounting to approximately 10% of total US medical expenditures [6]. In Germany, the cost of managing a multiply injured patient can exceed €60,000 [7]. The actual economic cost of injury is probably much higher, because the above figures do not include the cost of life and work years lost secondary to injury or death, the loss of property, and indirect costs such as decreased quality of life and mental health concerns. Many victims of trauma in the USA are among those who are without health insurance, and much of the economic cost of trauma care is either reimbursed directly by public funds or is not reimbursed at all, with the cost deferred in other billings. This places a disproportionate burden of the financial costs of injury on taxpayers and on providers of health care, and makes the provision of trauma care financially unattractive to US health care institutions [1].

In addition to the economic cost of traumatic injury, a considerable social burden is associated with it. Despite the acuity of its onset, trauma often becomes a chronic disease with significant long-term functional limitations and decrements in quality of life. In one epidemiologic study [8] 22% of survivors of severe injury suffered permanent disability and 57% had temporary disability. The life and work years lost by the relatively young population of injury victims has high associated costs in lost productivity and work years [9,10]. The impact of the long-term care of trauma patients on families and communities is an aspect of trauma care that vastly increases the cost to society. The accumulated costs of traumatic injury are large and not easily addressed at any single level. Trauma prevention is doubtless the most desirable way to decrease these burdens, and government and private efforts are active in this effort but, as illustrated by the statistics presented above, the problem remains. It is up to those involved in the care of the injured patient to continue striving for ways to optimize care and outcomes.

Epidemiology of traumatic fatality and hemorrhage

The epidemiology of trauma mortality in the USA has been investigated by a number of population-based studies over the past quarter of a century [11-14]. These and other trauma center-based studies [15,16] have provided a solid base of literature in which to examine the characteristics of injury patterns in the USA. The variety and quality of these investigations allow conclusions to be drawn regarding the epidemiology of traumatic fatality and the role of hemorrhage and hemorrhagic shock.

Definitions

In order to appreciate fully the epidemiology of trauma and injury, a clear understanding of definitions is necessary. Epidemiologic studies of trauma refer commonly to the terms 'cause of injury' and 'cause of death'. The former represents the mechanism of bodily harm to the patient (gunshot wound, motor vehicle crash, fall, etc.) but it does not account for the injuries sustained or their severity. The cause of death, on the other hand, is the result of the injuries sustained, and represents the proximate event leading to the fatality. Examples include hemorrhage, brain injury, and sepsis. Epidemiologic studies tend to present causes (mechanisms) of injury as being associated with fatality. This type of data focuses efforts on preventing the occurrence of a particular mechanism of injury. Although this is no doubt important, measurable improvements in this area are small over time [12]. As clinicians, those who care for trauma patients must focus their efforts on the causes of traumatic death in order to save lives.

Mechanism of injury

The proportions of various mechanisms of injury leading to eventual fatality are somewhat inconsistent across epidemiologic studies. In some analyses, penetrating injuries such as gunshot or stab wounds account for as many as 49% of traumatic deaths, whereas in others blunt injuries such as falls and motor vehicle crashes account for up to 60% of deaths [11,13,16]. Penetrating injuries tend to result in earlier fatality, with most deaths occurring during the first 72 hours of hospital admission [11,15].

Cause of death

Even with these inconsistent proportions of fatal mechanisms, the same analyses have all demonstrated that injury to the central nervous system (particularly head injury)

is the leading overall cause of death in the lethally injured patient, accounting for 40–50% of fatalities. Hemorrhage following traumatic injury accounts for 30–40% of deaths [13]. Fatal traumatic hemorrhage is primarily an acute problem; one epidemiologic study [13] found that 36% of patients who were found or declared dead at the scene of injury had exsanguinated. Bleeding also accounts for a larger share of mortality early on in trauma center admission, with the majority of exsanguinations occurring during the first 48 hours [15]. This pattern implies an intuitive association between penetrating mechanism and severe hemorrhage, given the predominance of early fatality from penetrating injuries.

Hemorrhagic shock

Hemorrhagic shock, in addition to directly resulting in early fatality, is a predictor of poor outcome in the injured patient. Early hypotension (systolic blood pressure = 90 mmHg) with hemorrhage in the field or at initial hospital evaluation is associated with complications such as eventual organ failure and the development of infections, including sepsis [17,18]. In addition to the consequences of shock itself, the current management of hemorrhagic shock in traumatic injury relies heavily on transfusion of red blood cells (RBCs). These transfusions are associated with the development of multiple organ failure (MOF), increased intensive care unit (ICU) admissions and length of stay, increased hospital length of stay, and mortality [19-22].

As a critically injured patient progresses through the phases of trauma care, death from causes unrelated to specific injuries becomes more common. Infections such as sepsis and pneumonia, systemic inflammatory response syndrome, and MOF become the primary etiologies of traumatic death in the hospitalized trauma patient [11,13,15].

Clinical aspects of traumatic hemorrhage

We have established that hemorrhage accounts for a considerable amount of mortality and morbidity among injured patients, and that most severe bleeding occurs during the acute phase of injury, typically as a result of the injuries sustained. We now examine the problem of traumatic hemorrhage in detail, focusing on specific factors that place injured patients at increased risk for severe bleeding and situations in which traditional hemostatic methods may prove inadequate.

