ELSEVIER
SAUNDERS

Surg Clin N Am 87 (2007) 157–184

SURGICAL
CLINICS OF
NORTH AMERICA

Lessons Learned from Modern Military Surgery

Alec C. Beekley, MD*, Benjamin W. Starnes, MD, James A. Sebesta, MD

US Army Medical Corps, Madigan Army Medical Center, 9040 Fitzsimmons Avenue, Fort Lewis, WA 98431, USA

The terrorist attacks of September 11, 2001 on the United States marked the beginning of the "Global War on Terror." The United States military responded with the first massive deployment of troops from all branches of service since the Persian Gulf War of 1991. Unlike that conflict, in which prewar casualty estimates far exceeded the actual number of casualties sustained, Operations Iraqi and Enduring Freedom have generated casualties in the largest numbers the United States military has sustained since the Vietnam War. As of June 23, 2006, a total of 18,572 United States military personnel have been wounded in Operation Iraqi Freedom, and another 773 have been wounded in Operation Enduring Freedom. Of these 19,345 casualties, 8975 of them have been wounded seriously enough to warrant evacuation out of the theaters of operations. In addition, 2511 soldiers or Department of Defense civilians have been killed in Operation Iraqi Freedom; 528 of these deaths were from non-hostile causes. An additional 302 personnel have been killed in and around Afghanistan [1].

The collection of combat casualty data from these operations has resulted in the largest combat trauma database in existence, dubbed the Joint Theater Trauma Registry (JTTR). Data from deployed medical and surgical units are pooled in a central databank at the United States Army Institute of Surgical Research at Brooke Army Medical Center in San Antonio. These data are currently being linked across three continents so that casualty data from point of injury to ultimate outcome in stateside military

The views expressed in this paper are those of the authors and do not reflect the official policy or position of the Department of the Army, the Department of Defense, or the United States Government.

* Corresponding author.
E-mail address: alec.beekley@amedd.army.mil (A.C. Beekley).

doi:10.1016/j.suc.2006.09.008 *surgical.theclinics.com*

medical facilities can be tracked. The logistic, administrative, and technical hurdles involved in this undertaking are obviously enormous, and the process and ease by which individual casualties or groups can be tracked is still somewhat cumbersome. Nevertheless, data analysis and actionable research findings continue to be generated from this extraordinary set of trauma data.

The evolution of a streamlined trauma system in the theaters of operations [2], the introduction of an in-theater institution review board process, and dedicated personnel to collect combat casualty data have resulted in improved data capture and real-time, on-the-scene research (personal communication, John B. Holcomb, MD COL, US Army Medical Corps, 2006). The result has been the generation of a tremendous body of research on multiple facets of combat casualty care; only a handful of topics are touched on in the current article.

This article first identifies how new or improved devices, dressing, or drugs have impacted prehospital care of casualties, and how prehospital triage guidelines and resuscitation strategies have been changed. The second section focuses on lessons learned at the level of surgical care of combat casualties, and how these concepts are crossing back into civilian practice and training initiatives. The authors conclude with a brief look at the future of combat casualty and, by extension, civilian trauma patient care.

Prehospital devices, dressings, and drugs

Improved helmets and body armor

There is overwhelming evidence that most survivable war injuries since the beginning of recorded time have been predominantly extremity injuries. This observation remains true of the current conflict [3]. Truncal injuries in prior conflicts carried an initial high mortality rate and many casualties did not survive to receive surgical treatment. Lethality of truncal injuries and effectiveness of modern body armor predict that a thorough understanding of the management of extremity injury to include complex vascular repair is paramount for successful outcome in most cases. The Israeli Trauma Group evaluated 669 recent terror-related firearm injuries and found that not only did body armor have a protective effect against high-velocity gunshot wounds but it also reduced the actual severity of injuries sustained to the chest and abdomen [4]. Current operational security restrictions prohibit detailed discussion of modern United States military body armor and resultant changes in wound patterns. Nevertheless, already published data suggest that because of the effectiveness of body armor, distinct new patterns of combat injuries are being encountered [5–7].

The combat casualty often presents to a treatment area with full body armor and armed with weapons or other ordnance, which may have been carried by the soldier or may be embedded in tissue (Figs. 1 and 2). Knowledge

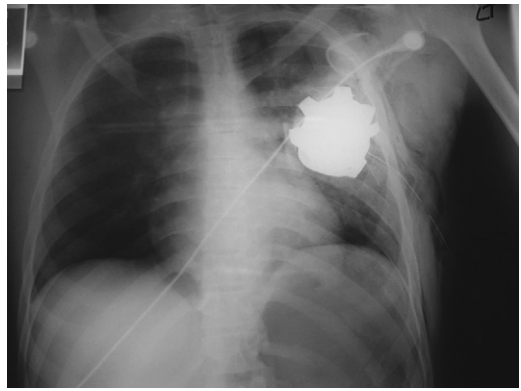

Fig. 1. Portable AP chest radiograph of patient who was hit during a firefight. The radiograph generated initial concern regarding the possibility that the patient had unexploded ordnance in his chest.

in the safe removal of this body armor and safe disarmament and storage of weapons and ordnance remains of paramount importance in protecting the casualty and the health care provider from grave injury. All United States military body armor has favorable photon attenuation characteristics. When medically advantageous, patients wearing standard military body armor can be examined radiographically with standard plain films or computed tomography [8].

Tourniquets

Prehospital tourniquet use, at times a matter of debate in trauma circles [9,10], plays a central role in hemorrhage control on the modern battlefield. Data from Bellamy's [11] landmark paper on causes of death on the modern

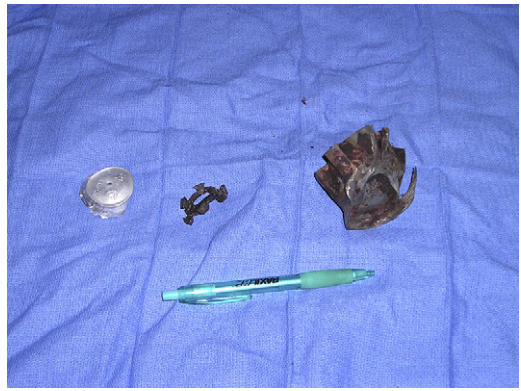

Fig. 2. Operation revealed tail-piece fragments from an explosive munition.

battlefield demonstrated that 9% of soldiers killed in action during the Vietnam War died of extremity hemorrhage. Initial evaluation of those killed in action in Iraq demonstrates a similar rate of soldiers dying from compressible extremity hemorrhage [12].

Analysis of casualties who arrived at a single combat support hospital (CSH) in Iraq with major vascular injuries or traumatic amputations treated with prehospital tourniquets demonstrated significantly improved hemorrhage control over those casualties who did not have prehospital tourniquets applied for the same injuries [13]. Although no survival benefit of tourniquets was identified in this data set (the data are notably biased to those casualties who survived to reach the CSH), analysis of the seven soldiers who did die of their wounds in this data set found that four of the deaths potentially could have been prevented if properly applied tourniquets had been used. Anecdotal reports of soldiers dying from hemorrhage from isolated extremity wounds potentially amenable to tourniquets have been published in national media outlets [14]. Finally, average prehospital tourniquet time was only 70 minutes, and no complications directly related to tourniquet use (secondary amputation, peripheral nerve injury) were identified in this group of patients.

The results of the cause of death analyses from the Vietnam War and Operation Iraqi Freedom, combined with the early experience described above, have resulted in fielding of individual tourniquets to each soldier. As of August 2005, more than 275,000 tourniquets had been deployed overseas to combat theaters (personal communication, John B. Holcomb, MD, COL, US Army Medical Corps, 2005) Current military doctrine mandates use of a tourniquet as a first-line treatment for casualties who have extremity hemorrhage when care is administered under hostile fire. Once the casualties are removed from hostile fire, the need for the tourniquet may be reassessed to determine if a lesser form of hemorrhage control (eg, a pressure dressing) would be sufficient [15]. In practice, this doctrine has resulted in many casualties arriving to a level of surgical care with tourniquets in place for extremity injuries, even when subsequent evaluation revealed that the tourniquets were not necessary (personal communication, Matthew J. Martin, MD, LTC, US Army Medical Corps, 2006). This current doctrine and the resulting liberal practical application are similar to those described by Lakstein and colleagues [16] in the Israeli Defense Forces study on prehospital tourniquet use. In the Israeli experience, 47% of tourniquets applied subsequently were deemed non-indicated.

