TACTICAL COMBAT CASUALTY CARE: TRANSITIONING BATTLEFIELD LESSONS LEARNED TO OTHER AUSTERE ENVIRONMENTS

Battlefield Trauma-Induced Hypothermia: Transitioning the Preferred Method of Casualty Rewarming

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For centuries, cold and wet weather has affected military combat operations leading to tremendous loss of manpower caused by cold-weather-related injuries including trench foot, frostbite, and hypothermia. The initial battlefield management of hypothermia in military personnel had not advanced significantly following many wars and conflicts until 2006. The aim of this review is to: 1) provide an overview of trauma-induced hypothermia (TIH); 2) highlight the Department of Defense strategy for the implementation of a hypothermia clinical management program for battlefield (prehospital) casualties; 3) highlight the research and development of the Hypothermia Prevention and Management Kit (HPMK) as the preferred field rewarming system for battlefield TIH; and 4) emphasize how the HPMK can be easily transitioned to the civilian sector for active rewarming of both accidental and TIH patients. The HPMK is ideal for those working in civilian Emergency Medical Services and austere prehospital care environments. This kit is a low cost, lightweight, small dimension commercial product that can provide effective passive management or active rewarming for both accidental (primary) and trauma-induced (secondary) hypothermia patients.

Keywords: hypothermia, trauma, coagulopathy, acidosis, injury, mortality, rewarming

Introduction

Since World War I, and through the recent military conflicts in Afghanistan and Iraq, advances in military trauma care have occurred after every protracted war and conflict.¹ Many of these clinical advances have transitioned to improve civilian trauma care. However, even with great medical advances following World War I (ie, wound care, correction of blood loss, etc.), there has been a persistent lack of improvement with casualties' outcomes in battlefield trauma care, and particularly when some injuries are potentially survivable.² These ongoing issues have been voiced as a primary concern of military surgeons, due to the lack of

advancement in battlefield prehospital care for the past 100 years.³

For the nearly 16 years of military conflicts in Iraq and Afghanistan, there have been vast changes in the initial prehospital care of combat casualties and during medical evacuation. Tactical Combat Casualty Care (TCCC) trauma management guidelines are a key component of medical advancements that have revolutionized how casualties are managed. The Committee on TCCC (CoTCCC) uses evidence-based research for ongoing updates that emphasize the treatment of preventable causes of combat mortality (see the articles by Butler⁴ and Giebner⁵ in this 2017 Special Edition issue). The TCCC Guidelines are also broken down into patient care during Care Under Fire, Tactical Field Care, and Casualty Evacuation phases, and are used across all military services in the Department of Defense (DoD) and by other allied militaries. However, since Operation Enduring Freedom in Afghanistan, numerous

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challenges remain. Recently noted failures to implement TCCC Guidelines and medical equipment have been reported from 2 formal assessments of prehospital care in Afghanistan.^{6,7} Each of these assessments found that TCCC concepts, medications, and equipment had been implemented incompletely across the operational forces in the combat theater of operation.

Even with a DoD policy for TCCC Guidelines' implementation across services and operational units the transition into full procedural compliance can take years, which is frustrating for personnel trained in TCCC Guidelines. Delay in TCCC Guidelines implementation was recently highlighted in a prospective observational study conducted in Afghanistan between November 2009 and November 2011.⁸ It is important to note that this study was initiated after the 2006 implementation of the Hypothermia Prevention and Management Kit (HPMK) (North American Rescue, Greenville, SC) into the TCCC hypothermia Guidelines.^{9–11} Laird and colleagues reported that wool blankets were still used most frequently for managing trauma-induced hypothermia (TIH) in combat casualties.⁸ This is unfortunate, since it essentially represents no improvement in the initial battlefield rewarming techniques since World War I, despite the availability of improved individual combat field equipment.¹² Thus, the aim of this review is to: 1) provide an overview of TIH; 2) highlight the DoD strategy for the implementation of a hypothermia clinical management program for battlefield (prehospital) casualties; 3) highlight the research and development of the HPMK as the preferred field rewarming system of choice to manage battlefield trauma; and 4) emphasize how the HPMK can be easily transitioned to the civilian sector for active rewarming of both accidental and TIH patients.