Surgical bleeding

The hemorrhaging trauma patient frequently has injuries that require urgent operation for control of bleeding, and more than 80% of trauma deaths that occur in the operating room do so as a result of hemorrhage [23]. These severe injuries comprise a category known as 'surgical bleeding' and account for about 50% of hypotensive patients. Surgical bleeding is not a well defined term, but it can be described broadly as including those injuries that can only be addressed through direct operative visualization and controlled with suture, packing, pressure, or application of a hemostatic agent. If surgical bleeding is not controlled in this manner, it will likely be fatal. Given the large proportion of operative deaths secondary to hemorrhage, prevention of these fatalities is clearly an area of potential improvement in the care of the injured patient, and early intervention to control bleeding is paramount.

Nonsurgical bleeding

Not all bleeding can or should be controlled surgically, however, and there are various injuries and situations that fall into the category of 'nonsurgical bleeding'. These are areas in which operative intervention has limited or no ability to control hemorrhage, and in which attempts at surgical control have the potential to exacerbate traumatic hemorrhage and lead to severe bleeding and coagulopathy. Trauma care is constantly evolving, and the trend is toward nonoperative management of hemorrhage that was previously considered 'surgical' in nature. Examples include hemorrhage from pelvic fractures, which may be better addressed with angiographic embolization than laparotomy; and coagulopathic bleeding, which should be addressed by restoring normal hemostatic physiology [24]. Operation for these problems can have disastrous consequences, leading to further blood loss, physiologic derangement, and possibly death. In addition, some instances of intracranial bleeding, including certain intracerebral and subdural hematomas, can be managed nonoperatively [25-30]. Conservative, nonoperative management of splenic and hepatic parenchymal bleeding without operation is well described and studied, and is now standard practice for all but the most severe injuries [24]. Keeping patients with these problems out of the operating room probably reduces morbidity and improves outcomes.

Medications

The injured patient may be predisposed to bleeding problems over and above those occurring as a result of their injuries. The use of medications that interfere with normal hemostatic physiology is one area in which this is the case, and the use of these medications is increasing. Warfarin and aspirin are commonly used anticoagulants, and their use increases the mortality rate from traumatic brain injuries by fourfold to fivefold [31,32]. Clopidogrel is a commonly used antiplatelet agent and has been shown to increase transfusion requirements in cardiac surgery [33,34]. Ibuprofen, the common nonsteroidal anti-inflammatory medication, is known to interfere with platelet function, and its use has also been shown to increase operative blood loss during hip surgery [35]. Any of these medications may exacerbate bleeding problems in trauma, although little research has been done in this area.

Medical conditions

Previously existing medical conditions may also predispose a trauma patient to bleeding problems. Patients with hemophilia

and other inherited diseases have a tendency toward spontaneous bleeding and to have unexpected hemorrhage with minor trauma. These bleeding diatheses can dramatically compound traumatic hemorrhage. In patients with cirrhosis, failure of the liver to synthesize clotting factors results in coagulopathy and poorer trauma outcomes, especially in the operated patient [36,37]. Patients with renal insufficiency often have platelet dysfunction resistant to platelet transfusion [24]. Alcohol use, so common in trauma patients, is also associated with platelet inhibition, although the effect appears to be transient [38].

Acquired coagulopathy of trauma

The acquired coagulopathy of trauma is an important clinical entity that is undergoing intensive study. The phenomenon is responsible for the majority of postoperative traumatic hemorrhagic fatalities, and the onset of an acute coagulopathy is associated with increased overall mortality [39-41]. The development of traumatic coagulopathy is associated with massive transfusion and resuscitation, increased injury severity, and the presence of hemorrhagic shock [42,43]. The sequential and additive effects of the 'lethal triad' of hemodilution, hypothermia, and acidosis on the coagulation cascade produce the 'bloody vicious cycle', and unless intervention is performed to break this cycle it leads rapidly to the demise of the injured patient from coagulopathic exsanguinations [39,43-46]. Attempts to interrupt the vicious cycle have resulted in the development of modern methods of caring for the severely hemorrhaging patient, including 'damage control' surgery, attention to effective resuscitation and rewarming, and appropriate blood and blood product transfusion. These management techniques are discussed below.

Current management of traumatic hemorrhage

Prehospital care

The development of systematic, regionalized trauma care occurred from the 1970s to the 1980s. In the USA and across Europe, Latin America, Australia, and other developed regions of the world, a number of structured systems exist at regional, national, and local levels to manage prehospital emergency care. A number of epidemiologic studies have demonstrated remarkable improvements in patient survival with the institution of these systematic approaches to prehospital care in the USA and elsewhere [8,47-49]. These systems are focused on trauma centers to which the most severely injured patients are transported either directly from the scene of injury or following stabilization at outlying facilities within a geographic area. The provision of trauma care is integrated from the level of the field emergency service providers through outlying hospitals to the trauma center. Rapid movement of patients from the scene of injury to definitive trauma center care is geared toward providing expeditious treatment of central nervous system injuries and operative intervention for severe hemorrhage. Transport is coordinated through a regional medical command, which allows for appropriate triage, efficient communication between care providers, and standardization of procedures.

