Prehospital advances in the management of severe penetrating trauma

Robert Mabry, MD; John G. McManus, MD, MCR

Background: **Historic advances in combat prehospital care have been made in the last decade. Unlike other areas of critical care, most of these innovations are not the result of significant improvements in technology, but by conceptual changes in how care is delivered in a tactical setting. The new concept of Tactical Combat Casualty Care has revolutionized the management of combat casualties in the prehospital tactical setting.**

Discussion: **The Tactical Combat Casualty Care concept recognizes the unique epidemiologic and tactical considerations of combat care and that simply extrapolating civilian care concepts to the battlefield are insufficient.**

Summary: **This article examines the most recent and salient advances that have occurred in battlefield prehospital care driven by our ongoing combat experience in the Iraq and Afghanistan and the evolution around the Tactical Combat Casualty Care concept. (Crit Care Med 2008; 36[Suppl.]:S258–S266)**

KEY WORDS: military; prehospital; penetrating trauma; hemorrhage; tactical

Warfare has historically resulted in significant advances in surgery and medicine. Although the present wars in Iraq and Afghanistan are asymmetric and unconventional conflicts, they are no exception. Like previous conflicts, this war presents military physicians and surgeons with tangible, new, and unique problems related to changing tactics, types of weapons, logistics, terrain, and environment. In the past, solutions were conceptualized only years after the war began. As a result, dating back to antiquity, lessons learned were forgotten and until the last 50 years, prehospital care changed very little. For example, Greek and Roman soldiers dressed wounds, applied splints, and moved casualties to the surgeon in a similar fashion as modern military medics. Historically, little attention was paid to prehospital battlefield care. Many believed soldiers were either not able, because of combat actions, or capable, because of their lack of education, to perform significant medical interventions on the battlefield. Physicians or skilled medical providers are rarely present at the point of injury during combat and many young soldiers die for lack of relatively simple life-saving interventions. In the last decade, U.S. military mind-set and doctrine changed resulting in significant advances in prehospital battlefield care. Furthermore, these advances were likely accelerated by necessity, driven by the recent conflicts in Iraq and Afghanistan.

From the Department of Emergency Medicine, Brooke Army Medical Center, Fort Sam Houston, TX.

The opinions or assertions contained here are the private views of the authors and are not to be construed as official or as reflecting the views of the Department of the Army or the Department of Defense.

The authors have not disclosed any potential conflicts of interest.

For information regarding this article, E-mail: robert.mabry@amedd.army.mil

DOI: 10.1097/CCM.0b013e31817da674

Recent innovations in tourniquets, hemostatic agents, and intravenous fluid (IV) resuscitation strategies, many of which are mainstays of current prehospital penetrating trauma resuscitation and treatment, have been around for decades. These advances do not represent quantum leaps in technology, but rather improvements of existing techniques and devices when combined with application of Tactical Combat Casualty Care (TCCC) principles. The most significant change is the current conceptualization of care on today's battlefield. Previously, military prehospital care principles were simply extrapolated from improvements in civilian trauma care developed in the last two decades. Unfortunately, those resuscitation and treatment principles are based to a large degree on blunt vehicular trauma and civilian trauma systems, which are inherently different from the battlefield environment.

Civilian prehospital trauma care presupposes adequate medical supplies, usually based around an ambulance, online and offline medical control, adequate number of providers, a stable and secure accident scene, and relatively rapid evacuation to a nearby hospital. These factors are all inverted on the battlefield where a single medic with limited supplies may be required to care for numerous casualties in a hostile or austere environment. For civilian providers, the casualty is the mission. For the military medic, the mission must often continue despite casualties. Unfortunately, many of these concepts are now applicable in certain civilian prehospital healthcare environments that become "austere" and/or tactical. Recent events such as the World Trade Center bombings and Hurricane Katrina have demonstrated the need for many of our out-of-hospital healthcare personnel to use some of the current military prehospital medical strategies. Finally, with the increased threat of possible terrorist bombings occurring on U.S. soil, civilian prehospital healthcare providers should be prepared to manage severe penetrating and explosive-related injuries.

The inadequacy of the civilian trauma model for application in tactical situations was recognized by Butler and Hagmann in their landmark 1996 paper (1). Since their publication, the concept of TCCC has been defined and now applied on today's battlefield (2–7). TCCC is a set of principles that aim to prevent further casualties, accomplish the tactical mission, save the maximum number of lives, and minimize morbidity of the injured. The TCCC guidelines are based on treating the leading preventable causes of battlefield death, which include hemorrhage from a compressible site, tension pneumothorax, and airway compromise (8, 9). In the most recent TCCC guidelines, attention to hypothermia prevention, intravenous access, and pain management techniques are now also addressed. Detailed discussion of all TCCC principles as well as the in-depth management of explosive and penetrating injuries is beyond the scope of this article. However, we discuss the most salient and recent innovations in the prehospital treatment of penetrating trauma that have evolved within and around the concept of TCCC.

Hemorrhage Control

Uncontrolled hemorrhage resulting from traumatic injuries continues to be the leading preventable cause of death in both the civilian and current military environments, accounting for up to 40% of civilian and 50% of combat-related deaths (9–11). Uncontrolled extremity or otherwise compressible hemorrhage remains the leading cause of preventable battlefield death; between 7% and 9% of all fatalities since the Korean conflict have occurred from wounds potentially amenable to first aid (9). It is natural therefore that most of the advances in the prehospital management of penetrating trauma have been made in the area of hemorrhage control. During the current conflict, newer tourniquets, hemostatic agents, and dressings as well as intravenous therapies have been developed, researched, and fielded by the military with unprecedented speed.

