Management of War-Related Burn Injuries: Lessons Learned From Recent Ongoing Conflicts Providing Exceptional Care in Unusual Places

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Abstract: Thermal injury is a sad but common and obligatory component of armed conflicts. Although the frequency of noncombat burns has decreased, overall incidence of burns in current military operations has nearly doubled during the past few years. Burn injuries in the military environment do not need to be hostile in nature. Burns resulting from carelessness outnumber those resulting from hostile action. Unfortunately, civilians are becoming the major targets in modern-day conflicts; they account for more than 80% of those killed and wounded in present-day conflicts.

The provision of military burn care mirrors the civilian standards; however, several aspects of treatment of war-related burn injuries are peculiar to the war situation itself and to the specific conditions of each armed conflict. Important aspects of management of burned military personnel include triage to ensure that available medical care resources are matched to the severity of burn injury and the number of burn casualties, initial management and resuscitation in the combat zone, and subsequent evacuation to higher echelons of medical care, each with increasing medical capabilities. Care of military victims is usually well structured and follows strict guidelines for first aid and evacuation to field hospitals by military personnel usually having had some form of training in first aid and resuscitation and for which necessary equipment and material for such interventions are more or less available. Options available for civilian injury intervention in wartime, however, are limited. Of all pre–hospital transport of civilian victims, 70% are done by lay public and 93% receive in the field, or during transport, some form of basic first aid administered by relatives, friends, or other first responders not trained for such interventions. Civilian casualties frequently represents 60% to 80% of all injured admitted to the level III facilities of overseas forces stationed throughout the host country. Unlike military personnel who are rapidly evacuated to higher echelons IV and V for definitive and long-term care, civilians must receive definitive burn treatment at these level III military facilities.

The present review was intended to highlight peculiar aspects of war-related burn injuries of both military personnel and civilians and their management based on the most recently published material that, for the most part, is related to the recent conflicts in Iraq and Afghanistan.

Key Words: Burn, war-related burns, burn triage

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Thermal injury is a sad but common and obligatory component of armed conflicts[1] and has been described for more than 5000 years of written history.[2,3] It is a ubiquitous threat in the military environment and is common to all military conflicts and wars,[1–3] constituting one of the main challenges in the new combat milieu, whether of low- or high-intensity warfare.[4,5] The development of weapons has had a colossal effect on the frequency and severity of burns in war,[6] and the invention of gunpowder and sophisticated explosives turned battlefields into burning infernos and changed for the worse the odds against protective measures.[3,7,8] Flame weapons, explosive blast, and ignition of combustible materials all create a burns hazard for those involved[2] whether they are civilians or military.

Although the frequency of noncombat burns has decreased, overall incidence of burns in current military operations has nearly doubled during the past few years.[9] In combat, burn injury accounts for 5% to 10% of combat casualties.[5,10–12] Of these, nearly 20% are categorized as severe or involving greater than 20% total body surface area (TBSA) and require significant intravenous resuscitation.[11,13] Warriors sustain thermal injuries from a variety of mechanisms.[10] Flame or flash burns may be caused by various agents contained in the explosive devices.[14] They may be due to explosions related to incendiary devices as well as fire secondary to a primary explosion that occurs due to ignition of nearby combustible materials.[10] Burn injuries in the military environment, however, do not need to be hostile in nature, as burns resulting from carelessness outnumber those resulting from hostile action.[14] Extensive use of the various fuels needed to provide both ground and air mobility for the present-day armed forces increases the risk of thermal burns in military personnel, as the possibility of the unintended ignition of these fuels is greatly increased during times of conflict.[14] In the austere environment of the overseas military post, noncombat burns primarily result from everyday life mishaps that are largely preventable occurring with the use of ammunition, fuel, and the burning of waste.[9,10] In fact, ignition of gasoline and other fuels accounts for the greatest number of thermal injuries.[14] During the Vietnam war, more than half of the burns were accidental (54%), and the rest (46%) were combat related. This example suggests that

