Lessons From the Tip of the Spear: Medical Advancements From Iraq and Afghanistan

LCDR Jason J Schrager MD (USNR), Richard D Branson MSc RRT FAARC, and Col Jay A Johannigman MD (USAF Reserve)

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Summary

The conflicts in Iraq and Afghanistan have seen the advancement of combat medicine. The nature of the conflicts, with troops located in remote areas and faced with explosive ordinance designed to focus massive injuries on dismounted personnel, have forced military medical personnel to adapt accordingly. There has been a rekindling of interest in the use of tourniquets to stop exsanguination from extremity wounds, as well as in the transfusion of fresh whole blood from walking blood banks. These previously discarded techniques, born on battlefields long ago, have been refined and perfected and have led to an unprecedented survival for our wounded warriors. New developments in the field of applied hemostatic agents, damage control surgical techniques, and the implementation of an efficient evacuation system have also contributed to these results. The field of combat medicine has taken several concepts initially designed in civilian settings, such as temporary abdominal packing and vascular shunting, and adapted them to the military setting to provide state of the art trauma management to our troops in combat. In turn, developments in the resuscitation of the trauma patient, using increased blood and plasma products and less crystalloid, have been pioneered in conflict and transitioned to the civilian sector. Advancements made during the wars in Iraq and Afghanistan, as well as those still being developed, will shape the care of the injured patient, in both civilian and military settings, for the foreseeable future. *Key words: massive transfusion; military medicine; tourniquets; fresh whole blood; damage control surgery; damage control resuscitation; aeromedical evacuation; coagulopathy of trauma.* [Respir Care 2012;57(8):1305–1313]

The authors are affiliated with the Division of Trauma/Critical Care, Department of Surgery, University of Cincinnati, Cincinnati, Ohio.

The opinions expressed in this paper are not to be construed as official or as reflecting the policy of the U.S. Navy Reserve, the U.S. Air Force Reserve, or the Department of Defense. The authors report no conflicts of interest related to the content of this paper.

Dr Johannigman presented a version of this paper as the Donald F Egan Scientific Memorial Lecture at the AARC Congress 2011, held November 5–8, 2011, in Tampa, Florida.

Correspondence: Jason J Schrager MD, Division of Trauma/Critical Care, Department of Surgery, University of Cincinnati, 231 Albert Sabin Way, PO Box 670558, Cincinnati OH 45267-0558. E-mail: jasonschrager13@hotmail.com.

DOI: 10.4187/respcare.01881

Introduction

The United States military has been engaged in 2 major conflicts over the past 10 years. These wars have created tremendous hardships, with over 6,000 fatalities inflicted on our service members. Thousands more have been wounded, whether physically or psychologically, and they struggle daily on the home front. War inflicts severe injuries that require innovative treatment, but also provides the opportunity to rapidly evaluate outcomes. The current conflict has afforded numerous advancements in the care for the wounded warrior. These advancements, in both tactics as well as system changes, have redefined the standard of care for the traumatically injured patient. These changes may also apply to the civilian setting. The conflict in Afghanistan, as well as the recently concluded operations in Iraq, have involved adversaries who are typically limited in both finances and technological access. With the common use of improved body armor by United States forces, the enemies have moved away from the standard assault rifles and have resorted to improvised explosive devices as their weapon of choice. These makeshift bombs often employ explosives taken from unused land mines, artillery shells, and other weapons, and focus them upon dismounted personnel. This has led to an unprecedented wounding pattern in terms of massive trauma inflicted on individuals. Even in light of these devastating injuries, with markedly increased injury severity scores, when compared to previous conflicts, the survival rate of our injured troops is at an all-time high.

The conceptual fundamentals for treating casualties of war have not changed substantially over the past 100 years:

- Safe evacuation from front-line combat
- Rapid control of hemorrhage
- Prevention of contamination/infectious sources (whether abdominally from injured bowel or from extremities with devitalized tissue)

The improved outcomes, while somewhat dependent on major breakthroughs in medical technology, have really been born from maximizing simple tactics and training at all stages of care, which together have served to amplify positive outcomes. These changes have led to unparalleled care for our combatants, and in many instances have since been transferred to the civilian sector as well. Advances have been enacted, through experience and research, at all phases of care of the wounded combatant. Broadly, these phases can be categorized as the pre-hospital/point of injury care, evacuation back to first line of medical treatment, surgical intervention within the combat theater, and then evacuation out of theater to medical facilities in Europe and the United States. Interventions in each of these aspects have had a beneficial effect on outcomes in our wounded warriors.

Pre-Hospital/Point of Injury Care

The pre-hospital/point of injury care is that which is provided to the wounded combatant from the time injury is inflicted, often under the pressures of ongoing combat, until the patient begins evacuation to a higher level of medical care. Primary areas of focus include the tending to the basics/essentials: A (airway), B (breathing), and C (circulation/hypotension/malperfusion). Combat experience has shown that utilizing a modified mnemonic, CABC, where the first C is control of catastrophic (and typically extremity) hemorrhage, is more practical. Changes during this period of care have focused on hemostasis (addressing catastrophic hemorrhage) as well as fluid resuscitation (addressing the second C, circulation) in the forward/battlefield setting.

