Chapter 33

TACTICAL MEDICINE

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INTRODUCTION

Medical practice in a limited-resource operational environment frequently differs from "standard" practice in a fully resourced hospital in the United States. Battlefield trauma care is based partly on standard US guidelines, such as the Advanced Trauma Life Support (ATLS) course, but also with an eye toward the unique considerations of a forward deployed environment. This chapter will highlight important operational medical skills and guidelines, such as those delineated in the Tactical Combat Casualty Care (TCCC) guidelines and the *Prehospital Trauma Life Support* (PHTLS) manual.[1] Thorough appreciation of these concepts is important not only for the practice of individual military medical officers (MMOs), but also for MMOs' oversight and empowerment of further forward deployed providers (eg, corpsmen and medics) who provide care close to the point of injury.

BACKGROUND

Tactical Environment

Delivering medical care in the tactical environment is one of the most daunting tasks an MMO will be asked to prepare for and accomplish. This care takes place at the confluence of several challenging situations, including austere environments, limited resources (in both personnel and equipment), unusual and severe wounds, and the possible presence of a dangerous enemy. Exhibit 33-1 provides a more complete listing of conditions and concerns in this environment.

Considering these factors, MMOs must prepare to care for the severely injured while also considering human performance issues related to environmental extremes. In extreme and austere settings, the human body is required to operate outside its normal daily training pattern and adjust to the effects of high altitude, cold, heat, or other factors. Each of these conditions involve a host of problems and medical treatment options, including the very real concerns of infectious disease. Health problems caused by these threats, collectively referred to as disease and nonbattle injury (DNBI), have been the leading cripplers of fighting forces throughout history. These topics are further discussed in Chapter 20, Physical Fitness; Chapter 21, Performance Nutrition; Chapters 22 through 24, on environmental extremes; and Chapter 40, Preventive Medicine in the Deployed Environment.

Environmental elements affect not just the human body, but also the equipment required to care for it. The battlefields of Operation Enduring Freedom (OEF) have seen temperatures from below freezing, in January at Bagram Airfield in Parwan Province, to upwards of 137°F, in August in Helmand Province. In the Hindu Kush mountains, to the extreme northeast, operations reportedly took place as high as 15,000 to 17,000 feet, higher than any peak in the continental United States. In both Iraq and Afghanistan, fine dust penetrates nearly any container except a tightly sealed zip-lock bag. Thus, any equipment used in these conditions can be expected to eventually fail. Blood products may rapidly be rendered useless when generators fail or blood reefers (refrigerators) simply cannot maintain products at 0°C to 10°C indefinitely.

To prepare for success in the tactical setting, mindset is a fundamental consideration for MMOs. In addition to normal US practice standards of care, MMOs must also know how to handle the unique wounding patterns, resource limitations, and tactical considerations common in this setting. There are three main objectives in providing care to a casualty during a tactical or combat mission:

1. Provide the best possible care for the casualty.
2. Minimize additional casualties.
3. Maximize the probability of mission success for the unit.

Mindset is also enhanced by remembering the differences between principles and preferences, as described in the PHTLS manual.[1(xxi)] "Principles" are medical care goals that must be accomplished to best take care of the patient. "Preferences" are how these

EXHIBIT 33-1

CHALLENGES OF THE TACTICAL ENVIRONMENT

- Hostile fire
- Darkness
- Altitude
- Weather extremes
- Prolonged evacuation
- Limited resources
- Provider training level
- Mission completion
- Tactical considerations
- Local disease prevalence

goals are accomplished in the context of the entire casualty care scenario. For example, in hemorrhage control, the principle is to stop the bleeding. The preference will depend on the unique casualty care scenario and the tactical setting. One might choose to immediately place a tourniquet while under effective hostile fire, even if there is only moderate bleeding, whereas in a safer environment, a provider might apply a pressure dressing as the initial action.

To deliver the very best care in challenging environments, MMOs must have a strong font of knowledge and a wider breadth of skills than their civilian counterparts. A provider should have multiple ways of accomplishing tasks such as securing an endotracheal tube. MMOs must also understand the tactics, techniques, and procedures unique to their unit; be thoroughly versed in the unit mission; and develop a collegial working relationship both with the command and with the medics or corpsmen working under their supervision. The joint operational environment US forces commonly work in requires an understanding of all other medical capabilities—those in other US units, interagency organizations, and coalition partners. Decisions must be made about which medical capability will be placed where during unit operations. Casualty scenarios almost always involve both medical and tactical problems. Thus, the MMO must communicate TCCC principles to unit leaders throughout their assignment to the unit so that appropriate management and evacuation plans can be developed in the context of the overall tactical situation.

Before discussing specific injuries in the combat environment, some further broad principles must be covered. Predeployment training for the different services continues to differ significantly, even for similar missions. It is incumbent on providers to pay close attention in training and to seek further training early once they are informed of a pending deployment. On their initial deployment, MMOs are rarely fully prepared to experience and manage combat trauma; thus, exposure to actual trauma, as well as contact with providers who recently returned from combat operations, is essential. Examples of in-depth trauma training for military providers can be found at the Navy Trauma Training Center at Los Angeles County/University of Southern California Medical Center, the Air Force Center for Sustainment of Trauma and Readiness Skills program at the University of Cincinnati Medical Center, and the Army Trauma Training Center at the University of Miami/Jackson Memorial Hospital Ryder Trauma Center. In addition to these programs, which leverage civilian-military partnerships, each service sponsors numerous local and unit training opportunities.

MMOs should study their unit's various missions in depth prior to deployment, because not all tactical medicine will occur on combat missions. For example, Exhibit 33-2 lists the numerous possible missions of a Marine expeditionary unit deployment. Lastly, the MMO should thoroughly study the environment of care and resources available in the specific area of operations. Limited treatment and rapid evacuation to a higher level of care may quite possibly be the best option for a given patient and tactical scenario.

History of Combat Death Statistics

To understand the basic statistics involved in describing combat casualties, the terms "killed in action" (KIA), "died of wounds" (DOW), and "case fatality rate" (CFR) must be defined. Up to 90% of all casualties who do not survive die on the battlefield before arriving at a dedicated field hospital. These casualties are described as KIA. KIA has classically served as an indicator of weapon lethality and the utility of protective measures, both of which have increased steadily over time. If a casualty survives to be admitted to a field hospital, but then later dies from injury, they are described as DOW. DOW has been seen as an indicator of the effectiveness of combat casualty care. A combination of KIA and DOW is the CFR, which is an indicator of the overall lethality of the battlefield.

Organized prehospital trauma care had its birth on the 19th century battlefields of the Napoleonic wars. With each major conflict since, lessons learned were

EXHIBIT 33-2

POSSIBLE MISSION PROFILES FOR A MARINE EXPEDITIONARY UNIT

- Amphibious assault
- Security, stability, transition, and reconstruction operations
- Support theater security cooperation activities
- Humanitarian assistance
- Noncombatant evacuation operations
- Tactical recovery of aircraft, equipment, personnel
- Airfield operations from expeditionary sea or shore-based sites
- Airfield or port seizure operations
- Joint and combined operations
- Maritime contingency operations
- Visit, board, search, and seizure operations

promulgated to the civilian sector; conversely, in times of peace, civilian medical advances were transitioned to the military medical community. These exchanges have not always been seamless, but the civilian community has often profited significantly from military medicine. The following examples of advances in military medicine led to major improvements in civilian medicine.