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a large percentage of military burn injuries are accidental and not directly attributable to the combat environment.[4,9]

The concept of the dedicated burn unit is relatively new. It is a product of wartime and disaster experience and is closely tied to developments in infectious disease treatment.[1] The provision of military burn care mirrors the civilian standards[15]; however, several aspects of treatment of war-related burn injuries are peculiar to the war situation itself and to the specific conditions of each armed conflict. To ensure the best medical care to injured military personnel, echelons of medical care have been developed, each with increasing medical capabilities.[16] Moreover, logistics for treatment of burned soldiers deployed overseas may be much more complex than caring for burn victims of armies involved in conflict on their own territory or for caring of enemy prisoners of war or even the local civilian population with burn injuries that cannot be evacuated overseas.

A well-documented fact about advances in military medicine is the enhanced survivability of those wounded in combat. In modern warfare, when a soldier sustains a wound, combat lifesavers immediately administer resuscitation, stabilize the wound, and relieve pain. Simultaneously, the wounded soldier is triaged, and medical evacuation takes place. Through a sophisticated and well-orchestrated medical evacuation system, the wounded soldier and even civilians can be in a tertiary medical treatment facility within hours to a few days.[17] It is well known that the management of combat casualties with severe burns and associated traumatic injuries requires a coordinated interaction of surgical, critical care, and evacuation assets. These patients present enormous challenges to the entire medical system as a result of the severity of injury combined with the great distance required for transport to definitive care.[10] The essence of the successful treatment of burn casualties, with or without other traumatic injuries, is thus effective triage, timely diagnosis, accurate assessment of surgical priority, and appropriate resuscitation.[14] The present review is intended to highlight peculiar aspects of war-related burn injuries and their management based on the most recently published material that, for the most part, is related to the recent conflicts in Iraq and Afghanistan.

INJURY PATTERN OF COMBAT-RELATED BURNS

Warfare burn injury has been largely ignored in the past. It was brought to the forefront of Army Medical Corps planning only at the end of World War II.[3] It is estimated at present that, in modern warfare, 1 in 4 injuries is a burn.[3] Whether the thermal injury occurs in a military or civilian environment, the severity of burn is generally determined by the intensity of the insulting energy to which the patient is exposed, the duration of exposure, and the body areas affected.[10] Because burns in wartime are associated with active intent to do harm through any means possible, other injuries in addition to burn or inhalation injury might be expected.[18]

Whereas most casualties in earlier wars were caused by bullet wounds, recent wars have been marked by an increase in explosive wounds caused by fragmenting antipersonnel weapons such as rockets, artillery shells, mortar bombs, and mines.[3,19] Explosive devices typically result in a greater number of injury sites and greater severity of injuries.[20] On the other hand, noncombat burn injuries usually are not as severe as those incurred in combat. The explanation for the disparity between combat and noncombat burns likely lies in the explosive nature of combat injuries, with an accordingly greater frequency of associated injuries.[9] A bomb blast is an instantaneous chain of events in which an explosive material is rapidly converted from a solid or liquid form to gas, with resultant energy release under extremely high temperatures and pressures.[3,21] The mechanisms of injury resulting from explosions include direct exposure to the blast wave, reflective blast waves, acceleration-deceleration forces, penetrating and nonpenetrating wounds, burns and inhalation of toxic gases, and building collapse.[3] These can produce classic injury patterns from blunt and penetrating mechanisms to several organ systems, but they can also result in unique injury patterns to specific organs including lungs and the central nervous system.[3] Temperatures from the explosive gases can reach 3000°C (5432°F) and may result in fatal third-degree burns in victims close to the detonation.[3]

