SHOCK, Vol. 41, Supplement 1, pp. 90–97, 2014

IMPLEMENTATION AND EXECUTION OF MILITARY FORWARD RESUSCITATION PROGRAMS

Timothy J. Hooper,* Roy Nadler,† John Badloe,‡ Frank K. Butler,§ and Elon Glassberg†

**UK Defence Medical Services, Anaesthetic Department, Frenchay Hospital, North Bristol Trust, Bristol, UK; †Surgeon General's Headquarters, Israel Defense Forces, Department of Military Medicine, Hebrew University, Jerusalem, Israel; ‡NATO Medical Blood Advisory Team, Military Blood Bank, Leiden, the Netherlands; and §Committee on Tactical Combat Casualty Care, Prehospital Trauma Care Joint Trauma System, Fort Sam Houston, San Antonio, Texas*

Received 16 Sep 2013; first review completed 1 Oct 2013; accepted in final form 21 Oct 2013

ABSTRACT—Through necessity, military medicine has been the driver of medical innovation throughout history. The battlefield presents challenges, such as the requirement to provide care while under threat, resource limitation, and prolonged evacuation times, which must be overcome to improve casualty survival. Focus must also be placed on identifying the causes, and timing, of death within the battlefield. By doing so, military medical doctrine can be shaped, appropriate goals set, new concepts adopted, and relevant technologies investigated and implemented. The majority of battlefield casualties still die in the prehospital environment, before reaching a medical treatment facility, and hemorrhage remains the leading cause of potentially survivable death. Many countries have adopted policies that push damage control resuscitation forward into the prehospital setting, while understanding the need for timely medical evacuation. Although these policies vary according to country, the majority share many common principles. These include the need for early catastrophic hemorrhage control at point-of-wounding, judicious use of fluid resuscitation, use of blood products as far forward as possible, and early evacuation to a surgical facility. Some countries place medical providers with the ability, and resources, for advanced resuscitation with the forward fighting units (perhaps at company level), whereas others have established en route resuscitation capabilities. If we are to continue to improve battlefield casualty survival, we must continue to work together and learn from each other. We must also carry on working alongside our civilian colleagues so that the benefits of translational experience are not lost. This review describes several countries current military approaches to prehospital trauma care. These approaches, refined through a decade of experience, merit consideration for integration into civilian prehospital care practice.

KEYWORDS—Battlefield, prehospital, evacuation, hemorrhage, shock, blood, damage control

INTRODUCTION

From trauma and emergency medicine, through infectious disease, antibiotics, transfusion, and more, military medicine has been a driver of medical innovation throughout history. Saving lives on the battlefield presents unique challenges such as the necessity to provide care while under threat, resource limitation, and resupply constraints; prolonged evacuation times; and working within austere environments, to name but a few. To meet these challenges focus must be placed on identifying causes of death, including timing and place within the battlefield. By doing so, military medical doctrine can be shaped, force build-up efforts prioritized, appropriate goals set, new concepts adopted, and relevant technologies investigated and implemented (1–3). Data registries (such as the US and UK Joint Theater Trauma Registries), meticulous feedback, and after-action reporting policies are the cornerstone of any improvement process, providing the necessary evidence for policy change, research, and product development.

Previous conflicts including World War II, Korean war, and Vietnam war have shown that approximately 90% of battlefield casualties die in the prehospital setting before ever reaching the surgeon's knife (3, 4), and more recently the Israeli conflicts of the late 1990s showed that 88% of battlefield deaths happened within 30 min of wounding (5). This percentage has changed little over the years: a 10-year study (2001–2011) looking at all US combat deaths showed that 87% died in the prehospital environment (3).

The mechanisms causing combat fatalities are dependent on the conflict and change over time. During the 1993 Somalia conflict, 78% of deaths were caused from penetrating injuries (6), whereas deaths over the last 10 years in Iraq and Afghanistan conflicts were increasingly more likely due to explosions (mainly improvised explosive devices) than gunshot wounds (74% and 22%, respectively) (3). The etiology of battlefield deaths, however, changes little. A model using historic war data showed that 50% died of hemorrhage, 36% of traumatic brain and spinal cord injuries, and the rest of other causes, mainly respiratory tract trauma (4). US Special Forces deaths between 2001 and

Address reprint requests to Elon Glassberg, MD, MHA, The Trauma and Combat Medicine Branch, Medical Corps, Surgeon General's Headquarters, Military POB 02149, Israel Defense Force, 02149, Jerusalem, Israel. E-mail: idf_trauma@idf.gov.il.

This study has no sources of support, including pharmaceutical and industry support.

The authors have no conflicts of interest to report.

The opinions or assertions contained herein are the private views of the authors and are not to be construed as official, or as reflecting the views of the US Department of the Army or the Department of Defense or the UK Defence Medical Services.

The THOR Network has proposed the term *remote damage control resuscitation* (RDCR) to reflect DCR within the prehospital setting. The aim is to differentiate it from that provided in hospital and acknowledge that the challenges and application of DCR in the prehospital environment may be quite different. This allows for modified and alternative approaches to be considered, to achieve the same overall aim of improved survival rates in battlefield casualties. However, the term is not recognized in UK medical doctrine. Here, instead, DCR reflects all interventions carried out from point of injury to definitive care and therefore incorporates RDCR.

DOI: 10.1097/SHK.0000000000000081

2004 that were potentially survivable were also mainly from hemorrhage (82%) (7), and US potentially survivable deaths in Iraq and Afghanistan show very similar patterns with 91% dying of hemorrhage, 8% of airway obstruction, and 1% of tension pneumothorax (3).