Tourniquets. Tourniquets have been used on the battlefield since 1674 (12). Controversy and debate about the appropriateness and circumstances of tourniquet use began soon after and has continued today (13–15). Despite many strong opinions against tourniquet use, this simple device is carried by every solider on today's battlefield and is used frequently. Although exact statistics are lacking, there is ample anecdotal evidence from physicians, surgeons, and medics with recent combat experience that many lives have been saved by liberal use of properly applied tourniquets on the battlefield. One of the authors (RM) managed a casualty in Afghanistan who had his life saved twice on the same day by a tourniquet. The solider sustained an injury to his superficial femoral artery after a rocket attack. A fellow soldier rapidly applied a tourniquet and stopped the hemorrhage. The patient remained alert and stable and was evacuated to a Field Surgical Team where he had his vessel repaired. During the 2-hr flight to a combat support hospital (CSH), his injury began to rebleed profusely and the patient developed hemorrhagic shock. A second tourniquet was applied to stop the bleeding, allowing him to receive definitive surgical therapy.

One major concern from physician detractors includes the concern for severe ischemic or neurologic injury from the use of tourniquets. Several recent case series and case reports demonstrate no evidence that tourniquet use on the battlefield resulted in increased limb loss or permanent disability even among those who had unneeded tourniquets applied (16–18). One case series reporting on tourniquet use during the Vietnam conflict detailed one case of limb loss secondary to tourniquet use out of thousands of casualties with vascular injuries. In these cases, fasciotomies were occasionally required when tourniquet time exceeded 2 hrs (19). Most of the tourniquets used in this report were improvised with rubber tubing, rifle slings, belts, and so on, and not commercially fabricated as they are today (Figs. 1 and 2). During that period, the Army issue strap-and-buckle tourniquets (NSN 6515-00-383-0565) were still used despite criticism regarding their ineffectiveness as early as World War II (20). Not surprisingly, improvised tourniquets are either ineffective and/or produce tissue injury by themselves. Rubber surgical tubing, for instance, generates a significant amount of pressure that is difficult to regulate (14). Improvised tourniquets are not recommended and should be used with extreme caution.

Interestingly, other statistics or case series regarding tourniquet use during the Vietnam conflict are unavailable except a report by Bellamy who documented 5,000 fatal injures that may have been amenable to tourniquets (8). Much of the derision over tourniquet use derives from surgeons in previous conflicts who have anecdotally witnessed casualties that lost a limb or experienced significant neurovascular injury as a result of prolonged application of an improvised tourniquet. However, these same surgeons did not see the casualties who never reached their care because they bled to death for want of a tourniquet. The current TCCC recommendation is for liberal use of tourniquets for uncontrolled extremity hemorrhage in the tactical environment.

Figure 1. Combat application tourniquet. Photograph courtesy of North American Rescue Products, Greenville, SC.

Figure 2. Combat application tourniquet in place. Photograph courtesy of North American Rescue Products, Greenville, SC.

Hemostatic Agents. A number of new hemostatic products have been developed and used in combat trauma settings for severe uncontrolled bleeding in the prehospital setting. In the past few years, tremendous advances have been made in the development of advanced hemostatic products for use in uncontrolled external hemorrhage on the battlefield. Current research and fielding of these agents has generated a great deal of excitement within the field of military combat casualty care. There is growing interest in the civilian trauma community, because these products hold the promise of saving lives both in civilian and military situations (20–23). Some of these U.S. Food and Drug Administration (FDA)-approved hemostatic products have been successfully used in current combat operations after evaluation in randomized animal studies.

Although several different hemostatic agents (Table 1) have been studied and/or are commercially available, our clinical experience demonstrates that not all are effective in severe hemorrhage. Moreover, several products are not FDA-approved and/or have not been thor-

Table 1. Hemostatic agents

Name	Company	Active Ingredient	Mechanism of Action	Approved Indication for Use
Dry Fibrin Sealant Dressing (DFSD)	American Red Cross, Holland Laboratory, Rockville, MD	Fibrinogen, thrombin, factor XIII, Ca^{+2}	Direct application of highly concentrated coagulation factors to site of injury; polymerization and cross-linking of fibrin	Not FDA-approved
Rapid Deployment Hemostat (RDH)	Marine Polymer Technologies, Danvers, MA	Proprietary algae-derived polysaccharide polymer, consisting of fully acetylated poly-*N*-acetyl-glucosamine (chitin)	Accelerates the concentration of red blood cells, clotting factors, and platelets at the bleeding site; induces vasospasm	External hemorrhage
Chitosan Dressing (HC)	HemCon, Inc., Tigard, OR	Polysaccharide polymer, consisting of deacetylated poly-*N*-acetyl-glucosamine (chitosan)	Adheres to tissue strongly, sealing wound site; may secondarily accelerate the concentration of red blood cells and platelets at the bleeding site	External hemorrhage
ChitoFlex	HemCon, Inc., Tigard, OR	Polysaccharide polymer, consisting of deacetylated poly-*N*-acetyl-glucosamine (chitosan)	Adheres to tissue strongly, sealing wound site; may secondarily accelerate the concentration of red blood cells and platelets at the bleeding site	External hemorrhage
QuikClot (QC)	Z-Medica, Newington, CT	Granular zeolite	Adsorbs water, concentrating red blood cells, clotting factors, and platelets at the bleeding site in an exothermic reaction	External hemorrhage

FDA, Food and Drug Administration.

oughly studied in human trials. Currently, three agents are used in ongoing military operations: QuikClot (Z-Medica, Wallingford, CT), HemCon Bandage (HemCon, Tigard, OR), and ChitoFlex (HemCon).