The substantial number of casualties arriving to hospitals with prehospital tourniquets has provided lessons for surgeons treating these casualties. First, casualties who sustained traumatic amputations, mangled extremities, or major vascular injuries may have had substantial hemorrhage before first responder treatment and tourniquet application. Bleeding may have slowed or stopped spontaneously because of hypotension combined with vessel spasm and retraction. The cues the medic looks for to know if a tourniquet

has been tightened enough (cessation of bright red bleeding) may not be present, or the pressure required to stop arterial bleeding may not be very high. The tourniquets thus may not be tight enough to control hemorrhage once resuscitation begins and higher blood pressures are restored. An only venous tourniquet can lead to more rapid exsanguination, which may not be noted immediately by providers if the patient is covered by blankets, warming devices, or surgical drapes. To prevent this rebleeding phenomenon, our practice is to bring pneumatic tourniquets from the OR to the ER and immediately replace a patient's field tourniquets with pneumatic tourniquets. We also recommended that surgical units' emergency bays stock pneumatic tourniquets so they are available immediately if needed.

Second, current military prehospital doctrine and training now emphasize that casualties who have hemorrhage control, normal mentation, and stable vital signs (even mild hypotension, or systolic blood pressure at 90), should have intravenous access established in the field but fluid administration withheld or minimized [17]. Casualties who have abnormal mental status, signs of intracranial injury, or profound hypotension are administered fluids, although in certain instances (eg, mass casualty situations) these casualties may be triaged into an expectant category. The practice of permissive hypotension is designed to decrease the incidence of rebleeding from quiescent or partially controlled hemorrhage sites. Receiving physicians must be aware that casualties may have received little or no resuscitation. Our strategy in patients who have proximal or multiple tourniquets, who present with hypotension, is to initiate a massive transfusion protocol emphasizing hemostatic products and early use of fresh whole blood. This strategy is discussed in greater detail later in this article.

Finally, the liberalized use of tourniquets must be studied to ensure that tourniquet-related ischemic or neurologic injuries are not occurring at unacceptably high rates, particularly in those patients on whom tourniquet use was retrospectively identified as unnecessary. Our series demonstrated no ischemic or peripheral neurologic injuries that could be related clearly to tourniquet use. The assessment of the causative factors for ischemia and peripheral neurologic deficits can be difficult in these patients because frequently adjacent nerves along with major vascular structures are injured by the wounding agent.

Hemostatic dressings

Hemostatic dressings are designed to treat battlefield injuries to proximal vascular structures not amenable to tourniquet control but nevertheless compressible with manual pressure. This type of proximal vascular injury was graphically illustrated in the film *Black Hawk Down*, in a scene with medics attempting to control bleeding from a soldier's transected external iliac/common femoral artery in a dark field environment. The scene demonstrated the success of direct manual pressure and the difficulty of attempting

to place surgical clamps on the bleeding vessel without appropriate lighting, anesthesia, and retraction. This event and others like it have guided research toward advanced dressings that could be applied to such a wound in a similar fashion to standard dressings but would have hemostatic products incorporated in the dressing to enhance or augment the body's own clotting mechanisms.

Although multiple products are available on the market, two products have been deployed by the United States military in large numbers into battlefield settings. These two products are zeolite (QuikClot, Z-Medica Corporation) and chitosan (HemCon, HemCon Hemorrhage Control Technologies, Inc.). The choice to deploy these products was based on their relative ease in application, portability, durability, and demonstrated success in controlling hemorrhage in animal models.

Zeolite, a granular mineral-based product, causes an exothermic reaction when exposed to water or blood, thereby concentrating blood-clotting factors and accelerating hemostasis [18,19]. Compared with standard gauze dressings, zeolite has been demonstrated to provide superior hemostasis, decreased blood loss, and decreased resuscitation requirements in several animal injury models, including a grade V liver injury [20] and a lethal groin injury model in swine [21]. Currently, only anecdotal reports regarding its use in humans exist [22], although a clinical series of casualties who had zeolite used on their wounds on modern battlefields has been collected and is being prepared for publication (personal communication, Matthew J. Martin, MD, LTC, US Army Medical Corps, 2006). Several concerns have been raised regarding the amount of heat generated by the dressing [22] and its stability during movement and transport of casualties. As a result, the company that produces QuikClot has recently marketed a product that contains the zeolite granules inside a gauze sack that is applied to the wound rather than pouring the free zeolite granules themselves into the wound [23,24]. As this product evolves it will require continued evaluation in carefully controlled animal studies and review of clinical uses in prehospital and hospital settings.

Another hemostatic product currently deployed in battlefield settings is the chitosan-based hemostatic dressing, HemCon. Chitosan is a nontoxic, biodegradable, complex carbohydrate derivative of chitin, a naturally occurring substance. In its acid salt form, chitosan has mucoadhesive properties that augment hemostasis [25]. The current deployed dressing product is lightweight and flexible and has no special storage requirements. It comes in a package similar to other standard dressings and can be opened rapidly and applied to a wound. It has a nonadhesive surface on the inactive side of the dressing to avoid sticking to the care provider's gloves, hands, or other standard gauze dressings and dislodging. Both the liquid forms of chitosan and the dressing that has been deployed in battlefield settings have demonstrated superiority in hemorrhage control over standard dressings in multiple animal models [26–28]. In addition, Wedmore and colleagues [29]

recently reported on the use of chitosan-based hemostatic dressings (HemCon) in 64 patients in a combat casualty setting. In 66% of these uses, chitosan dressings were used after standard gauze had failed and the chitosan dressings were successful 100% of the time. In 62 cases (97%), use of the chitosan dressing resulted in cessation of bleeding or improved hemostasis. The two failures of the chitosan dressings occurred in patients who had large cavitational wounds in which the bleeding sites were multiple or in which the chitosan was placed blindly into the cavity [29]. Anecdotal reports from medics and observations during live tissue training revealed similar pitfalls in the use of HemCon dressing. Like QuikClot, these limitations include rebleeding with resuscitation or dislodging of the dressing during transport of the casualty.

Overall, the animal injury models and early clinical experience demonstrate a clear superiority of these dressings over standard gauze dressings in providing hemorrhage control, particularly in injuries not amenable to tourniquet use. Further study and refinement of these dressings is necessary and ongoing.

Needle thoracostomy

In a review of the Vietnam Wound Data and Munitions Effectiveness Team study, tension pneumothorax was found to be the cause of death in 3% to 4% of fatal combat wounds [30]. In this review, 15 of the 26 casualties who had tension pneumothorax survived long enough to receive first aid from a medic or other medical personnel. These data confirm the need for proper training of medics and other care providers in early echelons of care to prevent these deaths. The use of needle thoracostomy in urban trauma systems has come under fire recently by some who believe that it is overused and ineffective [31–34]. This belief should not be applied to combat situations in which the most common mechanism of trauma is penetrating injuries. In addition, tactical situations and other factors may delay transportation of these patients to treatment facilities capable of diagnosing and definitively treating the tension pneumothorax.

Medics throughout the army are trained to identify and treat a tension pneumothorax. In the combat environment, however, the identification of a tension pneumothorax in the field may be nearly impossible. Most of the casualties have body armor that covers the entire chest and neck and surrounding noise prevents any possibility of auscultation of breath sounds. Medics are instructed to treat any patient who is hypotensive and has chest injury with needle thoracostomy. In addition to the standard placement of a needle in the second or third intercostal space, midclavicular line, medics are also taught to place a needle one hand's width below the axilla in the midaxillary line. This position allows placement without having to remove the soldier's body armor. This is also the thinnest area of the chest, which may prevent improper placement because of inadequate catheter length.

To date, there are no published combat outcomes related to the use of needle thoracostomy or complications recorded.

Intraosseous access

Acute hemorrhage is the leading cause of battlefield deaths in modern warfare, accounting for more than 50% of fatalities [11]. Standard resuscitation of casualties involves the variable administration of fluids or blood products to sustain blood pressure and perfusion of vital organs until hemorrhage can be arrested. More often than not, casualties presenting in overt shock have difficult intravenous access and a more technically demanding surgical venous cut-down is required. Some data suggest that the placement of an intravenous line in a trauma patient in a moving ambulance takes 10 to 12 minutes and has a 10% to 40% failure rate [35]. Translation of these ideal circumstances into a combat situation adds the complexity of a tactically hostile environment often in the dark of night with the need for extreme light discipline. Standard intravenous access often can seem nearly impossible under these circumstances.

Drinker and colleagues [36] introduced the concept of intraosseous infusion in 1922 as a result of a study of circulation of the sternum. Intraosseous vascular access devices are reemerging as an important field treatment option in a military setting [37–39]. Commonplace in the management of civilian pediatric trauma, the advantages of intraosseous infusion over conventional means of vascular access are ease and rapidity of insertion (114 seconds or less in one study [39]) and ability to infuse large amounts of either saline or colloid until better vascular access can be obtained. The adult sternum has distinct advantages as an intraosseous infusion site. The sternum is usually easy to expose in trauma patients and the cortical bone and marrow space are uniform, resisting collapse of the vascular space in the face of shock [38]. Johnson and coworkers [38] recently evaluated the First Access for Shock and Trauma system (Pyng Medical Corp., Vancouver, Canada) in 106 cadavers and found infusion rates of greater than 100 mL/min for either saline or colloid solutions. Rates of up to 250 mL/min could be delivered with single syringe infusion. In this study, a liter of fluid could be infused in less than 10 minutes and insertion force was similar to that of other devices at a mean of 8.5 kg. This system relied on the authors' finding that the thickest part of the manubrium was routinely in the midline of the sternum 15 mm below the sternal notch and this became the preferred insertion site [38].