The principal distinction that can be made between North American (USA and Canada) prehospital care and that in Europe is the proximity of the physician to the injured patient in the field. In North American trauma systems, field care and transport to hospital are performed nearly universally by nonphysician emergency medical services personnel who operate under the direction of a local medical director who is trained in emergency medicine [50]. In Europe, the field of prehospital trauma care has evolved differently, with more use of physicians in the field in many countries. Patients are triaged and treated at the scene of injury by the physician responder and often directly admitted to the hospital for definitive care. By virtue of these differences, field trauma care in Europe tends to be more intensive, and the time to definitive care can be shorter and initial triage more appropriate [51,52].

Phases of care

Despite the differences in prehospital care outlined above, the acute management of traumatic hemorrhage is similar around the world and follows well accepted published guidelines [53,54]. In order to explore the management of individual patients with traumatic hemorrhage, it is helpful to define the chronology of a critically injured patient's care as occurring in three, often overlapping segments: the resuscitative, operative, and critical care phases. The diagnosis and control of bleeding should be a high priority during all of the phases of trauma care and is especially important in the patient who is in hemorrhagic shock. Early attempts at hemorrhage control include direct control of visible sources of severe bleeding with direct pressure, pressure dressings, or tourniquets; stabilization of long bone and pelvic fractures; and keeping the patient warm. Table 1 presents a summary of measures to enhance hemostasis throughout the trauma patient's treatment course.

Resuscitative phase

The resuscitative phase in the care of the hemorrhaging patient begins in the field with the arrival of the first responder. The patient's airway is secured, respiration is assured or provided, and a circulatory assessment is made. A complete head-to-toe evaluation of the patient is undertaken according to the principles of Prehospital Trauma Life Support [53] and Advanced Trauma Life Support (ATLS) [54], life-saving procedures are performed as necessary, and transportation to a hospital is undertaken. Initial intravenous fluid is administered during the resuscitative phase, and fluid resuscitation can continue into and through the subsequent operative phase. It is important to note that attempts to curtail bleeding and prevent coagulopathy, and not just to normalize the patient's vital signs, are essential in the resuscitative care of the hemorrhaging patient. These are key points that can be easily overshadowed in the attempt to aggressively fluid-resuscitate a patient who is in hemorrhagic shock.

Table 1

Interventions to improve hemostasis in trauma care

Phase	Details
Early, prehospital interventions	Control overt hemorrhage Direct pressure Pressure dressing Tourniquet Diagnose and treat occult hemorrhage Stabilization of pelvis and long bone fractures Keep patient warm
Resuscitative phase	Warmed intravenous fluids Hypotensive resuscitation prior to surgical control of hemorrhage Appropriate transfusion of blood and blood products
Operative phase	Surgical control of life-threatening hemorrhage Damage control operations for critically ill patients Appropriate transfusion of blood and blood products
Critical care phase	Effective resuscitation End-points of tissue perfusion Physiologic support to prevent coagulopathy

The principles and practice of resuscitation are changing as more is learned about the physiology of hemorrhagic shock and fluid administration. One aspect in particular flux is the area of resuscitation end-points. For nearly a century, physicians have realized that excessive resuscitation may be detrimental to hemostasis [55]. Current ATLS guidelines call for the replacement of each milliliter of lost blood with three times the amount of isotonic crystalloid, while giving careful attention to the physiologic response of the patient. Attempts to restore 'normal' vital signs in the patient with uncontrolled hemorrhage can be detrimental, producing the consequences of volume overload and rebleeding, leading to coagulopathy and the bloody vicious cycle. A strategy of 'hypotensive resuscitation', whereby fluid is administered with the end-point of a safe but subnormal blood pressure until surgical control of bleeding can be achieved, has been studied in various animal and limited human trials and appears to be a promising way to mitigate some of the problems incurred by more traditional resuscitative strategies [56-62]. Hypotensive resuscitation is probably beneficial for only a limited duration, however, and prompt attention to hemorrhage control is vital.

In addition to changing perspectives on the end-points of intravenous fluid resuscitation, the choice of fluid is under investigation as well. There is experimental evidence that, in addition to the detrimental effect of the large volumes administered, the isotonic crystalloids themselves cause undue immune activation and increase regulation of cellular injury markers. These effects are seen with hypertonic and colloid solutions as well [63-65]. These cellular events may predispose patients to poor outcomes, but this has not been directly studied. Various potential replacements for normal saline and Ringer's lactate have been studied, and some are currently in use in various situations. These solutions include hyperosmolar colloid and hypertonic electrolyte compounds. Some, such as the 6% hydroxyethyl starches Hextend® (BioTime, Inc., Emeryville, California, USA) and Hespan® (BraunMedical, Inc., Irvine, California, USA) are approved for use in volume expansion in the USA. These and others such as RescueFlow® (BioPhausia AB, Stockholm, Sweden) and HyperHES® (Vidal, Issy Les Moulineaux, France) are approved and in use in Europe. Hypertonic solutions such as 7.5% saline, HyperHES®, RescueFlow®, and the combination fluid hypertonic saline–dextran have been studied in human resuscitation and found to be safe [66]. The evidence in support of the use of these fluids is not universal, and no study to date has demonstrated a clear positive effect on outcome, and so the debate continues regarding these fluids and their use [67-70].