What is apparent from this recent and historical data is that the majority of battlefield casualties still die before reaching a medical treatment facility (MTF) and that most potentially survivable deaths are still from hemorrhage. These data give the evidence needed to help guide future research and development, particularly in personal protective equipment (including body armor and helmets) and vehicle design. More importantly, perhaps from a medical point of view, it gives the evidence needed to change doctrine.

The purpose of this review was to describe several countries' current military approach to prehospital trauma care. These approaches have been refined through continuing use on the battlefield and merit consideration for integration into civilian prehospital care practice.

Medical facilities and evacuation chains

Deployment to remote, isolated, and austere locations without the benefit of relying on local medical infrastructure has necessitated militaries around the world to develop dedicated medical units and capabilities to provide this care. This is almost universally provided in a progressive manner. Self-aid and Tactical Combat Casualty Care (TCCC) start at the point of injury (POI), through damage control resuscitation (DCR) and surgery (DCS), to eventual definitive surgery and rehabilitation as the casualty moves along the evacuation chain.

Within NATO doctrine, and serving as a common language between countries, MTFs are designated a Role number to describe their functional capability to deliver a specific level of care, with higher levels of Role incorporating the capabilities of lower levels. Role 1 includes the provision of primary care and emergency resuscitation and is integral to major land-based units (usually in the form of battalion aid stations) and afloat platforms. Role 2 includes the reception and sorting of patients as well as the provision for DCR. It can be further enhanced to provide DCS and may be then referred to as a Role 2+ facility. Major specialist facilities including multiple surgical specialties, intensive care, and well-appointed laboratories are available within a Role 3 facility. Role 4 provides the full spectrum of definitive medical care including reconstructive surgery and rehabilitation. These definitions, although generally accepted, still do not correctly represent the entire capability spectrum. For example, a casualty within a Special Operation Unit may receive POI care by an advanced medical provider (who may be a physician) well before reaching a formal Role 1 facility. NATO has acknowledged the limitations of this rather formulaic and standardized nomenclature and is in the process of rewriting the medical doctrine to allow for a more fluid system.

In recent years, one of the biggest changes in NATO medical doctrine has been the adjustment in timelines for a battlefield casualty to receive increasing levels of medical care. Traditionally, the 1-2-4 timeline has applied: the casualty should receive hemorrhage and basic airway control within 10 min, medical evacuation (MEDEVAC) and advanced trauma care within 1 h, DCS within 2 h (at Role 2 or 3), and the first repair of wound damage within 4 h (at Role 3) (8). In 2011, NATO forces adopted a Life and Limb Saving Timeline (known as the 10-1-2 Medical Planning Guideline within UK medical doctrine) emphasizing the need for earlier DCR (9). With the new timeline, casualties should receive bleeding and airway control within 10 min (TCCC), DCR by emergency medical personnel within 1 h, and ideally DCS within 1 h, but no later than 2 h. Again, although accepted by NATO countries, others have not adopted these strict definitions and address the complex issue of casualty treatment and evacuation differently.

Damage control resuscitation—Damage control is now a commonly used medical term; however, the original meaning comes from the US Navy. It refers to the actions taken to avoid the sinking of a damaged ship, by concentrating the efforts on those crucial to the ship's survival before definitive repair when in port. The medical damage control concept is not new: utilized in the early part of the last century (10), the concept was lost after World War II, before being reintroduced into the trauma world in the 1980s and has since continued to gain popularity (11, 12). Damage control resuscitation is a newer concept: it encapsulates the established concept of DCS, providing a systematic approach to the major trauma patient from POI to definitive care, to minimize blood loss, maximize tissue oxygenation, and optimize outcome (13). In simplistic terms, it is the initiation and maintenance of treatment to address the lethal triad of acidosis, hypothermia, and coagulopathy (14).

While DCR starts at the POI, the general acceptance that the earlier advanced resuscitation techniques are initiated the better has led some countries to push them as far forward as possible. The belief in this concept has led to the adoption of the Life and Limb Saving Timeline by NATO, with other countries implementing similar policies. It is one of the major changes to combat casualty care in the last decade and a contributing factor to an impressive survival rate seen in battlefield casualties from the current Afghanistan conflict (15, 16).

DCR in the military setting

Medical care in smaller, often isolated, front-line units is generally based on providers who are team members with enhanced medical training, superior to that of every soldier's basic first aid drills (some armies deploy dedicated squads of providers to the company and regimental size units). The provider's capabilities are limited by frequently having to carry their own equipment, relying on generators to provide electricity (or perform without it), and potentially providing care at the POI while under fire. Despite these constraints, DCR today begins at the POI. Data indicating that hemorrhage is the primary cause of death in many battlefield casualties have led to major advances in hemorrhage control (3, 4, 7). The utilization of limb tourniquets (reintroduced within the Israeli Defense Forces by the early 2000s and the British military in 2006), Israeli-type wound dressings, intraosseous access, and novel hemostatic dressings (such as Celox Gauze [MedTrade Products, Crewe, United Kingdom] and Quickclot Combat Gauze [Z-Medica, Wallingford, CT]) are now standard in many armies around the world. The acknowledgment that balanced

resuscitation may prevent the development of coagulopathy and further bleeding has also led to reduced use of fluids at the POI and Role 1 (17, 18). Other life-threatening injuries can also be addressed, at least partially, far forward: tension pneumothoraces can be decompressed, airway compromise often managed with simple maneuvers or perhaps advanced interventions, and depending on the skill of the provider and the situation, pain ameliorated and infection control initiated with early administration of antibiotics.