During the Civil War, Jonathan Letterman established an ambulance corps under the command of a medical officer, and the concept of a field hospital emerged, as well as the correlation of treatment time and survival rates. The prolonged trench warfare of World War I led to a significant rise in DNBI cases of trench foot, frostbite, and hypothermia. Blood products, first used on the battlefield at the close of World War I, were further developed during the interwar years. During World War II, blood products were further improved, as were methods of pain control in combat casualty care. A formalized triage system was utilized to prioritize casualty evacuation. Antibiotics were developed.[2] Brian J. Ford, a British scientist, noted, "If any good can be said to become of war, then the Second World War must go on record as assisting and accelerating one of the greatest blessings that the twentieth century has conferred on man—the huge advances of medical knowledge and surgical techniques. War, by producing so many and such appalling casualties, and by creating such widespread conditions in which disease can flourish, confronted the medical profession with an enormous challenge, and the doctors of the world rose to the challenge of the last war magnificently."[3]

Moving surgical care further forward was the hallmark of the Korean War, with the development of mobile Army surgical hospital (MASH) units and helicopter casualty evacuation.[4] Helicopters were used extensively during the Vietnam conflict, but despite this rapid mode of casualty movement, the CFR remained essentially unchanged from World War II, due to a lack of significant changes in the training and equipment supplied to combatants and medics who provided initial care. Further, poorly designed and translated animal studies on blood volume replacement led to the recommendation to enhance lost circulating blood volume with crystalloid (replacing blood lost by a factor of three). In a 1970 cohort of 2,600 casualties, 7.9% of injuries resulted from isolated extremity wounds that would have been amenable to a simple tourniquet, and were likely worsened by crystalloid resuscitation.[5]

The CFR did not decrease significantly until OEF and Operation Iraqi Freedom (OIF)—from 16.5% in Vietnam to 8.8% today.[6] The KIA and DOW rates were similar in World War II and Vietnam: 88% and 12%, respectively. Considering OEF and OIF together, the KIA rate was 77% and the DOW was 23%. This indicates that casualties are surviving longer due to improved initial care and resuscitation (despite the increased lethality of weapons), and more severely injured casualties are making it to the combat support hospital before succumbing to their injuries.[7]

A major reason for this improvement was the change in tourniquet use. Early in OEF and OIF, there was still an inordinate amount of potentially preventable deaths. Holcomb et al[8] found that 25% of casualties in their series would have survived with the simple application of a tourniquet. Kelly et al[9] found a 7.8% rate of potentially preventable deaths resulting from failure to use a tourniquet when indicated. In the latest comprehensive study of deaths on the battlefield, by Eastridge et al,[10] there were 23.3 deaths per year from isolated extremity hemorrhage in the "pre-tourniquet" years, dropping dramatically to 3.5 deaths per year from this mechanism after tourniquets had been widely distributed on the battlefield and all combatants had been trained and encouraged in their use.

Wounding Patterns

For the past decade, the predominant type of injury on the battlefield has been penetrating wounds (75%). Survivability has been upwards of 90%; whereas in Vietnam it was 84%, and in World War II, 80%.[7] This increase is due to better trained tactical prehospital providers, better protective equipment, faster evacuation times, and improved far-forward care.

Better personal protective equipment such as modern body armor has changed the wounding patterns in the current conflicts in comparison to World War II, Korea, and Vietnam (Table 33-1). There are now fewer thoracic injuries and more head, neck, and extremity trauma. Most combat-related injuries are now from explosions, followed by gunshot wounds.[11] The extremities have the highest rate of injury, followed by the abdomen, face, and head.[12] The most common type of battlefield injury currently is the multiple fragment wound to multiple anatomic sites. Throughout all warfare over the past 2 centuries, the most common site of injury has been the extremity. Because the leading cause of preventable combat death is exsanguination from compressible hemorrhage, it is important to build a combat casualty care paradigm around hemorrhage control, moved as far forward as possible—even to the individual combatant and first responder.

TABLE 33-1

WOUNDING PATTERNS IN MAJOR US CONFLICTS

Conflict	Type of Warfare	Top Mechanisms (%)	Distribution, Top Sites (%)
Civil War	Napoleonic (set piece)	GSW, explosions	Data not found
WWI	Trench (defensive)	Explosions	Extremity (70) Head/neck (17) Other (4)
WWII	Mechanized land, amphibious assault	Mortar (39) Bullet (33) Grenade (12)	Extremity (75) Thorax (8) Other (9)
Korea	Amphibious, mechanized	Data not found	Extremity (67) Head/neck (17) Thorax (7) Abdomen (7)
Vietnam	Jungle warfare, COIN	Bullet (30) Mortar (19) IED (17)	Extremity (74) Head/neck (14) Thorax (7)
OIF/OEF	COIN, asymmetric warfare	IED (64) Bullet (26) Mortar (3)	Extremity (55) Head/neck (27) Abdomen (6)

COIN: counterinsurgency
GSW: gunshot wound
IED: improvised explosive device
OIF/OEF: Operation Iraqi Freedom/Operation Enduring Freedom
WW: World War

TACTICAL COMBAT CASUALTY CARE OVERVIEW

Although the "golden hour" concept has been controversial when studying the injured as a population,[13,14] what is unquestioned is that the lives of the injured overwhelmingly lie in the hands of those who place the first dressing. The right treatment, in the right tactical situation, and at the right time requires the focus of research, training, and education to be on the role and capabilities of the forward prehospital provider.

For decades, prehospital (and hospital) providers had been trained to care for combat casualties with principles based on civilian trauma care. However, combat trauma and civilian-based trauma differ in terms of wounds, resources, and environmental conditions. Toward the end of the 20th century, it was realized that the principles of ATLS, though sound within a civilian framework, were not just deleteriously affecting the outcome of the combat casualty, but were also dangerous for those delivering care at the point of injury. For example, treating a gunshot wound to the face in a tactical situation at night, a provider could blindly focus on the ATLS "A" for airway, leading to violation of tactical lighting principles and exposure to enemy fire. Airway maneuvers could wait until the patient had been moved to an area of cover, and maneuvers that do not require any bright "white" light could be performed, protecting both the patient and provider. As is stated throughout the TCCC curriculum: good medicine can be bad tactics, and bad tactics can get others killed and/or cause the mission to fail.

Origins

TCCC was an initiative that began at the Naval Special Warfare Command in 1993, resulting in the publication of the first introductory paper on the concept in 1996.[15] Although this article provided a solid foundation, the sheer volume of rapidly advancing research in the field of combat trauma has required the Committee on TCCC (CoTCCC) to meet regularly to review new research, direct findings from the battlefield, and recommendations from leaders in the field of combat trauma. The CoTCCC is composed of trauma surgeons, emergency physicians, operational unit physicians, combat medics, corpsmen, and pararescue specialists, spanning the entire realm of providers who might be called on to treat the injured.

The CoTCCC was initially independent, then became part of the Defense Health Board before being integrated into the Joint Trauma System. Recommendations and curriculum changes are published in the *Journal of Special Operations Medicine* and in the PHTLS manual. TCCC is the only set of battlefield trauma guidelines to receive a triple endorsement by the American College of Surgeons Committee on Trauma, the National Association of Emergency Medical Technicians, and the Department of Defense (DoD). The guidelines can be viewed open source at http://www.naemt.org/education/TCCC/guidelines_curriculum. Recently, the Committee on En Route Casualty Care and the Committee on Surgical Combat Critical Care were established by the Joint Trauma System at the Army Institute of Surgical Research in San Antonio, Texas, to broaden standardized treatment guidelines for combat trauma patients.

As recent lessons learned from war became integrated into civilian trauma care in the United States, a synergistic and reciprocal relationship developed between TCCC and Tactical Emergency Medicine Support (TEMS) protocols, which are practiced by law enforcement tactical teams, the FBI, and other state and federal agencies. Although the relationship between TCCC and TEMS is quite strong and direct, the relationship between the principles of TCCC and ATLS is less so.

Definitive Proof of Effectiveness

In the late 1990s, the 75th Ranger Regiment was directed by its commanding officer (General Stanley McChrystal) to aggressively adopt TCCC. McChrystal directed this elite combat unit to focus on four items in training: (1) marksmanship, (2) physical training, (3) small unit tactics, and (4) medical training (TCCC). Thus, TCCC was integrated into programs of instruction, training exercises, and planning at all levels. This integration, along with tactical leader assumption of responsibility for the casualty response system, continues to be an entirely different method from the training and casualty response approach taken by other ground combat units within the DoD—a paradigm that must change for battlefield trauma care to be improved. Results of a comprehensive analysis showed that on more than 8,000 missions over a 10-year period, the Rangers lost only 28 men, despite being one of the most heavily engaged units in combat operations. None of these deaths were from a preventable cause.[16] Recognizing its effectiveness, the Defense Health Board now recommends that TCCC training be provided in a tiered fashion to all personnel operating in the battle space.[17]

Phases of Care

TCCC is divided into three phases of care, with the priorities of care shifting depending on the phase. In care under fire (CUF), a provider is required to take actions in caring for a casualty when under "effective" hostile fire. While this definition is vague, in CUF fire is being directed toward the provider or casualty. The priority is to ensure that the uninjured provider stays reasonably safe so that medical care can be delivered when the situation allows (a dead or injured medical provider cannot provide effective care). The casualty should be retrieved only when suppressive fire can be effectively provided. The only two pieces of "medical" gear utilized at this time are a weapon (the best medicine on the battlefield is fire superiority) and a tourniquet (to stop life-threatening hemorrhage). Tourniquets are applied immediately by the casualty (self-aid) or by someone else once the casualty has been moved to cover (buddy aid or medical care).