The transfusion of blood and blood products is a cornerstone of the resuscitation of the severely bleeding patient. ATLS calls for the administration of packed RBCs along with continued isotonic crystalloids if a patient does not respond or responds only transiently to the initial 2 l crystalloid infusion. Hemoglobin-based oxygen carriers are a promising group of compounds that are undergoing study as potential resuscitative fluids or as compounds to limit transfusion [71,72]. Transfusion of blood products such as fresh frozen plasma, cryoprecipitate, and platelet concentrate are used to treat coagulopathy and prevent or interrupt the bloody vicious cycle. Blood and blood product transfusions are discussed further in other articles in this supplement.

Operative phase

The operative phase follows the initial resuscitative phase, but fluid resuscitation often continues while the patient is in the operating room. Although not all patients undergo an operation, most severe hemorrhages require surgical intervention, and approximately 50% of patients in hemorrhagic shock are moved to the operating room from the emergency department [17]. Efforts to control bleeding and repair damaged tissue surgically are made, and in the critically ill patient an abbreviated 'damage control' procedure is performed, whereby life-threatening injuries are quickly addressed, the patient is taken to the ICU for continued resuscitation and restoration of physiology, and is then returned to the operating room at a later time to complete the procedures [24]. Restoring physiology involves attempts to interrupt the bloody vicious cycle through aggressive rewarming, effective resuscitation, and correction of acidosis. Resuscitation continues in a dynamic fashion with responses to the rapidly changing physiologic status of the patient. Even with aggressive approaches to the correction of the hypothermia and acidosis commonly associated with the

coagulopathy of traumatic injury, once the bloody vicious cycle has begun it is exceedingly difficult to salvage the patient [41,44].

Critical care phase

The critical care phase in the care of the bleeding trauma patient follows either the operative phase or is a continuation of resuscitation in the ICU. Efforts to attain and preserve normal physiology are initiated and continued, the patient is closely monitored (often invasively), and support is provided as needed as the patient recovers from injury. End-points and goals for the resuscitation of severely injured patients are undergoing constant reappraisal. Standard hemodynamic parameters such as blood pressure and heart rate are no longer regarded as the best measures of physiologic derangement in the critically ill trauma patient. Shock is defined as a state of decreased tissue perfusion, and values that characterize this state more closely represent the status of a patient in and recovering from shock. Examples of these include measures of oxygen delivery, mixed venous oxygen saturation, base deficit and lactate, end-tidal carbon dioxide, gastric tonometry, and more direct measures of peripheral tissue perfusion such as subcutaneous electrode oxygen and carbon dioxide measurements and near infrared spectroscopy. None of these measures is able to predict with perfect reliability the outcome of a patient, but they are more specific measures of physiologic status and research is ongoing to improve them [73].

As the injured patient undergoes the physiologic changes associated with injury and recovery, several complications can arise. The most devastating of these are infections, primarily sepsis, and MOF. These are the leading causes of late traumatic fatality, and much of the ICU care administered to critically ill patients aims at their prevention [13,15,16]. Vigilant attention to all major organ systems and an integrated team approach to patient care involving specialist physicians, nurses, and allied health providers are critical to the achievement of good outcomes.

Traumatic hemorrhage therapy and outcome

Now that the scope of the problem of traumatic hemorrhage has been defined and current management strategies outlined, we explore the various ways in which the effect of modern developments in trauma care, such as those addressed in this supplement, can be measured. The control of hemorrhage in severe trauma is a complicated issue that is influenced by numerous factors, and likewise measuring outcomes in these patients is not straightforward. The remainder of this review discusses outcome measures that should be part of the evaluation of any proposed hemorrhage control therapy. Table 2 presents such measures.

Table 2

Outcome measures for hemostatic interventions in trauma

Outcome measure	Details
Mortality	Overall
	Early
	Late
Complications	Organ failure
	Acute respiratory distress syndrome
	Renal failure
	Inotropes
	Hyperbilirubinemia
	Infection
	Sepsis
	Pneumonia
	Coagulopathy
	Continued bleeding
	Transfusion requirement
Costs	Inpatient care
	Outpatient care
	Rehabilitative care
	Life and work years lost
Other	Hospital days
	Intensive care
	Hospital
	Ventilator
	Laboratory tests
	Prothrombin time
	Partial thromboplastin time
	Thromboelastography
	Transfusion requirement
	Packed red blood cells
	Fresh frozen plasma
	Platelets
	Cryoprecipitate

Mortality

The most widely used and clinically significant trauma outcome measure is mortality, and we have pointed out that hemorrhage accounts for a large portion of deaths. Saving lives is the ultimate goal of most clinical interventions, and to this end the prospect of reducing mortality from hemorrhage presents great potential benefit to the injured. Because of the wide spectrum of traumatic injuries and their severities, however, it has been difficult to show improvements in mortality with most new interventions. We know of no interventions for the control of bleeding or fluid resuscitation that have been approved based on a reduction in mortality in trauma patients.