The presence of associated traumatic wounds in patients with burn injuries may complicate the management of their burns and vice versa.[14] Burns sustained in a combat zone invariably are associated with multiple open soft tissue wounds sustained in a dirty environment combined with hemorrhage related to the traumatic insult,[10,13,15,22] the burn injury itself being most often the less severe of other multiple injuries,[15] and it is a fact that the mortality and morbidity of combined injury victims are higher than those of the injuries separately.[23] The incidence of nonburn injury has been reported to be significantly greater in combat-related burns when compared with local civilian burns (37% vs 11%).[24,25]

The pattern of injury for military casualties is also often related to the protective equipment worn at the time of exposure to the thermal energy.[10] Although advances in protective gear, not available for protection of civilians, such as helmets and body armor are saving lives, these protective measures cannot keep soldiers from being injured or killed.[3] The new armored Kevlar vests composed of a multiple-layer mesh of woven fabrics that soldiers are wearing in the present war in Iraq, for example, stop projectiles and bullet rounds, efficiently protecting the human torso, and have definitely saved countless lives. Unfortunately, the surviving victims are often paying a terrible price and are left with serious mutilations and handicaps from burns and shrapnel wounds over body areas not protected by the vest.[3] Despite active efforts to ensure optimal protection against flame for the combatant, the face and hands continue to be those areas least protected.[10,26] The predominance of injury to the hands and head is not new and has been reported throughout recent military history.[12,22,27,28] More than 75% of Israeli military burn casualties from the Lebanese War during 1982 sustained burns to the hands and face.[12,29] In Iraq, 80% of combat casualties sustained burns to the hands and 77% to the head.[12,27] Despite this, isolated hand and head burns accounted for only 15% of casualties, whereas isolated hand burns alone accounted for only 6%.[12,27]

Many antipersonnel weapons used in present-day warfare contain white phosphorus. This element ignites on contact with air, and fragments of phosphorus will be scattered throughout any wounds caused by such weapons. Most of the injuries caused by such weapons are conventional burns that result from the ignition of clothing. It is, however, a real problem to deal with a wound in which the embedded particles of phosphorus will ignite as soon as the tissue dries out. In addition, medical teams as well as patients are in danger.[2] When surgical treatment is available, the wet wound can be irrigated with a freshly prepared solution of 1% copper sulfate. This solution combines with phosphorus to form black copper sulfate, which impedes violent oxidation and identifies the particles that can be subsequently removed with forceps and placed in a dish filled with water. After completing the procedure, the copper sulfate solution must be washed away, and the wound should be excised and dressed in the way described above.[2]

Napalm is another intensely flammable agent in a liquid form, which will cling to the injured patient and cause serious and extensive burns.[2] Napalm burns are invariably of full thickness, with coagulation of muscles and other deep tissues. Nephrotoxicity is a serious complication, and the mortality may be high in proportion to the total body surface area involved. A full-thickness napalm burn of only 10% of the body surface area may result in renal failure.[2]

CIVILIAN INJURIES DURING WARFARE

Although indiscriminate or intentional harm to civilians violates humanitarian principles and basic human rights,[30] civilians are becoming the major targets in modern-day conflicts[3,19,31,32] because of combat tactics and the weapons used near and among them.[30] Whereas before the increase in wartime civilian mortality was seen as an indirect effect of the war because of social disruptions caused by material deprivation, crowding, and breakdowns in normal sanitary systems, in recent wars, the increase in civilian mortality and morbidity is attributed directly to the war itself.[19,33] In World War I, civilians accounted for 5% to 19% of all war-related deaths. In World War II, civilian mortality increased to 48%. Today, civilians account for more than 80% of those killed and wounded.[3,19,34,35] Civilian injuries may involve all body parts and are usually more serious than those seen in military personnel wearing their protective gears. The burden of such civilian war trauma in terms of physical, social, and economic factors is overwhelming.[19]