Other infusion sites are possible and include the adult tibia, femur, iliac crest, humerus, radius, and clavicle [38]. These sites in adults have a large portion of the less vascular yellow marrow, which is inferior to the sternum regarding infusion rates. The entire concept of intraosseous infusion is extremely attractive in a combat setting given the potential number of casualties and long evacuation times, allowing for a stretching of the envelope of

resuscitation when minutes are a matter of life and death because of exsanguinating hemorrhage.

Pain medications and antibiotics by medics

Effective analgesia is an essential part of casualty management. Fewer options exist for relief of pain in a combat situation than in routine civilian medical care. Before the current conflict in Iraq, several Special Operations physicians instituted a protocol of providing each soldier with a wound pack of oral medications containing acetaminophen, rofecoxib, and a fluoroquinolone. Soldiers were instructed to take these medications if wounded to decrease the level of pain and potentially reduce the potential for wound infections in a battlefield environment [40]. Historically, morphine has been administered on the battlefield by way of auto-injectors (10–20 mg intramuscularly) to relieve severe pain [41]. Limitations of intramuscular morphine administration revolve around uncertain rates of absorption. Intravenous morphine provides for rapid pain relief but requires the insertion of a simple intravenous catheter, which often may be delayed by tactical requirements. With newer availability of oral transmucosal fentanyl citrate or "fentanyl lollipops," up to 1600 μg of fentanyl may be self-administered by a casualty and provide rapid analgesia. Only 25% of the drug is absorbed by the oral mucosa and the remainder is absorbed through the gastrointestinal tract [42]. Kotwal and colleagues [42] described the use of fentanyl lollipops on 22 casualties from Operation Iraqi Freedom. Side effects were few but did include nausea and vomiting, suggesting that an antiemetic may be of benefit for simultaneous administration. Advantages of this analgesic technique include the ability of the casualty to titrate to effect. When adequate pain relief is assumed, the soldier can remove the lollipop from his mouth.

Other evolving techniques of battlefield analgesia involve the concept of continuous peripheral nerve block (CPNB). This technique was successfully used by Buckenmaier and coworkers [43] to treat a severely injured soldier's extremity in the current conflict. The technique involves simultaneous continuous lumbar plexus block and sciatic nerve block. Standard epidural catheters are inserted in juxtaposition to the relevant neural plexus after first localizing the nerve with 0.5 mA or less of current transmitted through a peripheral nerve stimulator. The lumbar plexus and sciatic catheters are then infused first with 1% lidocaine as a test dose followed by infusion of 0.2% ropivacaine at 6 mL/hr and 10 mL/hr, respectively [43]. The catheters placed in Iraq were maintained for 16 days without signs or symptoms of infection. Unfortunately, the soldier eventually required below-knee amputation because of ischemic compromise from his war wound. The authors recommend exercising caution with the use of CPNB for potentially ischemic extremities as it may cloud examination findings consistent with an advancing compartment syndrome.

Antibiotics have advanced the successful management of war wounds. Since 1943, when systemic penicillin was introduced onto the battlefield, the risk for wound myonecrosis and gas gangrene has decreased dramatically [44]. Although a useful adjunct, antibiotic treatment cannot replace adequate debridement of devitalized and dead tissue from a war wound. Timing of antibiotic therapy is critical. In an extensive review of the value of antibiotics on the battlefield, Konrad Hell stated in 1991 [45]:

> For prophylaxis for wound sepsis, a single injection of a long-acting, broad-spectrum antibiotic should be given as soon as possible after injury. It should remain at sufficiently high levels in tissues for 24 hours, or over the whole period of risk of infection from the moment of injury until surgical debridement is completed.

Hell suggested that this antibiotic be ceftriaxone; however, today armed forces carry an oral fluoroquinolone for self-administration.

Complications from antibiotic therapy for war wounds also are well described. Current casualty statistics reveal an increased incidence of war wound infection and osteomyelitis, especially caused by multi-drug–resistant *Acinetobacter* species [46]. In fact, many military treatment facilities have reported dramatic increases in the rate of multi-drug–resistant *Acinetobacter* infections. Treatment aimed at these infections poses considerable challenges and at many military treatment facilities involves dual therapy with Imipenem (500 mg every 6 hr) in combination with high-dose Amikacin (15–20 mg/kg daily) [46]. Recent investigation by the military medical community suggests that these are nosocomial infections; however, their exact source remains unclear (Fig. 3).

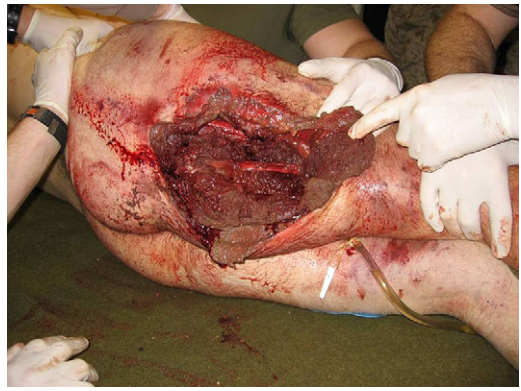

Fig. 3. Casualty who had severe contamination with mud and dirt from fragment wounds. Patients such as this are at high risk for infection even with aggressive surgical debridement and broad-spectrum antibiotic use. (Courtesy of Lowell W. Chambers, MD, Westerville, Ohio.)

Hextend

Hextend (BioTime, Inc) has replaced lactated Ringer as the fluid carried by medics in the field. It is storable at room temperature and has no recommended refrigeration requirements. Hextend is a hydroxyethyl starch in a solution of electrolytes, physiologic levels of glucose, and a lactate buffer. It is believed to provide a more favorable acid–base balance compared with other colloids. It has been shown to reduce resuscitative fluid requirements [47]. Hextend is effective in hypotensive resuscitations and potentially has a benefit as the sole resuscitation fluid after severe traumatic brain injury by reducing fluid requirements and eliminating the need for mannitol without affecting the coagulation profile [48].

Hypothermia prevention

Hypothermia is a significant problem in the management of combat casualties. In a recent review of combat injuries, Arthurs and colleagues [49] showed that 18% of combat casualties presented to the 31st CSH hypothermic (temperature $<36^{\circ}C$). The presence of hypothermia was an independent predictor of operative management, damage control procedures, factor VIIa use, and mortality. Temperature less than 34°C was associated with nearly 100% mortality. It also was associated with longer operative times, larger blood loss, and an increase in blood product requirement. Prevention of hypothermia before arrival to the upper echelon of care is critical and is emphasized at every level of care. At the lowest echelons, medics are trained to treat and prevent hypothermia after addressing ongoing hemorrhage, airway, and breathing problems. This is performed initially by limiting exposure of the patient to areas being treated and then completely covering the patient with blankets or solar blankets. Permissive hypotension is integral in limiting the amounts of cold fluids given to a casualty. In patients who require resuscitation, fluid warming devices, such as the Thermal Angel (Estill Medical Technologies, Inc., Dallas, Texas), can be used. The Thermal Angel is a portable battery-operated fluid warmer. It is disposable and requires no additional parts except for a standard infusion set. The most effective use of this device would probably be during transportation between echelons of care. The battery makes the unit heavy and limits its ability to be carried by medics in the field. In testing, the Thermal Angel was more effective at warming Hextend than lactate Ringer and it was not able to fully rewarm refrigerated fluids [50]. It was able to raise the temperature of Hextend an average of 14.8°C when starting at room temperature. In fixed treatment facilities, larger more effective fluid warmers are used. Additional techniques that have been effective in preventing hypothermia are the use of damage control procedures at forward surgical units and rapid transportation of the patient to higher echelons of care. A body bag is an effective transportation enclosure for patients that can reduce the loss of heat. Casualties are placed in the bag and covered with blankets. A hole is cut for the patient's

face and for fluid access. The bag is closed, leaving only the face of the patient exposed, and then placed on a stretcher for transportation.