Discussion

MILITARY WINTER OPERATIONS AND COLD-WEATHER INJURIES

There is a long history of describing how cold and wet weather have affected military operations and tactics (eg, in 218 BC, General Hannibal's troops passing over the Alps, American Revolutionary War, Civil War, World War I, World War II, Korean War, Vietnam War, and, more recently, US Special Operations Forces in Afghanistan mountain warfare). In addition to the direct impact of cold on infantry personnel and combat casualties, the challenges of operating medical transport and equipment in cold environments further degrades medical care. For example, ambulances break down, intravenous solutions and other medications freeze, plastic components

become brittle, batteries may not work, etc. Moreover, military personnel have experienced a significant loss of fighting force caused by trench (immersion) foot, frostbite, hypothermia, coagulopathy, and death.^{12–15} When combat casualties incur hemorrhage and shock, the effects of TIH create a cascade of physiological effects. This results in poor patient outcomes and accelerated mortality, even with minor decreases in core temperature (see further discussion in Trauma-Induced Hypothermia section).

BATTLEFIELD TRAUMA EPIDEMIOLOGY

The most definitive 10-year study (2001–2011) to date on battlefield trauma assessment during the Afghanistan and Iraq conflicts was conducted recently by Eastridge and colleagues.² In brief, these investigators analyzed 4596 battlefield fatalities and reported that 87% of all injury mortality occurred in the prehospital environment. Of those prehospital deaths, 76% (n=3040) were classified as nonsurvivable, and 24% (n=976) were deemed potentially survivable (eg, exsanguination from an extremity injury and airway obstruction). The causes for the lethal injuries were primarily improvised explosive device (fragmentation injury) and gunshot wounds. The potentially survivable injuries were hemorrhage (91%) and airway compromise (8%). From the perspective of injury severity in the potentially survivable casualties, 29% had an injury severity score (ISS) of ≤ 25 , 61% had an ISS between 25 and 50, and 10% had an ISS > 50 . The authors noted that with an ISS of 25, there is a predicted mortality of 20 to 30% with a near linear increase in mortality from an ISS of 25 to 75, which is associated with an approximately 75% mortality. These battlefield trauma statistics suggest that the mortality from potentially survivable injuries is higher than expected based on the ISS. Given that most mortality (87%) occurred in the prehospital phase, these authors conclude that there is a substantial opportunity for greater research to focus on how to improve casualty outcomes at the point of injury.²

TRAUMA-INDUCED HYPOTHERMIA

Accidental or primary hypothermia is defined as the unintentional fall in core body temperature below 35°C (95°F), caused by the impact of the cold environment in otherwise healthy individuals who did not sustain injury.¹⁶ In contrast, hypothermia secondary to trauma is a metabolic derangement in which a shift to anaerobic metabolism results in significantly less heat-generating capacity, making these patients particularly vulnerable to hypothermia, and they have a very poor prognosis as core temperature decreases.^{17,18} Consequently, a separate

hypothermia classification was created for trauma victims, which begins at $\leq 36^{\circ}\text{C}$ ($\leq 96.8^{\circ}\text{F}$). It is appropriate to use a higher temperature threshold to define TIH because there is increased morbidity and mortality starting at this core temperature when compared to accidental hypothermia patients. In these injured patients, mild hypothermia is defined as a temperature between 34 to 36°C (93 – 96.8°F), whereas moderate hypothermia occurs between 32 to 34°C (90 – 93°F), and severe hypothermia is $< 32^{\circ}\text{C}$ ($< 90^{\circ}\text{F}$).¹⁷ Both civilian^{18–21} and military^{22–28} trauma studies report that an > 15 ISS is associated with progressive increase in the frequency and severity of TIH. These studies clearly indicate that no matter the mechanism of injury, traumatized patients are more likely to become hypothermic resulting in greater mortality. It is important to note that TIH was recorded in combat casualties independent of the ambient temperature (eg, hot Middle Eastern deserts).^{23,25,28} Thus, it is now recommended in both civilian and military trauma courses to initiate early and aggressive use of active rewarming as the standard of care in traumatized patients.^{29,30}