Identification and classification of the numerator in civilian injury studies, however, are extremely difficult because the definition of civilian versus military personnel in recent wars is blurred and the classification coding is not adequate to deal with the various types of war trauma.[3,19] From the limited data available, specific trends can be delineated through the comparison of recent wars in terms of demographics, distribution of wounds by area of wounding, the lethality of wounds, and changes in the methods of fatal wounding.[3,19] In Eastern Slavonia, a comparison of sex and age distribution between civilian and noncivilian (paramilitaries, territorial defense, and army) war victims revealed that more than 80% of noncivilian victims were men in the group aged 21 to 40 years, whereas in the civilian population, all age groups and sexes were represented, including children younger than 10 years and persons older than 90 years.[3,33] Similar demographics were found in Croatia,[36] Bosnia,[37] Lebanon,[38] and Afghanistan.[39]

Options available for civilian injury intervention in wartime are limited. During war, 70% of all pre–hospital transport of civilian victims is done by lay public (friends and relatives of the victims) or other first responders. From a review of 200 trauma cases, 93% received in the field, or during transport, some form of basic first aid administered by relatives, friends, or other first responders not trained for such interventions.[19,35] Care of military victims, however, is usually well structured and follows strict guidelines for first aid and evacuation to field hospitals by military personnel usually having had some form of training in first aid and resuscitation and for which necessary equipment and material for such interventions are more or less available.

TRIAGE

Triage is the dynamic process of sorting casualties by priority of their severity of injury and need for emergent care. It is also a process intended to maximize available resources by determining who will actually benefit from high dependency care when the ratio between resources and patients is low.[40–42] It is a tactical art that requires situational awareness, decisiveness, and clinical expertise and is driven by the real-time events and the constraints of the evolving scenario. Different settings drive different management options.[42]

Burn casualties represent a group of seriously injured patients.[15] In civilian practice, with optimum resources available, every burn patient receives emergency care; however, in the combat setting, the tactical situation, logistical limitations, or limited availability of health care personnel may necessitate reduction in the upper limits of TBSA burned that would benefit from aggressive treatment.[14] Triage decisions during mass casualty events or in austere settings where resources are limited can be difficult. Decisions can include withholding care from a severely ill or wounded patient who, under normal circumstances, would have been aggressively supported. These patients are usually designated as expectant, meaning their care would require substantial use of resources, which could jeopardize the lives of many others.[40,41]

Triage is an important aspect of military burn care to ensure that available medical care resources are matched to the severity of burn injury and the number of burn casualties.[4] With limited resources, burn care resources should be applied to that group of patients in which greatest benefit will be realized, with less attention given to those with lesser burns or those with more extensive burns. In a situation with resource restrictions or large numbers of casualties, hospital care can be delayed for those patients with burns of 20% or less of the total body surface. Similarly, expectant care should be applied to those patients with burns exceeding 70% of the total body surface and the available care facilities and resources applied to those with burns of from 20% to 70% of the total body surface. With even greater restriction of health care availability, the upper limit of the maximum treatment group should be reduced by stepwise decrements of 10% until the surgical workload matches available resources. Triage modifiers include significant coexisting inhalation injury and associated mechanical injury, each of which lowers the upper limit of the maximum treatment group by 10%. Conversely, burns of the hands, face, feet, and perineum, occurring in patients with lesser total body surface burns, will increase the medical care necessary for such patients.[14]

IMMEDIATE RESUSCITATION AND INITIAL BURN CARE IN A COMBAT ZONE

Even under the conditions of operations, out-of-area severely burned soldiers have to receive a treatment that is, in its outcome, equivalent to the medical standard.[43] Initial care provided in the combat zone near or at the time of injury should emphasize safety of the patient and the personnel caring for the patient.[44] Even under perfect circumstances, the "textbook" resuscitation is a rare occurrence. Adding an evacuation out of an austere environment to a combat support hospital (CSH), then air evacuation across 3 continents with care delivered by multiple teams of providers along the way significantly increases the degree of difficulty in achieving an optimal resuscitation.[13]