Hemostasis

One change in pre-hospital combat care that has demonstrated substantial benefit has been the re-emergence of tourniquets. Though by no means a "new" development, tourniquets fell out of favor during the second half of the 20th century, due to a perceived high complication rate (with complications largely related to ischemia of muscle and nerves in non-amputated limbs) as well as the ineffectiveness in stemming hemorrhage by commonly utilized versions. The changes in wounding patterns in the current conflict, influenced by the weapons and body armor, have put a premium on rapid treatment of massive extremity trauma.

Early analysis from the conflicts in Afghanistan and Iraq, based on autopsy reports, emphasized preventable deaths due to exsanguination from extremity trauma as a key focus of intervention.[1,2] This information, coupled with advancements in the basic tourniquet supplied to our forces, making them easier and more efficacious to use, has led to widespread implementation at the point of injury (Fig. 1). Recent reviews of tourniquet use in combat demonstrated a low complication rate and a positive survival benefit (Fig. 2).[3,4]

A key aspect in this has been aggressive, functional training of medical and non-medical personnel in the use of tourniquets. These individuals, often with little to no formal medical training, are thrust into the role of primary responder at the point of injury. Major extremity vascular injuries can rapidly lead to exsanguination and death without intervention by personnel at the scene at the time of injury; waiting for field medics, nurses, or physicians to provide this care is not an option. Advanced management of airway emergencies, massive thoraco-abdominal hemorrhage, and serious head injuries are beyond the scope

Fig. 1. Standard issue Combat Application Tourniquet (CAT). Supplied to all military personnel with extensive training prior to combat deployments, they are applied more easily and more effectively than prior formats. (Courtesy of Composite Resources, Rock Hill, South Carolina.)

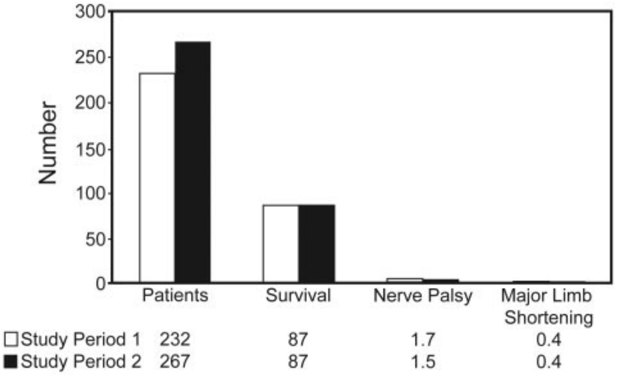

Fig. 2. Summary of data from 2 studies of patients presenting to a combat hospital in Iraq with tourniquets placed for extremity trauma. Both documented high survival rates and low morbidities associated with placement (with major morbidities being nerve palsies at the tourniquet site and substantial limb shortening potentially due to tourniquet damage). These studies combined to show that early application (pre-hospital) had a superior survival, when compared to placement on arrival to a hospital facility (89% vs 78% hospital, $P < .01$). Additionally, there was a survival benefit noted when tourniquets were placed prior to the onset of shock (96% versus 4% survival when placed after the onset of shock). (Data from Reference 4.)

and capabilities of the "buddy care" that your average infantryman can provide. Rapid application of tourniquets, however, is a simple measure that is trainable and useable in the field, and has been proven to save lives at the point of injury.[5] Sentiment for the utility of tourniquets is spreading to the civilian sector, with the most recent advanced trauma life support recommendations endorsing their use in appropriate circumstances. By the end of 2012, tourniquets will be required on all basic life support ambulances.

An adjunct to tourniquets for life threatening hemorrhage control in a field setting is the use of topical hemostatics. These products are agents applied to hemorrhaging vessels to facilitate activation of the coagulation cascade and are designed to be applied to extremities early in the treatment process. The intended utilization is to control hemorrhage in junctional anatomic regions. These are areas that are located in anatomical bridges, such as the axilla and high groin, and are areas often not amenable to proper placement of tourniquets, to staunch life-threatening hemorrhage. This is commonly known as "non-compressible" hemorrhage. Personnel having to deal with massive hemorrhage from junctional wounds are left with prolonged manual pressure as the only means of assistance. Due to the kinetics of the battlefield, with changing geography and enemy fire, the need to move the patient repeatedly during evacuation, as well as the general difficulty in applying adequate pressure in these regions, such application of pressure is neither practical nor efficacious.

This has led to the development of topical substances that can accelerate coagulation for wounds that are not adequately controlled with tourniquets. The earlier version was a granule based product with zeolite as the active component. This product worked by evacuating the fluid content of the hemorrhaging vessel, promoting coagulation, as well as activating several steps in the clotting cascade. One drawback to this agent was that a tremendous amount of heat was generated. This heat production was subsequently implicated in cutaneous burns in patients. Additionally, while very effective if utilized properly, it often required more technical capabilities to clear the wound, temporarily dry it, and rapidly place the granules than were readily available in a far-forward, point of injury location. A more recently developed topical hemostatic utilizes a variant of rolled gauze impregnated with kaolin, which rapidly activates the coagulation cascade. The application is simple, as most medical and non-medical personnel are capable of packing a wound with gauze.[5] Continued testing and development of topical agents is a priority for military medicine.