Tactical field care (TFC) occurs once effective hostile fire is no longer present. There still may be a threat of hostile fire, but the risk is lower (if more enemy move into the area, the threat may increase and providers may find they are back in CUF). TFC is conducted in the forward environment, so gear remains limited to what the medic or far-forward medical officer carries on their person. This equipment will vary depending on the operation and available resources. If vehicles are in use, there may be extra equipment carried in a vehicle kit. If infiltration is by airborne operations or forced march, the equipment will be limited to a small medical pack.

The final phase of TCCC is tactical evacuation (TACEVAC). This phase may provide the first opportunity to begin resuscitation with blood products. There should be additional monitoring equipment available, as well as the presence of ventilators and other more advanced equipment. Older terms for evacuation are casualty evacuation (CASEVAC) and medical evacuation (MEDEVAC); CASEVAC usually indicates a "vehicle of opportunity" where dedicated medical care is not present, and MEDEVAC usually indicates the presence of a dedicated medical provider. In reality, these terms overlap considerably and have led to confusion, so TCCC refers to any evacuation as simply TACEVAC.

Contrast to Civilian Prehospital Care

The approach to trauma care in combat is different than the approach of ATLS in a civilian environment. The ATLS mnemonic "ABCDE" (Airway, Breathing, Circulation, Disability, Exposure) is not used in a

tactical environment; instead, combat trauma is prioritized according to the "MARCH" paradigm: Massive hemorrhage, Airway, Respirations, Circulation, Hypothermia.

Control of bleeding takes precedence over all other efforts. Once a casualty loses blood, there may be a significant delay before volume can be replaced. Tourniquets should be used readily and early, with frequent reassessments for their need. Attention to the airway and cervical spine are delayed until the TFC phase, when the casualty and rescuer are both removed from hostile fire. Airway maneuvers require too much risk to the provider in terms of time and exposure in CUF. Because the majority of injuries are penetrating, the likelihood of an unstable cervical spine fracture is negligible during combat operations, unless there is significant blunt force trauma (as in a large explosive device blast or vehicular crash).

Casualties with loss of consciousness who are spontaneously breathing are given a nasopharyngeal airway and placed in the recovery position (on their side with slight flexion). To minimize the risk of hypothermia, clothing is removed only where necessary to treat injuries. Intravenous (IV) access is not performed for casualties with a strong radial pulse and normal mentation in the setting of mild to moderate wounds. Oral rehydration is adequate in these casualties.

Another concept included in TCCC is the futility of basic cardiopulmonary resuscitation (CPR) for any casualty without signs of life. The pathophysiology of circulatory arrest in a trauma scenario is completely different than in a medical scenario. Closed-chest CPR requires that the heart have adequate volume to pump. In trauma, an arrest is usually from causes that do not respond to closed chest compressions: hypovolemia due to hemorrhage results in inadequate volume; tension pneumothorax (TPTX) prevents venous return to the heart, leading to inadequate preload for CPR to be effective; and cardiac tamponade prevents the atria and ventricles from filling. Specific TCCC principles and techniques, shaped by the combat trauma setting, are discussed in detail below.

HEMORRHAGE CONTROL

Tourniquets

Tourniquets should be applied early and liberally if there is any question of exsanguinating hemorrhage. Despite the obvious effectiveness of tourniquets at saving lives due to exsanguination from extremity injuries, the tourniquet has fallen in and out of favor periodically over centuries.[18–20] Concerns historically related to tourniquet application include loss of limb, ischemic pressure damage, rhabdomyolysis, nerve or vascular damage, and reperfusion syndrome. However, with updated technology and proper training, modern tourniquets applied properly do not result in these complications. Documented complications from currently approved tourniquets are primarily caused by improper application. Despite reported rates of "non-indicated" tourniquets ranging from 47%[21] to 74%,[22] research has shown that morbidity from liberal tourniquet use in the global war on terror has been minimal, and no permanent complications have been documented as a result of proper tourniquet application and management.[23–25] While a complete discussion of the history of tourniquet use is beyond the scope of this chapter, no controversy currently exists as to the effectiveness of properly applied tourniquets at saving lives.

Numerous articles have been published on the evolution of the modern tourniquet.[26–28] The push for an effective battlefield tourniquet was a direct result of continued cases of death from extremity exsanguination early in OIF/OEF. Several factors were taken into consideration, including ease of self-application; durability; logistics (cost, weight, and volume); and width. Wider tourniquets provide arterial occlusion at lower pressures and therefore lower the risk of direct pressure damage to tissue.

Of the CoTCCC-approved tourniquets, the most important factor in selecting which to carry is familiarity. More rapid application is associated with decreased blood loss. Proper training leads to familiarity and more rapid application (both in the decision to apply and in actual device employment). In a study of Canadian military personnel, the primary tourniquet fielded over several years was applied the fastest by trained medics.[29]

Proper application of a tourniquet includes stopping arterial flow distal to the tourniquet; venous tourniquets represent a significant concern. A tourniquet may be applied with enough force to initially stop visual bleeding, but it may not stop all arterial flow to the extremity. This eventually leads to paradoxical bleeding as venous return is impeded and tissues become engorged.[30] The risk of venous tourniquets is high in the CUF phase. With lifesaving maneuvers taking precedence over diagnostic maneuvers in some tactical situations, the patient's uniform is not likely to be removed (so there is incomplete evaluation of the wound site) and boots may remain on their feet (so absence of distal pulse is not confirmed). Rates of venous tourniquet placement in the prehospital

setting as high as 83% have been documented. Given the potential complications associated with a venous tourniquet, proper application is extremely important.

Properly applied tourniquets cause ischemia that starts at the area of application and extends distally. Factors such as duration of application, temperature, and location affect the extent of tissue injury. Despite the general consensus that tourniquets applied for less than 2 hours are safe,[31,32] there is no consensus on the upper limit of "safe" tourniquet use. A recent extensive review published in the orthopedic surgery literature was unable to definitively answer this question.[33] Further complicating the discussion is a documented case of an upper extremity tourniquet left in place for 16 hours with successful return of function to the injured limb. Factors such as distal placement and cold ambient temperatures likely contributed to the good outcome in this case.[34]

With emphasis on early placement of tourniquets in the CUF phase of TCCC, any applied tourniquet must be repeatedly reevaluated for proper placement (absence of arterial pulse) and the need for continued use. The careful and deliberate process of evaluating tourniquets for removal is called conversion. The potential for significant blood loss and hemodynamic decompensation with the haphazard removal of tourniquets has been documented back to World War II.[35] Contraindications to attempted conversion include amputations, active shock, and an inability to continuously monitor the extremity. Tourniquets that have been in place for more than 6 hours should not be removed until the patient has reached a definitive care setting with laboratory and close monitoring capabilities. In 2015, the TCCC guidelines were updated to ensure that all tourniquets are reevaluated at each level of care and no more than 2 hours after initial placement. A step-by-step process for conversion was first published in 2005[27] and updated in 2015.[31]

Hemostatic Dressings

The last decade has witnessed a surge of products designed to manage severe bleeding in compressible areas not amenable to tourniquet application, or for use when a tourniquet might be deemed inappropriate. Collectively, these products are termed hemostatic dressings or hemostatic agents. However, despite extensive research, no single hemostatic dressing has emerged as superior. The ideal properties of current TCCC-recommended hemostatic dressings are listed in Table 33-2.[36]

In 2003, the first hemostatic agent selected by the CoTCCC was the HemCon (Medline, Northfield, IL) bandage; this was followed by QuikClot (Z-Medica, Wallingford, CT) granules.[37] After continued research into more efficacious products, in 2008 Combat Gauze (Z-Medica) was selected by the CoTCCC as the first-line hemostatic dressing. Today there are three products that meet the CoTCCC requirements for effective hemostatic dressings: HemCon ChitoGauze, QuikClot Combat Gauze, and Celox Gauze (MedTrade Products, Crewe, UK).