Prehospital concepts

Prehospital provider triage guidelines

Triage is a dynamic process that occurs at many levels of care, including the battlefield, battalion aid station, and the level of initial surgical care. For prehospital providers, it is particularly important to have a quick and reliable means of establishing priority of casualties not only for field care but also for order of evacuation on helicopters or ambulances. For this purpose, the traditional categories of immediate, delayed, minimal, and expectant casualties still apply. The definitions of these categories are well established elsewhere [51]. More critical are the training and means by which prehospital providers sort patients into these categories. Recent data demonstrate that manual vital signs and verbal and motor scores of the Glasgow Coma Scale (GCS) are as reliable as more sophisticated monitoring at identifying the need for life-saving interventions [52]. Medics and other prehospital personal are taught to assess radial pulse character and the GCS motor score; those patients who have a strong radial pulse character and a GCS motor score of 6 are triaged to a lower category of urgency. Obviously, patients who have signs of impending or actual airway compromise, uncontrolled hemorrhage, weak radial pulse or decreased mental status without head injury; patients who have penetrating or blunt injuries of the trunk, neck, head, or pelvis; and patients who have multiple long bone fractures are assumed to be unstable and require triage into an immediate category [51].

Permissive hypotension (in prehospital setting)

In 2003, COL John B. Holcomb [53] described the evolution of the term ''hypotensive resuscitation'' in a paper entitled, ''Fluid Resuscitation in Modern Combat Casualty Care: Lessons Learned from Somalia''. The recommended consensus algorithm for resuscitation of combat casualties is one that all military medical personnel should familiarize themselves with before deployment into a combat theater. In 1994, Bickell and colleagues [54] described a no-fluid resuscitation protocol in hypotensive patients after penetrating truncal injuries and concluded that traditional rapid fluid resuscitation significantly decreased survival in these patients. This study was the impetus for a drastic change in philosophy regarding management of an injured soldier on the battlefield and has been adopted by American Military [53,55,56] and Israeli Defense Forces [57].

Small volume resuscitation helps compensate for logistic problems in providing enough fluid on the battlefield to resuscitate a casualty adequately. Combat medics can only carry so much weight and still be effective.

Hypertonic saline dextran or HSD (7.5% NaCl/6% dextran-70) is an effective resuscitation fluid when used in small volumes [58]. The combination of intraosseous infusion and small volume resuscitation in line with the theme of hypotensive resuscitation are attractive and synergistic concepts for arming military first responders with the tools they need to save lives. Studies evaluating the efficacy of these synergistic modalities are currently underway.

Much remains to be elucidated regarding the concept of permissive hypotension. It currently is not known whether permissive hypotension would increase the incidence of late complications resulting from incomplete resuscitation [58]. It must be remembered that permissive hypotension is absolutely contraindicated in the setting of traumatic brain injury because of a resultant severe cerebral hypoperfusion with a potentially catastrophic outcome [59].

Casualty evacuation

Because of tactical situations, the combat casualty often presents to a forward surgical team (FST) or CSH several hours after the injury occurred. Prolonged evacuation time has long been a criticism of casualty care within the combat zone. Incoming fire, the need for light discipline in darkness, and other environmental factors have a profound impact on evacuation times. Military objectives remain to treat casualties in the field, prevent additional casualties, and complete the intended mission. Other than well-planned and executed evacuation routes and mass casualty exercises, there is little that will effect an improvement on evacuation times in a combat zone. This remains a reason to train combat medics, who often accompany these casualties during evacuation, in advanced techniques of resuscitation to include proper control of exsanguinating hemorrhage from wounded extremities.

Casualty evacuation (CASEVAC) can apply to injured soldiers or civilians and is used to denote the emergency evacuation of injured people from a war zone. CASEVAC can be accomplished by ground or air, the latter being done almost exclusively by helicopter. CASEVAC aircraft are not equipped with specific life saving equipment or specially trained medical personnel. Their primary purpose is to ferry personnel from the battlefield to the nearest appropriate medical facility available as quickly as possible. They are permitted to be armed and the pilots and crews often assume much more risk to their plane and crew to evacuate wounded personnel.

Standards for intra-theater medical evacuation are well established and routinely proceed in a unidirectional fashion from point of injury to the third echelon of care, typically a CSH [60–62]. Success of this system depends in large part on the maturity of the combat theater. In the early phases of a conflict, evacuation patterns are not well established and the Army FSTs at level 2 play a crucial role [63]. In 1997, Mattox [64] stated that the success of any forward deployed combat casualty management

system relied on ''qualified first responders,'' continuing care during secondary transport, and optimization of practical tele-medical technology. In reality, a large proportion of casualties presenting to a CSH do not follow standard routes of evacuation. A large number of casualties may be brought in by unit members in armored vehicles or HUMVEES or on flatbed trucks by local nationals, or simply walk in with significant penetrating injury.

Some authors have identified current military en route care as ''not ideal,'' especially in an immature theater where precious personnel and resources are consumed during transport [63]. The current authors express concern over the existing intra-theater medical evacuation system. Rotary wing transport is space constrained and allows limited capacity for en route management of the acutely injured patient. In the authors' experiences, incidences occurred in which a casualty was stabilized at level 2, transported to level 3 by rotary wing, and arrived either in extremis or dead. In-flight monitoring is available but limited because of light discipline and other factors in a typically hostile environment. After-action reviews involving helicopter crews and receiving medical personnel for the purpose of quality and performance improvement are nearly impossible because of the rapid pace and high demands helicopter crews face. Fixed-wing aircraft, although more cumbersome and resource intensive, offer the unique advantage of allowing for general anesthesia and open surgery in flight as described by Peoples and coworkers in 2005 [65]. The intra-theater medical evacuation system, although vastly improved from prior conflicts, is in need of essential improvements to maximize casualty care during secondary transport.

Hospital care: concepts

Triage and evaluation of casualties at the level of surgical care

The manner in which triage was performed at the level of surgical care depended on the physical layout of the treatment facility, the provision of adequate shelter for casualties, and the primary means by which casualties arrived to the facility. Several CSHs regularly received incoming rocket and mortar fire, which on several occasions impacted the structures or the immediate surrounding areas. Creating an unprotected triage area outside the emergency department bay thus was not feasible. In addition, the casualties rarely arrived in large groups, but instead trickled in off multiple helicopter or ground transport vehicles in groups of two to eight patients. Gaining an overview of the entire group of patients before engaging in treatment in a given mass casualty event was difficult.

A rapid assessment using simple manual physical examination parameters, such as GCS and radial pulse character, was again used to sort casualties into three general categories: emergent, non-emergent, and expectant. A single experienced surgeon was designated as the sole triage officer and directed casualties into the main trauma bay if deemed emergent and into

a secondary bay if deemed non-emergent. The triage officer assigned a trauma team, lead by a staff general surgeon, to each emergent casualty. Remaining general surgeons and orthopaedic surgeons would evaluate the non-emergent casualties who had been directed to the secondary emergency bay. As predicted in the latest edition of the War Surgery Manual, only 10% to 20% of arriving casualties would require immediate life-saving interventions. Ambulatory patients who had minor injuries were directed out of the immediate emergency department area to an outpatient clinic area for further assessment.

Casualties were systematically evaluated by the trauma team leader. In the setting of multiple casualties, a portable ultrasound machine to perform focused abdominal sonography for trauma (FAST) was used as a triage and evaluation tool. In unstable patients who had multisystem injuries, a positive FAST directed the surgeon to the operating room for exploration of the abdomen. In stable patients, a positive FAST allowed prioritization of patients going for further imaging using a CT scan. In patients arriving to one CSH after being injured by enemy fire, 3% had a reported motor vehicle crash or other blunt mechanism (eg, fall) as a secondary mechanism after the attack. In at least four of these instances in the authors' experiences, the blunt injury was the one that required surgical intervention.

Negative FAST examination was demonstrated to be unreliable in the authors' experiences, and hence patients with penetrating abdominal, flank, back, and buttock wounds who were hemodynamically stable and had a negative FAST underwent CT scan of the abdomen and pelvis. The presence of intra-abdominal or retroperitoneal fragments generally prompted exploratory laparotomy. Patients without penetration of the peritoneum or retroperitoneum were successfully managed nonoperatively in most cases [66].

Treatment of truncal injuries: damage control

The use of damage control techniques is essential in the management of the combat casualty. Casualties of modern warfare suffer massive tissue injury created by high-velocity weapons and improvised explosive devices (IED). The IED commonly damages patients with a combination of burns, amputation, penetrating, blunt, and inhalation injuries. High-velocity bullets or fragments that penetrate and cross the abdomen or pelvis create devastating injuries involving fractures, bowel, urologic, neurologic, and vascular systems. Tactical situations may delay the treatment and transportation of the patients, resulting in additional blood and heat losses. The constellation of injuries, evacuation times, and limited resources in the face of multiple casualties made damage control techniques essential to avoid physiologic burnout in severely injured patients.