Fluid Resuscitation

Continuing at the point of injury, a major evolution that has occurred in care for the wounded combatant is the initial fluid resuscitation of the hypotensive/hemorrhaging patient. This concept stresses early reversal of the lethal triad: coagulopathy, acidosis, and hypothermia. This process starts in the field with control of substantial hemorrhage, as already described, through the use of tourniquets and topical hemostatics. Crystalloid fluids are then largely withheld, practicing permissive hypotension. It has long been known, though not widely practiced, that patients in hemorrhagic shock should be resuscitated to a minimal acceptable blood pressure until formal surgical control of hemorrhage can be obtained. In the combat setting this translates to a mildly depressed though appropriate mental status and/or palpable peripheral pulses.[5] This process helps keep traumatically severed blood vessels in a relatively low flow, low pressure state until surgical control is possible, and prevents the phenomenon of "popping" the clot. Popping the clot occurs when elevating blood pressure pre-hospital causes damaged vessels that had spontaneously thrombosed in a low flow state to dislodge this clot and begin hemorrhaging again.[6-10] Functionally, it also permits field medics to shed the weight and space that crystalloid fluid takes up in their packs.

Physiologically, there are many benefits to withholding aggressive crystalloid administration. Though commonly utilized during the Vietnam conflict, and subsequently adapted to civilian practice as well as advanced trauma life support courses, there has never been evidence that demonstrates a survival advantage to administering crystalloid in the pre-hospital setting.[2,10] Similarly, it has now been postulated that increased use of crystalloid during all phases of resuscitation in the traumatically injured patient may increase the incidence of ARDS (or "Da Nang Lung," as seen in combat hospitals in Vietnam), as well as abdominal compartment syndrome. Additional physiologic derangements that aggressive crystalloid administration leads to are more profound acidosis, as normal saline (pH 5.0) and lactated Ringer's solution (pH 6.5) are both acidotic in nature: this acidosis is accompanied by increased coagulopathy, as the enzymatic reactions of the coagulation cascade all function suboptimally at a lowered pH.[2] Current recommendations are for use of small amounts of colloid solution to be administered only in the event that the patient loses consciousness and/or peripheral pulses while being tended to at point of injury and in the initial pre-hospital resuscitation.[5]

Evacuation From Point of Injury

Rapid evacuation from point of injury to the next level of medical care is vital in improving survival of the injured combatant. Maintaining a high level of care while expeditiously evacuating to a situation where surgical hemorrhage can be arrested is paramount. Evacuation times are traditionally tied to the "golden hour" concept—that traumatically injured patients need aggressive attention within 1 hour of wounding. While there is little factual data to support 60 min being a breaking point for survival outcomes, clearly earlier surgical control of hemorrhage and contamination is better than later.[11,12]

Fig. 3. Wounded patient getting transported to higher echelon of medical care in Afghanistan by United States Army medical transport.

This, however, must be balanced with the inherent complications of conducting medical operations in a combat setting. Security for a far forward medical and/or helicopter unit, safety/accessibility of the road network, availability of attack helicopters to fly "escort" for medical evacuations, or the ability to utilize flights of opportunity, and non-medical transports that are in proximity to the point of injury are all factors that must be considered.

Battlefield specifics play a major role in evacuation times: when focus of combat operation shifted from Iraq to Afghanistan, huge logistical issues were encountered. Afghanistan has very little in the way of paved roads, and the few traversable roadways present are frequently laden with improvised explosive devices, as the enemy is aware there are no alternative routes for convoys. This eliminated ground evacuation as a viable means of evacuating critically ill patients (Fig. 3). Additionally, in this less mature battlefield safe compounds from which helicopters could launch were also scarce. This led to an increase in evacuation times from point of injury to surgical facilities, from well under 1 hour to over 2 hours after time of wounding.

Both military and civilian data have demonstrated that delays in obtaining surgical intervention lead to increasing mortality for certain wounding patterns, particularly those with non-compressible hemorrhage such as penetrating abdominal wounds. The ability to decrease the evacuation time is largely a theater-dependent phenomenon. It requires construction of additional roadways, availability of additional helicopters, and potentially placement of surgical units further out toward the front line (placement of which carries the need for more medical personnel as well as the security and logistics to maintain these facilities).

Independent of these infrastructure changes, alterations in practice have allowed improved utilization of the transport and pre-surgical period, in a way bringing resuscitation to the patient and in some ways extending the "golden hour." One such technique has been in utilizing the concept of damage control resuscitation and initiating it in far forward locations. Damage control resuscitation is a process that recognizes at risk patients for requiring massive transfusions (> 10 units packed red blood cells transfused in first 24 h period post injury), allowing for permissive hypotension, initiating aggressive blood product replacement in lieu of crystalloid, and then performing focused, essential damage control operations in the unstable/stabilizing patient.[2,13,14] In the forward, non-surgical facilities and transport, this entails all but the final component.