Even though mortality in combat casualties with hypothermia is double that of normothermic casualties with similar injuries,²⁴ TIH is a topic not solely unique to combat casualties.¹⁸ The majority of these TIH peer-reviewed studies emanate from civilian trauma surgeons primarily beginning the 1980s.^{19–21,31} These retrospective and prospective studies all report the relationship between trauma, hypothermia, coagulopathy (known as trauma triad), and greater mortality. This is principally caused by a thermoregulatory dysfunction resulting in decreased metabolic heat production particularly in patients with hemorrhagic shock, that typically uncouples normal metabolic pathways. Hypothermia is further exacerbated by secondary causes (eg, based on prolonged ground exposure with conductive heat loss or accelerated convective heat loss in cold and windy environments, and/or the administration of cool intravenous fluids during patient management). One documented clinical challenge is that 40 to 50% of moderate to severely traumatized patients arrived hypothermic at civilian hospitals, and $> 80\%$ of nonsurviving patients had a core temperature $< 34^{\circ}\text{C}$ ($< 93^{\circ}\text{F}$).^{32–34} In both civilian and military trauma studies, it is reported that 100% mortality occurred when core temperature is $\leq 32^{\circ}\text{C}$ ($\leq 90^{\circ}\text{F}$).^{23,31}

The effect of hypothermia on the coagulation system is multifactorial.^{35–37} Moderate hypothermia directly reduces coagulation activity approximately 10% for each degree Celsius decrease in temperature.²⁵ The acquired coagulopathy accounts for a large percentage of early and preventable trauma deaths when not managed early.^{37–40} Both civilian and military trauma centers

have linked TIH and coagulopathy on arrival with increased mortality.^{22,23,39,40} The primary mechanism of acute traumatic coagulopathy (ATC) is complex, but this pathophysiological cascade is beginning to be unveiled.^{27,35,36,40–43} There are 6 primary mechanisms for ATC: tissue trauma, shock, hemodilution, hypothermia, acidemia, and inflammation.²⁷

The poor outcome of traumatized patients presenting with hypothermia is well documented.²⁴ Eastridge and colleagues retrospectively reviewed over 1100 combat casualties presenting to surgical support hospitals during Operation Iraqi Freedom from January to July 2004. They reported that in normothermic versus hypothermic patients, the survival rate was 98% and 75% ($P < .05$), respectively. They also observed that 88% of hypothermic patients versus 65% of normothermic patients ($P < .05$) required surgery on arrival.

During Operation Iraqi Freedom, military trauma teams noted that many combat casualties were hypothermic after arriving from the battlefield to combat medical treatment facilities (MTF).^{24,27} They viewed this as a trauma system-related problem that needed a rapid intervention starting at the point of injury, during medical evacuation, and after arrival at military MTFs. Subsequently, Beekely describes the enhanced measures that addressed hypothermia prevention and management.²⁵ See Table 1 for hypothermia-related DoD policies. Since the implementation of methods to standardized hypothermia prevention within the combat theater trauma system, the rate of casualties arriving at military MTFs with TIH dropped from 7 to $< 1\%$.²⁴

HYPOTHERMIA REWARMING RESEARCH AND DEVELOPMENT

Seeking a solution for the DoD hypothermia management strategy, Allen and colleagues⁴⁴ evaluated rewarming systems on the core temperature of a fluid torso model for hypothermic combat casualties. They tested 3 active warming systems for prehospital use (HPMK, Ready-Heat thermal blanket, and Bair Hugger Forced Air System) and 5 passive hypothermia prevention products (wool blanket, mylar space blanket, Blizzard blankets, Human Remains Pouch (body bag), as well as a hot pocket system (combination of 2 wool blankets, one-space blanket inside a Human Remains Pouch). Active warming devices included products with chemically or electrically heated systems (See Table 2).