Damage control resuscitation may also exploit the use of more advanced hemorrhage control (including resuscitative thoracotomy at the extremes): fluid resuscitation includes transfusion of crystalloids, colloids, blood (in the form of packed cells or whole blood), and plasma (fresh frozen or freeze dried). Anesthesia or sedation can be used to facilitate ongoing management, and active warming initiated to prevent hypothermia and its consequences. There is of course a logistic and personnel burden associated with these resuscitative processes. Countries, and indeed subunits within armies (especially Special Forces), have developed differing approaches to get DCR forward.

Over the years, militaries and medical organizations have chosen to use different resuscitation strategies, policies, and fluids. Although the scenarios and considerations vary, it is of importance to appreciate the differences and learn from each other's experience. In the following sections, we offer a description of the way several militaries around the world have implemented DCR into their doctrine and current practice.

DCR in the Israel Defense Forces

The Israel Defense Forces (IDF) medical support is an echelon-based system, not unlike the one previously described. However, the IDF is, as its name implies, a defensive force and as such operates in relative proximity to the civilian population, infrastructure, and facilities. The proximity to civilian medical centers allows for their incorporation into the medical care provided to soldiers wounded in action. It has been decades since the IDF Role 3 facilities have deployed in a combat scenario; instead, it is the civilian medical centers that serve as the evacuation destinations, functioning as both Role 3 and Role 4 facilities.

Strengthened by published data from Operation Iraqi Freedom, Operation Enduring Freedom (3), and that gathered from local conflicts (19), the IDF Medical Corps force buildup plan includes the allocation of medical capabilities to forward positions. It aims to push medical providers and equipment as close as possible to the POI. The IDF Medical Corps doctrine is designed to be relevant to the IDF's tactical mode of operation, while sharing several key concepts with the TCCC.

Control of compressible extremity hemorrhage is expected to occur very soon after injury, with the first provider being the casualty themselves. Every combatant undergoes basic medical training and is equipped with basic medical equipment, including a tourniquet and a personal bandage.

Combat medics, trained to the level of basic life support providers, are stationed at the platoon level among regular forces and at the squad level elsewhere. These medics have specialized training in compressible hemorrhage control (from both extremity and junctional wounds), intravenous cannulation, splintage, and administration of a limited number of medications including intramuscular narcotics. They are equipped with several combat application tourniquets, hemostatic dressings (Quickclot Combat Gauze (Z-Medica, Wallingford, CT)), and compression wound bandages and can administer crystalloid fluid resuscitation if needed. Ringer's lactate is the crystalloid of choice, with an initial 500 mL judiciously administered to casualties who have sustained significant injuries and are showing signs of hemodynamic compromise (ie, heart rate >100 beats per minute). Subsequent doses, up to a total of 2,000 mL, will be administered only when signs of substantial shock exist (ie, systolic blood pressure <80 mmHg).

Advanced life support (ALS) capabilities are available at the company level, in the form of either a paramedic or a physician. Battlefield casualties are therefore expected to receive

FIG. 1. **History repeats: a recent image of an Israeli paramedic transfusing FDP at the point of injury, alongside an American medic doing the same in World War II.**

ALS care shortly after their injury, with the standard of care to receive it at POI. Advanced life support providers are equipped with similar means for hemorrhage control as combat medics and additionally carry a 26F balloon catheter to tamponade deep, narrow, bleeding wounds not amenable to tourniquet application. Unlike combat medics, however, they use freeze-dried plasma (FDP) as their primary resuscitation fluid in the hypovolemic shocked patient. The use of FDP (type AB), which is stored at room temperature, easy to carry, and rapidly reconstituted, allows for widespread availability right at the POI (20, 21). Again, this concept is not new and is highlighted by the photographs in Figure 1, showing a recent image of an Israeli paramedic transfusing FDP at the POI and an American medic doing the same in World War II. As evidence suggests that early administration of tranexamic acid (TXA) is associated with improved efficacy, all physicians and paramedics carry it for administration at the POI (as part of the secondary survey) or en route (22).

Battalion level Role 1 facilities (termed *battalion aid stations*) are composed of several ALS providers. These facilities are deployed at the frontline and must be highly mobile, either on armored vehicles or man-portable, and therefore have significant logistical constraints (ie, no refrigeration capabilities and as a result no availability of packed red blood cells [PRBCs]). In terms of DCR capabilities, these facilities are relatively similar to the single ALS provider stationed at the company level (with the additional availability of active warming) but are capable of providing medical care to several casualties simultaneously.

Role 2 facilities consist of medical platoons and are part of the regimental medical support. The medical personnel of these facilities include several physicians, including a critical care or anesthesia specialist. These facilities have cold storage capabilities and are thus the first level of care in which PRBCs can be transfused. The resuscitation protocols for Role 2 facilities follow current DCR principles including a 1:1 PRBCs-to-plasma (as FDP) ratio. Role 2 facilities also have other advanced care capabilities including advanced ventilation and monitoring options and mobile ultrasound. Surgical capabilities can be joined to a Role 2 facility (Role 2+), expanding it to include DCS as early, and as close, as possible to the POI.

Aerial evacuation platforms in the IDF are also manned by ALS providers, with a typical team comprising of a physician, a paramedic, and 3 medics. Apart from ALS interventions, these teams have the ability to administer FDP, PRBCs, and TXA as part of their battlefield casualty management.

Despite the emphasis placed on POI care, all medical teams are trained to prioritize casualty evacuation ahead of almost all medical interventions. Damage control resuscitation, including advanced resuscitation techniques, will thus preferably be performed en route to the next echelon of care and by no means should be allowed to delay casualty evacuation.