In recognizing the at risk patient, there are 5 telltale signs that have been shown in reviews of combat wounding to portend a worse outcome. These 5 factors include the lethal triad of acidosis (base deficit > 6 mEq/L), coagulopathy (international normalized ratio > 1.5), and hypothermia (temperature < 96°F), and add hypotension (systolic blood pressure < 90 mm Hg) and anemia (hemoglobin < 11 g/dL).[15-19] Presentation with one or more of these risk factors at the first level of care warrants aggressive intervention at the earliest opportunity.

Just as valuable as these parameters is clinical judgment and pattern recognition: patients presenting with 1 or more amputated limbs and penetrating torso trauma can be deemed at risk even if at a facility unable to rapidly obtain vital signs and/or lab values. In determining the at risk patient in the forward setting, prioritizing patients for immediate evacuation back to a more robust, surgically capable facility can be undertaken. This is important, because at the time of presentation any patient with multiple injuries may seem overwhelming to the receiving medic/physician. However, with limited resources for evacuation available, and the realities of flight in a combat zone making any transport risky to the flight crew, determining those patients in need of immediate evacuation is important.

Identification of the patient at risk for massive transfusion also leads to initiating aggressive reversal of as many ominous factors as possible. The patient is aggressively warmed, both through passive methods such as removing wet clothing and placement of warm blankets, as well as actively with the use of blood and fluid warmers. The most prominent aspect of this is in terms of aggressive blood product replacement. Data from the recent conflicts have shown a positive survival advantage to 1:1 resuscitation—that is, transfusing 1 unit of fresh frozen plasma for every 1 unit of red blood cells (and ideally concurrently).[20,21] This goes against previous beliefs that ratios in the order of 1:4 or greater were acceptable. Aggressive use of plasma early helps correct the coagulopathy that is often present at the time of wounding.[13,15,16,21]

To facilitate this resuscitation strategy, forward care units are provided the capability to transfuse packed red blood cells and frequently fresh frozen plasma, despite not having operative capabilities. Previous doctrine had blood being located only at surgical facilities. This doctrinal change has pushed the resuscitation out closer to the point of injury, initiating it at the earliest possible moment.[14,21-24] These interventions are conducted with the understanding that surgical control of hemorrhage is still at least one transport away, and so again the concept of permissive hypotension and control of extremity hemorrhage, through the use of appropriately placed tourniquets and topical hemostatics, still applies.

An example of further extending the "golden hour" is by utilizing the air transport period to continue the resuscitation of the injured patient. It has become commonplace for United States casualty evacuation teams to carry packed red blood cells on the helicopters for administration en route to higher echelons of care, either from the point of injury or from a unit-specific medical station within the combat theater.[2,23] Care providers include specially trained en route care critical care nurses, as well as combat medics, to oversee this ongoing resuscitation. The United Kingdom has taken this concept a step further in employing a medical emergency response team for their in-country casualty evacuations to surgical facilities. Operating in southern Afghanistan, where there is a substantial United States military presence, these teams include flight nurses, as well as a physician skilled with airway management (either anesthesiologist or emergency physician). They also carry both packed red blood cells and thawed fresh frozen plasma for administration during transport. Data from these missions have demonstrated that the presence of a physician, as well as the availability of blood products, may be beneficial to outcomes for injured combatants and in effect turn the helicopter into an airborne trauma bay.[14,22,24]

Surgical Care

Arrival at a surgical facility offers the ability to more definitively address ongoing hemorrhage. The basic tenets that have already been discussed are carried out: aggressive rewarming and continued 1:1 resuscitation. Additional benefits include the obvious ability to surgically control hemorrhage as well as limit contamination. Changes in resuscitation, coupled with implementation of a damage control mindset to operative intervention, have spearheaded the new focus of combat surgery: aggressive, early reversal of hemorrhage and coagulopathy with quick transition/evacuation to the next level of care.

Resuscitation

The surgical facility will typically be able to offer all of the resuscitation efforts seen in the field and at first line medical facilities, but with far greater blood product availability. Depending on the severity of the injury and the blood products available, fresh whole blood from a walking blood bank may be utilized. Further research has demonstrated the importance of platelet transfusion, in both military and civilian settings, in addition to plasma in patients requiring or at risk for massive transfusions.[14,21,24,25] Due to the relatively short half-life of platelets (5–7 d), these are frequently not available anywhere other than the most robust facilities in theater. The relative scarcity of platelets may be offset by the use of fresh-whole blood, which replaces blood in a 1:1:1 (with platelets) fashion. When platelets are scarce and/or the overall availability of component therapy does not meet the needs of the patient, utilization of the walking blood bank is a vital way to bridge the gap.