The products with active heating performed better to prevent heat loss than most passive prevention methods. The original HPMK achieved and maintained significantly higher temperatures than all other methods at 120 minutes ($P < .05$). None of the devices with an actively

<i>Problem</i>	<i>Initial and long-term hypothermia strategy implementation</i>	<i>Combat medics</i>	<i>Forward surgical teams and military treatment facilities</i>
Recurring hypothermia in combat casualties arriving for surgical intervention	Initial: Iraq–Theater-wide implementation Long term: Assistant Secretary of Defense of Health Affairs HA Policy: 06-005, Defense-wide Policy on Combat Trauma Casualty Hypothermia, February 2006; https://www.naemt.org/docs/default-source/education-documents/tccc/10-9-15-updates/dhb-memo-101210-hypothermia-prevention.pdf?sfvrsn=2	Disseminate simple hypothermia prevention measures to the operational unit combat medics Emphasis on effective hemorrhage control Limit removal of clothing to areas only needing treatment Wrap casualties in wool or solar blankets Use inline IV fluid warmers during en route care	Education initiatives for surgeons at level II and III to emphasize recognition of hypothermia, and to install guidelines for the prevention of heat loss Use of solar blankets, heated blankets, vinyl body bags, and forced air warming devices (Bair Hugger) Use warmed inline IV fluids Use warmed blood products Use continuous arteriovenous rewarming
	CoTCCC approves new hypothermia guidelines, November 2005	Mandatory use of Hypothermia Prevention and Management Kits for all rotary wing evacuation/ ground evacuation for urgent litter or intubated or immediate triage casualties	
	TCCC Guidelines: Update	Greater Emphasis on Trauma-Induced Hypothermia in the Prehospital Trauma Life Support 6th edition, 2006	
	Medical Director, Joint Theater Trauma System: Clinical Practice Guidelines		Hypothermia Prevention, Monitoring and Management, October 2006

effective as active warming devices other than the original HPMK.

Extrapolating results from this study to efficacy in humans may be questionable, because the fluid model (37°C/98.6°F) had no ability to generate heat intrinsically. Another limitation of this study is that they only studied these products at one environmental temperature (37.8°C/100°F). Consequently, the results may be much different when

Table 2. Passive and active warming products evaluated by Allen and colleagues⁴²

<i>Product</i>	<i>Warming methods</i>	<i>Company</i>	<i>Product material</i>	<i>Website URL</i>
HPMK (Original version)	Active	North American Rescue Products, Greer, SC	Blizzard blanket, 4-cell Ready-Heat blanket and head cover	www.narescue.com
HPMK (Current version)	Active	North American Rescue Products, Greer, SC	Heat Reflective Shell and 4-cell Ready-Heat blanket	www.narescue.com
Ready-Heat blanket	Active	TechTrade LLC, New York, NY	Constructed of a strong weave paper with 4 pouches containing the exothermic chemical powder mixtures designed to fit on the torso of a casualty	www.techtradellc.com/
Active	Arizant Healthcare, Eden Prairie, MN	Forced air-warming device consists of a warming unit and telescoping hose that attaches to a reinforced paper blanket with cells, which provide venting of the warmed air	www.arizanthhealthcare.com	Bair Hugger (Model 505)
Blizzard blanket	Passive	Blizzard Protection Systems Ltd, UK	Large reflective wrap designed to cover most adults completely, and is made from a proprietary material called Reflexcell	www.arizanthhealthcare.com
Heat Reflective Shell	Passive	North American Rescue Products, Greer, SC	A polyolefin, 4-ply, composite fabric with a protected nonconductive thermal reflective layer that is waterproof and windproof	www.narescue.com
US Army wool blanket	Passive	NA	Standard issue 100% wool blanket	NA
Mylar space blanket	Passive	NA	A reflective, plasticized tarpaulin version that has cross-hatched plastic thread reinforcements	NA
Human Remains Pouch	Passive	NA	A body bag that is the current device used in the military and is constructed of an outer plastic or canvas cover with a rubber leak proof inner core	NA

NA, not applicable.

Table 3. TCCC Guideline recommendations for hypothermia prevention and management (2016)^{*}*Prevention of hypothermia*

- a. Minimize casualty's exposure to the elements. Keep protective gear on or with the casualty if feasible.
- b. Replace wet clothing with dry if possible. Get the casualty onto an insulated surface as soon as possible.
- c. Apply the Ready-Heat blanket from the Hypothermia Prevention and Management Kit to the casualty's torso (not directly on the skin), and cover the casualty with the Heat Reflective Shell (HRS).
- d. If an HRS is not available, the previously recommended combination of the Blizzard Survival Blanket and the Ready-Heat blanket may also be used.
- e. If the items mentioned above are not available, use dry blankets, poncho liners, sleeping bags, or anything that will retain heat and keep the casualty dry.
- f. Warm fluids are preferred if IV fluids are required.