The HemCon (HC) bandage is an FDA-approved hemostatic agent that is currently used in combat and in a limited portion of the civilian prehospital environment for the external control of severely bleeding wounds. The HC dressing has previously demonstrated efficacy in both human (24) and animal studies (25, 26). Chitosan is a biodegradable, nontoxic, complex carbohydrate derived from chitin (poly β[1 to 4]-N-acetyl D-glucosamine), a naturally occurring substance. Chitosan is the deacetylated form of chitin. The generic term chitosan generally is applied when the extent of deacetylation is above 70% and the generic term chitin is used when the extent of deacetylation is insignificant or below 20%. In the form of an acid salt, chitosan demonstrates mucoadhesive activity (27). Different forms of chitosan have been used to enhance hemostasis in animal studies involving bleeding from esophageal varices, arterial catheter puncture sites, peritoneal abrasions, or similar experimental insults (28, 29). Initial distribution to the military included forward-deployed medics followed by a more general distribution to physicians and physician assistants located in both Iraq and Afghanistan as more bandages became available. Over 600,000 bandages have now been distributed into combat operations in Iraq and Afghanistan. The use of this bandage is a standard component of the Prehospital Trauma Life Support military section and is taught to all Special Operations Forces and conventional Army medics in their respective

Figure 3. Hemcon or chitosan dressing. Photographs courtesy of North American Rescue Products, Greenville, SC.

training schools. One report cites the HC bandage as successfully controlling hemorrhage in 97% of uses. This report has numerous methodologic flaws, is retrospective in nature, and includes uses of the dressing in minor injuries (24). The U.S. Army currently supplies an HC bandage (Fig. 3) to every deployed soldier, three for every Combat Life Saver, and five to every medic in the combat theater. These bandages now join the tourniquets carried by all soldiers as the individual- and medic-carried hemostatic devices of choice for severe combat injuries in the U.S. Army. Unlike other products, there are no known harmful effects associated with use of this dressing.

QuikClot (QC) is an FDA-approved hemostatic agent consisting of a granular zeolite powder with 1% residual moisture that, when placed on a bleeding wound, absorbs water in an exothermic reaction, thereby concentrating platelets, erythrocytes, and clotting factors at the site of application (20). QC is stable in ambient temperature extremes and does not require special packaging or preparation before use. In one swine study of lethal grade V liver injury, QC was found to be effective (30) as well as in both femoral arterial and venous injury (31). QC was found to decrease both blood loss and the time to hemostasis in nonlethal wounds of skeletal muscle, liver, and the femoral vein, although this was not found in longitudinal wounds of the femoral artery. QC has been included within the newly redesigned Marine Corps individual first aid kit, and there are a number of anecdotal case reports from U.S. Naval medical personnel of successful use in injured troops in Iraq and Afghanistan (31).

One major concern about QC is the potential for surrounding tissue damage caused by the exothermic reaction (32). Another important issue includes the extent of training necessary to use the product effectively and safely (33). The company recently modified QC to decrease the exothermic reaction.

More recently, a more flexible chitosan-based bandage was FDA-approved, the ChitoFlex (CF). The CF bandage uses the same materials and technology as the HC bandage but is designed to be packed into a wound track to control bleeding. This bandage may be especially helpful to control severe bleeding from small penetrating injuries such as those resulting from small arms fire or shrapnel that cannot be addressed by other means. Successful use of the CF bandage is documented by military medical personnel in the prehospital and the Level III (CSH) facility in Operation Iraqi Freedom.

The ideal prehospital hemostatic agent would require little training; be nonperishable, durable, flexible, and inexpensive; adhere to the wound only; pose no direct risk of disease; not induce a tissue reaction; and effectively control hemorrhage from arterial, venous, and soft tissue bleeding. Obviously, no single ideal advanced hemostatic agent currently meets all of these criteria for either military or civilian use. However, most of the current FDA-approved hemostatic agents appear to be safe with the exception of the exothermic reaction induced by the original QC product, although thermal tissue damage depends on the ratio of QC and blood at the site of injury. Currently, many of these hemostatic agents are used for uncontrolled hemorrhage on today's battlefield and have contributed to reduced morbidity and mortality in penetrating combat trauma.

Hemostatic Intravenous Agents. Active research to optimize prehospital hemorrhagic control in the combat prehospital environment in the future focuses on the use of IV hemostatic agents. Recombinant Factor VII activated (fVIIa), for example, has been used on hundreds of casualties dying from hemorrhagic shock and requiring massive transfusion. In one CSH, fVIIa was associated with improved coagulopathy, decreased blood requirements, and a trend toward improvement in mortality. As a result of the retrospective nature of these data and the confounding factors associated with the treatment of these patients in the combat zone, definitive recommendations regarding its use cannot be made. The appropriate indications for use are still being evaluated but in selected combat prehospital settings, and a prospective multicenter study is ongoing to evaluate the efficacy and safety of fVIIa in trauma patients (34).

Intravenous Access and Fluid Resuscitation

Before the development of the TCCC concept, battlefield medics were trained to follow the American College of Surgeons' Advanced Trauma Life Support guidelines, including the insertion of large-bore IV catheters and infusion of 2 L or more crystalloid fluid. Although this practice may be appropriate in the hospital setting, Bickell demonstrated that patients with penetrating trauma to the torso given IV fluid resuscitation in the field had increased mortality than those not given IV fluids in the field (35). The rationale for the mortality differences seen in these patients with uncontrolled sources of hemorrhage includes subsequent vasodilation, increased arterial pressure, and dilution of clotting factors with liberal administration of crystalloid resuscitation, which worsens bleeding through injured vessels (36).

Before Operation Iraqi Freedom/ Operation Enduring Freedom, medics carried as much as 30 pounds of crystalloid IV fluids to the field. Often, individual soldiers carried an IV infusion set and 1-L bag of fluid weighing more than 2 pounds each. In the past, military units placed significant training emphasis on soldiers' ability to obtain IV access. This skill, likely because of its technical and invasive nature, is unfortunately regarded as "great medical training" by many soldiers and commanders alike, often to the detriment of more mundane yet more important skills such as hemorrhage control and tourniquet application. In 1993, one of the authors (RM) placed IVs in several casualties while under fire during a battle in Mogadishu, Somalia. He carried 6 L of crystalloid, weighing 13 pounds, starting IVs in all casualties with gunshot wounds. Soon there were more than a dozen casualties with only one losing a significant amount of blood and showing clinical signs of shock from a gunshot would to the leg. By this time, his IV fluids were depleted. In hindsight, working to place IV lines in mostly stable combat casualties while under enemy fire was a foolish waste of time.