The walking blood bank is a labor intensive process. It requires pre-screening potential donors for basic infectious risks and maintaining an up-to-date donor pool (challenging in a combat theater with frequent movement and turnover by units) and the necessary personnel to handle the donation process. There are also life-threatening risks, as there is no universal donor for whole blood, and therefore the blood types of both donor and recipient must be correct and verified, and as often as 2–11% of the time blood types on standard records are incorrect.[26] The walking blood bank must also have a reliable, and ideally practiced, method for rapid activation. The walking blood bank and fresh whole blood, for all its efforts, can potentially be life-saving.

Component therapy, the separating of donated blood into plasma, packed red blood cells, and platelets, was adopted after experiences by the United States military in the Korean conflict. It was noted that most blood being shipped to Korea from the United States was expiring before it could be used. Component therapy was designed as a means of prolonging its viability and facilitating its transport.[2] While component therapy is clearly superior in its ability to be stored for an extended period of time, survival/patient benefits have never been documented with component therapy over matched whole blood. There are also anti-coagulants and preservatives that can potentially exacerbate the coagulopathy of trauma as well as provide excessive volume to the patient; these are issues that fresh whole blood circumvents.

The benefits of fresh whole blood in the forward setting are clear: there is no need for storage, it replaces platelets (allowing for a 1:1:1 resuscitation in an austere setting), and its fresh/warm nature contributes to active reversal of hypothermia and coagulopathy.[27] Recent analysis of United States military personnel transfused at least one unit of fresh whole blood has also demonstrated a 30 day survival advantage, when compared to component therapy alone.[28] These findings have inspired investigation of whole blood use in appropriate civilian populations.

Another advance in blood product administration pioneered in the field hospitals of Iraq and Afghanistan has been the push to administer more recently donated, "fresher" packed red blood cells. Current FDA regulations and storage methods permit donated, separated packed red blood cells to be utilized for up to 42 days post-donation. While permissible, elongated storage times lead to increased denaturation of cells and theoretically less functional capability than more recently donated products. There have been documented detrimental morbidity and mortality outcomes in civilian trials in both trauma and cardiac surgery patients when comparing the transfusions of older versus newer packed red blood cells.[29,30] These outcomes can be exacerbated in patients requiring massive transfusion volumes, such as those seen in combat. The logistics involved with supplying in-theater blood banks dictated use of "older" packed red blood cells, typically $>$ 30 days old, during the first years of these conflicts. Thanks to efforts at all levels of the transport and storage chain, the average age of blood transfused in Afghanistan is 23 days.[2] While not ideal, it is a substantial improvement; this, however, does lend some support to utilization of fresh whole blood in the most critically ill patients, despite possible increased infectious risks.

Surgical Intervention

From a surgical standpoint, new concepts as well as adaptations of civilian practices have evolved since the start of these conflicts. The major change that has been adopted is that of damage control surgery. This process, originally demonstrated in civilian settings in the 1980s, has been adapted to the combat setting.[31,32] Conceptually, this involves doing the minimal necessary intervention at far-forward surgical settings while the patient is still very much unstable. It places a priority on controlling hemorrhage, preventing contamination, and debriding devitalized tissue. Complete operations, including bowel anastomosis and delicate vascular repairs, are not undertaken.

Vascular injuries to major arterial structures present a unique set of surgical problems to military surgeons. They are a source of substantial blood loss that needs to be controlled, yet they often provide blood flow to vital structures, and so simple ligation is not a viable option. Their repair often involves delicate, protracted operations. In forward surgical settings with limited resources, suboptimal operating conditions, and, frequently, a patient in extremis, no definitive vascular procedures are attempted. Instead patients are sent to the next level of care with

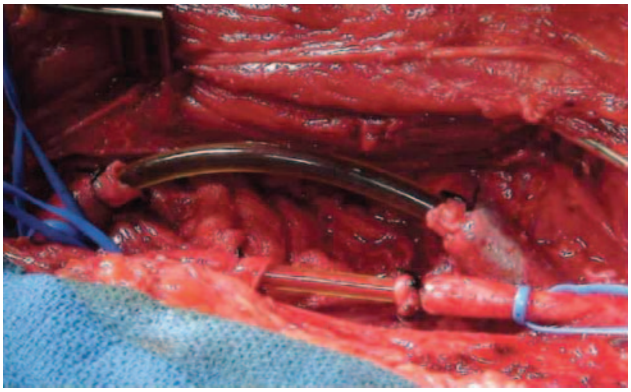

Fig. 4. Vascular shunt, essentially plastic tubing that temporarily connects 2 severed ends of artery. This allows for rapid reperfusion of the distal segment, and allows deferring of complicated repair in an austere forward surgical facility. (From Reference 33, with permission.)

temporary shunts in place that connect the 2 severed ends of the vasculature (Fig. 4).[33] These shunts are typically no more advanced than sterile plastic tubing, often adapted from other, preexisting materials. In more robust, centrally located field hospitals, definitive vascular procedures, often time consuming, are attempted only when the physiology of the patient (coagulopathy, hypothermia) has been returned to a relative baseline. Temporary vascular shunts have demonstrated prolonged patency, and with rates up to 85% for proximal injuries on presentation to the next echelon of care.[34] Long-term (2 year) limb salvage rates have been numerically, though not statistically, greater with use of shunts, versus initial definitive repair.[35]