En route DCR in the British forces

The United Kingdom adheres to, and helps shape, NATO medical doctrine for the delivery of casualty care on the battlefield. It has recently produced the Operational Patient Care Pathway that provides a single capability model of how UK medical support is provided on operations (23). It illustrates the continuous, seamless, and escalatory increase in care provided to the operational patient and introduces the term *progressive resuscitation*. This term defines the use of multiple techniques to restore physiological function in an individual who has become a casualty through exposure to any hazard on operations (both battle casualties and disease and nonbattle injuries). It incorporates DCR for the treatment of the trauma patient.

Forward and rear deployed hospital care facilities are positioned according to the tactical situation, taking into account multiple factors including threat, troop density, other Allied Forces facilities, and timelines to higher echelons of care. In the prehospital phase, DCR (or progressive resuscitation) starts at the POI with tactical field care (TFC) and includes care under fire. This involves undertaking interventions necessary to save and stabilize life and prepare the casualty for MEDEVAC. Enhanced field care follows, utilizing progressive resuscitation techniques by a clinical team, and continues until the casualty reaches deployed hospital care.

Effective treatment must be seen as a continuum, with the tempo of aggressive early treatment maintained throughout. The juxtaposition of early DCR, preferably at the POI, and necessity for urgent casualty evacuation to a surgeon have led to the development, or rather redevelopment, of en route DCR. As with other aspects of military doctrine, this is not a new concept: previous conflicts, including the Suez Crisis of 1956, have utilized helicopter MEDEVAC with the provision of an on-board physician and blood products. British Forces achieve Forward MEDEVAC, in part, with the deployment of the medical emergency response team (MERT). It can be defined as "the medical component of an incident response team, where the capability may be delivered in the maritime, littoral, land, or air environments. Medical emergency response team is used when the clinical situation dictates the need for specialist prehospital emergency care interventions during MEDEVAC (8). It is part of TFC, and in essence, allows advanced DCR techniques to be brought forward of the surgeon, into the prehospital environment, while not impacting on evacuation timelines.

In historical medical doctrine, the MERT configuration includes nurses, paramedics, and other ALS providers, being enhanced by a physician when needed [designated by MERT(e)]. However, since it became established in 2006 (having evolved from the incident response team), the configuration has always included a physician (with either an emergency medicine or anesthesia background) and is now generically known as MERT (24). Primarily helicopter based, the overarching aims are to stabilize, prevent further deterioration, and improve the physiological status of the battlefield casualty, while considering the humanitarian aspects of their care. Within the current Afghanistan conflict, there are a number of other MEDEVAC platforms, including the American PEDRO and DUSTOFF, with similar principles but differing levels of acuity. It is imperative that these platforms are intelligently tasked so that every battlefield casualty gets the appropriate level of care needed.

Initial rapid assessment and triage of the battlefield casualties take place on the ground to facilitate an appropriate load plan, with patients generally loaded in order of priority. On-scene time is kept to a minimum, and all interventions are performed en route to higher echelons of care (typically Role 3).

Patients undergo further assessment, in terms of both primary and secondary survey, with treatment being initiated as appropriate. Resuscitation follows the established <C>ABC (catastrophic hemorrhage control, airway, breathing, circulation) approach (25) and, depending on the number of casualties, will be horizontal rather than vertical in application.

The aim is to control catastrophic hemorrhage with tourniquets, novel hemostatic agents, blast dressings, pelvic splintage, and perhaps even resuscitative thoracotomy (to gain proximal control). Ideally, airways are maintained with simple maneuvers, but advanced techniques are available, including drug-assisted intubation and surgical airway insertion. Understanding that positive pressure ventilation may be deleterious in terms of its hemodynamic effects means that, if possible, patients are kept spontaneously breathing with oxygen augmentation. If the need for ventilation arises, a mechanical ventilator is available. Chest injuries, including pneumothoraces and hemothoraces, can be treated with an open thoracostomy or chest drain insertion.

Access for fluid resuscitation is gained via the intravenous or intraosseous route. Hypovolemic shock is treated with the administration of warmed blood products and procoagulant drugs, including TXA and calcium. Medical emergency response team currently carries 4 units of fresh frozen plasma and 4 units of PRBCs (amounting to >2 L of blood products) in temperature-controlled boxes. Hypothermia prevention is undertaken using in-line blood warming administration sets and active rewarming blankets.

Analgesia can be provided using a number of different drugs (including morphine, ketamine, and transmucosal fentanyl) and other modalities such as fracture splintage. Sedation and anesthesia can be induced and maintained using similar drugs, while traumatic brain injury management aims to reduce the secondary insult. Pertinent to this is the adequate delivery of oxygen, tight control of arterial carbon dioxide (with ventilation if needed), reduction of cerebral metabolic demand (with analgesia or anesthesia) while maintaining perfusion, and administration of osmotically active drugs to reduce cerebral edema (such as hypertonic saline).

Emphasis is placed on patient monitoring, while appreciating it is generally difficult in these settings and technology gaps continue to exist for the effective monitoring of the critically ill, hypovolemic patient. This is discussed in more detail elsewhere in the supplement.

Battlefield casualty treatment is clearly multiphase, making it difficult to tease out whether particular elements are improving patient outcome. It is also important to remember that these elements are inextricably linked: if a tourniquet is not appropriately tightened at the POI for example, no amount of blood products on MERT or surgical intervention at Role 3 will reverse the potentially lethal oxygen debt that has already accumulated. However, evidence is starting to be published that may show that this type of MEDEVAC capability can improve outcome. Several recent articles have shown a mortality benefit in some groups of battlefield casualties when MERT is utilized as a MEDEVAC platform (26, 27). Benefit is seen in patients with a high injury severity score (ISS 15-50), suggesting that patients with a low ISS (<15) are likely to survive, and those with a very high ISS (>50) are likely to die, regardless of evacuation means. This, again, reiterates the need for intelligent tasking of MEDEVAC platforms and highlights the need for further research and development into identifying this "middle" group of patients. This is difficult using available means, despite prehospital care providers gaining much experience in the last 10 years of conflict.

