

Decreasing Killed in Action and Died of Wounds Rates in Combat Wounded

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Combat Demographics

From retrospective analysis, the majority of “potentially survivable” injuries resulting in death on the battlefield and after reaching a surgical facility are caused by hemorrhage.^{1–3} In combat, hemorrhage is the cause in 83% to 87% of all such potentially survivable deaths. Of these deaths, approximately 50% are attributed to noncompressible hemorrhage from penetrating truncal injury (Fig. 1).^{2,3}

Therefore, the primary target for making a significant impact on death in combat, both before (killed in action [KIA]) and after reaching a deployed surgical facility (died of wounds [DOW]), is to address noncompressible hemorrhage from penetrating truncal injury.⁴ Because of the potential for prolonged evacuation time during combat operations and the relatively limited options available for treatment of truncal penetrating injury before admission to a surgical facility, the prehospital phase of evacuation offers the greatest opportunity to mitigate the hemorrhagic sequelae of battlefield injury.^{5,6}

Current State-of-the-Art Battlefield and En-Route Care for Penetrating Truncal Trauma Before Arrival at a Surgical Facility

Combat medics are taught the principles of tactical combat casualty care for use on the battlefield.⁷ Current guidelines (February 2009) specify the use of pulse character and mental status (in the absence of traumatic brain injury) to evaluate for shock and then to administer 500 mL of Hextend intravenously if the casualty is in shock. This dosage is to be repeated as needed once in 30 minutes if the patient is still in shock as determined by the aforementioned pulse character and/or mental status. Continued efforts to resuscitate must be weighed against

logistical and tactical considerations and the risk of incurring further casualties. With the goal of minimizing the effect of Hextend and crystalloids on coagulopathy and blood pressure, Hextend is limited to a total of 1 L, and the principle of “hypotensive resuscitation” is recommended. Although the widespread training of medics in tactical combat casualty care has clearly saved lives, the use of saline and colloid starch by medics on the battlefield does not represent a significant technological advance in ability since saline was first used for resuscitation in 1831.

1831

The first mention in the medical literature of the use of intravenous saline for restoration of intravascular volume in hypovolemic cholera patients occurred in 1831 and was reported in *The Lancet* in 1832.^{8–10} In 1831, during the cholera epidemic in Great Britain and a number of European countries, Drs. Thomas Latta and Robert Lewins of London injected a saline solution and titrated the dosing based on the nature and rate of the pulse of hypovolemic cholera patients. Dr Lewins wrote about his experience with one patient:

“The patient’s pulse at the commencement was 180, very small and feeble. She was excessively restless, with a feeling of great weakness and tormenting thirst. Before twelve ounces had been injected, the pulse began to improve; it became fuller and slower, and it continued to improve, until, after 58 ounces had been injected, it was down to 110.”¹⁰

He went on to add, “Verily Sir, this is an astonishing method of medication, and I predict will lead to wonderful changes and improvements in the practice of medicine.” Little did he know that his monitoring techniques and the saline-based resuscitative fluids that he described would be used by medics on the modern battlefield in 2010.

Goals of Battlefield Resuscitation

Because military evacuation of combat wounded can be prolonged as a consequence of enemy activity, geographic barriers, and adverse weather conditions, the time from point of injury to arrival at a surgical facility can vary greatly.^{5,11,12} A long evacuation time will allow for significant hemorrhage in the patient with penetrating truncal trauma.

Currently, a method for mechanically stopping non-compressible truncal hemorrhage before surgical hemostasis is not available and remains in the distant future. The focus in the near term is to improve resuscitative strategies.