TABLE 33-2

PROPERTIES OF TCCC-RECOMMENDED HEMOSTATIC DRESSINGS

Criteria	Combat Gauze*	Celox Gauze†	HemCon Chitogauze‡
Stops arterial bleeding after 2–3 min of compression	Yes	Yes	Yes
Low side effects	Yes	Yes	Yes
Easy to use	Yes	Yes	Yes
Light weight	Yes	Yes	Yes
Tolerates environmental extremes	Yes	Yes	Yes
Long shelf life	3 years	4 years	3 years
FDA approved	Yes	Yes	Yes
Effective in coagulopathy	No	Yes	Yes

*Z-Medica, Wallingford, CT
†MedTrade Products, Crewe, UK
‡Medline, Northfield, IL
FDA: Food and Drug Administration

There are three main mechanisms of action for the hemostatic properties of these products. Dressings that concentrate clotting factors work through the rapid absorption of the water content of blood, leaving remaining coagulation proteins and platelets at the site of the wound. The archetype product with this mechanism of action was the original QuikClot granular formulation, adopted by the US Navy and the Marine Corps as their initial hemostatic agent of choice. QuikClot contained a zeolite mineral that absorbed water; however, its loose granules and an exothermic reaction caused safety concerns.[38]

Mucoadhesive agents (chitosans) react with blood and wounded tissue to form a glue-like substance that effectively seals or tamponades the wound. The hemostatic properties of chitosan appear to be by direct electrostatic interaction between negatively charged cell membranes of the erythrocytes and positively charged chitosan. These agents display strong adherence to tissues and physically seal bleeding wounds.[39] The first

mucoadhesive product approved was the HemCon bandage, adopted by the US Army as its first-line hemostatic agent. However, because the mucoadhesive barrier is a physical phenomenon, there is a theoretical danger of re-bleeding if an initially hypotensive patient is resuscitated to a normal blood pressure.[40]

Procoagulants act by either activating the coagulation cascade or by supplying clotting factors at the site of injury. Combat Gauze is the only current FDA-approved product in this category. It is a gauze impregnated with kaolin, which activates the intrinsic pathway of coagulation.[41] Due to the efficacy concerns with HemCon and the safety concerns with the original granular QuikClot, the CoTCCC recommended Combat Gauze as the only hemostatic dressing that passed both efficacy and safety testing. Later, both Celox Gauze and ChitoGauze (two mucoadhesive products) were included, after well-designed studies showed their efficacy to be similar to Combat Gauze.[42,43]

Successful application of these agents requires that a wound be firmly packed so there is a direct interface between the hemostatic gauze and the injured tissue. After application, pressure is maintained by the tightly packed wound, supplemented with an adequate pressure dressing. For most hemostatic dressings, pressure is held manually after wound packing for a minimum of 2 minutes before pressure dressing application. In fact, in some wounds the method of packing appears to be more important than the hemostatic dressing utilized.[44] Additional methods to provide pressure similar to a pressure dressing are to use a stapler to approximate the wound edges over the dressing, apply a non-vented chest seal over the wound, or place a new device on the wound called the iTClamp (Innovative Trauma Care, Edmonton, Canada).

Junctional Hemorrhage

A recent review of battlefield casualties over a 10-year period found that 90.9% of deaths were due to hemorrhage. Sites of lethal hemorrhage were truncal (67.3%), junctional (19.2%), and peripheral extremity (13.5%).[10] Junctional regions are those areas of the body where the extremities join the torso, such as the groin or axilla, and are too proximal for extremity tourniquet application. High junctional wounds are often not amenable to hemostatic dressings and are therefore termed noncompressible. If one of the new junctional tourniquet devices had been applied to the casualties with junctional hemorrhage, it is postulated that up to three US casualties per month would have been saved over the last decade of combat operations.[45]

Three junctional devices are currently approved by the FDA: the SAM Junctional Tourniquet (SJT; SAM Medical Products, Portland, OR); the Combat Ready Clamp (CRoC; Combat Medical Systems, Fayetteville, NC); and the Junctional Emergency Treatment Tool (JETT; North American Rescue, Greer, SC). The unilateral CRoC device has been evaluated on humans as well as in swine, manikin, and cadaver models. Assembly time to final application was reported to range between 55 and 90 seconds, depending on the surface condition and casualty model used.[46] In the swine model, the device was 100% successful in controlling bleeding just superior to the inguinal ligament using four to nine turns of the windlass.[47] Both the JETT and SJT treat combined pelvic and lower extremity injuries by incorporating a pelvic binder with bilateral hemorrhage control devices at the femoral arteries just distal to the inguinal ligament. In a fresh human cadaver model designed to recreate arterial flow at normal physiologic blood pressures, blood flow was halted in the femoral arteries with four to eight complete turns of the windlass handle, achieving success in controlling hemorrhage in all cases. Bilateral control of hemorrhage was achieved in 10 to 17 seconds after application, whereas the CRoC took 68 seconds to achieve bilateral control.[48] Improvised control of hemorrhage at junctional sites can also be achieved by securing either a rigid water bottle or a rolled SAM splint over the inguinal area and securing tightly with a regular (extremity) tourniquet.

AIRWAY MANAGEMENT

Airway problems in the tactical setting may seem daunting, but treatment is usually not difficult with appropriate predeployment training and a planned approach. Airway management begins during the TFC phase of TCCC. Control of significant external hemorrhage remains the first priority.

Most casualties who need airway management are simply unconscious or have altered mental status; the most likely source of airway compromise is occlusion by the tongue. This can be addressed in several ways. Immediate placement of the casualty in the recovery position is the favored initial maneuver. After this has been done, a nasopharyngeal airway is recommended to allow for a patent airway past the tongue and soft tissues of the oropharynx. Casualties may go in and out of consciousness; therefore, oropharyngeal airways should be avoided because they may stimulate the gag reflex and vomiting.

Traumatic airway obstruction, commonly related to facial or neck trauma, may also occur. These inju-

ries have accounted for nearly 2% of combat-related deaths in OIF and OEF.[49] Airway obstruction of this nature ranks as the third leading cause of preventable combat death. Depending on the training and skill of the operator, endotracheal intubation in the tactical setting may be difficult, so a surgical airway (cricothyroidotomy) is frequently the airway of choice. However, recent evidence suggests that the failure rate of cricothyroidotomy can be as high as 33% when conducted by prehospital providers.[50] Using the Cric-Key technique is currently the preferred method.[51]

While researchers look for improved methods of surgical airway management, MMOs should be prepared for other options such as supraglottic airways. These are more beneficial for the patient who may have airway compromise due to sedation or pain control. Because most airway compromise is from tongue occlusion or facial trauma, and most of these patients have an airway occlusion but are otherwise spontaneously breathing, it is usually not necessary to place the casualty on a ventilator or use a bag valve mask. However, if providers have the skills for advanced airway management, they should also be able to conduct positive pressure ventilation with these devices. Due to equipment failure and battery life problems, the presence of a bag valve mask is essential.

CHEST TRAUMA

According to the Joint Theater Trauma Registry, thoracic trauma has been the cause of lethal injury in 5% to 7% of all deaths in OEF and OIF.[52,53] TPTX, which is lethal yet readily preventable, ranks as the second leading cause of preventable combat death. Thus, the evaluation of the chest, and the immediate treatment of life-threatening injuries that compromise breathing, ranks only behind controlling massive hemorrhage in preventing death in combat casualties. Potentially life-threatening wounds also include closed pneumothorax and open pneumothorax (a sucking chest wound that can significantly compromise breathing efforts). The most serious condition, TPTX, can result in rapid collapse of respiratory and cardiovascular function. This occurs as air progressively enters the intrapleural space over time from either the external environment (via a chest wound with a ball-valve effect) or from internal bronchopulmonary disruption. The progressive "tension" of air pressure decreases venous return to the heart. This decreases preload, places pressure on the heart chambers that further decreases filling, and collapses the ipsilateral lung, which impedes pulmonary oxygen exchange. Clinical hallmarks are symptoms of progressive dyspnea and altered mental status. Signs are hypotension, hypoxia, cyanosis, jugular venous distension, decreased breath sounds, and hyperresonance to percussion on the injured side of the chest.