TCCC in the US military

The US military now trains its forces to manage combat trauma on the battlefield using the principles of TCCC (28). Conceived and initially used by the US Special Operations community, it has now been adopted by most conventional units. Tactical Combat Casualty Care was designed to replace the tradition-based trauma care practices being taught to military medics in the early 1990s with evidence-based trauma management strategies customized for the battlefield environment.

Responding to new publications in the medical literature, and lessons learned in Afghanistan and Iraq, TCCC has been constantly evolving since the events of 9/11. The TCCC guidelines are reviewed and updated by the Committee on TCCC (CoTCCC) on an ongoing basis. The CoTCCC is composed of trauma surgeons, emergency medicine physicians, combatant unit physicians, combat medics, corpsmen, and pararescue jumpers (28). The CoTCCC now functions as the prehospital arm of the Department of Defense Joint Trauma System. The TCCC effort at present also includes representatives from the many organizations within the Department of Defense and from our allied nations who work to advance trauma care.

Tactical Combat Casualty Care has helped to introduce major advances in battlefield trauma care. Tourniquets, for example, which were discouraged by the US medical establishment at the start of the Afghanistan conflict, have since been reintroduced because of a strong combined effort from TCCC and other US military command and medical and research organizations. It is said that tourniquets have been the signature success in prehospital trauma care in Afghanistan and Iraq.

Before their reintroduction, US military personnel were taught that tourniquets should be used only as a last resort for extremity hemorrhage control. This approach was essentially the same as that used in Vietnam, where 7.9% of fatalities resulted from exsanguination from extremity wounds (29). At the start of the Afghanistan conflict, similarly high rates of potentially preventable deaths due to extremity hemorrhage persisted (30). However, following the expanded use of tourniquets in accordance with TCCC guidelines in 2005, this cause of preventable death declined sharply to a rate of only 2.6% over a period from 2001 to 2011 (3). It is felt that this dramatic decrease in death from extremity hemorrhage is a direct result of the ubiquitous fielding and aggressive use of modern tourniquets (31). This is further highlighted by the success seen in the 75th Ranger Regiment over the same period, where potentially preventable prehospital deaths dropped to zero. This has been attributed in part to the Ranger First Responder course, where every ranger is taught to perform the lifesaving external hemorrhage control interventions recommended by TCCC for himself and his teammates (32).

TABLE 1. **TCCC guidelines 2013 excerpts**

- Phased care to ensure that the care provided to casualties is appropriate to the tactical flow during a combat engagement. These phases include care under fire, TFC, and tactical evacuation care
- Combat Gauze to control life-threatening hemorrhage from external bleeding at sites not amenable to tourniquet use
- Using sit-up and lean-forward positioning if possible for initial airway management in casualties with maxillofacial trauma
- Surgical airways when needed for airway compromise due to maxillofacial trauma when sit-up and lean-forward positioning is not feasible or if unsuccessful
- Intravenous access only when required for medications or fluid resuscitation
- Intraosseous access when vascular access is needed, but intravenous access is difficult
- Hypotensive resuscitation with Hextend for casualties in shock when no blood products are available
- Battlefield analgesia with oral transmucosal fentanyl citrate lozenges or ketamine, rather than intramuscularly administered morphine
- TXA for casualties at risk of hemorrhagic shock
- Junctional tourniquets for hemorrhage in junctional areas where extremity tourniquets cannot be used
- An easy-to-use TCCC Casualty Card documenting POI care and after-action report

The TCCC guidelines cover the breadth of US prehospital battlefield casualty management. An example includes the use of aggressive needle thoracostomy for the treatment of suspected tension pneumothorax, with a 3.25-inch needle now being recommended rather than the shorter 2-inch needle that was used previously. Further examples of the 2013 guidelines can be seen in Table 1.

Blood product considerations in combat casualty care—the Netherlands experience

Prehospital treatment of battlefield casualties within the Dutch military is broadly similar to that of the UK and US military. Being part of NATO, it adheres to the same medical doctrine mentioned previously and utilizes similar management protocols, including the TCCC guidelines (33). Hemostatic resuscitation is based on rapid hemorrhage control and hypotensive resuscitation with crystalloids or colloid fluid (Hextend), with emphasis placed on early evacuation to surgical facilities. Currently, there is no capability for blood product resuscitation forward of the Role 2 MTFs.

Literature from the current conflicts in Afghanistan and Iraq reports that as many as 15% of casualties will require massive transfusions (>10 units in 24 h) and that mortality in this group is 20% to 50% (34, 35). The recent concept of hemostatic resuscitation involves the immediate and sustained provision of blood products, while paying particular attention to appropriate transfusion ratios. Underpinning this concept is the understanding that circulating whole blood contains red blood cells, plasma, and platelets, and therefore resuscitation should include replacement of each of these components early and ideally before trauma-induced coagulopathy developing (36–38). For this reason, many trauma experts currently recommend early transfusion with PRBCs, fresh frozen plasma, and platelets in a 1:1:1 ratio, thus restoring volume, oxygen carrying capacity, plasma-borne coagulation factors, and thrombus-generating platelets (39). Accepting that early blood product provision in trauma is now the standard of care raises the question of how these products can be provided and reliably resupplied, particularly in remote or austere environments. The inability to provide an appropriate range of blood products potentially undermines the resuscitative capability of any Role 2 facility. It is further complicated by fluctuating demand, which may be unpredictable at times.