Mortality in trauma patients occurs throughout the course of treatment. Most deaths that occur early, within 48 hours from injury, are the result of the severity of injuries sustained [13]. This pattern has resulted in the thought that such early deaths are difficult to address and has led to a strong emphasis on preventing later deaths from complications such as sepsis and MOF. The predominance of acute traumatic death from hemorrhage makes hemorrhage control an important area of research if early traumatic deaths are to be prevented.

Complications

The trauma literature is replete with articles on the development of complications during an injured patient's clinical course. The two most significant complications are organ failure and infections because these are common causes of late traumatic fatality [13,14,16,19]. Various factors have been associated with the development of MOF, including the presence of hypovolemic shock, advanced age, severe injury, and blood transfusion. Therefore, this complication seems to be a reasonable marker for the overall condition of the patient, given their injuries, and thus is an appropriate intermediate outcome measure [18,19,22]. Serious infectious complications such as sepsis and pneumonia are common in the severely injured, especially those who have been in shock, and so this is another reasonable outcome measure for hemorrhage intervention [18].

Intensive care unit and hospital factors

Patients who suffer severe hemorrhage and shock are typically critically ill, requiring urgent operation and ICU admission [17]. Their critical care courses can be lengthy and fraught with multiple complications as noted above. Length of stay in the ICU and overall hospital days can be used as global measures of the pace of an injured patient's recovery. Number of days spent on a ventilator may serve as an indicator of the overall progress of the patient, as may the development and course of any pulmonary complications such as acute respiratory distress syndrome. The eventual disposition of an injured patient may also be used as an outcome measure, representing the overall progress of an injured patient at the time of hospital discharge.

Patients are discharged home with or without outpatient rehabilitation, or to the various levels of inpatient care. This may take the form of long-term or short-term acute care for those patients who remain significantly debilitated, or of acute or chronic rehabilitation for those patients who are improving but require ongoing therapy following hospital discharge.

Laboratory evaluation and transfusion

The requirements for RBC and blood product transfusions have been associated with other trauma outcome measures and are important indicators of the severity of hemorrhage and coagulopathy as well as the effectiveness of interventions to improve hemostasis. Reduction in RBC transfusion requirement is a good indicator that a hemostatic intervention is efficacious. Laboratory measures may be used to assess more specifically the performance of techniques used to minimize hemorrhage and especially to address coagulopathy. Laboratory monitoring of traumatic coagulopathy is important in order to address occult hemorrhage in patients whose bleeding has been surgically controlled. In addition to the commonly used prothrombin and partial thromboplastin times, which have been demonstrated to lack accuracy in hypothermic patients [74], thromboelastography – used commonly in cardiac and transplant surgery – is emerging as a potentially useful test in traumatic coagulopathy [75].

Costs

The significant financial costs of trauma care are increasing rapidly with improvements in critical care. Critically ill trauma patients are living longer but with increased morbidity, both in the acute and chronic phases of their care and illness. The impact of any proposed intervention in these patients must be weighed carefully against its cost. The patient's prognosis for recovery must be included in the consideration to use a powerful but expensive new intervention. To adopt the use of such methods and agents without consideration of their potential effect on survival or the prevention of complications will inevitably lead to inappropriate use in some cases and increased cost for very little benefit.

Conclusion

Traumatic injury is an international problem, affecting all nations and people from all walks of life. Hemorrhage is a major contributor to the morbidity and mortality of injury, and attaining and maintaining hemostasis is a key consideration in trauma care. Modern trauma care practices have been developed to expeditiously identify and efficiently treat traumatic hemorrhage, but numerous factors can contribute to severe traumatic hemorrhage and the development of coagulopathy. These can be difficult to treat, and novel methods of hemostasis have the potential to produce great benefit in these cases.

Competing interests

The author(s) declare that they have no competing interests.