Closed pneumothoraces are rare in the combat setting but can occur as a result of blunt trauma. This condition is rarely diagnosed in the prehospital setting and should not be expected to result in a TPTX unless the patient is placed under positive pressure ventilation. If penetrating chest trauma has occurred and there is any significant hemodynamic instability or respiratory distress, the presence of a TPTX should be assumed. Performing a needle thoracentesis has the potential to save a life in this situation, and even if TPTX physiology is not present, a pneumothorax is likely. The downside of needle thoracentesis is small compared to the potential life saved.

The standard first-line intervention for a suspected TPTX in the prehospital setting is the placement of a needle thoracostomy (NT) with a 14-gauge, 3.25-inch (8.25-cm) angiocatheter in the thorax to relieve pressure. However, concerns about this technique have arisen due to the technical aspects of needle placement. The classic teaching is to perform an NT at the second intercostal space in the midclavicular line, and that an audible and palpable rush of air should be heard and felt if any significant pressure is relieved. However, recent studies have challenged the effectiveness of this approach. Some of the disadvantages cited have been inadequate catheter length, kinking of the catheter, and occlusion by clots.[54,55] Autopsy and computed tomography chest studies have demonstrated a 50% failure rate for standard length angiocatheters in the second intercostal space due to chest thickness. Other studies indicate that placement of the chest tube at the fourth intercostal space, anterior axillary line, has a higher success rate.[56] This location can be readily accessed without the removal of body armor, an advantage in certain combat settings.

When NT was isolated and standardized in a porcine model of TPTX, the failure rate of NT compared to tube thoracostomy (TT) was 58% (TT was successful in 100%).[57] It must be noted that an earlier paper by Holcomb et al showed a success rate for NT of 100%.[58] Careful analysis of the model showed that the definition of TPTX was a fall in cardiac output of 20% in the Holcomb paper, which was much milder than the definition in the former study, where cardiovascular collapse was precipitated (fall in systolic blood pressure [SBP] >50% or pulseless electrical activity). The conclusion could be made that NT is

effective at relieving less severe compromise from tension physiology, but that finger thoracostomy or TT is likely required in the casualty who is rapidly decompensating.

The experience of the Israeli Defense Forces is instructive in this regard. Although their transport times are much shorter than the US experience in OEF and OIF, providers treated 111 casualties with NT over a 5-year period, and reported a failure rate of treatment for presumed TPTX with NT of 32%. All the failures required a TT in the field.[59] In the austere setting, it is likely that finger thoracostomy followed by an overlying vented chest seal is superior with respect to time, technical skill, and contamination than TT, but this has not been studied. The classical teaching of applying a three-sided dressing to allow for air to escape the chest has no evidence to support it, whereas vented chest seals have been very effective in animal models. TT may be favored when there is a Pleur-evac (Teleflex, Morrisville, NC) available and the casualty is spontaneously breathing, or if there is suspected significant hemothorax and a cell saver is available for autotransfusion. Neither of these situations is likely in the prehospital environment due to logistical restraints.

Open pneumothoraces are usually not lethal in and of themselves, but can lead to significant morbidity when they are large enough to compromise the natural physiology of breathing. When the chest wall defect is equal to or greater than two-thirds the size of the trachea, air will preferentially enter the chest through the wound during normal spontaneous respirations.[60] The use of a fully occlusive dressing, which has been recommended for decades, does not allow accumulating air to exit the chest. This has the potential of converting a less lethal wound (open pneumothorax) to a more lethal one (TPTX).[61] Thus, occlusive/non-vented chest seals require constant vigilance if used, which is not a desirable situation in a far-forward environment with possible multiple casualties and a rapidly evolving tactical situation. For this reason the current recommendation is to use vented chest seals to treat open pneumothoraces. Several studies indicate that most commercial vented chest seals are highly efficacious, unlikely to lose their seal (a dangerous complication) or become ineffective due to clotting blood.[62,63]

DAMAGE CONTROL RESUSCITATION

"Damage control" is a term of naval origin and refers to the capacity of a ship to absorb damage and maintain mission integrity. If a ship is damaged and begins to take on water, there are approaches used to minimize the damage so that the vessel remains afloat and suffers minimal "physiological disruption" to its critical systems and infrastructure. The term "damage control surgery" (DCS) was coined to refer to this same approach in a severely traumatized patient. DCS entails immediate surgery to control internal bleeding and minimize contamination from gastrointestinal trauma. In the present era, DCS has become the standard of care for battlefield trauma surgery. "Damage control resuscitation" (DCR), a logical offshoot of DCS, has become the standard of care for expeditionary medical facilities treating combat casualties.[64,65] DCR focuses on minimizing the effects of the lethal triad (hypothermia, acidosis, and coagulopathy). It entails early transfusion of blood products to restore intravascular volume (minimizing crystalloid use), permissive hypotension, keeping the patient warm, and using adjuncts to support the coagulation system (tranexamic acid [TXA], fibrinogen, Factor VIIa). DCR should begin at the point of injury and continue to the time of initial lifesaving surgery and beyond.

Because 90% of battlefield deaths occur before the casualty reaches a medical facility, there is a keen interest in pushing damage control principles and techniques further forward.[66] Care of the severely traumatized combatant is difficult at the point of injury and differs significantly from civilian practice. Civilian concepts and procedures often have to be "unlearned," and military medical practice may need adjustment to better fit the tactical situation.[67] Additionally, although the categories of shock are useful as a theoretical construct, in reality they are often unreliable in the individual casualty. In one study, for patients who had an estimated blood loss of over 40% (class IV shock), the median heart rate was 95 and the median systolic blood pressure was 120.[68] Vital sign derangements may signal that a patient is in shock, but normal signs do not ensure they are not in shock.

Ideally, casualties beginning to show the first signs of shock should receive fresh whole blood (FWB), or blood components that mimic the constituency of whole blood. Because this is not logistically feasible for mobile combat units dispersed away from organized medical facilities, a focus on hypotensive resuscitation and minimal fluid administration appears to be the only legitimate strategy. Circulatory access is obtained via the IV or intraosseous (IO) route, and fluid is administered to achieve enough perfusion to maintain a conscious patient with a palpable radial pulse. If fluid must be administered, it can be given via oral, IV, or IO routes.[69]

An important caveat to fluid resuscitation is that it must be determined whether the patient's hemorrhage is definitively controlled versus uncontrolled (or even possibly uncontrolled). For casualties with definitively controlled external hemorrhage, the resuscitation endpoint should be an adequate SBP (≥110).[70] For any casualty with controlled external hemorrhage, but at risk of ongoing internal hemorrhage (eg, from a gunshot wound to the torso or high amputation from an improvised explosive device), the provider should still consider hypotensive resuscitation targets, which are adequate mentation, a palpable radial pulse, or an SBP of 90 to 110,[70] as the mainstay of prehospital resuscitation endpoints. While it may seem unnerving and counterintuitive based on protocols in civilian trauma, hypotensive resuscitation has reduced the risk of death in all trials in which it has been investigated.[71]

The 1994 landmark, paradigm-shifting paper by Bickell et al showed that crystalloid resuscitation for patients with penetrating torso trauma produced a lower survival rate than delayed resuscitation.[72] However, transport times in this study averaged 15 minutes, whereas, in the combat environment, evacuation times can be from 2 to 4 hours (Desert Storm) to 15 hours (Mogadishu), depending on the conflict, region, and existing military presence and medical evacuation structure.[73] Fortunately, ATLS now only recommends 1 L of crystalloid.[74] The Bickell study, along with mounting information that IV fluid resuscitation exacerbates the profound inflammatory state of hemorrhagic shock, prompted the Office of Naval Research to ask the Institutes of Medicine to review fluid resuscitation strategies.[75] Ultimately, the TCCC guidelines were rewritten to limit fluid resuscitation to patients in shock, with the use of blood products, lower volumes, and specific endpoints as a goal.[76]

Since the 2005 World Health Organization expert consensus panel on prehospital care for the trauma patient found little evidence that advanced prehospital interventions were superior to basic interventions,[77] it is imperative that *every* medical provider be an expert in hemorrhage control, know how to quickly move the patient to a surgical facility, and be cognizant of the nuances of DCR. When considering fluid resuscitation for the patient in shock, there are four objectives in the prehospital setting:

1. Enhance clot forming ability.
2. Minimize the negative effects of resuscitation (edema, hemodilution).
3. Restore intravascular volume and organ perfusion.
4. Optimize the delivery of oxygen.