In the face of periods of interrupted vascular flow, once restored even with temporary shunts, fasciotomies of affected extremities are utilized liberally to prevent compartment syndrome. Due to the perils of prolonged and frequent air transport, evaluation for the onset of compartment syndrome in the affected limb cannot always be conducted at regular intervals. Even if able to evaluate the patient, the ability to intervene in flight is limited/nonexistent. Conservative management and observation, often practiced in civilian settings, are not an option. Additionally, lessons learned from these conflicts have shown that the degree of swelling following a blast injury in a healthy young patient is substantially greater than that typically seen in acute vascular ischemia in civilian practice. There the patients tend to be older, with chronic vascular disease, and the inciting event possesses far less energy and inflicts less soft-tissue destruction. Because of these findings, fasciotomies need to be larger than what civilian practice would deem standard, in order to accommodate the greater tissue edema.[2,26]

Injuries involving the abdominal organs are similarly dealt with in a temporary fashion. No bowel anastamosis is embarked upon unless in a hardened field hospital, and the abdomen itself is often packed to control for any ongoing hemorrhage. The goal with intra-abdominal injuries is control of hemorrhage and contamination: prevent further leakage of small bowel and colonic contents with rapid repair or by stapling off and removing the damaged segment without placing the bowel back in continuity. In the event more complicated injuries are encountered, such as involving the biliary or pancreatic ducts, these can be drained extensively to limit contamination. The coupling of rapid, focused damage control operative procedures with ongoing damage control resuscitation focused on correcting hypothermia, acidosis, and coagulopathy has the end result of taking patients who present initially in the chain in peri-arrest extremis and concludes only hours later with normothermia, hemodynamic stability, and a patient able to tolerate potentially long air transport in the immediate future. Deferring any extensive, definitive cases allows the patient to recover physiologically from the immense insult suffered and to be better able to handle long procedures. Additionally, from a surgical standpoint it moves these delicate procedures to facilities better suited for success: better lighting, sturdier operating room equipment, and less concern for critically ill in-coming casualties arriving at a moment's notice (Fig. 5). This also provides the opportunity for the patient to be evaluated by a different team—a fresh set of eyes—who can still easily enact a different course of treatment if need be.[2,26,36]

Fig. 5. Forward surgical facility in southern Afghanistan. Designed for rapid surgical control for hemorrhage and contamination. Typically, more involved surgical procedures will be deferred to higher echelons of medical care.

Evacuation to Central Field Hospital in Theater and Out of Theater

The final aspect of the mission is bringing the wounded casualty either from their initial surgical procedure to a

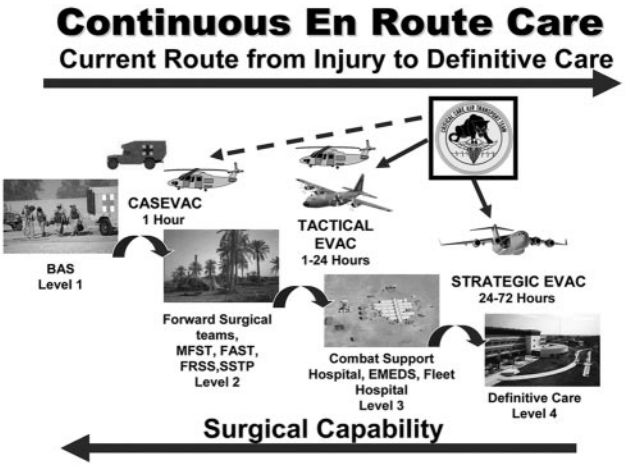

Fig. 6. Example of Critical Care Air Transport Team (CCATT) missions between the various levels of surgical care within and then out of the combat theater. Thousands of critically ill combat casualties have been transported throughout both Iraq and Afghanistan, and then to Germany and the United States, with exceedingly low morbidity/mortality rates. Casevac = casualty evacuation. BAS = battalion aid station. MFST = mobile field surgical team. FAST = flying ambulance surgical trauma. FRSS = forward resuscitative surgical system. SSTP = surgical shock trauma platoon. EMEDS = expeditionary medical support. (From Reference 23, with permission.)

hardened field hospital in the combat zone or from theater to a United States military hospital in Germany (and then eventually from Germany back to the United States). The United States Air Force has developed Critical Care Air Transport Teams (CCATTs) that specialize in transporting critically ill warriors for flights of up to 24 hours in length (Fig. 6). These teams were developed after analysis of medical shortcomings in the Gulf War. They include a physician intensivist, an ICU nurse, and a respiratory therapist, as well as the needed materials for transport. Each team can transport 6 patients, with up to 3 requiring mechanical ventilation. Damage control resuscitation, including blood product administration, continues en route. Additionally, patient monitoring, including arterial lines, ventilator management, and intracranial pressure monitoring and treatment, occurs in flight.