References

1. Cinat ME, Wilson SE, Lush S, Atkins C: **Significant correlation of trauma epidemiology with the economic conditions of a community.** *Arch Surg* 2004, **139:**1350-1355.
2. Peden M, McGee K, Sharma G: *The Injury Chart Book: a Graphical Overview of the Global Burden of Injuries*. Geneva: World Health Organization; 2002.
3. Peden M: *World Report on Road Traffic Injury Prevention: Summary*. Geneva: World Health Organization; 2004.
4. Krug E, Dahlberg L, Zwi A, Mercy J, Lozano R (Eds): *World Report on Violence and Health*. Geneva: World Health Organization; 2002.
5. Centers for Disease Control and Prevention: *Web-based Injury Statistics Query and Reporting System (WISQARS)*. Atlanta: US Department of Health and Human Services, CDC, National Center for Injury Prevention and Control; 2002.
6. Centers for Disease Control and Prevention: **Medical expenditures attributable to injuries—United States, 2000.** *MMWR Morb Mortal Wkly Rep* 2004, **53:**1-4.
7. Pape HC, Grotz M, Schwermann T, Ruchholtz S, Lefering R, Rieger M, Troger M, Graf von der Schulenburg JM, Krettek C; AG Polytrauma der DGU: **The development of a model to calculate the cost of care for the severely injured—an initiative of the Trauma Register of the DGU [in German].** *Unfallchirurg* 2003, **106:**348-357.
8. Shackford SR, Mackersie RC, Hoyt DB, Baxt WG, Eastman AB, Hammill FN, Knotts FB, Virgilio RW: **Impact of a trauma system on outcome of severely injured patients.** *Arch Surg* 1987, **122:** 523-527.
9. Holbrook TL, Anderson JP, Sieber WJ, Browner D, Hoyt DB: **Outcome after major trauma: 12-month and 18-month follow-up results from the Trauma Recovery Project.** *J Trauma* 1999, **46:**765-771.