Other than FWB, the ideal resuscitative fluid is yet to be found. The debate about crystalloids versus colloids in the treatment of shock has continued unabated since they were introduced. Blood components such as packed red blood cells (PRBCs), while necessary to transport oxygen, also increase morbidity and mortality.[78] Artificial hemoglobin carriers have significant side effects that continue to restrict their use in humans. No resuscitative fluid is totally benign, and all may potentiate the cellular injury associated with hemorrhagic shock if not used judiciously. These agents should be viewed as medications with specific indications and dosing parameters.

It should be noted that only combined resuscitation with red blood cells (RBCs) and plasma is associated with improved survival, even when evacuation times are short.[79] In a recent article on fluid resuscitation by the CoTCCC,[80] the preferred fluids for hemorrhagic shock in descending order of preference were:

1. FWB.
2. 1:1:1 plasma, RBCs, and platelets.
3. 1:1 plasma and RBCs.
4. Reconstituted dried plasma, liquid plasma, or thawed plasma alone or RBCs alone.
5. Hextend.
6. Lactated Ringer (LR) solution or Plasma-Lyte A (Baxter Healthcare, Deerfield, IL).

Fresh Whole Blood

Nothing replaces lost blood from hemorrhage like FWB from an immediate donor. Because it is fresh, one unit has the hemostatic power of 10 units of platelets.[81] The only prehospital guidelines that currently support the use of FWB are the TCCC guidelines (TACEVAC section). Whole blood transfusion was the standard for resuscitation from hemorrhagic shock in World War II, Korea, and Vietnam.[82] Since the Vietnam era, objections to FWB use have arisen, including the risks of ABO incompatibility, transfusion-related disease, graft versus host disease (GVHD), and reduced exercise tolerance in donors. However, current evidence appears to refute these concerns. In OIF III (2003–2011), 13% of all transfused patients received FWB[83] without significant sequelae. Approximately 10,000 FWB transfusions to US personnel occurred in OEF and OIF, and only two complications of survivable transfusion-related reactions were recorded, as well as one fatal case of GVHD.[84] In an article on blood donation in the Norwegian Special Forces, there was no decrease in either physical or skill (shooting) performance after donating one unit (450 mL) of blood for "buddy transfusion."[85] Cold-stored whole

blood is FDA approved for up to 21 days; however, FWB is not currently FDA approved and has been utilized only in emergency combat trauma scenarios. Currently the US Army's 75th Ranger Regiment has an approved protocol[86] based on updated evidence[87] that allows providers to draw O-negative blood from donors prior to missions for use in case of severe trauma with significant hemorrhage. This program is now becoming more widely used within US Special Operations Command.

Stored Constituents of Blood

The past century has witnessed many changes to the practice of blood administration. One of the most profound has been the transition from using whole blood to using components of blood (RBCs, plasma, platelets), which came about without clinical validation of which patients needed which products.

Stored blood transfusion involves major complications, and is an independent predictor of mortality in civilian trauma, likely due to the toxic products of stored components that accumulate over time.[78] When FWB is not available, thawed plasma at a 1:1 ratio with PRBCs is the current resuscitation strategy for hypovolemic shock due to blood loss at combat support hospitals. Simultaneously, a whole blood donor drive is initiated.

Plasma alone is an effective volume expander, does not activate the pathways of cellular injury, and provides physiologic quantities and ratios of clotting factors. Freeze-dried plasma is used extensively by the Israeli Defense Forces,[88] but is approved for use by only a few US special forces far forward. Freeze-dried plasma can be reconstituted in minutes and given to expand plasma volume, provide clotting factors, and buffer the acidosis that occurs with shock. However, plasma has all the drawbacks of blood product transfusion, and frozen plasma involves the logistical burden of cold storage and transport. DoD-funded investigations continue on autologous freeze-dried plasma, and its use may spread from the special operations community to regular combat medical units. Currently freeze-dried plasma is not FDA approved, and there is no mechanism by which conventional medics and corpsmen can utilize it.

Artificial Colloids

Colloids are more effective than crystalloids at expanding plasma volume because of the oncotic properties of the large molecules they contain.[89] There are many colloids on the market, but the most widely used in TCCC is Hextend, which is a hydroxyethyl starch in a balanced salt solution similar to LR. Another product, Hespan (B. Braun Medical, Bethlehem, PA), is hydroxyethyl starch in a normalized saline solution. Hextend remains the TCCC forward resuscitative fluid of choice due to its volume-expanding capabilities (6 to 8 hours), decreased logistical burden, and less deleterious coagulation effects than Hespan.[90]

A recent Cochrane review concluded that when fluid resuscitation is required, there is no appreciable difference in outcomes after resuscitation with colloids versus crystalloids.[91] Because combat casualties are resuscitated in a much different environment than civilians, however, colloids offer the distinct advantage of less volume and weight. Resuscitation with Hextend results in one-third the volume requirement of LR[92]; additionally, it has a favorable acid-base profile and has been shown to decrease overall fluid requirements. For these reasons Hextend has replaced LR as the fluid of choice carried by medics in the field.[93]

Crystalloids

During the Vietnam War, crystalloid resuscitation became the standard of care, and volume replacement was recommended at three times the amount of blood loss.[94] This approach was later found to worsen outcomes and also contributed to the development of abdominal compartment syndrome and acute respiratory distress syndrome (known as Da Nang lung when it was first characterized).[95,96] It was not until the Bickell study that this practice of aggressive crystalloid resuscitation began to change. This is not a new concept; in 1918 Cannon et al had written that "inaccessible or uncontrolled sources of blood loss should not be treated with IV fluids until the time of surgical control."[97] Fluid resuscitation in uncontrolled hemorrhage is now known to dilute clotting factors and exacerbate coagulopathy, worsen acidosis (normal saline [NS] and LR have a pH of 5.0 and 6.5, respectively), and disrupt early thrombus.[98]

Crystalloid resuscitation may be considered if no other fluids are available and the casualty needs some sort of volume replacement to maintain blood pressure and mental status. Large volume IV fluid resuscitation is associated with coagulopathy on arrival in the emergency department[99] and contributes to the coagulopathy of trauma.[100] This coagulopathy almost doubles mortality in certain patients.[101] Crystalloids distribute rapidly to the interstitial space and are not as effective for expanding blood volume as colloids, adding only 275 mL to the intravascular space for every 1 L infused.[102] If blood products or Hextend are not available, LR is preferred to NS because it does not induce hyperchloremic acidosis as NS does.[103]

Special mention must be made of one particular crystalloid, hypertonic saline (HTS), for use in the casualty with multitrauma who also has traumatic brain injury (TBI). In TBI, secondary injury, usually related to some degree of hypotension or hypoxia, may be avoidable. Mortality doubles in a hypotensive patient with TBI when compared to normotensive TBI casualties.[104] HTS may be the optimal resuscitative fluid for these patients when hypotension must be treated and cerebral edema avoided.[17] HTS refers to any concentration of sodium chloride above physiologic (0.9%); common concentrations are 2%, 3%, 5%, 7%, and 23%. The osmotic actions of HTS have been well categorized. The discovery of extraosmotic actions such as immune modulation and augmentation of cerebral blood flow are intriguing and invite further study, but the evidence remains mixed. A metaanalysis of six trials and 604 subjects showed that HTS-dextran provided a discharge survival rate of 38%, versus 27% for the NS control, in the subgroup of patients who had sustained multitrauma with concomitant TBI.[105] A randomized, controlled trial in TBI cases comparing HTS (7.5%) to LR showed no difference in ultimate neurologic outcomes or mortality.[106] Data from the Research Outcomes Consortium likewise showed no benefit of HTS solutions in TBI.[107] Once started, HTS should be titrated to keep serum sodium concentrations at 145 to 155 mEq/L, and cessation should be gradual secondary to concerns of rebound cerebral edema and herniation.