The current recommendations for IV resuscitation on the battlefield focus only on those patients with signs of hemorrhagic shock. The best indicators of hemorrhagic shock on the battlefield are altered mental status in absence of head injury and a weak or absent radial pulse. Because the majority of combat casualties present with nonlife-threatening penetrating extremity injuries, the number of casualties actually requiring IV fluids in the field is few. Current TCCC guidelines recommend an infusion of 500-mL bolus of Hextend (BioTime, Inc., Berkeley, CA) with a repeat bolus in 30 mins only if shock is still present. Further fluid administration is not likely to be of benefit and is not advised, the exception being the head-injured patient in whom additional fluids may be of benefit in preventing secondary brain injury from hypotension defined as systolic blood pressure <90 mm Hg.

Hextend, a synthetic colloid, is currently recommended over crystalloid solutions. Hextend remains in the intravascular space longer resulting is improved volume resuscitation and less fluid requirements overall. These factors are critical when supplies must be carried in the medic's pack. Future battlefield resuscitation strategies may include hypertonic saline or combinations of hypertonic solutions and colloids (37). A growing scientific literature supports limited volume resuscitation. The degree of sustainable hypotension is contentiously debated among experts.

IV access methods have evolved to fit the tactical setting as well. TCCC focuses on placement of IVs and IV therapy in only patients displaying clinical signs of shock. Not uncommonly, these patients demonstrate significant vasoconstriction making placement of a peripheral IV difficult. As a result, medics are now trained to obtain intraosseous (IO) access for fluid administration. Current TCCC recommendations list the Pyng FAST-1 sternal IO (Richmond, British Columbia, Canada) as the device best suited for trauma care on the battlefield (38–40). IO devices that have been used extensively in pediatrics have been previously thought to be difficult to use in adults because of ossification. Contrary to this popular belief, we have used IO devices in thousands of combat-related injuries on adults with great success both in the sternum/clavicle as well as the tibia. Large volumes of resuscitative fluids as well as medications can be safely and effectively administered IO.

Chest Wounds

Tension pneumothorax represents the second leading cause of potentially preventable battlefield death resulting in 3% to 4% of all fatal injuries (41, 42). McPherson and colleagues studied radiologic and autopsy examinations of 978 fatalities from the Vietnam conflict (41) and discovered that 15 of the casualties with identified tension pneumothorax lived long enough to be treated by a medic. Unfortunately, none underwent needle decompression and all died.

Insertion of a needle into the chest wall to relieve a tension pneumothorax is a controversial procedure in the civilian trauma setting with some prominent trauma physicians strongly recommending against it (42). The true incidence of this injury is unknown in the civilian setting, although its occurrence is rare and an evidence-based trial to determine whether patients benefit or do worse from needle decompression is not feasible.

Tension pneumothorax is likely more prevalent in the military setting in which penetrating injuries predominate. The exact incidence in the current conflict is unknown and efforts are underway to replicate McPherson's study with Iraq and Afghanistan casualty data. It is likely that the universal prevalence of body armor worn by all U.S. combatants has decreased the incidence below that in Vietnam. However, until new data are available, tension pneumothorax must be assumed to remain the second leading cause of preventable battlefield death.

Currently, TCCC guidelines recommend consideration of needle decompression in casualties with chest trauma and progressing respiratory distress (26). Recent radiologic studies done by Harke et al. showed the mean chest wall thickness of most deployed soldiers is 5.36 cm. Based on his findings, an 8-cm angiocatheter is recommended for needle decompression (43).

Airway Management

Airway compromise is the third leading cause of potentially preventable battlefield death (8). Although the incidence in the conflicts in Iraq and Afghanistan is unknown and is currently being studied, historically, airway compromise is responsible for approximately 1% of fatal injuries on the battlefield. According to Bellamy's analysis from the Vietnam era, approximately 80% of these injuries are the result of facial or neck trauma causing obstruction and compromise of the airway (8).

Given the high incidence of trauma as a cause of airway obstruction, cricothyroidotomy is currently emphasized as definitive airway management on the battlefield. In unconscious patients with intact upper airway anatomy at risk for airway compromise, the recovery position and minimally invasive adjuncts such as the nasal pharyngeal and the oral pharyngeal airway are emphasized (21).

The emphasis placed on cricothyroidotomy as the definitive airway management maneuver of choice by enlisted field medics causes many hospital-based physicians some anxiety. It has been suggested by some that medics perform endotracheal intubation or use other adjuncts such as the laryngeal mask airway, the Combitube (Tyco-Kendall, Mansfield, MA), or the King Laryngeal Tube (King Systems, Noblesville, IN) airway. Endotracheal intubation is not emphasized because it requires significant training and experience to correctly perform. Recent research in the civilian prehospital setting has documented some significant complications arising from rapid sequence intubation performed in the field by trained paramedics in busy urban trauma systems. The practice of rapid sequence intubation by medics in the field is being challenged by some researchers (44, 45). As a result, enlisted medics are not trained in the performance of rapid sequence induction. This is a specialized skill requiring a significant amount of training not only in performing the motor skills of inserting an endotracheal tube, but also in understanding the pharmacology of the requisite sedating and paralyzing drugs. The initial training requirements as well as sustainment training of this skill for all military medics are simply not feasible. Additionally, the white light required for laryngoscopy may draw enemy fire on the battlefield. Furthermore, based on the best available data, the majority of patients who need airway management will likely have disrupted upper airway anatomy and will require a cricothyroidotomy anyway. Adjuncts such as the laryngeal mask airway and Combitube will also require sedation to be tolerated and may be difficult to place if the anatomy is disrupted as a result of trauma. This is an area of continued research and evolution.

Hypothermia Management

Hypothermia has been well recognized as an independent contributing factor for increased morbidity and mortality in trauma patients. Previous studies demonstrate that hypothermia is associated with increases in coagulopathy, multiple organ failure, length of hospital stay, and mortality (46, 47). In the care of the patient with traumatic injuries, focus has been placed on prevention and correction of hypothermia, especially in the prehospital setting. Hypothermia occurs in trauma patients for several reasons, including prolonged prehospital times, cold fluid administration, environmental factors affecting patients' core temperature, and the trauma in itself, which causes bleeding and hypoperfusion, both altering the body's thermoregulation with resultant hypothermia.