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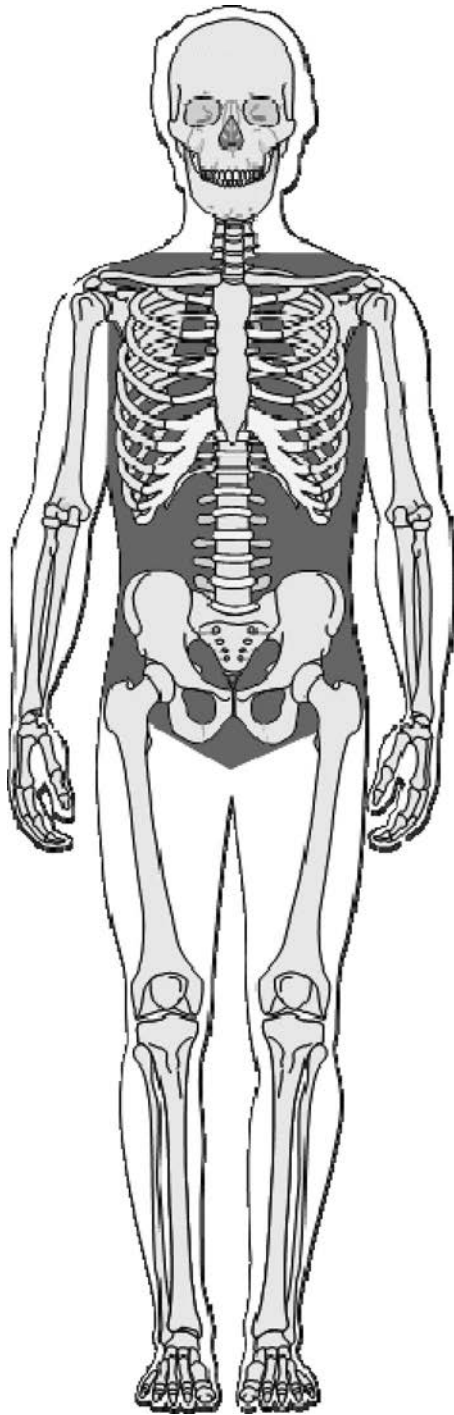


Figure 1. Anatomic area defined as the site of penetrating noncompressible truncal hemorrhage.

The goals of battlefield and en-route resuscitation of penetrating truncal trauma are twofold:

1. Decrease KIA rate: prevent prehospital exsanguination.
2. Decrease DOW rate: decrease physiologic deterioration before admission to a surgical facility.

These goals can be achieved by:

1. Infusing sufficient fluid to provide adequate tissue blood flow and prevent cell death and severe ischemic insult.
2. Minimizing the effects of the acute coagulopathy of trauma to reduce bleeding and further loss of intravascular volume.

New approaches in prehospital combat resuscitation must achieve those goals and maintain viability throughout the evacuation process to prevent death before definitive surgical treatment (KIA) or after initial operation (DOW).

Severe Ischemia Threshold

Although currently undefined, the existence of a threshold for patient survival (severe ischemia threshold) can be extrapolated from the relationship of the progression of shock from the time of admission to the development of the “lethal triad” of acidosis, hypothermia, and coagulopathy, and ultimately mortality in severely wounded patients.^{13–16} Variables documented to be associated with mortality in combat wounded include acidosis (pH [<7.25] and base deficit [<6]), hypothermia ($<36^{\circ}\text{C}$), coagulopathy (international normalized ratio >1.5), tachycardia (heart rate >105 beats/min), hypotension (systolic blood pressure <110 mm Hg), and hematocrit ($<32\%$).^{17–21} These threshold values are most likely dynamic, are a function of time, tissue injury burden, and blood loss, and are closely associated with the acute coagulopathy of trauma.^{19,22,23} This threshold lies between the blood loss associated with near-universal mortality, the so-called irreversible shock that begins with loss of approximately 50% of intravascular blood volume and the blood loss associated with near-universal survival (Fig. 2).²⁴

Fatal Exsanguination Threshold

Uncontrolled blood loss will result in exsanguination in all patients at some point. The percentage of total intravascular volume resulting in irreversible shock is likely to be different for each individual patient but will be within a relatively narrow range of volume loss and begins at approximately 50% loss of intravascular blood volume.²⁴ This