Best Strategies for Fluid Resuscitation

Two broad approaches may be considered for resuscitation in combat casualties. In the delayed resuscitation approach, fluid is withheld until bleeding is definitively controlled. This was the approach in the Bickell paper; it is appropriate if transport times are very short, typically less than 30 minutes. In contrast, permissive hypotension is the TCCC-recommended approach. Here fluid is given only to improve SBP to approximately 90 mm Hg, which corresponds to preserved mentation and a palpable radial pulse. This standard TCCC approach should be utilized in almost all combat casualty care scenarios. A Hextend bolus of 500 mL is given if blood products are not available, and this may be repeated once if required by resuscitation endpoints.

Resuscitation endpoints generally used are mental status, heart rate, SBP, mean arterial pressure (MAP), skin texture and color, and urine output. Laboratory tests such as lactate or base deficit are beneficial only to guide resuscitation after hemorrhage has been controlled.[108] However, these tests are usually not available until a Role 2 facility is encountered and thus are not useful in the initial management of severely injured casualties. Once natural hemostasis has occurred in penetrating trauma animal models, re-bleeding has been found to occur at around 94 mm Hg.[109] In the only randomized controlled trial in humans of hypotensive endpoints versus normal resuscitation strategy, there was no difference in survival.[110] Thus it is reasonable to promote an endpoint strategy of normal mentation and an SBP of 80 to 90 mm Hg or MAP of 60 to 65 mm Hg, corresponding to a palpable radial pulse.

Hypothermia is common in combat casualties, and even mild hypothermia can affect the function of platelets and clotting factors.[111] Thus, the capability to deliver warmed fluids is critical in the far-forward setting. To preserve heat in casualties, the patient's clothing and protective gear should be left on (when feasible) during transport. Forward providers should have hypothermia prevention management kits available and use them aggressively. Doors should be closed on vehicles and aircraft during transport.

Emerging Adjuncts to Damage Control Resuscitation

Advances in controlling extremity and junctional hemorrhage over the last decade have left truncal hemorrhage as the source of most potentially survivable injuries. In the landmark paper by Eastridge et al, truncal hemorrhage represented 67.3% of all potentially survivable injuries due to hemorrhage.[10] Two innovations may possibly contribute to reducing deaths due to truncal hemorrhage when there is a delay to surgical care. Resuscitative endovascular balloon occlusion of the aorta (REBOA) involves placement of an endovascular balloon into the aorta to control hemorrhage and increase afterload in patients with exsanguinating hemorrhage. Civilian trauma centers have successfully used REBOA, and it is beginning to transition into forward resuscitative care.[112] It is imperative that the balloon be placed either in zone I (supraceliac aorta) or zone III (infrarenal aorta). Zone I placement is essentially a balloon "cross-clamp" of the aorta, so balloon inflation time is limited to less than one hour due to mesenteric ischemia. Zone III placement may be helpful in cases of pelvic fractures, but placement here with a vascular wound proximal to the balloon would result in more rapid exsanguination.[113] In civilian trauma centers, placement is confirmed by fluoroscopy, which is not available in forward theater. The use of ultrasound is difficult due to its user-dependent nature. Therefore, a landmark approach is normally used. Because of mixed civilian results, lack of methods to reliably confirm balloon position, and uncertainty of the internal wounding

pattern, REBOA is not currently recommended for use in the combat environment, but research on the technique will continue.

Self-expanding polyurethane foam to control severe intraabdominal hemorrhage is also gaining traction as a method to decrease potentially survivable deaths due to truncal bleeding. It is nearing FDA approval, is more easily administered by prehospital providers than REBOA, and may be used for up to 4 hours as a hemostatic bridge to definitive surgical care.[114]

MEDICATIONS

Tranexamic Acid

The acute coagulopathy of trauma is gaining recognition as a significant factor in treating patients with traumatic hemorrhage. Recent reports show that coagulation derangements are present on presentation to the emergency department in 38% of combat casualties[115] and 25% of civilian trauma victims[116] presenting to a level I trauma center. While the causes of coagulopathy are multifactorial (consumption of factors and platelets, dilution from prehospital resuscitation, hypothermia, acidosis, inflammation), the phenotype of this initial coagulopathy appears to be primarily fibrinolytic (increased fibrinolysis), particularly when standard prehospital resuscitation strategies are followed.[117] If this is true, then stabilizing initial thrombus with an antifibrinolytic such as TXA makes sense. Several recent studies have shown this to be an effective therapy to decrease mortality from hemorrhage in trauma patients.

The largest and most important study was the CRASH-2 trial.[118] This prospective randomized controlled trial included 20,211 trauma patients with significant hemorrhage or at risk of significant hemorrhage. The patients were randomized to receive either placebo or TXA (1 g of TXA over 10 minutes within 8 hours of injury, and then an additional 1 g as an infusion over 8 hours). Absolute risk reduction in the TXA group was significant in this trial, and the number needed to treat was around 68 overall.

Early treatment with TXA is important. The CRASH-2 trial analysis showed a significant survival advantage if given within 1 hour of injury ($P < .0001$). If given from 1 to 3 hours post injury, the significance fell ($P = .03$). Given after the 3-hour point, the risk of death due to bleeding increased ($P = .004$).[119]

The MATTERS trial, a retrospective study of 896 patients who required a blood transfusion, took place at Camp Bastion, a large combat support hospital in Helmand Province, Afghanistan.[120] In this trial, 293 casualties received TXA (the remainder did not). The TXA group had a lower unadjusted mortality ($P = .03$) despite being more severely injured (higher injury severity score; $P < .001$). Benefit was greatest in a subgroup of patients who received a massive transfusion ($P = .004$). TXA use was independently associated with survival (CI 3–17) and less coagulopathy ($P = .003$).

Dosing of TXA is per current TCCC guidelines: if it is anticipated that a patient will need a significant blood transfusion (eg, presents with hemorrhagic shock, one or more major amputations, penetrating torso trauma, or evidence of severe bleeding), then 1 g of TXA in 100 mL NS or LR should be administered as soon as possible, ideally within the first hour of injury. The second infusion of 1 g TXA should begin after other IV fluid treatment. The greatest survival benefit reported is when TXA is given within 1 hour of injury and continues for up to 3 hours after injury. If it is initiated beyond that timeframe, the risk of death due to bleeding could increase.

Pain Control

Recent military conflicts have prompted significant advances in controlling pain (see Chapter 36, Acute Pain Management in the Deployed Environment). These advances have benefited patients (and providers) from the point of injury through definitive care in the United States. Three areas in particular have driven this change. The first is the need to deliver pain medications without IV access. This has led to advances in transmucosal (oral and nasal) medication administration. The second is the resurgence of ketamine use in the US military. During a period when the US military relied on the morphine auto-injector, other military[121,122] and civilian[123] providers around the world in austere, resource-limited situations were proving ketamine's safety and efficacy. The third is the recognition that early control of pain on the battlefield decreases the incidence and severity of posttraumatic stress disorder (PTSD).[124]

Advanced knowledge of limited resuscitation strategies among providers has decreased the need for IV or IO access in the combat environment. Access is logistically challenging (carrying supplies) and technically difficult (unsterile conditions, evacuation, and vehicle movement) in the combat environment. Providers are comfortable and familiar with oral medications such as nonsteroidal antiinflammatory drugs (NSAIDs), acetaminophen, and opiates/opioids from training and hospital practice. They are much less likely to be familiar with oral transmucosal fentanyl citrate

(OTFC), expanded use and variable-dose ketamine, and the intranasal administration of medications including fentanyl, ketamine, midazolam, naloxone, and flumazenil. In 2014, the CoTCCC published expanded pain control guidelines under the title "Triple Option Anesthesia," and the Wilderness Medical Society published "Practice Guidelines for the Treatment of Acute Pain in Remote Environments." Both organizations included recommendations for the use of OTFC and ketamine.[125,126]

While a broad array of analgesic and sedative options exist, this discussion will focus on OTFC, ketamine, and intranasal medication administration. Common hospital practice for pain control relies primarily on acetaminophen, NSAIDs, and oral or IV opioids. Very few formal training programs include a discussion of alternative drugs and alternative routes of administration. One exception is ketamine, which has seen an expanded profile of use over the last decade in civilian care. Ketamine has been used extensively outside of the United States and by other militaries for decades. Low-dose ketamine is used in acute and chronic pain control, intraoperative and postoperative burn care, depression, emergence reactions to general anesthesia, and postoperative opioid hyperalgesia. Historical concerns related to increases in intracranial[127–129] and intraocular pressure[130] have been dispelled by recent literature. Ketamine has been shown not to increase the incidence of PTSD in at-risk military personnel[131] and has even been used to treat PTSD.[132] Another benefit of ketamine is multiple routes of administration, including IV, IM, and intranasally. Given logistical challenges in the austere setting, intranasal delivery can be particularly useful. Other medications that can be delivered intranasally include fentanyl, midazolam, naloxone, and flumazenil.