TCCC emphasizes prevention of hypothermia (<34°C) in patients with penetrating trauma. Attention to hypothermia prevention decreases the deleterious effects of heat loss and decreases deaths from uncontrolled hemorrhage and is much easier than treatment of hypothermia. Therefore, prevention of heat loss should start as soon as possible after wounding. This will be optimally accomplished in a layered fashion with rugged, durable products located at close to the point of injury. Several techniques are being used in the current conflict, including the improvised "hot pocket" whereby a casualty is wrapped in successive layers of wool blankets, a reflective survival blanket, and placed in a modified body bag. North American Rescue Products (Greenville, SC) markets a hypothermia prevention kit, which includes a high-performance, heat-reflective shell that is self-heating and allows 360° access to the patient. Several other devices are currently being tested and fielded in the combat prehospital setting for hypothermia prevention (Table 2).

Table 2. Hypothermia prevention devices

Blizzard Rescue Blanket
TechTrade "Ready-Heat" Blanket
Space Blanket
Thermal Angel
Chill Buster
Belmont FMS 2000

Triage and Advanced Vital Signs

It has been hypothesized that some trauma deaths may be preventable if the severity of blood loss could be recognized earlier during prehospital medical care. Current trauma triage criteria are used to determine the patient's mode of transport, the priority of treatment, destination for treatment, injury severity, mortality, and need for a lifesaving intervention (LSI) (48–57). However, most of these existing triage tools are based in part on the presence of abnormal standard vital signs in the patient (58, 59).

Common vital signs are used in the civilian prehospital setting because these measurements are usually readily obtainable and it is assumed that they provide a snapshot of patient stability. However, such an assumption is problematic because the physiology of the trauma patient experiencing severe hemorrhage is dynamic and may not reflect the true degree of hypoperfusion present as a result of normal physiological compensatory mechanisms. Initial systolic blood pressure less than 90 mm Hg and a Glasgow Coma Score motor component less than 6 has previously been shown to provide higher sensitivity and better specificity for prediction of mortality and the need for a possible LSI than most traditional vital signs (respiratory rate, heart rate, and so on) (58). More sensitive markers of acute hypoperfusion are required to identify hemorrhage and circulatory shock at the earliest time to improve resuscitation outcomes. Unfortunately, vital signs are not very sensitive because studies demonstrate that young patients can lose up to 60% of total circulating blood volume and remain relatively asymptomatic (60). Therefore, determining the injury status in patients with normal vital signs is a critical step for the improvement of current field classification systems and development of triage decisions. Thus, the current process and practice of prehospital trauma triage and care may be significantly improved by providing additional advanced, noninvasive physiological measurements of early indicators for blood volume loss and impending circulatory collapse.

In an attempt to provide new possibilities for more efficient algorithms that may assist in determination of treatment and evacuation priorities for patients with unrecognized hypovolemia, new and more accurate noninvasive indicators of the underlying physiological status in trauma patients who possess initial normal systolic blood pressure and Glasgow Coma Score motor component have been investigated and implemented in current combat operations. Some of these earlier and possibly more reliable indicators of hypovolemia include derived physiological variables (that is, shock index, pulse pressure, field trauma score) (61–63) and continuous "real-time" variables (electrocardiographic R-wave amplitude, heart rate variability) (64, 65).

Transportation and Monitoring

Currently, the care for combat casualties in transport is varied depending on location, type of transportation used, tactical situation, and location of receiving facility. Military capabilities for care of casualties during transport differ from civilian capabilities in three fundamental ways: a) combat medical personnel who accompany the casualty during transport may not have advanced medical training compared with civilian emergency medical system medics; b) combat flight medics must perform their role as warfighters to assure crew and aircraft safety in a hostile environment; and c) the availability of resources such as monitors, oxygen, and resuscitation fluids are restricted as a result of weight and space limitations in the combat environment. Furthermore, for combat casualty transportation, there exists a wide variety of transportation platforms ranging from improvised litters to mobile intensive care units. Preplanned surface evacuation vehicles are usually ground ambulances, but potentially could be watercraft in some scenarios. Preplanned air evacuation from tactical settings is most often accomplished by helicopter, but airplanes may be required for longer distances. Vehicles of convenience can be used when absolutely vital, but this necessity usually represents a failure of premission contingency planning.

Because of these vast differences in transport medical vehicles and personnel capabilities, the TCCC program has focused on developing monitors that use advanced development of a semiautomated decision support capability for closed-loop resuscitation and oxygen delivery (66, 67). The use of such "closed systems" may provide advanced decision support and treatment protocols to aid in decreasing morbidity and mortality in combat trauma patients. Current systems use standard vital signs (for example, blood pressure, arterial oxygen saturation) but, as previously discussed, are unfortunately inadequate for early detection implementation of LSI for patients in early shock. Thus, recent research has focused on the use of metrics and advance physiological variables that may be more specific for detecting early shock (62–67).

Analgesia

Pain is one of the most common reasons soldiers seek medical attention in the combat environment. However, the combat environment exacerbates the typical challenges found in treating acute pain, including lack of supplies and equipment, delayed or prolonged evacuation time and distances, devastating injuries, provider inexperience, and dangerous tactical situations. These factors contribute to the difficulty in controlling a soldier's pain in combat. Previous studies have shown that failure to recognize and appropriately treat acute pain may result in an increased incidence of chronic pain and posttraumatic stress disorder (47, 68). Because of this, there have been several developments in prehospital combat analgesia for the recognition, treatment, education, and research for battlefield pain management.