Traditionally, there have been two methods of providing blood products to military operations: The first is continual resupply with refrigerated liquid products from a central (military) organization in the home country. This is severely limited by the shelf life of these products and requires complex logistical solutions (40). The shelf life of commonly used blood products can be seen in Table 2. The alternative model has been the use of warm, fresh whole blood, relying on blood donation at the time of transfusion requirement. Fresh whole blood has a number of beneficial features (41, 42), including the fact it has not undergone prolonged storage, with the inevitable deterioration of the product. Often referred to as the "walking blood bank," it will almost certainly remain an option under extreme circumstances (43), but has some potentially significant disadvantages including the risk of infection transmission and the need for a large donor pool. A third, more recent, option is cryopreservation of blood products, whereby their biological structure and function are preserved by storing them at ultralow temperatures. To date, this is the only technique available to substantially extend the shelf life of blood products required for effective hemostatic resuscitation strategies where resupply times are impractical.

The Netherlands Military Blood Bank (MBB) is able to reliably, sustainably, and effectively support their military operations on land and at sea with the required blood products (44). Blood is purchased from the Sanquin Blood Foundation, the central civilian agency responsible for the collection, processing, and testing of all blood products in the Netherlands. The MBB is then entirely responsible for processing, deep freezing (cryopreservation to −80°C), storing, dispensing, and administering all deep frozen products. It supplies cryopreserved glycerolized PRBCs (type O), leuko-depleted platelets, and deep frozen, male-only AB plasma (DFP). Shelf life of these products can be seen in Table 2. Thawing of frozen platelets and frozen plasma takes 5 to 30 min, depending on product, and in the case of frozen red cells, thawing and deglycerolization are required extending the process to 100 min. However, once thawed, the

TABLE 2. **Shelf life comparison between standard liquid stored blood products and deep frozen blood products (the Netherlands MBB)**

Blood product	Standard liquid	Deep frozen (at −80°C)
Red blood cells	35 d at 4°C	10 y*
Plasma	2 y at −30°C	7 y†
Platelets	7 d at 22°C	2 y‡

*+2 Weeks at 4°C after sterile thawing and washing.
†+1 Week at 4°C after thawing.
‡+6 h At 22°C after thawing.

PRBCs may be stored for 14 days at 2°C to 6°C until needed. (This has been a Food and Drug Administration–approved procedure since 2002.) Worthy of note is the fact that thawed deep frozen platelets are activated and that the onset of clotting and clot development is faster compared with fresh platelets. They have been shown to be more effective *in vivo* at stopping nonsurgical bleeding than liquid stored platelets (45).

The frozen products are stored at −80°C in mechanical freezers, with carbon dioxide backup cylinders (maintaining the freezer at −65°C or lower) should electrical or mechanical occur. Products are then transferred to ships or operational peripheral blood banks using dry ice (intrinsic temperature of −80°C) in transport containers, with a capacity of 10 to 192 units. These containers will maintain the products at the required temperature for 4 to 8 days, depending on the volume of dry ice added and environmental conditions.

Once cryopreserved products have been deep frozen, stored, and then transported to the operational environment, there is a requirement for an appropriate in-theater facility to store, thaw, and process the products. The Dutch have developed specific containers to provide this capability, termed *peripheral blood banks*. Although advantageous, they are not mandatory. A deep frozen capability can be achieved by allocating an area of a Role 2 facility as the "peripheral blood bank," with the required equipment transported in separate containers. This is the preferred option for maritime operations.

The development of effective cryopreservation techniques for PRBCs, DFP, and platelets, which maintains *in vivo* biological activity, has provided the option of a unique blood banking strategy. This technology greatly enhances the storage life of vital products, making the provision of these products in remote and austere environments more reliable. The Netherlands military have demonstrated the ability to establish just such a capability to support their military operations, both at sea and on land. Over the last decade, this capacity has provided deep frozen blood products to casualties in Bosnia, Liberia, Iraq, Pakistan, Somalia, and Afghanistan. In the last 6 years, 1,011 patients have been transfused with 7,125 units of deep frozen blood products (2,439 PRBCs; 3,001 DFP; and 1,070 platelets), compared with the transfusion of 879 units of standard liquid PRBCs over the same period. Greater than 95% of the transfusions were in trauma patients, of which 14% required a massive blood transfusion. In these massively transfused patients, survival improved from 44% (n = 16) to 84% (n = 32) after the introduction of a "1:1:1 transfusion policy" in November 2007 (46). During this period, no fresh whole blood was used, and no blood shortages were encountered.

Other defense forces could potentially enhance their transfusion ability by adopting a similar strategy, whereas partnering in current multioperational settings could help overcome many of the technical and logistic obstacles to the establishment of such a service.

SUMMARY

What is evident is that countries have adopted differing strategies with the aim of achieving the same goal: to push advanced DCR techniques forward of the surgeon and into the prehospital setting, to improve battlefield casualty survival. We must continue to work together and learn from each other to achieve this goal. We must also continue to work alongside our civilian colleagues so that the benefits of translational experience are not lost. Further research and development are needed, focusing on technology and concepts specific to the prehospital military environment, to produce better "field-ready" products, improve portable monitoring and testing devices, and develop appropriate goal-directed therapy protocols. We should also learn from history: many of these "new" concepts have been utilized before. As Aldous Huxley said, "that men do not learn very much from the lessons of history is the most important of all the lessons of history."