Low-dose (subdissociative) ketamine is typically given at doses of 0.2 to 0.5 mg/kg by slow IV push or drip over several minutes. Dissociative dosing is 1 to 2 mg/kg IV or 4 to 5 mg/kg IM. Intranasal dosing is 0.5 mg/kg/dose. TCCC guidelines recommend titrating lower doses of ketamine until pain control is achieved or nystagmus is observed. In the authors' experience, dissociation via the intranasal route is very difficult to achieve because the patient becomes less and less cooperative.

No discussion of ketamine would be complete without a discussion of its psychiatric and behavioral side effects. These behavioral disturbances are classically referred to as emergence reactions, but they actually occur in two distinct phases. The first is during the titration of low-dose ketamine, when the patient becomes incompletely dissociated and occasionally quite difficult to control. These side effects may also be observed as dissociative doses of ketamine are wearing off, which is the classic emergence reaction. In either instance, most cases resolve with reassurance, but some cases may require additional medications. The tactical situation dictates whether the provider needs to calm the patient with midazolam or completely dissociate the patient with additional ketamine. One example is during TACEVAC, when uncooperative or agitated patients present a danger to themselves, the providers, and the aircraft/aircrew. Midazolam can cause respiratory depression, which is challenging to observe and manage during flight, so increasing the dosage of ketamine may be the best option.

Several military studies have been published on the safety and efficacy of OTFC. The original dose of 1,600 μg was shown to be safe and effective without side effects, except in cases where IV opioids were coadministered.[133] A more extensive and recent review of lower dose OTFC (800 μg) demonstrated safety and efficacy as well.[134] Wedmore was the first to discuss the additional safety measure of taping the fentanyl "lollipop" to the patient's finger.[135] This has commonly been described as the "SOF PCA" (Special Operation Forces patient-controlled analgesia). The weight of the patient's upper extremity will pull the medication out of the mouth when and if the patient becomes somnolent. This prevents both overdosing and choking on the lollipop.

Antibiotics

Antibiotics also fall into a specific group of medications that are considered time sensitive in combat injuries.[136] Early tactical care recommendations for antibiotics were based on likely tactical situations where irrigation and surgical debridement were not immediately available.[137] Choices focused on antibiotics with the most favorable logistical (and tactical) properties, such as broad spectrum of action, ease of administration, long duration of action, and lower cost.[138]

Current TCCC guidelines recommend moxifloxacin, cefotetan, or ertepenem for use, as soon as tactically possible, at the point of injury. Moxifloxacin is given to casualties who can tolerate oral medication administration without vomiting or risk of aspiration. Ertepenem or cefotetan can be given IV or IM for patients unable to tolerate oral medications. Anecdotally, medics tend to prefer ertepenem for its once-daily dosing and lack of reactivity in patients allergic to penicillin or cephalosporin. Broad-spectrum antibiotics are discontinued as soon as possible, tailored to the patient's wounding pattern and operative care. In addition to published TCCC guidelines and updates,

the best available evidence and expert recommendations were compiled in 2008[139] and updated in 2011 by the Infectious Diseases Society of America and the Surgical Infection Society.[140–142]

In 2009, a review of antibiotic use in patients with combat wounds who were treated and returned to duty found decreased wound infection rates with systemic antibiotic prophylaxis.[143] More recently, in 2011, a larger retrospective review of point-of-care antibiotics was conducted. The authors found no benefit and no harm from antibiotics alone (such as multidrug-resistant infections).[144] This study does not provide enough information to dissuade providers from administering antibiotics early; rather, it demonstrates the complicated nature of the problem, which includes difficulty adhering to guidelines,[145] mechanism of injury,[146] evacuation time, and time to surgical care. The 2011 study also supports data showing that multidrug-resistant pathogens do not contaminate the initial wound.[144,147,148] Rather, colonization and infection by multidrug-resistant pathogens are healthcare related.[149,150] The 2011 panel weighed their recommendations for antibiotics as 1C (strong recommendation/low-quality evidence) for point-of-injury antibiotics, and 1B (strong recommendation/moderate-quality evidence) for the antibiotics to be given within 3 hours. The fact that no recommendation received a 1A (strong recommendation/high-quality evidence) reinforces the challenges associated with reviewing care in the most austere conditions.

CASE REVIEW

A remarkable example of coordinated use of recent techniques, tactics, and procedures in tactical medicine occurred on a cold night in mountainous terrain in February 2016. During a Special Operations-led assault force mission in the early morning hours, several members were injured, including one US combatant who was shot in the chest twice just above the ballistic plates in his armor with 7.62-mm caliber rounds. The patient was immediately moved to a protected area and evaluated. In addition to the gunshot wounds (two entrance wounds in the high chest and one large exit wound in the back) he had shrapnel wounds from a grenade on his arms and face. IV access was obtained early, and TXA and freeze-dried plasma were administered. The patient was then transported by litter (during which his IV was lost) to a helicopter landing zone and turned over to an aeromedical team. The patient was evacuated via a 15-minute flight to a prepositioned DCS team.

During the flight, evaluation showed the patient in obvious shock with a weak radial pulse at 130 beats per minute and an oxygen saturation in the 80s. Due to the ambient temperature, the oxygen saturation was deemed unreliable and mental status was used as evidence of end-organ perfusion (pain medication was withheld after the patient stated he could forgo it). A sternal IO needle was placed when no adequate IV access could be found, and the patient received an additional unit of RBCs. Also, a small amount of hemostatic dressing was used on the still actively bleeding exit wound, and a vented chest seal was placed over the dressing. An ultrasound quickly ruled out cardiac tamponade or intrabdominal bleeding, but showed large hemothoraces bilaterally. Additional needle thoracostomies were performed bilaterally due to respiratory distress. The patient was more comfortable sitting up, so he was allowed to remain in that position during the flight.

On arrival to the surgical team, the patient continued to worsen. Tube thoracostomies were performed bilaterally, with a few hundred milliliters drained from the left and two liters drained from the right. The patient was intubated, and a large bore central line was placed. He subsequently lost vital signs, and a left lateral thoracotomy was performed. Open cardiac massage was performed for several minutes while intravascular volume was restored. The casualty regained spontaneous circulation after several minutes, and resuscitation continued while he was transported to a Role 3 facility. His Purple Heart ceremony was conducted the next day, and his recovery was uneventful.[151]

This case is presented because it represents the successful translation of evidence-based trauma care to the far-forward environment. The casualty's DCR was begun at the point of injury with an antifibrinolytic and plasma. IO access was used when IV access was difficult. No crystalloid, other than that used to carry reconstituted medications, was used at all. His 1:1 RBC-to-plasma resuscitation was continued nonstop until he reached Role 3 care (at a combat support hospital). The surgical team was very far forward, while still in a secure location. If the surgical team had not been located where it was, the next nearest location would have been over 2 hours away by helicopter. If standard ATLS protocols had been followed by the aeromedical team, the patient would have been intubated or a surgical airway placed (because he was hypoxic with bleeding around the mouth), he would have been given crystalloid, and he would have received medications that might alter his mental status. If any

of these maneuvers had been used, the patient might not have survived. The medical team was extremely well trained and drilled together intensely and often, which is a testament to the value placed on military medicine. Military medical providers protect those who protect the nation.

CONCLUSION

Optimized medical care in the tactical setting is a challenging and rapidly evolving field. If approached with the right mindset, the correct predeployment training, and a proper understanding of the both the principles of Tactical Combat Casualty Care and the overall context of the current resources in the area of operations, good outcomes will be ensured for those who go forth to secure the interests of the nation.

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