In the experience of one CSH, 92 damage control procedures were performed on patients of all ages. This figure represented nearly 30% of all initial laparotomies. Damage control was the default procedure for casualties

who had multiple injuries, and only if the patient's physiologic status remained stable or improved during the procedure would definitive procedures be performed. The use of damage control surgery was based on the number and types of injuries per patient, the physiologic status of the patient (ie, pH, temperature, and base deficit), and the types and numbers of patients waiting for surgery. A patient who required multiple procedures, such as laparotomy followed by intracranial or major vascular procedures, would have damage control procedures to temporize the abdominal injuries to allow a more rapid intervention on the other wounds. Forward surgical units performed damage control procedures and then promptly evacuated patients to higher echelons, such as the CSH, where more robust treatment capabilities were available. Second-look procedures occurred between 12 and 24 hours but could be performed as soon as the patient's physiologic status had improved. Patients required an average of 3.4 procedures and 77% of those that survived had definitive treatment of their injuries and closure of the abdomen at the CSH. The ability to transport critically injured patients out of the theater, including patients who had open abdomens after the initial damage control procedures, was routinely available. This transportation before definitive repair may be associated with higher complication rates, including failure to close the abdomen. If the patient remained in-theater, the average time to closure was 3.3 days. The overall survival was 72.8% and patients who had damage-control surgery at forward surgical units had a similar outcome of 66.6% survival.

Treatment of vascular injury in the field: damage control

The phrase "damage control" implies a rescue situation in which prevention of further injury is achieved. When applied to extremity vascular injuries, damage control is defined as control of exsanguinating hemorrhage, rapid restoration of blood flow to an ischemic limb and prevention of compartment syndrome. When dealing with the multiply injured patient, limb salvage may be a secondary priority or not a priority at all, depending on the physiologic status of the patient [67]. Pneumatic tourniquets, mentioned previously in this article, have proven invaluable in the combat setting [68]. When appropriately applied, they may serve as a proximal vascular clamp until definitive repair, damage control with rapid placement of an indwelling shunt, or debridement amputation can be performed (Fig. 4).

Shunts

Temporary intraluminal shunts allow for rapid restoration of blood flow to an ischemic limb while other procedures to include wound debridement, external fixation of fractures, or more life saving procedures such as trauma laparotomy or thoracotomy can be accomplished [69–71]. Shunts may be placed easily and rapidly after proximal vascular control with either

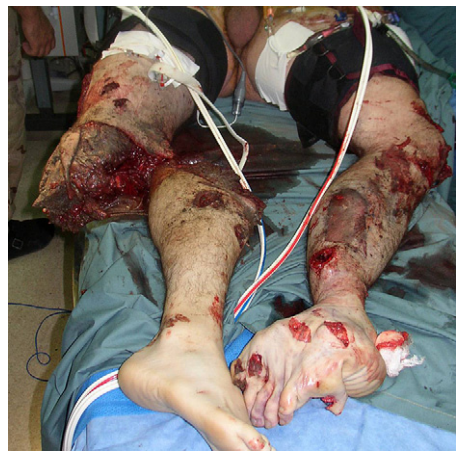

Fig. 4. Pneumatic tourniquets placed in emergency room for patient who had bilateral mangled lower extremities and traumatic amputations.

a pneumatic tourniquet or vascular clamp, and secured in place with Rummel tourniquets or simple silk ties to prevent dislodgement. After placement, patency should be confirmed with intraoperative continuous wave Doppler of the shunt. The authors recommend the specific use of Sundt shunts because their design minimizes risk for dislodgement when appropriately inserted. The Sundt shunt (Integra Lifesciences Corp., Plainsboro, New Jersey) is lined with an inner coil to prevent kinking or collapse. There is one small area within the shunt of discontinuous coils that should be used for clamping if needed. Clamping the shunt in any other location will crush the coil and occlude the shunt.

In a damage control setting in the far forward arena, an appropriately placed shunt can provide enough distal blood flow to perfuse a severely injured extremity until definitive repair can be performed at the CSH or, in some special situations, after strategic evacuation out-of-theater. We emphasize that most casualties who have shunts in place should be evacuated over short distances between facilities in-theater only, such as from the site of injury to an FST or CSH, or from FST to CSH. Casualties may have multiple injuries with associated coagulopathy, thus reducing the need for systemic heparinization [70]. The use of heparin in this setting is controversial, however, as some early reports from Operation Iraqi Freedom report that shunts that were inserted on the battlefield had clotted during tactical evacuation back to the CSH (47th CSH personal communication from MAJ Jerome McDonald, 2005). We emphasize the use of systemic heparinization in stable patients. Once the patient is evacuated to a facility where definitive repair can be performed, wound debridement and orthopedic repair is initiated first followed by vascular reconstruction.

Fasciotomy

One of the most important factors in managing the acutely injured extremity on the battlefield is the liberal use of fasciotomy to avoid or treat compartment syndrome [72]. A thorough understanding of the technique of fasciotomy for upper and lower extremities along with feet and hands must be possessed by a member of the surgical team. Principles for performance of fasciotomy in the lower extremity include two long skin incisions; at least 15 cm, on the medial and lateral aspect of each wounded extremity. Indications for fasciotomy in a combat zone are listed in Box 1.

Note the absence of compartment pressure measurement as an indication. As a routine, compartment pressures are not measured in a combat setting. Because of evacuation times and distance and discontinuous care by multiple providers, the mere thought of measuring compartment pressures should elicit fasciotomy. Regional pain management, such as CPNB, may cloud the examination of a casualty and the decision for fasciotomy should be dictated by the surgeon's experience and index of suspicion for development of compartment syndrome.

Massive transfusion, use of fresh whole blood, and hemostatic resuscitation

Multiple logistic hurdles to maintaining a robust blood bank exist in deployed settings. These hurdles include long transport times, limited number of temperature-controlled storage containers and vehicles, and rapid degradation or use of products. In particular, stored platelets were not readily available to CSHs until late December 2004, when a platelet apheresis machine capable of producing fresh platelets was brought into theater to the 86th CSH (personal communication, Kenneth Azarow, MD, COL, US Army Medical Corps, 2005). In addition, because of the aforementioned logistic problems, the storage age of red blood cells (RBC) in-theater was higher than in stateside trauma centers. The 31st CSH was deployed in

Box 1. Indications for fasciotomy in the combat setting

Greater than 4- to 6-hr evacuation delay to revascularization
Combined arterial and venous injuries
Crush injuries
High kinetic energy mechanism
Vascular repair
Arterial or venous ligation
Comatose, closed head injury, or epidural analgesia
Tense compartments
Prophylactic

Iraq from January to December 2004; during that time, 5294 RBC units were transfused in 930 patients. The mean age of the RBC units on delivery to the CSH was 27 days, and the mean age of the RBC units on transfusion was 33 days [73,74]. Several studies have suggested a detrimental effect of transfusions of blood greater than 14 to 21 days old [75–78].

The frequency of massive transfusions, defined as greater than 10 units of RBC in 24 hours [79,80], was high during the time period the authors' CSH was in-theater. During this year, the first Marine assault into Fallujah in April 2004, the assault on An Najaf in August 2004, and the second Marine assault on Fallujah in November 2004 occurred. These months represent some of the highest number of casualties to date for the war [1]. During this time period, 201 patients received massive transfusions [81]. The frequency of these cases meant that the hospital's blood bank would frequently be outstripped of standard blood products. By necessity, the CSH instituted a fresh whole blood program that recruited donors from within the hospital and from other neighboring units in the area. A total of 545 units of fresh whole blood were transfused in 87 patients during the CSH's deployment [73].

This experience of surgeons resuscitating with fresh warm whole blood provided anecdotal impressions of a hemostatic and perhaps survival benefit of fresh whole blood. Few modern clinical studies have revealed a benefit of fresh whole blood, partially because of its relative lack of use in favor of component therapy, although Manno and colleagues [82] demonstrated that use of whole blood or stored blood less than 72 hours old reduced blood loss and blood use in neonates post cardiac surgery. The use of fresh whole blood was integrated into a massive transfusion protocol that favored the delivery of fresh frozen plasma (FFP) to RBC in a ratio of 1:1, with the addition of early use of cryoprecipitate and recombinant factor VIIa, until the first units of fresh whole blood were available (usually in about 60 minutes from initiation of the blood drive) (Fig. 5). Once fresh whole blood was available, this became the favored resuscitation product in casualties requiring massive transfusion. This topic is being studied intensely by investigators from the 31st CSH and US Army Institute of Surgical Research, and early reports identify a survival benefit in patients receiving fresh whole blood compared with component therapy alone (personal communications, Philip Spinella, MD, MAJ(P), US Army Medical Corps and Jeremy Perkins, MD, MAJ, US Army Medical Corps, 2006). The rapid evacuation of casualties out of theater and across multiple continents has made accurate tracking of outcomes and complications challenging.