Initial management of the burn casualty in the combat zone requires a strategy of rapid assessment, airway protection, and appropriate resuscitation in addition to a thorough examination for associated injuries common to the battlefield casualty.[15] To prevent organ failure and death, appropriate volume replacement in the burn patient can be very challenging, requiring that the practitioner provide adequate intravascular replacement in the first 24 to 48 hours after burn, whereas simultaneously striving to avoid the potentially devastating complications associated with high-volume crystalloid overresuscitation.[11,13,15,24,45] In fact, patients occasionally arrived at the 28th CSH in Iraq with evidence of overresuscitation. Such overresuscitation was manifested by fluid infusion volumes well in excess of the Parkland formula prediction and by high rates of abdominal and extremity compartment syndromes.[46] Exposure before evacuation and prolonged transport in helicopters without complete temperature regulation is another complicating factor that often exacerbates hypothermia even with high environmental temperatures and is a particular threat to burn patients. Hypothermia was in fact the worst arrival problem for burn patients at the 28th CSH in Iraq.[46] Moreover, patients with severe facial burns, those demonstrating signs or symptoms suggestive of inhalation injury, and those with large burns for which a significant resuscitation and associated

edema are anticipated must be preemptively intubated soon after injury to ensure airway protection and adequate mechanical ventilatory support.[13,15]

The goal of fluid resuscitation after severe burn is to replace loss of intravascular volume with intravenous crystalloid to maintain adequate tissue perfusion throughout the 48-hour period of increased capillary leak and relative hypovolemia at the lowest physiologic cost. It is important to consider that patients with severe burns, extensive soft tissue trauma, inhalation injury, or electrical injury will require the administration of increased amounts of fluid to prevent burn shock.[13] Adequate initial management of burn casualty in a combat zone, however, may not be smoothly administered and in fact can be problematic. First, the responsibility of burn resuscitation of the war wounded in the critical days immediately after injury lies on the shoulders of physicians and nurses who do not specialize in burn care and whose priorities are not focused on stabilization but rather evacuation to the place of definitive care. Second, the burn casualty will typically be cared for by a number of providers at multiple levels in the evacuation chain before arriving at the burn center. Variations in practice are expected and continuity of care is absent. Third, documentation of care can be either very poor or nonexistent, making it extremely difficult to assess and identify problem areas. Fourth, communication across various services, disciplines, and hospitals at the different echelons of care throughout the evacuation process usually is very fragmented.[11]

Fear of underresuscitation seems to be the predominant concern in the early management of the burn soldiers. Recently, the dangers of exceeding the amount of intravenous resuscitation required to allow for adequate tissue perfusion have been recognized.[13] Heavy volume infusion and higher blood pressures may be counterproductive.[42] "Resuscitation morbidity" is a constellation of complications that may include abdominal compartment syndrome (ACS), airway obstruction, extremity compartment syndromes, and pulmonary edema.[13,45,47,48] A resuscitation volume greater than 237 mL/kg during 12 hours (or 16 L during a 12-h period in a 70-kg man) seems to be the threshold for the development of ACS.[13,49] Abdominal compartment syndrome results in decreased renal blood flow and subsequent renal failure, intestinal ischemia, respiratory failure, and death if not recognized and treated early.[13,50] Even when recognized, the mortality of a decompressive laparatomy for ACS in burned patients is documented to be 60% to 100%, depending on the TBSA and on the presence of inhalational injury.[13,51]