10. Vazquez MG, Rivera FR, Perez AA, Gonzalez CA, Fernandez ME, Navarrete NP: **Analysis of quality of life in polytraumatized patients two years after discharge from an intensive care unit.** *J Trauma* 1996, **41:**326-332.
11. Baker CC, Oppenheimer L, Stephens B, Lewis FR, Trunkey DD: **Epidemiology of trauma deaths.** *Am J Surg* 1980, **140:**144-150.
12. Potenza BM, Hoyt DB, Coimbra R, Fortlage D, Holbrook T, Hollingsworth-Fridlund P: **The epidemiology of serious and fatal injury in San Diego County over an 11-year period.** *J Trauma* 2004, **56:**68-75.
13. Sauaia A, Moore FA, Moore EE, Moser KS, Brennan R, Read RA, Pons PT: **Epidemiology of trauma deaths: a reassessment.** *J Trauma* 1995, **38:**185-193.
14. Shackford SR, Mackersie RC, Holbrook TL, Davis JW, Hollingsworth-Fridlund P, Hoyt DB, Wolf PL: **The epidemiology of traumatic death. A population-based analysis.** *Arch Surg* 1993, **128:**571-575.
15. Acosta JA, Yang JC, Winchell RJ, Simons RK, Fortlage DA, Hollingsworth-Fridlund P, Hoyt DB: **Lethal injuries and time to death in a level I trauma center.** *J Am Coll Surg* 1998, **186:**528-533.
16. Stewart RM, Myers JG, Dent DL, Ermis P, Gray GA, Villarreal R, Blow O, Woods B, McFarland M, Garavaglia J, *et al.*: **Seven hundred fifty-three consecutive deaths in a level I trauma center: the argument for injury prevention.** *J Trauma* 2003, **54:**66-70.
17. Franklin GA, Boaz PW, Spain DA, Lukan JK, Carrillo EH, Richardson JD: **Prehospital hypotension as a valid indicator of trauma team activation.** *J Trauma* 2000, **48:**1034-1037.
18. Heckbert SR, Vedder NB, Hoffman W, Winn RK, Hudson LD, Jurkovich GJ, Copass MK, Harlan JM, Rice CL, Maier RV: **Outcome after hemorrhagic shock in trauma patients.** *J Trauma* 1998, **45:**545-549.
19. Durham RM, Moran JJ, Mazuski JE, Shapiro MJ, Baue AE, Flint LM: **Multiple organ failure in trauma patients.** *J Trauma* 2003, **55:**608-616.
20. Malone DL, Dunne J, Tracy JK, Putnam AT, Scalea TM, Napolitano LM: **Blood transfusion, independent of shock severity, is associated with worse outcome in trauma.** *J Trauma* 2003, **54:**898-905.
21. Moore FA, Moore EE, Sauaia A: **Blood transfusion. An independent risk factor for postinjury multiple organ failure.** *Arch Surg* 1997, **132:**620-624.
22. Sauaia A, Moore FA, Moore EE, Haenel JB, Read RA, Lezotte DC: **Early predictors of postinjury multiple organ failure.** *Arch Surg* 1994, **129:**39-45.
23. Hoyt DB, Bulger EM, Knudson MM, Morris J, Ierardi R, Sugerman HJ, Shackford SR, Landercasper J, Winchell RJ, Jurkovich G: **Death in the operating room: an analysis of a multi-center experience.** *J Trauma* 1994, **37:**426-432.
24. Mattox KL, Feliciano DV, Moore EE: *Trauma*. New York: McGraw-Hill, Health Professions Division; 2000.
25. Ceylan S, Kuzeyli K, Ilbay K, Akturk F: **Non operative management of acute extradural hematomas in children.** *J Neurosurg Sci* 1992, **36:**85-88.
26. Mandera M, Zralek C, Krawczyk I, Zycinski A, Wencel T, Bazowski P: **Surgery or conservative treatment in children with traumatic intracerebral haematoma.** *Childs Nerv Syst* 1999, **15:**267-269.
27. Mathew P, Oluoch-Olunya DL, Condon BR, Bullock R: **Acute subdural haematoma in the conscious patient: outcome with initial non-operative management.** *Acta Neurochir (Wien)* 1993, **121:**100-108.
28. Wong CW: **The CT criteria for conservative treatment – but under close clinical observation – of posterior fossa epidural haematomas.** *Acta Neurochir (Wien)* 1994, **126:**124-127.
29. Wong CW: **Criteria for conservative treatment of supratentorial acute subdural haematomas.** *Acta Neurochir (Wien)* 1995, **135:**38-43.
30. Wong CW: **CT and clinical criteria for conservative treatment of supratentorial traumatic intracerebral haematomas.** *Acta Neurochir (Wien)* 1995, **135:**131-135.
31. Mina AA, Knipfer JF, Park DY, Bair HA, Howells GA, Bendick PJ: **Intracranial complications of preinjury anticoagulation in trauma patients with head injury.** *J Trauma* 2002, **53:**668-672.
32. Mina AA, Bair HA, Howells GA, Bendick PJ: **Complications of preinjury warfarin use in the trauma patient.** *J Trauma* 2003, **54:**842-847.
33. Chen L, Bracey AW, Radovancevic R, Cooper JR, Jr., Collard CD, Vaughn WK, Nussmeier NA: **Clopidogrel and bleeding in patients undergoing elective coronary artery bypass grafting.** *J Thorac Cardiovasc Surg* 2004, **128:**425-431.
34. Englberger L, Faeh B, Berdat PA, Eberli F, Meier B, Carrel T: **Impact of clopidogrel in coronary artery bypass grafting.** *Eur J Cardiothorac Surg* 2004, **26:**96-101.
35. Slappendel R, Weber EW, Benraad B, Dirksen R, Bugter ML: **Does ibuprofen increase perioperative blood loss during hip arthroplasty?** *Eur J Anaesthesiol* 2002, **19:**829-831.
36. Demetriades D, Constantinou C, Salim A, Velmahos G, Rhee P, Chan L: **Liver cirrhosis in patients undergoing laparotomy for trauma: effect on outcomes.** *J Am Coll Surg* 2004, **199:**538-542.
37. Tinkoff G, Rhodes M, Diamond D, Lucke J: **Cirrhosis in the trauma victim. Effect on mortality rates.** *Ann Surg* 1990, **211:**172-177.
38. Rubin R, Rand ML: **Alcohol and platelet function.** *Alcohol Clin Exp Res* 1994, **18:**105-110.
39. Brohi K, Singh J, Heron M, Coats T: **Acute traumatic coagulopathy.** *J Trauma* 2003, **54:**1127-1130.
40. Lynn M, Jeroukhimov I, Klein Y, Martinowitz U: **Updates in the management of severe coagulopathy in trauma patients.** *Intensive Care Med* 2002, **28(suppl 2):**S241-S247.
41. MacLeod JB, Lynn M, McKenney MG, Cohn SM, Murtha M: **Early coagulopathy predicts mortality in trauma.** *J Trauma* 2003, **55:**39-44.
42. Ferrara A, MacArthur JD, Wright HK, Modlin IM, McMillen MA: **Hypothermia and acidosis worsen coagulopathy in the patient requiring massive transfusion.** *Am J Surg* 1990, **160:**515-518.
43. Staab DB, Sorensen VJ, Fath JJ, Raman SB, Horst HM, Obeid FN: **Coagulation defects resulting from ambient temperature-induced hypothermia.** *J Trauma* 1994, **36:**634-638.
44. Cosgriff N, Moore EE, Sauaia A, Kenny-Moynihan M, Burch JM, Galloway B: **Predicting life-threatening coagulopathy in the massively transfused trauma patient: hypothermia and acidoses revisited.** *J Trauma* 1997, **42:**857-861.
45. Ferrara A, MacArthur JD, Wright HK, Modlin IM, McMillen MA: **Hypothermia and acidosis worsen coagulopathy in the patient requiring massive transfusion.** *Am J Surg* 1990, **160:**515-518.
46. Watts DD, Trask A, Soeken K, Perdue P, Dols S, Kaufmann C: **Hypothermic coagulopathy in trauma: effect of varying levels of hypothermia on enzyme speed, platelet function, and fibrinolytic activity.** *J Trauma* 1998, **44:**846-854.
47. Shackford SR, Hollingworth-Fridlund P, Cooper GF, Eastman AB: **The effect of regionalization upon the quality of trauma care as assessed by concurrent audit before and after institution of a trauma system: a preliminary report.** *J Trauma* 1986, **26:**812-820.
48. West JG, Trunkey DD, Lim RC: **Systems of trauma care. A study of two counties.** *Arch Surg* 1979, **114:**455-460.
49. Arreola-Risa C, Mock CN, Lojero-Wheatly L, de la CO, Garcia C, Canavati-Ayub F, Jurkovich GJ: **Low-cost improvements in prehospital trauma care in a Latin American city.** *J Trauma* 2000, **48:**119-124.
50. Benitez FL, Pepe PE: **Role of the physician in prehospital management of trauma: North American perspective.** *Curr Opin Crit Care* 2002, **8:**551-558.
51. Dick WF: **Anglo-American vs. Franco-German emergency medical services system.** *Prehospital Disaster Med* 2003, **18:**29-35.
52. Ummenhofer W, Scheidegger D: **Role of the physician in prehospital management of trauma: European perspective.** *Curr Opin Crit Care* 2002, **8:**559-565.
53. American College of Surgeons. Committee on Trauma: *PHTLS: Basic and Advanced Prehospital Trauma Life Support.* Chicago: American College of Surgeons; 2003.
54. American College of Surgeons: *ATLS, Advanced Trauma Life Support.* Chicago, IL: The College; 2004.
55. Cannon W, Fraser J, Cowell E: **The preventive treatment of wound shock.** *JAMA* 1918, 618-621.
56. Bickell WH, Wall MJ Jr, Pepe PE, Martin RR, Ginger VF, Allen MK, Mattox KL: **Immediate versus delayed fluid resuscitation for hypotensive patients with penetrating torso injuries.** *N Engl J Med* 1994, **331:**1105-1109.