Nevertheless, several findings from this research are available. First, Borgman and colleagues [81] demonstrated that increased number of stored RBC units transfused in the first 24 hours of admission was independently associated with decreased survival, whereas increased units of FFP transfused in the first 24 hours of admission was independently associated with improved survival. The median ratio of FFP:RBC was 1:1.7 in survivors

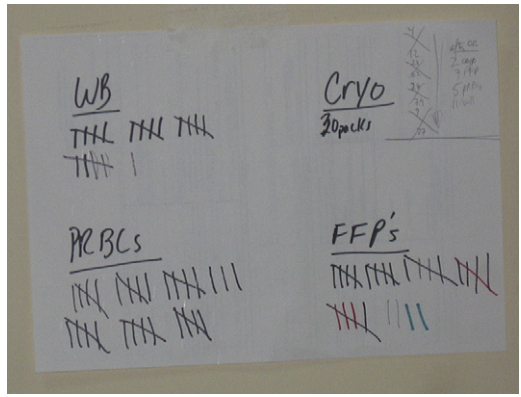

Fig. 5. Running tally of blood products hung on wall above casualty's bed. WB, fresh whole blood, 21 units; PRBCs, packed red blood cells, 33 units; Cryo, cryoprecipitate, 30 packs; FFP, fresh frozen plasma, 29 units. The casualty, treated by the authors (Beekley and Sebesta) and other members of a CSH, sustained the following injuries from multiple transabdominal gunshot wounds: Through-and-through perforation of distal esophagus, splenic rupture, splenic artery laceration, laceration to distal tail of pancreas, multiple perforations of stomach, left lobe of liver laceration, left diaphragm injury, multiple small bowel perforations, evisceration through left flank, right internal iliac artery and vein injury, intra- and extraperitoneal bladder perforations, extraperitoneal rectal injury, and open proximal left tibia/fibula fracture. He arrived somnolent with a blood pressure of approximately 50. As illustrated, the ratio of PRBC to FFP to cryoprecipitate packs he received was close to 1:1:1. The patient also received 21 units of fresh whole blood, which became his primary resuscitation modality once available. The patient received several doses of recombinant factor VIIa early in his course (drug was ordered in the emergency room). The patient survived his injuries and initial operations but ultimately succumbed to sepsis about 3 months later.

compared with 1:3 in nonsurvivors ($P < .001$). In addition, 30% of survivors received recombinant factor VIIa compared with 16% of nonsurvivors, although this did not reach significance ($P = .059$) [81]. The use of component therapy in a ratio of 1:1 for RBC, FFP, and platelets is becoming the standard resuscitation regimen in some trauma centers. Baltimore Shock Trauma Center currently thaws fresh frozen plasma each morning, allowing for the immediate transfusion of fresh thawed plasma once a trauma patient requiring transfusions arrives [83].

This early use of hemostatic products is based on data demonstrating that severely injured patients are suffering from a coagulopathy on arrival to hospital care, not just acquiring a coagulopathy from the resuscitation fluids [84,85]. In addition, hyperfibrinolysis may be more common in trauma patients than previously recognized. A recent study using rotational thromboelastography has shown that approximately 20% of multi-trauma patients suffering from massive bleeding have marked fibrinolysis [86]. Another recent large animal study demonstrated that fibrinogen replacement in a thrombocytopenic uncontrolled liver hemorrhage pig model provided improved median clot firmness, median blood loss, and survival time when

compared with treatment with platelets or saline control [87]. Current military massive transfusion protocols feature early replacement of fibrinogen with FFP and cryoprecipitate, along with early use of recombinant factor VIIa, which reduces clot susceptibility to fibrinolysis [88]. Although no survival benefit favoring use of fresh whole blood was demonstrated in this analysis, the use of fresh whole blood as part of a comprehensive approach to resuscitation began in the second half of the 31st CSH's deployment. Earlier in the year, fresh whole blood at the 31st CSH was used as a therapy of last resort or after standard component resuscitation had failed or exhausted the blood bank's supply, rather than a central part of the resuscitation strategy. A comparison of its use and related clinical outcomes before and after its institution into a massive transfusion protocol is ongoing. In addition, accurate injury scoring for casualties is just now being completed for 31st CSH data to allow meaningful subgroup analysis (personal communication, Philip Spinella, MD, MAJ[P], US Army Medical Corps, 2006).

The other obvious issue with the use of fresh whole blood is the safety of its use from an infectious disease standpoint and from transfusion-related adverse events. The 31st CSH used a rapid immunochromatographic test (Biokit, Spain) for HIV 1 and 2, hepatitis B surface antigen (HBsAg), and hepatitis C virus (HCV). This test is not currently FDA approved. Manufacturer-reported sensitivities and specificities are shown in Table 1. The results of donors screened with this test are shown in Table 2. The two units contaminated with HCV were not transfused [89].

These results demonstrate that a fresh whole blood program can and should be integrated into deploying military medical units' blood bank plans. This program can provide an appropriately low risk for viral transmission as long as accurate point-of-care tests are available. The use of fresh whole blood is being reevaluated in civilian settings. For example, the Israeli medical system's blood banks now keep several of the daily collected units temporarily available as whole blood for use in patients who have severe hemorrhage, coagulopathy, or those that need massive transfusion. Unused units are separated and stored as components after 24 hours [90].

Recently, a clinical practice guideline was published governing the use of some of these controversial products and practices. Patients who have the following characteristics on arrival are candidates for early (as close to

Table 1
Manufacturer-reported sensitivities and specificities for rapid immunochromatographic test (Biokit, Spain) for HIV 1 and 2, HBsAg, and hepatitis C virus

Test	Specificity (%)	Sensitivity (%)
HIV 1, 2	98.2	98.5
HCV	98.7	99.4
HBsAg	>98	Not reported

Abbreviations: HBsAg, hepatitis B surface antigen; HCV, hepatitis C virus.

Table 2
The results of donors screened with rapid immunochromatographic test (Biokit, Spain) for HIV 1 and 2, HBsAg, and hepatitis C virus

Test	Positive results of rapid screening
HIV 1, 2	0/460
HCV	2/406
HBsAg	0/406

Abbreviations: HBsAg, hepatitis B surface antigen; HCV, hepatitis C virus.

casualty arrival as possible) use of hemostatic products, such as recombinant factor VIIa, cryoprecipitate, and FFP, and initiation of a fresh whole blood drive: international normalized ration greater than or equal to 1.5; base deficit (BD) greater than 6; temperature less than 96°F; hemoglobin less than 11; and systolic blood pressure (SBP) less than 90 on arrival in the setting of military trauma. This approach currently is being studied in-theater (personal communication, John B. Holcomb, MD, COL, US Army Medical Corps, 2006). Use of recombinant Factor VIIa has been shown in ex vivo studies to function in the setting of hypothermia but not in the setting of profound acidosis [91].

Critical care aeromedical transport

The US Air Force Critical Care Aeromedical Transport (CCAT) provides long-range transportation of critically injured patients while continuing sophisticated medical care. The CCAT program was developed after Operation Just Cause when aeromedical evacuation systems designed to transport stable patients found themselves transporting and treating fresh casualties. In addition, the change in United States military doctrine from large forward-based infrastructure of the Cold War era to today's light expeditionary forces required the development of a method to transport all patients to higher echelons of care. This change resulted in the inclusion of physicians on aeromedical flights to provide and direct treatment. CCAT teams have transported thousands of injured troops from Iraq and Afghanistan to Germany and the United States. The CCAT team consists of a physician who has significant intensive care background, a critical care nurse, and a respiratory therapist. Each CCAT team is capable of treating six low-acuity patients or three high-acuity patients. In addition to their normal training, each member completes additional training in aerospace physiology, equipment training, and medical care in austere environments. Teams also can complete additional training and sustainment of trauma skills by rotating at a stateside level one trauma center. CCAT team's equipment has been designed and tested for use at various altitudes and cabin pressures. The portable nature of this equipment makes it ideal for transporting patients by way of different modes of transportation including fixed-wing and rotary-winged aircraft. CCAT teams must be able to function in low-light and high-noise areas with limited access to the patients.

Training

The rapid expansion of knowledge regarding care of the combat casualty since the start of the Global War on Terror has required constant updating of training regimens and courses for prehospital providers, physicians, surgeons, and deploying units.

Currently, prehospital providers, in particular combat medics from line units, receive at least a 3-day training course called Combat Medic Advanced Skills Training, and many receive a 4- or 5-day Tactical Combat Casualty Care course that is enhanced with simulator mannequin (SimMAN, Laerdal Corporation) and controlled live-tissue training models. This training is administered as close to a unit's deployment as possible but at least within 6 months of a unit's upcoming deployment. The Pre-Hospital Trauma Life Support manual now has a chapter specifically dealing with prehospital care of the combat casualty, and provides a recommended equipment list for combat medics to carry.

In an effort to maintain trauma skills in military physicians and forward surgical teams who normally may not have any exposure to trauma on a day-to-day basis, the military uses stateside level 1 trauma centers for training. Teams rotate for 2- to 3-week long training at centers such as Ryder trauma center in Miami and Los Angeles County Hospital. The training includes didactic and laboratory sessions, animal and tissue models, simulators, and then training in an area of interest, such as the ICU, operating room, or the trauma bay as part of the resuscitation team. Additional instruction and exercises develop plans for mass casualty situations, triage scenarios, teamwork, and team building. After completing the initial training period, teams then take over the role as the trauma team and respond and treat all trauma patients for a given period of time. This practice allows teams to use all areas of training, practice sleep/rest cycles, and identify areas required for additional training. These training centers play an integral part in the preparation of teams and team members to prevent poor outcomes during the steep learning curve of treating combat casualties.