The immediate efforts to avoid the consequences of both underresuscitation and overresuscitation of the combat burned patient include the standardization of initial burn care, a method of accurate reliable documentation, and an avenue for constructive feedback.[13] Moreover, the development of standardized protocols based on the best available clinical knowledge helps improve care in various clinical settings.[13] The choice of fluids in burn resuscitation remains, however, controversial.[4] Small studies have demonstrated great potential in limiting the amount of fluid required for resuscitation by using plasma, hypertonic saline, and high-dose vitamin C during the initial burn resuscitation.[13,52–54] These adjuncts, which have been found to decrease "resuscitation morbidity," may also prove to be logistically useful.[13] Colloid solutions such as Hespan (6% hetastarch; Bristol-Myers Squibb, New York, NY), a large–molecular weight colloid, may have particular advantages under conditions of increased microvascular permeability seen in burn injuries. In addition to being an effective resuscitation fluid, which spares excess volume infused, it may also be an excellent solution to the packing constraints imposed by the battlefield reducing the weight of intravenous fluids transported while maintaining the ability to replace lost volume in injured soldiers.[11,13,42] Further research is needed to establish the best infusion regimens for early colloid use in burns and their subsequent responses and outcomes.[4] Oral hydration solutions may be lifesaving in conditions where intravenous therapy is logistically impossible. It could be considered in special operations warfare or mass casualties when no alternatives exist[4] especially in patients with low TBSA injuries.

In a recent communication with the Brook Army Burn Unit, a computerized system is being constructed that will aid in guiding the resuscitation of the burn patients based on the last hour urine output. The infusion rate will be determined by normalizing for previous data entered into the system. Preliminary results were reported during the 41st American Burn Association meeting in San Antonio, and the results seem to be promising in limiting the fluid creep and in guiding the non burn staff in their resuscitation.[55]

LONG-RANGE EVACUATION AND TRANSPORT

Although accurate resuscitation is essential for the optimal care of the burn casualty, rapid treatment and critical care transport is an important requirement for the survival of those soldiers injured thousands of miles away from the definitive care facilities.[10,15] In burn patients, evacuation presents a unique problem because it usually takes place during the resuscitation phase (in the first 24–48 h after burn injury).[13] The ability to safely transport burn casualties first to a field hospital then across long distances, while continuing resuscitation, allows expeditious delivery of the patient to a facility able to provide definitive care with the goal of early surgical excision of burn wounds and coverage with autografts.[10,11,56] This capability is a key to the overall process of burn care for military as well as for collateral civilian burn casualties.[10]

The evacuation of injured personnel has evolved with each new conflict,[1] and the policy, which determines how long casualties may remain in the combat zone once wounded, is tailored to the situation on the ground.[46] The optimal medical evacuation system during the local armed conflicts and wars consists to an initial stage of first medical aid, usually a field hospital, then to a second stage of specialized medical care.[57] The most elaborate evacuation system was set by the United States to evacuate victims of the current conflicts in Iraq and Afghanistan. Casualties are initially treated by military medics or corpsmen closest to the point of injury. Initial treatment is focused on the priorities of airway protection, hemorrhage control, and initiation of volume resuscitation. The wounded are then rapidly evacuated to the next higher level of care where the patient can be further assessed and stabilized in preparation for transport back to a burn center as safely and expeditiously as possible to facilitate early excision and grafting, minimize ventilatory days, and institute rehabilitation therapy.[10,15]

In contrast to most burn injuries in the civilian life, the military burn patient is often transported to one or more intermediary facilities before final evacuation within 96 hours of injury thousands of miles back to specialized burn centers.[10] Critical advances in air evacuation of the war, wounded with the emergence of a specialized Air Force Critical Care Air Transport Team program in the 1990s, have made this possible by maximizing available Air Force aircraft for patient evacuation.[11] Military burn casualties from the war in Iraq and Afghanistan, for example, are transported across 3 continents, with one stop in Germany with total ground and air transport times exceeding 24 hours for 3 to 6 days.[11,24] It is a well-known fact that medical care capability increases as a casualty is transported from point of injury to level (formerly echelon) I through level III and outside the combat zone to level IV and V.[20] Level I provides care as close as possible to the time of injury and consists of immediate stabilization and evacuation to an initial aid station. Level II offers short-term holding capacity and initial resuscition.[20,57] Level III, such as the Army's CSH, the Air Force Theater Hospital, and the Navy's hospital ship, provides complete resuscitative and hospital

care. Assets at this level of care include a myriad of surgical specialties and support and are equivalent to a well-staffed community hospital.[20,58] Care provided at level IV during the current Iraqi conflict is delivered at a Regional Medical Center in Germany, rendering more definitive surgical care outside the combat zone.[20,59] Level V care is the most definitive rehabilitative and tertiary level of care and is provided in military and Veterans Affairs medical centers located in the United States.[20]