REFERENCES

1. Glassberg E, Nadler R, Gendler S, Abramovich A, Spinella PC, Gerhardt RT, Holcomb JB, Kreiss Y: Freeze Dried Plasma at the Point of Injury—From Concept to Doctrine. *Shock* 40(6):444–450, 2013.
2. Lipsky AM, Abramovich A, Nadler R, Feinstein U, Shaked G, Kreiss Y, Glassberg E: Tranexamic acid in the prehospital setting: Israel Defense Forces' initial experience. *Injury* 45(1):66–70, 2014.
3. Glassberg E, Nadler R, Rasmussen TE, Abramovich A, Erlich T, Blackbourne LH, Kreiss Y: Point-of-injury use of reconstituted freeze dried plasma as a resuscitative fluid: a special report for prehospital trauma care. *J Trauma Acute Care Surg*. 75(2 Suppl 2):S111–S114, 2013.
4. Holcomb JB, Wade CE, Michalek JE, Chisholm GB, Zarzabal LA, Schreiber MA, Gonzalez EA, Pomper GJ, Perkins JG, Spinella PC, et al.: Increased plasma and platelet to red blood ceil ratios improves outcome in 466 massively transfused civilian trauma patients. *Annals of surgery* 248(3):447–458, 2008.
5. Makley AT, Goodman MD, Friend LA, Deters JS, Johannigman JA, Dorlac WC, Lentsch AB, Pritts TA: Resuscitation with fresh whole blood ameliorates the inflammatory response after hemorrhagic shock. *J Trauma* 68(2): 305–311, 2010.
6. Blackbourne LH, Baer DG, Eastridge BJ, Kheirabadi B, Bagley S, Kragh JF Jr, Cap AP, Dubick MA, Morrison JJ, Midwinter MJ, et al.: Military medical revolution: prehospital combat casualty care. *J Trauma Acute Care Surg* 73(6 Suppl 5):S372–S377, 2012.
7. Blackbourne LH, Baer DG, Eastridge BJ, Renz EM, Chung KK, Dubose J, Wenke JC, Cap AP, Biever KA, Mabry RL, et al.: Military medical revolution: deployed hospital and en route care. *J Trauma Acute Care Surg* 73(6 Suppl 5):S378–S387, 2012.
8. Eastridge BJ, Mabry RL, Seguin P, Cantrell J, Tops T, Uribe P, Mallett O, Zubko T, Oetjen-Gerdes L, Rasmussen TE, et al.: Death on the battlefield (2001–2011): implications for the future of combat casualty care. *J Trauma Acute Care Surg* 73(6 Suppl 5):S431–S437, 2012.
9. Bellamy RF: The causes of death in conventional land warfare: implications for combat casualty care research. *Mil Med* 149(2):55–62, 1984.
10. Scope A, Farkash U, Lynn M, Abargel A, Eldad A: Mortality epidemiology in low-intensity warfare: Israel Defense Forces' experience. *Injury* 32(1):1–3, 2001.
11. Mabry RL, Holcomb JB, Baker AM, Cloonan CC, Uhorchak JM, Perkins DE, Canfield AJ, Hagmann JH: United States Army Rangers in Somalia: an analysis of combat casualties on an urban battlefield. *J Trauma* 49(3):515–528; discussion 528–529, 2000.
12. Holcomb JB, McMullin NR, Pearse L, Caruso J, Wade CE, Oetjen-Gerdes L, Champion HR, Lawnick M, Farr W, Rodriguez S, et al.: Causes of death in U.S. Special Operations Forces in the global war on terrorism: 2001–2004. *Ann Surg* 245(6):986–991, 2007.
13. Joint Doctrine Publication 4-03 (JDP 4-03). 3rd ed. March 2011. Available at: www.gov.uk/government/uploads/system/uploads/attachment_data/file/36065/20121115_jdp4_03_inc_Chg_1_.pdf. Accessed October 2013.
14. NATO Life and Limb Saving Timeline. Committee of the Chiefs of Military Medical Services in NATO, June 2011. Available at: www.coemed.hu/coemed/images/stories/nato_medical_lessons_learned_newsletter_sep_2011.pdf. Accessed October 2013.
15. Pringle JH: Notes on the arrest of hepatic hemorrhage due to trauma. *Ann Surg* 48(4):541–549, 1908.
16. Stone HH, Strom PR, Mullins RJ: Management of the major coagulopathy with onset during laparotomy. *Ann Surg* 197(5):532–535, 1983.
17. Rotondo MF, Schwab CW, McGonigal MD, Phillips GR 3rd, Fruchterman TM, Kauder DR, Latenser BA, Angood PA: "Damage control": an approach for improved survival in exsanguinating penetrating abdominal injury. *J Trauma* 35(3):375–382; discussion 382–383, 1993.