A 3-day Emergency War Surgery Course involving didactic sessions and practical exercises in cadavers or live-tissue models exists and was designed specifically for deploying surgeons. This course currently is being evaluated as a refresher for deploying surgeons (personal communication, David Burris, MD, COL, US Army Medical Corps, 2006). Another similar multidisciplinary course that involves training for surgeons and other trauma team members also has been created recently, and is being used as a combat casualty care preparation course by some deploying combat support hospitals. The Madigan Army Medical Center (MAMC) general surgery residency provides a twice-yearly live animal lab for residents to learn advanced laparoscopic skills. MAMC staff surgeons returning from combat-zone deployments (including the authors of this chapter) have since insisted on adding an afternoon session to this lab that focuses on identification and treatment

of less common intraabdominal injuries, rapid mobilization of organs for various anatomic exposures, and damage control techniques. In addition, the MAMC vascular surgery service has hosted a Combat Extremity Trauma course, which is a didactic, saw-bones, and cadaver limb-based course that provides training in vascular exposures, vascular anastomoses, shunt placement, fasciotomies, and placement of external fixators.

Summary

The era of global terrorism and asymmetric warfare heralded by the September 11, 2001 attacks on the United States has continued with the Bali bombings and the Madrid and London train bombings (and other smaller terrorist events too numerous to list here). These types of incidents blur the traditional lines between civilian and military trauma victims. In addition, national and international natural disasters, such as Hurricane Katrina and the Asian tsunami in December 2004, have created intense focus on the medical community's preparation for such events. The lessons learned by physicians in the theaters of war, particularly regarding the response to mass casualties, blast and fragmentation injuries, and resuscitation of casualties in austere environments, likely resonate more strongly with our civilian counterparts in this current era. It is critical that we continue to share these valuable lessons with our civilian colleagues and in turn get critiques, guidance, and constructive feedback from these civilian trauma experts.

References

[1] US Department of Defense website. Operations Iraqi and Enduring Freedom US casualty status. http://www.defenselink.mil/news/casualty.pdf. Accessed June 27, 2006.
[2] Beekley AC. United States military surgical response to modern large-scale conflicts: the ongoing evolution of a trauma system. Surg Clin North Am 2006;86(3):689–709.
[3] Fox CJ, Gillespie DL, O'Donnell SD, et al. Contemporary management of wartime vascular trauma. J Vasc Surg 2005;41(4):638–44.
[4] Peleg K, Rivkind A, Aharonson-Daniel L. Does body armor protect from firearm injuries? J Am Coll Surg 2006;202(4):643–8
[5] Xydakis MS, Fravell MD, Nasser KE, et al. Analysis of battlefield head and neck injuries in Iraq and Afghanistan. Otolaryngol Head Neck Surg 2005;133(4):497–504.
[6] Helling E, McKinlay AJ. Considerations for the head-injured air-evacuated patient: a case report of frontal sinus fracture and review of the literature. Mil Med 2005;170(7):577–9.
[7] Gondusky JS, Reiter MP. Protecting military convoys in Iraq: an examination of battle injuries sustained by a mechanized battalion during Operation Iraqi Freedom II. Mil Med 2005;170(6):546–9.
[8] Harcke HT, Schauer DA, Harris RM, et al. Imaging body armor. Mil Med 2002;167(4): 267–71.
[9] Husum H, Gilbert M, Wisborg T, et al. Prehospital tourniquets: there should be no controversy. J Trauma 2004;56(1):214–5.
[10] Navein J, Coupland R, Dunn R. The tourniquet controversy. J Trauma 2003;54(5 Suppl): S219–20.

[11] Bellamy RF. The causes of death in conventional land warfare: implications for combat casualty care research. Mil Med 1984;149(2):55–62.
[12] Cuadrado D, Arthurs Z, Sebesta J, et al. Cause of death analysis at the 31st combat support hospital during Operation Iraqi Freedom. Presented at the 28th Annual Gary P. Wratten Army Surgical Symposium. Walter Reed Army Institute of Research, Silver Spring, Maryland. May 2006.
[13] Beekley A, Sebesta J, Blackbourne L, et al. Pre-hospital tourniquet use in Operation Iraqi Freedom: effect on hemorrhage control and outcomes. Presented at the 36th Annual Scientific Meeting of the Western Trauma Association. Big Sky, Montana. March 2006.
[14] Little R. Modern combat lacking in old medical supply. Baltimore Sun. March 6, 2005.
[15] Mabry RL. Tourniquet use on the battlefield. Mil Med 2006;171(5):352–6.
[16] Lakstein D, Blumenfeld A, Sokolov T, et al. Tourniquets for hemorrhage control on the battlefield: a 4-year accumulated experience. J Trauma 2003;54(Suppl 5):S221–5.
[17] Rhee P, Koustova E, Alam HB. Searching for the optimal resuscitation method: recommendations for the initial fluid resuscitation of combat casualties. J Trauma 2003;54(Suppl 5): S52–62.
[18] Alam HB, Burris D, DaCorta JA, et al. Hemorrhage control in the battlefield: role of new hemostatic agents. Mil Med 2005;170(1):63–9.
[19] Pusateri AE, Holcomb JB, Kheirabadi BS, et al. Making sense of the preclinical literature on advanced hemostatic products. J Trauma 2006;60(3):674–82.
[20] 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(3):555–62.
[21] 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(5): 974–83.
[22] Wright JK, Kalns J, Wolf EA, et al. Thermal injury resulting from application of a granular mineral hemostatic agent. J Trauma 2004;57(2):224–30.
[23] Arnaud F, Tomori T, Saito R, et al. Efficacy of Zeolite in groin injury: comparison of granular and bagged QuikClot. Abstract obtained at 1st International Miltranet Symposium. Koblenz, Germany. May 2006.
[24] McKeague A, Arnaud F, Tomori T, et al. Evaluation of bagged and powdered formulations of Zeolite hemostatic agent (QuikClot). Abstract obtained at 1st International Miltranet Symposium. Koblenz, Germany. May 2006.
[25] 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(1):177–82.
[26] 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(4):333–8.
[27] Klokkevold PR, Subar P, Fukayama H, et al. Effect of chitosan on lingual hemostasis in rabbits with platelet dysfunction induced by epoprostenol. J Oral Maxillofac Surg 1992;50(1): 41–5.
[28] 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(1): 49–52.
[29] Wedmore I, McManus JG, Pusateri AE, et al. A special report on the chitosan-based hemostatic dressing: experience in current combat operations. J Trauma 2006;60(3):655–8.
[30] McPherson JJ, Feigin DS, Bellamy RF. Prevalence of tension pneumothorax in fatally wounded combat casualties. J Trauma 2006;60(3):573–8.
[31] Cullinane DC, Morris JA Jr, Bass JG, et al. Needle thoracostomy may not be indicated in the trauma patient. Injury 2001;32(10):749–52.
[32] Jenkins C, Sudheer PS. Needle thoracocentesis fails to diagnose a large pneumothorax Anaesthesia 2000;55(9):925–6.