Though all of these fall under what would be considered standard critical care management, it occurs in a tactical situation. Crews are faced with extreme noise ($>$ 85 dB) from the aircraft, limited lighting for tactical reasons (frequently red lamps), space limitations, and are forced to deal with altitude considerations. Several thousand patient transports have occurred during the current conflict, ranging from several hours going from forward based surgical facilities to major in-theater field hospitals, to days transporting between Iraq/Afghanistan and Germany and then Germany to the United States. Despite the critical nature of the patients and the environmental hurdles these transports present, the in-flight mortality has been $< 1\%$.[23] CCATT transport teams are moving patients who are technically not "unstable" but may not be truly stabilized and are clearly in a window of time when acute complications may arise.

The benefits of these missions are that patients are brought to state-of-the-art medical facilities in safe locations in Europe and the United States within 24–48 hours of wounding.[2] This is in sharp contrast to the Vietnam conflict, where patients were kept in-country until requiring minimal medical care and did not reach facilities in Japan and the United States for upwards of 3 weeks post-injury. While requiring substantial planning and logistics, the CCATT system precludes the need for moving numerous medical supplies and equipment to the combat theater and allows for wounded troops to begin rehabilitation at an earlier point in their care.

Summary

The conflicts in Iraq and Afghanistan have created a change in how medical care is delivered to our injured troops in austere settings. This evolution has created a system in which wounded combatants have survival and functional outcomes that have been unmatched in history. This is due in part to the advances in blood product resuscitation, evacuation, and surgical techniques. They are getting resuscitated more aggressively early, are being moved faster out of theater, and then starting rehabilitation sooner than seen in any previous conflict. We are now seeing the transfer of lessons learned in the combat theater to patient care in the civilian setting in the United States and the world. The information garnered in combat is currently being applied to blood product administration, where 1:1 resuscitation is becoming more standardized in civilian trauma centers. Limiting the early use of intravenous crystalloid and field/emergency department hemostasis techniques (such as tourniquets) are being implemented as well.

Combat medicine, however, continues to evolve. The future of military trauma care is currently being forged in Afghanistan and in training environments in the United States. Resuscitation tactics at the point of care utilizing lyophilized plasma is an area of current research that could further decrease the need for storage of fresh frozen plasma as well as the reliance of non-blood colloids as a first line of resuscitation. Technical advancements in transport monitoring and ventilators aiming to decrease the footprint of equipment needed in tactical settings are another area of interest. The key to further development will be to remember the lessons learned in these recent conflicts, build upon them in civilian settings, and then implement them in future fields of battle should the need arise.