57. Burris D, Rhee P, Kaufmann C, Pikoulis E, Austin B, Eror A, DeBraux S, Guzzi L, Leppaniemi A: **Controlled resuscitation for uncontrolled hemorrhagic shock.** *J Trauma* 1999, **46:**216-223.
58. Capone AC, Safar P, Stezoski W, Tisherman S, Peitzman AB: **Improved outcome with fluid restriction in treatment of uncontrolled hemorrhagic shock.** *J Am Coll Surg* 1995, **180:** 49-56.
59. Kowalenko T, Stern S, Dronen S, Wang X: **Improved outcome with hypotensive resuscitation of uncontrolled hemorrhagic shock in a swine model.** *J Trauma* 1992, **33:**349-353.
60. Mapstone J, Roberts I, Evans P: **Fluid resuscitation strategies: a systematic review of animal trials.** *J Trauma* 2003, **55:**571-589.
61. Sondeen JL, Coppes VG, Holcomb JB: **Blood pressure at which rebleeding occurs after resuscitation in swine with aortic injury.** *J Trauma* 2003, **54:**S110-S117.
62. Stern SA: **Low-volume fluid resuscitation for presumed hemorrhagic shock: helpful or harmful?** *Curr Opin Crit Care* 2001, **7:**422-430.
63. Deb S, Martin B, Sun L, Ruff P, Burris D, Rich N, DeBreux S, Austin B, Rhee P: **Resuscitation with lactated Ringer's solution in rats with hemorrhagic shock induces immediate apoptosis.** *J Trauma* 1999, **46:**582-588.
64. Deb S, Sun L, Martin B, Talens E, Burris D, Kaufmann C, Rich N, Rhee P: **Lactated ringer's solution and hetastarch but not plasma resuscitation after rat hemorrhagic shock is associated with immediate lung apoptosis by the up-regulation of the Bax protein.** *J Trauma* 2000, **49:**47-53.
65. Rhee P, Koustova E, Alam HB: **Searching for the optimal resuscitation method: recommendations for the initial fluid resuscitation of combat casualties.** *J Trauma* 2003, **54:**S52-S62.
66. Mattox KL, Maningas PA, Moore EE, Mateer JR, Marx JA, Aprahamian C, Burch JM, Pepe PE: **Prehospital hypertonic saline/dextran infusion for post-traumatic hypotension. The U.S.A. Multicenter Trial.** *Ann Surg* 1991, **213:**482-491.
67. Boldt J: **Fluid choice for resuscitation of the trauma patient: a review of the physiological, pharmacological, and clinical evidence.** *Can J Anaesth* 2004, **51:**500-513.
68. Protheroe R, Nolan J: **Which fluid to give?** *Trauma* 2001, **3:**151-160.
69. Rizoli SB: **Crystalloids and colloids in trauma resuscitation: a brief overview of the current debate.** *J Trauma* 2003, **54:**S82-S88.
70. Whinney RR, Cohn SM, Zacur SJ: **Fluid resuscitation for trauma patients in the 21st century.** *Curr Opin Crit Care* 2000, **6:**395-400.
71. Greenburg AG, Kim HW: **Hemoglobin-based oxygen carriers.** *Crit Care* 2004, **8(Suppl 2):**S61-S64.
72. Proctor KG: **Blood substitutes and experimental models of trauma.** *J Trauma* 2003, **54:**S106-S109.
73. Tisherman SA, Barie P, Bokhari F, Bonadies J, Daley B, Diebel L, Eachempati SR, Kurek S, Luchette F, Carlos PJ, *et al.*: **Clinical practice guideline: endpoints of resuscitation.** *J Trauma* 2004, **57:**898-912.
74. Reed RL, Johnson TD, Hudson JD, Fischer RP: **The disparity between hypothermic coagulopathy and clotting studies.** *J Trauma* 1992, **33:**465-470.
75. Kaufmann CR, Dwyer KM, Crews JD, Dols SJ, Trask AL: **Usefulness of thromboelastography in assessment of trauma patient coagulation.** *J Trauma* 1997, **42:**716-720.