In previous conflicts, the main treatment for acutely wounded soldiers in the prehospital setting of the battlefield was morphine, usually delivered by the intramuscular route. However, on today's battlefield, IV morphine is emphasized for combat casualties requiring analgesia. As discussed previously, improved IV access training and newer IO devices have improved access and delivery of analgesia. Furthermore, many medics now carry promethazine to relieve nausea associated with pain and narcotic administration. In addition to improved delivery and titration of narcotics for combat pain, most special operation forces in the prehospital, combat environment carry a "pill pack." This pack contains a cyclooxygenase-2 (COX-2) preferential inhibitor, meloxicam, and acetaminophen to be self-administered by the individual soldier who sustains a painful injury. The use of preferential COX-2 inhibitors instead of nonspecific nonsteroidal anti-inflammatory drugs for moderate pain on the battlefield is because nonsteroidal anti-inflammatory drugs have the potential for platelet dysfunction (69). Meloxicam does not appear to have this effect (70). An earlier iteration of the pill pack contained the selective COX-2 inhibitor rofecoxib, which was replaced with meloxicam after concerns arose regarding rofecoxib. The combination of these oral medications is synergistic, provides multimodal analgesia, is opioid-sparing, and does not prevent the soldier from carrying his or her weapon.

Finally, other newer agents and routes of delivery are currently being used on the battlefield to treat analgesia. Oral transmucosal fentanyl citrate has been found to relieve moderate to severe pain on the battlefield and is currently carried by many special forces medics. An initial dose of 400 μg is used, which typically causes peak plasma concentrations of no greater than 2 ng/mL; this plasma concentration is associated with a marked increase in the risk of respiratory depression. Oral transmucosal fentanyl citrate has a black box warning and its use is off-label for the treatment of acute pain in opioid-naïve patients (71). Because it reaches maximum serum levels after approximately 30 mins, redosing may start 15 mins after the previous unit has been completed (30 mins after the start of the previous unit). It is important to note that although the median time to peak plasma concentration for 400 μg was 25 mins, time to peak plasma concentration demonstrated a wide range (20–240 mins) (71).

Ketamine has also been used successfully as a prehospital analgesic in the combat setting (72). Ketamine in subanesthetic doses is an almost ideal analgesic because of its profound pain relief, its potentiation of opioids, its role in preventing opioid hyperanalgesia, and its large margin of safety (73–75).

Education, training, and performance of peripheral nerve blocks are also now being used in the prehospital combat environment, especially for extremity injuries (72). More difficult techniques like catheters and advanced blocks are not done in this setting as a result of limitations in equipment and training. However, local wound infiltration or basic blocks such as fascia iliacus, intercostal, or suprascapular placed before transport can provide profound analgesia (76, 77). These blocks also afford a very low risk–benefit ratio. Use of regional anesthesia is an important technique for combat casualties. When performed in the prehospital setting on the battlefield, limited regional anesthesia techniques carry little risk such as changes in respiratory or mental status and allow the soldier to possibly perform some minimal duty while awaiting evacuation. More advanced techniques such as the suprascapular or interscalene block can be associated with diaphragm dysfunction and higher incidences of inadvertent intraarterial injection or pneumothorax.

Training and Education

Proper training and education is also a challenge for military prehospital providers. To ensure the discussed initiatives are appropriately trained and retained, newer methods to educate and train prehospital providers have been adapted. The use of scenario-based, "real-time" training, simulators, and live tissue training have all been incorporated with success (78). This type of training focuses on "evidence-based" epidemiology from the current battlefield collected by the Joint Theater Trauma System (79). Use of such "real-time" epidemiology and feedback could help guide future education training and equipment for prehospital trauma.

CONCLUSION

Improved medical training and education and technologic advances have resulted in the lowest mortality seen in U.S. history. Even in this new global era, some readers may wonder why and how combat casualty care is important to them and their patients. The reasons become readily apparent when examining the parallels between combat settings and other austere or hostile environments such as tactical emergency medical support for law enforcement, wilderness, and disaster medicine and in coping with the effects of weapons of mass destruction. The lessons of Vietnam and the development of trauma systems, the "golden hour," and air medical services provide additional reminders of the mutual benefits gained by military and civilian practice from previous conflicts. The role of combat prehospital medical care continues to be diverse, conflicting, and disquieting at times yet remains a pioneering and crucial part of modern medicine and national defense.

REFERENCES

1. Butler FK Jr, Hagmann J, Butler EG: Tactical combat casualty care in special operations. *Mil Med* 1996; 161(Suppl):3–16
2. Butler F. Tactical combat casualty care: combining good medicine with good tactics [Editorial]. *J Trauma* 2003; 54(Suppl):S2–3
3. Butler FK: Tactical medicine training for SEAL mission commanders. *Mil Med* 2001; 166:625–631
4. Butler FK, Greydanus D, Holcomb J: Combat Evaluation of TCCC Techniques and Equipment: 2005. USAISR Report 2006-01, November 2006
5. Butler FK, Holcomb JB: The Tactical Combat Casualty Care transition initiative. U.S. Army Medical Department Journal. April–June 2005
6. Butler FK, Hagmann J, eds: Tactical management of urban warfare casualties in special operations. *Mil Med* 2000; 165(Suppl):1–48
7. Butler FK, Holcomb JB, Giebner SD, et al: Tactical Combat Casualty Care 2007: evolving concepts and battlefield experience. US