[33] Jones R, Hollingsworth J. Tension pneumothoraces not responding to needle thoracocentesis. Emerg Med J 2002;19(2):176–7.
[34] Mines D, Abbuhl S. Needle thoracostomy fails to detect a fatal tension pneumothorax. Ann Emerg Med 1993;22(5):863–6.
[35] Lewis FR Jr. Prehospital intravenous fluid therapy: physiologic computer modelling J Trauma 1986;26(9):804–11.
[36] Drinker CK, Drinker KR, Lund CC. The circulation in the mammalian bone marrow. Am J Physiol 1922;62:1–92.
[37] Dubick MA, Holcomb JB. A review of intraosseous vascular access: current status and military application. Mil Med 2000;165(7):552–9.
[38] Johnson DL, Findlay J, Macnab AJ, et al. Cadaver testing to validate design criteria of an adult intraosseous infusion system. Mil Med 2005;170(3):251–7.
[39] Calkins MD, Fitzgerald G, Bentley TB, et al. Intraosseous infusion devices: a comparison for potential use in special operations. J Trauma 2000;48(6):1068–74.
[40] Butler F, O'Connor K. Antibiotics in tactical combat casualty care 2002. Mil Med 2003; 168(11):911–4.
[41] Hocking G, De Mello WF. Battlefield analgesia: an advanced approach. J R Army Med Corps 1999;145(3):116–8.
[42] Kotwal RS, O'Connor KC, Johnson TR, et al. A novel pain management strategy for combat casualty care. Ann Emerg Med 2004;44(2):121–7.
[43] Buckenmaier CC, McKnight GM, Winkley JV, et al. Continuous peripheral nerve block for battlefield anesthesia and evacuation. Reg Anesth Pain Med 2005;30(2):202–5.
[44] Dougherty PJ. Wartime amputations. Mil Med 1993;158(12):755–63.
[45] Hell K. Characteristics of the ideal antibiotic for prevention of wound sepsis among military forces in the field. Rev Infect Dis 1991;13(Suppl 2):S164–9.
[46] Davis KA, Moran KA, McAllister CK, et al. Multidrug-resistant Acinetobacter extremity infections in soldiers. Emerg Infect Dis 2005;11(8):1218–24.
[47] 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(4):337–43.
[48] King DR, Cohn SM, Proctor KG. Changes in intracranial pressure, coagulation, and neurologic outcome after resuscitation from experimental traumatic brain injury with hetastarch. Surgery 2004;136(2):355–63.
[49] Arthurs Z, Cuadrado D, Beekley A, et al. The impact of hypothermia on trauma care at the 31st combat support hospital. Am J Surg 2006;191(5):610–4.
[50] Dubick MA, Brooks DE, Macaitis JM, et al. Evaluation of commercially available fluid-warming devices for use in forward surgical and combat areas. Mil Med 2005;170(1): 76–82.
[51] Emergency War Surgery. In: Burris DG, Fitzharris JB, Holcomb JB, Hetz SP, Jenkins DH, Muskat P, Roberts LH, Uhorchak JM, Venticinque S, Wedmore I, editors. 3rd United States Revision. Washington, DC: Borden Institute; 2004.
[52] 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(4):821–8.
[53] Holcomb JB. Fluid resuscitation in modern combat casualty care: lessons learned from Somalia. J Trauma 2003;54(5 Suppl):S46–51.
[54] Bickell WH, Wall MJ Jr, Pepe PE, et al. Immediate versus delayed fluid resuscitation for hypotensive patients with penetrating torso injuries. N Engl J Med 1994;331(17):1105–9.
[55] Champion HR. Combat fluid resuscitation: introduction and overview of conferences J Trauma 2003;54(Suppl 5):S7–12.
[56] Butler FK Jr, Hagmann JH, Richards DT. Tactical management of urban warfare casualties in special operations. Mil Med 2000;165(Suppl 4):1–48.
[57] Krausz MM. Fluid resuscitation strategies in the Israeli army. J Trauma 2003;54(Suppl 5): S39–42.

[58] Dubick MA, Atkins JL. Small-volume fluid resuscitation for the far-forward combat environment: current concepts. J Trauma 2003;54(Suppl 5):S43–5.
[59] Sumann G, Kampfl A, Wenzel V, et al. Early intensive care unit intervention for trauma care: what alters the outcome? Curr Opin Crit Care 2002;8(6):587–92.
[60] Bricknell MC. The evolution of casualty evacuation in the 20th Century (Part 5)—Into the future. J R Army Med Corps 2003;149(4):357–63.
[61] Heaton LD. Emergency war surgery. Am J Surg 1965;110:358–9.
[62] Marshall TJ Jr. Combat casualty care: the Alpha Surgical Company experience during Operation Iraqi Freedom. Mil Med 2005;170(6):469–72.
[63] Bilski TR, Baker BC, Grove JR, et al. Battlefield casualties treated at Camp Rhino, Afghanistan: lessons learned. J Trauma 2003;54(5):814–21.
[64] Mattox KL. Introduction, background, and future projections of damage control surgery. Surg Clin North Am 1997;77(4):753–9.
[65] Peoples GE, Gerlinger T, Craig R, et al. The 274th Forward Surgical Team experience during Operation Enduring Freedom. Mil Med 2005;170(6):451–9.
[66] Beekley A, Blackbourne L, Sebesta J, et al. Evaluation for intra-abdominal injury from combat fragmentation wounds. Poster presentation at the American Association for the Surgery of Trauma meeting, Atlanta, Georgia, September 2005.
[67] Beekley AC, Watts DM. Combat trauma experience with the United States Army 102nd Forward Surgical Team in Afghanistan. Am J Surg 2004;187(5):652–4.
[68] Lovric Z, Lehner V, Wertheimer B, et al. Tourniquet occlusion technique for lower extremity artery reconstruction in war wound. J Cardiovasc Surg (Torino) 1997;38(2): 153–5.
[69] Johansen K, Bandyk D, Thiele B, et al. Temporary intraluminal shunts: resolution of a management dilemma in complex vascular injuries. J Trauma 1982;22(5):395–402.
[70] Granchi T, Schmittling Z, Vasquez J, et al. Prolonged use of intraluminal arterial shunts without systemic anticoagulation. Am J Surg 2000;180(6):493–6.
[71] Eger M, Golcman L, Goldstein A, et al. The use of a temporary shunt in the management of arterial vascular injuries. Surg Gynecol Obstet 1971;132(1):67–70.
[72] Jacob JE. Compartment syndrome. A potential cause of amputation in battlefield vascular injuries. Int Surg 1974;59(10):542–8.
[73] Spinella PC, Perkins J, Grathwohl K, Repine T, Sebesta J, Beekley A, et al. The Use and Risks of Warm Whole Blood to Manage Life Threatening Hemorrhage from Combat Injuries. Poster presentation at the 1st International Miltranet Symposium, Koblenz, Germany, May 2006. Ref Type: Generic.
[74] Spinella PC, Grathwohl K, Holcomb JB, et al. Fresh warm whole blood use during combat. Presented at the Society of Critical Care Meeting, January 2006. Crit Care Med 2005; 33(Suppl 12):A39, 146–S.
[75] Basran S, Frumento RJ, Cohen A, et al. The association between duration of storage of transfused red blood cells and morbidity and mortality after reoperative cardiac surgery. Anesth Analg 2006;103(1):15–20.
[76] Fitzgerald RD, Martin CM, Dietz GE, et al. Transfusing red blood cells stored in citrate phosphate dextrose adenine-1 for 28 days fails to improve tissue oxygenation in rats. Crit Care Med 1997;25(5):726–32.
[77] Purdy FR, Tweeddale MG, Merrick PM. Association of mortality with age of blood transfused in septic ICU patients. Can J Anaesth 1997;44(12):1256–61.
[78] Martin CM, Sibbald WJ, Lu X, et al. Age of transfused red blood cells is associated with ICU length of stay [Abstract]. Clin Invest Med 1994;17:124.
[79] Erber WN. Massive blood transfusion in the elective surgical setting. Transfus Apher Sci 2002;27(1):83–92.
[80] Stainsby D, MacLennan S, Hamilton PJ. Management of massive blood loss: a template guideline. Br J Anaesth 2000;85(3):487–91.

[81] Borgman M, Spinella PC, Perkins J, et al. Blood product replacement affects survival in patients receiving massive transfusions at a combat support hospital. Poster presentation at the 1st International Miltranet Symposium. Koblenz, Germany May 2006.
[82] Manno CS, Hedberg KW, Kim HC, et al. Comparison of the hemostatic effects of fresh whole blood, stored whole blood, and components after open heart surgery in children. Blood 1991;77(5):930–6.
[83] Dutton RP. Haemorrhage control in US trauma care. Presented at the 1st International Miltranet Symposium. Koblenz, Germany. May 2006.
[84] Brohi K, Singh J, Heron M, et al. Acute traumatic coagulopathy. J Trauma 2003;54(6): 1127–30.
[85] MacLeod JB, Lynn M, McKenney MG, et al. Early coagulopathy predicts mortality in trauma. J Trauma 2003;55(1):39–44.
[86] Martinowitz U, Michaelson M. Guidelines for the use of recombinant activated factor VII (rFVIIa) in uncontrolled bleeding: a report by the Israeli Multidisciplinary Task Force J Thromb Haemost 2005;3(4):640–8.
[87] Fries D, Velik-Salchner C, Haas T, et al. The effect of fibrinogen on thrombocytopenia. Poster presentation at the 1st International Miltranet Symposium. Koblenz, Germany. May 2006.
[88] Veldman A, Hoffman M, Ehrenforth S. New insights into the coagulation system and implications for new therapeutic options with recombinant factor VIIa. Curr Med Chem 2003; 10(10):797–811.
[89] Spinella PC, Grathwohl K, Holcomb JB, et al. Risks associated with fresh warm whole blood compared to PRBC transfusions during combat. Presented at the Society of Critical Care meeting, January 2006. Crit Care Med 2005;33[Suppl 12]:A44, 165-S.
[90] Martinowitz U. Recombinant Factor VIIa and Hemostatic Resuscitation. Invited address to 1st International Miltranet Symposium. Koblenz, Germany. May 2006.
[91] Schreiber MA, Holcomb JB, Rojkjaer R. Preclinical trauma studies of recombinant factor VIIa. Crit Care 2005;9(Suppl 5):S25–8.