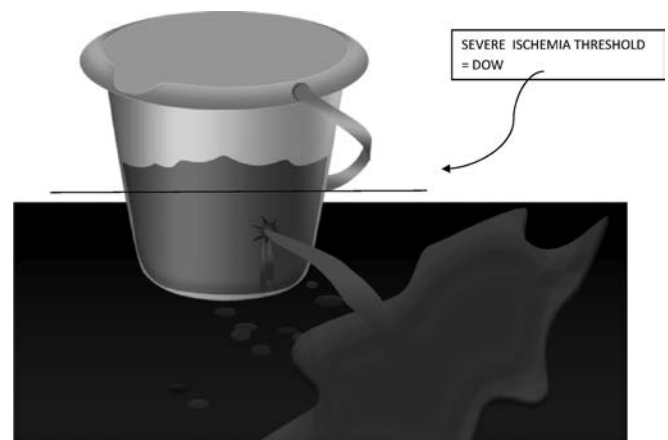


Figure 2. “Leaky bucket” analogy for hemorrhage approaching the severe ischemia threshold.²⁴

threshold represents the prehospital hemorrhage in those wounded in combat who are KIA.

Replacing Intravascular Volume

Replacing intravascular volume with the goal of avoiding exsanguination and the severe ischemia threshold can be achieved theoretically by replacing lost intravascular blood volume above both of these thresholds. Current prehospital resuscitation with Hextend, lactated Ringer's solution, and/or saline solutions will increase the intravascular volume; unfortunately, these fluids also dilute intravascular clotting factors and platelets.^{25–29}

The increased intravascular volume will increase perfusion pressure and, in the face of increasing coagulopathy, will increase the propensity for clot disruption and continued bleeding.³⁰ Currently, continued bleeding will result in administration of more colloid or crystalloid—potentially further exacerbating the coagulopathy. Combat wounded who arrive in a coagulopathic state to a role III deployed surgical facility have a significant risk of death.¹⁹

Optimal Fluid for Replacing Intravascular Blood Loss

Withholding intravenous fluid resuscitation or minimal prehospital use of resuscitation is commonly practiced in civilian Level I trauma centers for penetrating truncal trauma.³¹ Although feasible for an environment with very short evacuation times, the potentially longer evacuation times in combat operations render this concept untenable. These evacuation times may be associated with combat wounded exsanguinations or the development of severe ischemia as a consequence of evacuation time, tissue injury burden, and hemorrhage rate.^{5,6,23} Inhospital resuscitation strategies, however, may offer insight into optimal prehospital resuscitation fluid.

Retrospective analysis of data from combat and civilian trauma patients who received a massive transfusion (>10 units of blood in 24 hours) has been interpreted as showing that these patients may benefit from a high ratio of plasma (clotting factors) and platelets. Based on that assessment, the US Military has adopted the principles of damage control resuscitation (DCR).^{32–38}

The DCR clinical guidelines for resuscitation of combat wounded in hemorrhagic shock requiring a massive transfusion recommend the infusion of fresh frozen plasma: packed red cells: platelets in a 1:1:1 ratio and the minimization of crystalloids and/or synthetic colloids.³⁹ Packed red cells by themselves dilute the other components, including clotting factors and platelets; and young healthy trauma patients can tolerate relatively low hemoglobin levels.^{40–42}

Platelets have a fragile existence, and the challenge of the deleterious effects of hypothermia and acidosis in severe shock may limit the utility of early infusion in the prehospital arena.⁴³ Plasma represents a colloid fluid for intravascular volume replacement, which provides clotting factors to ameliorate coagulopathy.^{27,44,45} Dried plasma, as infused on the battlefield in World War II, offers the best opportunity for evacuation platforms and possible battlefield infusion during prolonged evacuation situations in the near term.^{6,46}

CONCLUSION

Effective methods for the treatment of noncompressible penetrating truncal injury have the greatest potential to impact DOW and KIA rates in current overseas contingency operations. The prehospital arena offers the best opportunity for impact.

Coagulopathy in trauma patients is associated with a higher mortality. The infusion of synthetic colloids and saline solutions may exacerbate trauma-induced coagulopathy. Prehospital plasma infusion may correct or ameliorate the coagulopathy of trauma, and its early use may decrease mortality in combat wounded. Infusion of dried plasma before surgical hemostasis offers the potential of improving life-sustaining perfusion and amelioration of coagulopathy in severely injured combat wounded. Bringing DCR—our best practice in robust surgical facilities where all options are available—as far forward as possible is a logical goal.

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