18. Hodgetts TJ, Mahoney PF, Kirkman E: Damage control resuscitation. *J R Army Med Corps* 153(4):299–300, 2007.
19. Holcomb JB: Damage control resuscitation. *J Trauma* 62(Suppl 6):S36–S37, 2007.
20. Rasmussen TE, Gross KR, Baer DG: Where do we go from here? *J Trauma Acute Care Surg* 75(2 Suppl 2):S105–S106, 2013.
21. Gerhardt RT, Strandenes G, Cap AP, Rentas FJ, Glassberg E, Mott J, Dubick MA, Spinell PC, THOR Network and RemTORN Study Groups: Remote damage control resuscitation and the Solstrand Conference: defining the need, the language, and a way forward. *Transfusion* 53(Suppl 1):9S–16S, 2013.
22. Lipsky AM, Ganor O, Abramovich A, Katzenell U, Glassberg E: Walking between the drops: Israeli Defense Forces' fluid resuscitation protocol. *J Emerg Med* 44(4):790–795, 2013.
23. Lakstein D, Blumenfeld A, Soklov T, Lin G, Bssorai R, Lynn M, Ben-Abraham R: Tourniquets for hemorrhage control on the battlefield: a 4-year accumulated experience. *J Trauma* 54(Suppl 5):S221–S225, 2003.
24. Schwartz D, Glassberg E, Nadler R, Hirschhorn G, Marom OC, Aronson-Daniel L: Injury patterns of solders in the second Lebanon war. *J Trauma Acute Care Surg* 76(1):160–166, 2014.
25. The Operational Patient Care Pathway (a paper by Medical Operations and Capability—Headquarters Surgeon General). Joint Service Publication 950, Leaflet 1-4-1, July 15, 2013. Currently not in open source format.
26. Kehoe A, Jones A, Marcus S, Nordmann G, Pope C, Reavley P, Smith C: Current controversies in military pre-hospital care. *J R Army Med Corps* 157(3 Suppl 1):S305–S309, 2011.
27. Hodgetts TJ, Mahoney PF, Russell MQ, Byers M: ABC to <C>ABC: redefining the military trauma paradigm. *Emerg Med J* 23(10):745–746, 2006.
28. Morrison JJ, Oh J, DuBose JJ, O'Reilly DJ, Russell RJ, Blackbourne LH, Midwinter MJ, Rasmussen TE: En-route care capability from point of injury impacts mortality after severe wartime injury. *Ann Surg* 257(2):330–334, 2013.
29. Apodaca A, Olson CM Jr, Bailey J, Butler F, Eastridge BJ, Kuncir E: Performance improvement evaluation of forward aeromedical evacuation platforms in Operation Enduring Freedom. *J Trauma Acute Care Surg* 75(2 Suppl 2): S157–S163, 2013.
30. Butler FK Jr, Blackbourne LH: Battlefield trauma care then and now: a decade of Tactical Combat Casualty Care. *J Trauma Acute Care Surg* 73(6 Suppl 5): S395–S402, 2012.
31. Maughon JS: An inquiry into the nature of wounds resulting in killed in action in Vietnam. *Mil Med* 135(1):8–13, 1970.
32. Kelly JF, Ritenhour AE, McLaughlin DF, Bagg KA, Apodaca AN, Mallak CT, Pearse L, Lawnick MM, Champion HR, Wade CE, et al.: Injury severity and causes of death from Operation Iraqi Freedom and Operation Enduring Freedom: 2003–2004 versus 2006. *J Trauma* 64(2 Suppl):S21–S27, 2008.
33. Kotwal RS, Butler FK, Edgar EP, Shackelford SA, Bennett DR, Bailey JA: Saving lives on the battlefield: a Joint Trauma System review of pre-hospital trauma care in Combined Joint Operating Area–Afghanistan (CJOA-A) executive summary. *J Spec Oper Med* 13(1):77–85, 2013.
34. Kotwal RS, Montgomery HR, Kotwal BM, Champion HR, Butler FK, Mabry RL, Cain JS, Blackbourne LB, Mechler KK, Holcomb JB: Eliminating preventable death on the battlefield. *Arch Surgery* 146:1350–1358, 2011.
35. Tactical Combat Casualty Care Guidelines, September 2012. *J Spec Oper Med*. Available at: www.JSOMonline.org. Accessed October 2013.
36. Beekley AC, Martin MJ, Spinella PC, Telian SP, Holcomb JB: Predicting resource needs for multiple and mass casualty events in combat: lessons learned from combat support hospital experience in Operation Iraqi Freedom. *J Trauma* 66(4 Suppl):S129–S137, 2009.
37. Neuhaus SJ, Wishaw K, Lelkens C: Australian experience with frozen blood products on military operations. *Med J Aust* 192(4):203–205, 2010.
38. Shaz BH, Dente CJ, Harris RS, MacLeod JB, Hillyer CD: Transfusion management of trauma patients. *Anesth Analg* 108(6):1760–1768, 2009.
39. Dries DJ: The contemporary role of blood products and components used in trauma resuscitation. *Scand J Trauma Resusc Emerg Med* 18(63):63, 2010.
40. Mitra B, Mori A, Cameron PA, Fitzgerald M, Paul E, Street A: Fresh frozen plasma (FFP) use during massive blood transfusion in trauma resuscitation. *Injury* 41(1):35–39, 2010.
41. Rosenblatt MS, Hirsch EE, Valeri CR: Frozen red blood cells in combat casualty care: clinical and logistical considerations. *Mil Med* 159(5):392–397, 1994.
42. Bowling E, Pennardt A: The use of fresh whole blood transfusions by the SOE medic for hemostatic resuscitation in the austere environment. *J Spec Oper Med* 10(3):25–35, 2010.
43. Spinella PC, Perkins JG, Grathwohl KW, Beekley AC, Holcomb JB: Warm fresh whole blood is independently associated with improved survival for patients with combat-related traumatic injuries. *J Trauma* 66(4 Suppl):S69–S76, 2009.
44. Lelkens CC, Koning JG, de Kort B, Floot IB, Noorman F: Experiences with frozen blood products in the Netherlands military. *Transfus Apher Sci* 34(3): 289–298, 2006.
45. Khuri SF, Healey N, MacGregor H, Barnard MR, Szymanski IO, Birjiniuk V, Michelson AD, Gagnon DR, Valeri CR: Comparison of the effects of transfusions of cryopreserved and liquid preserved platelets on hemostasis and blood loss after cardiopulmonary bypass. *J Thorac Cardiovasc Surg* 117(1):172–183; discussion 183–184, 1999.
46. Valeri CR, Ragno G: An approach to prevent the severe adverse events associated with transfusion of FDA-approved blood products. *Transfus Apher Sci* 42(3):223–233, 2010.