REFERENCES

1. Holcomb JB, McMullen NR, Pierce L, Caruso J, Wade CE, Oetjen-Gerdes L, et al. Causes of death in US special operations forces in the global war on terrorism: 2001–2004. Ann Surg 2007;245(6):986-991.
2. Johannigman J, Rhee P, Jenkins D, Holcomb J. Modern combat casualty care. In: Mattox K, Moore E, Feliciano D, editors. Trauma, 7th edition. New York: McGraw-Hill Professional; 2012 (in press).
3. Kragh JF, Walters TJ, Baer GC, Fox CJ, Wade CE, Salinas J, Holcomb JB. Practical use of emergency tourniquets to stop bleeding in major limb trauma. J Trauma 2008;64(2 Suppl):S38-S49.
4. Kragh JF, Littrel ML, Jones JA, Walters TJ, Baer GC, Wade CE, Holcomb JB. Battle casualty survival with emergency tourniquet use to stop limb bleeding. J Emerg Med 2011;41(6):590-597.
5. Committee on Tactical Combat Casualty Care. Pre-hospital trauma life support–military, 7th edition. St Louis: Mosby-Elsevier; 2010.
6. Bickell WH, Wall MJ, Pepe PE, Martin RR, Ginger VF, Allen MK, Mattox KL. Immediate versus delayed fluid resuscitation for hypotensive patients with penetrating torso injuries. N Engl J Med 1994;331(17):1105-1109.
7. Kowalenko T, Stern S, Dronen S, Wang X. Improved outcomes with hypotensive resuscitation of uncontrolled hemorrhagic shock in a swine model. J Trauma 1992;33(3):349-353.
8. Stern SA, Dronen SC, Birrer P, Wang X. The effect of blood pressure on hemorrhage volume and survival in near-fatal hemorrhage model incorporating a vascular injury. Ann Emerg Med 1993;22(2):155-163.
9. Burris D, Rhee P, Kaufmann C, Pikoulis E, Austin B, Eror A, et al. Controlled resuscitation for uncontrolled hemorrhagic shock. J Trauma 1999;46(2):216-222.
10. Carrico CJ, Canizaro PC, Shires GT. Fluid resuscitation following injury: rationale for the use of balanced salt solutions. Crit Care Med 1976;4(2):46-54.
11. Fatovich DM, Phillips M, Jacobs IG, Langford SA. Major trauma patients transferred from rural and remote Western Australia by the Royal Flying Doctor Service. J Trauma 2011;71(6):1816-1820.
12. Clifford CC. Treating traumatic bleeding in a combat setting. Mil Med 2004;169(12S):8-10.
13. Brohi K, Singh J, Heron M, Coats T. Acute traumatic coagulopathy. J Trauma 2003;54(6):1127-1130.
14. Jansen JO, Thomas R, Loudon MA, Brooks A. Damage control resuscitation for patients with major trauma. BMJ 2009;338:1436-1440. DOI: 10.1136/bmj.b1778.
15. Holcomb JB, Jenkins D, Rhee P, Johanningman J, Mahoney P, Mehta S, et al. Damage control resuscitation: directly addressing the early coagulopathy of trauma. J Trauma 2007;62(2):307-310.
16. Niles SE, McLaughlin DF, Perkins JG, Wade CE, Li Y, Spinella PC, Holcomb JB. Increased mortality associated with early coagulopathy of trauma in combat casualties. J Trauma 2008;64(6):1459-1465.
17. Greiser B, Jurkovich G, Luterman A. Severe hypothermia: an ominous predictor of mortality in trauma victims. J Trauma 1986;26(7):675.
18. Bruns B, Lindsey M, Rowe K, Brown S, Minej JP, Gentilello LM, Shafi S. Hemoglobin drops within minutes of injuries and predicts need for intervention to stop hemorrhage. J Trauma 2007;63(2):312-315.
19. McLaughlin DF, Niles SE, Salinas J, Perkins JG, Cox ED, Wade CE, Holcomb JB. A predictive model for massive transfusion in combat casualty patients. J Trauma 2008;64(2 Suppl):S57-S63.
20. Borgman MA, Spinella PC, Perkins JG, Grathwohl KW, Repine T, Beekley AC, et al. The ratio of blood products transfused affects mortality in patients receiving massive transfusions at a combat support hospital. J Trauma 2007;63(4):805-813.
21. Holcomb JB, Wade CE, Michalek JE, Chisholm GB, Zarzabal LA, Schreiber MA, et al. Increased plasma and platelet to red blood cell ratios improves outcome in 466 massively transfused civilian trauma patients. Ann Surg 2008;248(3):447-458.
22. Calderbank P, Woolley T, Mercer S, Schrager J, Kazel M, Bree S, Bowley DM. Doctor on board? What is the optimal skill-mix in military pre-hospital care? Emerg Med J 2011;28(10):882-883.
23. Johannigman J. Maintaining the continuum of en route care. Crit Care Med 2008;36(7 Suppl):S377-S382.
24. Dawes R, Thomas GO. Battlefield resuscitation. Curr Opin Crit Care 2009;15(6):527-535.
25. Inaba K, Lustenberger T, Rhee P, Holcomb JB, Blackbourne LH, Shulman I, et al. The impact of platelet transfusion in massively transfused trauma patients. J Am Coll Surg 2010;211(5):573-579.
26. Department of Defense. Emergency war surgery, 3rd United States revision. 2004. Washington, D.C.: Borden Institute; 2004:7.6-7.12, 12.1-12.10, 22.7-22.12. http://www.bordeninstitute.army.mil/other_pub/ews/TableOfContents.pdf. *Accessed May 23, 2012.*
27. Spinella PC. Warm fresh whole blood transfusion for severe hemorrhage: US military and potential civilian applications. Crit Care Med 2008;36(7 Suppl):S340-S345.
28. Spinella PC, Perkins JG, Gratwohl KW, Beekley AC, Holcomb JB. Fresh whole blood is independently associated with improved survival for patients with combat-related traumatic injuries. J Trauma 2009;66(4 Suppl):S69-S76.
29. Weinberg JA, McGwin G, Vandromme MJ, Marques MB, Melton SM, Reiff DA, et al. Duration of red cell storage influences mortality after trauma. J Trauma 2010;69(6):1427-1431.
30. Koch CG, Li L, Sessler DI, Figueroa P, Hoeltge GA, Mihaljevic T, Blackstone EH. Duration of red-cell storage and complications after cardiac surgery. N Engl J Med 2008;358(12):1229-1239.
31. Sharp KW, Locicero RW. Abdominal packing for surgically uncontrollable hemorrhage. Ann Surg 1992;215(5):467-474.
32. Rotondo MF, Schwab CW, McGonigal MD, Phillips GR, Fruchterman TM, Kauder DR, et al. Damage control: an approach for improved survival in exsanguinating penetrating abdominal injury. J Trauma 1993;35(3):375-382.
33. Fox CJ, Patel B, Clouse WD. Update on wartime vascular injury. Perspect Vasc Surg Endovasc Ther 2011;23(1):13-25.
34. Rasmussen TE, Clouse WD, Jenkins DH, Peck MA, Eliason JL, Smith DL. The use of temporary vascular shunts as a damage control adjunct in the management of wartime vascular injury. J Trauma 2006;61(1):8-12.
35. Borut LT, Acosta CJ, Tadlock LC, Dye JL, Galarneau M, Elshire CD. The use of temporary vascular shunts in military extremity wounds: a preliminary outcome analysis with 2-year follow-up. J Trauma 2010;69(1):174-178.
36. Blackbourne LH. Combat damage control surgery. Crit Care Med 2008;36(7 Suppl):S304-S310.