^{*} For full TCCC Guidelines, see http://www.naemt.org/education/TCCC/guidelines_curriculum.

evaluated at colder environmental temperatures. These data do not support the continued use of wool blankets solely; they should be used together as insulation along with an impermeable outer layer, such as a Human Remains Pouch, Blizzard blanket, or the Heat Reflective Shell.

RESEARCH AND DEVELOPMENT FUTURE DIRECTION

The study by Allen and colleagues⁴⁴ was the best evidence supporting a lightweight, nonconsumable heating source for prehospital rewarming of hypothermic patients. Although there were no published clinical studies with the use of the HPMK, their study was the basis for selecting this kit by DoD personnel. The HPMK and enhanced hypothermia management procedures were added to the TCCC Guidelines as a means to provide a rapid active rewarming in the prehospital for severely traumatized combat casualties. See Table 3 for the current hypothermia management recommendations in the TCCC Guidelines. Additional research is needed to confirm the findings from Allen et al⁴⁴, ideally using human volunteers and varying cold air exposures. An ongoing study is currently evaluating 5 commercial warming systems, including the HPMK, using human volunteers (personal communication, Gordon Giesbrecht, PhD on June 15, 2016). This study may provide evidence for more effective rewarming devices for hypothermic patients in the prehospital environment.

TRANSITION OF THE HYPOTHERMIA PREVENTION MANAGEMENT KIT

A core skill taught in wilderness and prehospital medicine is how to manage an accidental hypothermic patient, with an emphasis on preventing further heat loss with an improvised passive heat retention system.⁴⁵⁻⁴⁸

This system, traditionally known as a hypothermia wrap, basically consists of a vapor-tight waterproof tarp, 1 to 3 ground insulation pads, and 1 to 3 sleeping bags. The patient is placed in the middle sleeping bag, and the outer layer then is folded up systematically to prevent cold air entry and to maximize heat retention. This approach is equipment intensive, bulky, and generally limited to those personnel responding to manage a hypothermic patient. The advantages of the HPMK are that it is lightweight, 1.6 kg (3 lb. 8 oz), packaged in a small dimension, 17 cm x 27 cm x 14 cm (6.75 in. x 10.5 in. x 5.5 in.), and vacuum sealed as a kit. The HPMK can also be used with or without the Ready-Heat thermal blanket. It is available in either smaller torso or full-body sizes, both with 10 hours of continuous dry heat by an oxygen-activated (15 to 20 minutes to 40°C [104°F]), self-heating liner that has no external power supply requirement. As compared to the traditional hypothermia wrap, the HPMK provides an option of active rewarming, most ideal for moderate to severe hypothermia, particularly in trauma patients in austere environments. Transitioning the HPMK to wilderness medicine and other prehospital programs should be investigated, and is likely to be highly successful for managing accidental and TIH patients.

Conclusions

TIH occurred frequently in combat casualties during recent military conflicts in Afghanistan and Iraq. The rate of hypothermia decreased in theater after implementing hypothermia management strategies, which included education and training for combat medics and trauma teams. Other critical components of this strategy included a new policy on hypothermia management signed by the Assistant Secretary of Defense for Health Affairs; development of a hypothermia Clinical Practice

Guideline by the Joint Trauma System, US Army Institute of Surgical Research; and new research funding for the development for an active rewarming system, followed by the subsequent implementation of the HPMK throughout the DoD. In 2006, the CoTCCC made an update to the trauma guidelines for hypothermia management recommendations. After 10 years since the implementation of these hypothermia management strategies, it is essential to transition battlefield lessons learned to civilian prehospital care. The HPMK system is a low cost and lightweight commercial product that can provide both passive and active rewarming to hypothermic patients in urban or austere environments, and during ground or air medical evacuations.

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