Army Institute of Surgical Research Technical Report. March 30, 2007
8. Bellamy RF: The cause of death in conventional land warfare: Implications for combat casualty care reaserch. *Mil Med* 1984; 149: 55–62
9. Holcomb JB, McMullin NR, Pearse L, et al: Causes of death in U.S. Special Operations Forces in the global war on terrorism: 2001–2004. *Ann Surg* 2007; 245:986–991
10. Sauaia A, Moore FA, Moore EE, et al: Epidemiology of trauma deaths: A reassessment. *J Trauma* 1995; 38:185–193
11. Maughon JS: An inquiry into the nature of wounds resulting in killed in action in Vietnam. *Mil Med* 1970; 135:8–13
12. Schwartz AM: The historical development of methods of hemostasis. *Surgery* 1958; 44: 604–610
13. Navein J, Coupland R, Dunn R: The tourniquet controversy. *J Trauma* 2003; 54: S219–S220
14. Walters TJ, Mabry RL: Issues related to the use of tourniquets on the battlefield. *Mil Med* 2005; 170:770–775
15. Mabry RL: Tourniquet use on the battlefield. *Mil Med* 2006; 171:352–356
16. Mabry RL, Holcomb JB, Baker AM, et al: United States Army Rangers in Somalia: an analysis of combat casualties on an urban battlefield. *J Trauma* 2000; 49:515–529
17. Lakstein D, Blumenfeld A, Sokolov T, et al: Tourniquets for hemorrhage control on the battlefield: A 4-year accumulated experience. *J Trauma* 2003; 54:S221–S225
18. Wolff L, Adkins T: Tourniquet problems in war injuries. *Bull US Army Med Dep* 1945; 87:77–84
19. Welling D, Burris J, Hutton S, et al: A balanced approach to tourniquet use: Lessons learned and relearned. *J Am Coll Surg* 2006; 203:1:106–115
20. Alam HB, Burris D, DaCorta JA, et al: Hemorrhage control in the battlefield: Role of new hemostatic agents. *Mil Med* 2005; 170:63
21. Holcomb JB: Methods for improved hemorrhage control. *Crit Care* 2004; 8(Suppl 2): S57–60
22. Robinson K: Controlling bleeding in the field: Hemostatic powders and dressings debut in the prehospital setting. *J Emerg Nurs* 2004; 30:160–161
23. Neuffer MC, McDivitt J, Rose D, et al: Hemostatic dressings for the first responder: A review. *Mil Med* 2004; 169:716–720
24. Wedmore I, McManus J, Pusateri A, et al: The chitosan-based hemostatic dressing: Experience in current combat operations, a retrospective review. *J Trauma* 2006; 60:655–658
25. Kheirabadi BS, Acheson EM, Deguzman R, et al: Hemostatic efficacy of two advanced dressings in an aortic hemorrhage model in Swine. *J Trauma* 2005; 59:25–34, discussion 34–35
26. Pusateri AE, McCarthy SJ, Gregory KW, et al: Effect of a chitosan-based hemostatic dressing on blood loss and survival in a model of severe venous hemorrhage and hepatic injury in swine. *J Trauma* 2003; 54:177–182
27. Evans EE, Kent SP: The use of basic polysaccharides in histochemistry and cytochemistry: IV. Precipitation and agglutination of biological materials by aspergillus polysaccharide and deacetylated chitin. *J Histochem Cytochem* 1962; 10:24–28
28. Fukasawa M, Abe H, Masaoka T, et al: The hemostatic effect of deacetylated chitin membrane on peritoneal injury in rabbit model. *Surg Today* 1992; 22:333–338
29. Klokkevold PR, Fukayama H, Sung EC, et al: The effect of chitosan (poly-N-acetyl glucosamine) on lingual hemostasis in heparinized rabbits. *J Oral Maxillofac Surg* 1999; 57:49–52
30. Pusateri AE, Delgado AV, Dick EJ Jr, et al: Application of a granular mineral-based hemostatic agent (QuikClot) to reduce blood loss after grade V liver injury in swine. *J Trauma* 2004; 57:555–562; discussion 562
31. Alam HB, Chen Z, Jaskille A, et al: Application of a zeolite hemostatic agent achieves 100% survival in a lethal model of complex groin injury in swine. *J Trauma* 2004; 56: 974–983
32. McManus J, Hurtado T, Pusateri A, et al: A case series describing thermal injury resulting from QuickClot use for hemorrhage control in combat operations. *Prehosp Emerg Care* 2007; 1:67–71
33. Schwartz RB, Bullock DM, Watkins MR, et al: Perceived use of a hemostatic agent in nonmedical Marine Corp personnel [Abstract]. *Prehosp Emerg Care* 2006; 10:107–149
34. Spinella PC, Perkins JG, McLaughlin DF, et al: The affect of recombinant activated factor VII on mortality in combat-related casualties with severe trauma. *J Trauma* 2008; 64: 286–293
35. Bickell WH, Wall MJ, Pepe PE, et al: Immediate versus delayed fluid resuscitation for hypotensive patients with penetrating torso injuries. *N Engl J Med* 1994; 331:1105–1109
36. Handrigan MT, Bentley TB, Oliver JD, et al: Choice of fluid influences outcome in prolonged hypotensive resuscitation after hemorrhage in awake rats. *Shock* 2005; 23: 337–343
37. Alam HB, Rhee P: New developments in fluid resuscitation. *Surg Clin North Am* 2007; 87: 55–72
38. Miller DD, Guimond G, Hostler DP, et al: Feasibility of sternal intraosseous access by emergency medical technician students. *Prehosp Emerg Care* 2005; 9:73–78
39. Calkins MD, Fitzgerald G, Bentley TB, et al: Intraosseous infusion devices: A comparison for potential use in Special Operations. *J Trauma* 2000; 48:1068–1074
40. McSwain NE, Salome JP, eds: *Prehospital Trauma Life Support Manual*. Sixth Edition. Akron, OH, Mosby, 2006
41. McPherson JJ, Feigin DS, Bellamy RF: Prevalence of tension pneumothorax in fatally wounded combat casualties. *J Trauma* 2006; 60:573–578
42. Cullinane DC, Morris JA, Bass JG, et al: Needle thoracostomy may not be indicated in the trauma patient. *Injury* 2001; 32:749–752
43. Harke HT, Pearse LA, Levy AD, et al: Chest wall thickness in military personnel: Implications for thoracentesis in tension pneumothorax. *Mil Med* 2007; 172:12:1260–1263
44. Spaite DW, Criss EA: Out-of-hospital rapid sequence intubation: Are we helping or hurting our patients? *Ann Emerg Med* 2003; 42: 729–730
45. Zink BJ, Maio RF: Out-of-hospital endotracheal intubation in traumatic brain injury: Outcomes research provides us with an unexpected outcome. *Ann Emerg Med* 2004; 44:451–453
46. Eddy VA, Morris JA Jr, Cullinane DC: Hypothermia, coagulopathy, and acidosis. *Surg Clin North Am* 2000; 80:845–854
47. Otis JD, Keane TM, Kerns RD: An examination of the relationship between chronic pain and post-traumatic stress disorder. *J Rehabil Res Dev* 2003; 40:397–405
48. Mullins RJ, Veum-Stone J, Helfand M, et al: Outcome of hospitalized injured patients after institution of a trauma system in an urban area. *JAMA* 1994; 271:1919–1924
49. Zimmer-Gembeck MJ, Southard PA, Hedges JR, et al: Triage in an established trauma system. *J Trauma* 1995; 39:922–928
50. Hedges JR, Feero S, Moore B, et al: Comparison of prehospital trauma triage instruments in a semirural population. *J Emerg Med* 1987; 5:197–208
51. Phillips JA, Buchman TG: Optimizing prehospital triage criteria for trauma team alerts. *J Trauma* 1993; 34:127–132
52. Baxt WG, Berry CC, Epperson MD, et al: The failure of prehospital trauma prediction rules to classify trauma patients accurately. *Ann Emerg Med* 1989; 18:1–8
53. Baxt WG, Jones G, Fortlage D: The trauma triage rule: a new, resource-based approach to the prehospital identification of major trauma victims. *Ann Emerg Med* 1990; 19: 1401–1406
54. Emerman CL, Shade B, Kubincanek J: Comparative performance of the Baxt Trauma Triage Rule. *Am J Emerg Med* 1992; 10: 294–297
55. Fries GR, McCalla G, Levitt MA, et al: A prospective comparison of paramedic judgment and the trauma triage rule in the prehospital setting. *Ann Emerg Med* 1994; 24: 885–889
56. Emerman CL, Shade B, Kubincanek J: A comparison of EMT judgment and prehospital trauma triage instruments. *J Trauma* 1991; 31:1369–1375
57. McManus J, Yershov AL, Ludwig D, et al: Radial pulse character relationships to systolic blood pressure and trauma outcomes. *Prehosp Emerg Care* 2005; 9:423–428
58. Holcomb JB, Niles SE, Miller CC, et al: Prehospital physiologic data and lifesaving interventions in trauma patients. *Mil Med* 2005; 170:7–13
59. Holcomb JB, Salinas J, McManus JM, et al:

Manual vital signs reliably predict need for life-saving interventions in trauma patients. *J Trauma* 2005; 59:821–828; discussion 828–829
60. Scalea TM, Maltz S, Yelon J, et al: Resuscitation of multiple trauma and head injury: Role of crystalloid fluids and inotropes. *Crit Care Med* 1994; 22:1610–1615
61. Eastridge B, Salinas J, McManus JG, et al: Hypotension begins at 110 mm hg: Redefining 'hypotension' with data. *J Trauma* 2007; 63:291–299
62. Salinas J, Eastridge B, McManus J, et al: Field Triage Score (FTS): development and validation of a simple and practical prehospital triage instrument. *J Trauma*, In press
63. Salinas J, McManus JG, Ryan KL, et al: Predicting life saving interventions in trauma patients with normal vital signs. *Aviat Space Environ Med*, In press
64. Cooke WH, Salinas J, McManus JG, et al: Heart period variability in trauma patients may predict mortality and allow remote triage. *Aviat Space Environ Med* 2006; 77: 1107–1112
65. McManus J, Convertino V, Cooke W, et al: R-wave amplitude in lead II of an electrocardiograph correlates with central hypovolemia in human beings. *Acad Emerg Med* 2006; 13:1003–1010
66. Convertino VA, Ryan KL, Rickards CA, et al: Identifying physiological measures for improved decision support of closed-loop fluid resuscitation and oxygen delivery. *J Trauma* In press
67. Johannigman J, McManus JG, Pearce F, et al: Autonomous health care for austere environments: an overview. *J Trauma*, In press
68. Asmundson GJ, Coons MJ, Taylor S, et al: PTSD and the experience of pain: Research and clinical implications of shared vulnerability and mutual maintenance models. *Can J Psychiatry* 2002; 47:930–937
69. Buttar NS, Wang KK: The 'aspirin' of the new millennium: Cyclooxygenase-2 inhibitors. *Mayo Clinic Proc* 2000; 75:1027–1038
70. Van Ryn J, Kink-Eiband M, Kuritsch I, et al: Meloxicam does not affect the antiplatelet effect of aspirin in healthy male and female volunteers. *J Clin Pharmacol* 2004; 44: 777–784
71. Actiq [package insert]. Salt Lake City, UT, Cephalon, 2001
72. Wedmore IS, Johnson T, Czarnik J, et al: Pain management in the wilderness and operational setting. *Emerg Med Clin North Am* 2005; 23:585–601
73. Himmelseher S, Durieux ME: Ketamine for perioperative pain management. *Anesthesiology* 2005; 102:211–220
74. Nadeson R, Tucker A, Bajunaki E, et al: Potentiation by ketamine of fentanyl antinociception. I. An experimental study in rats showing that ketamine administered by nonspinal routes targets spinal cord antinociceptive systems. *Br J Anaesth* 2002; 88:685–691
75. Koppert W, Sittl R, Scheuber K, et al: Differential modulation of remifentanil-induced analgesia and postinfusion hyperanalgesia by S-ketamine and clonidine in humans. *Anesthesiology* 2003; 99:152–159
76. Candal-Couto JJ, McVie JL, Haslam N, et al: Pre-operative analgesia for patients with femoral neck fractures using a modified fascia iliaca block technique. *Injury* 2005; 36: 505–510
77. Karmakar MK, Ho AM: Acute pain management of patients with multiple fractured ribs. *J Trauma* 2003; 54:615–625
78. Sohn V, Rush R, Miller J, et al: From the combat medic to the Forward Surgical Team (FST): The Madigan model for improving combat trauma readiness of brigade combat teams fighting the global war on terror. *J Surg Res* 130; 2:249
79. Eastridge BJ, Jenkins D, Flaherty S, et al: Trauma system development in a theater of war: Experiences from Operation Iraqi Freedom and Operation Enduring Freedom. *J Trauma* 2006; 61:1366–1373