It is now clear, however, that rapid global evacuation of burn patients, usually occurring in the first few critical hours after injury, had created a unique and challenging set of problems that required resolution to optimize care.[11,13] Approximately 2 years into the Iraqi conflict, a high incidence of resuscitation-related morbidity in evacuated military casualties was observed. Specifically, a series of resuscitation-related ACSs and extremity myonecroses were observed.[11]

CARING FOR HOST NATION MILITARY AND CIVILIAN BURN VICTIMS

Modern warfare is often fought in an urban environment and has its own attendant risks, which are significantly different from those found on the conventional open battlefield.[4] Events resulting in thermal injuries are not isolated to military personnel.[60] Civilians are even more at risk. Collateral damage to civilian populations is usually large.[4] Host nation civilians of all ages, as well as paramilitary personnel such as police and security forces, may also be subject to thermal injuries.[60] In accordance with the Geneva Conventions, armed forces are committed to caring impartially for casualties, without regard to national or combatant status. Therefore, care of enemy prisoners of war, local civilians, and even children has been part of overseas military operations since World War II.[46] In the current US combat zones, there is a large non-US patient population that is receiving damage control surgery and definitive therapy without evacuation to higher levels of care. This population frequently represents 60% to 80% of all injured casualties admitted to level III facilities and receives burn treatment at military facilities of overseas forces stationed throughout the host country. Irrespectively, these patients should be managed according to the guidelines for levels IV and V.[42,60,61]

Military medical personnel assigned to any of a number of facilities must therefore be prepared to treat patients with thermal injuries, whether they will be rapidly evacuated out of the region, as in the case of overseas forces, or whether they will remain at the local facility for definitive care.[60,61] Hence, level III facilities intended to provide short-term care and stabilization of combat burn casualties before rapid evacuation are usually confronted with caring as well of local victims who cannot be evacuated abroad and should be capable of providing levels IV and V long-term care for burn victims.[46] The 28th CSH in Iraq for example, under challenging conditions, provided emergency and definitive care to a wide range of coalition and Iraqi, adult and pediatric, burn patients.[46] During this phase of the war, the United States assumed responsibility for the long-term care of Iraqi patients of all ages. Of these, patients with burns, major soft tissue injuries, and paraplegia/quadriplegia were particularly difficult to treat. Burn care was even more difficult in the absence of burn-trained occupational therapists, physical therapists, nurses, and other team members. Facilities for bathing patients usually were also lacking.[61] In such a facility, the largest obstacles to burn care were related to knowledge, materiel, and disposition of Iraqi burn victims.[46]

War creates substantial humanitarian needs not only by generating casualties but also by disrupting local medical systems. Simultaneous efforts to reconstruct the host nation's medical infrastructure are as important as caring for the victims.[46,62] Ongoing initiatives to support education and training of the host nation's medical personnel as they seek to increase their knowledge and skills in the treatment of burn patients are of critical importance. These efforts ultimately result in survival and improved outcomes for dozens of host nation personnel without the need for overseas transport.[60] In the absence of trained personnel, nonsurgeons and even nonmedical personnel may be trained to assist in burn care.[61]

INFECTION CONTROL AND SYSTEMIC ANTIBIOTIC PROPHYLAXIS

All wounds have certain characteristics that promote the development of infections. Those factors include the presence of devitalized tissue, foreign bodies, clots, fluid collections, and contamination of wounds with bacteria from the casualty's skin, the environment, and the hospital. All of these factors culminate in placing the casualty at risk for developing an infection.[63] Peculiar to all combat-related injuries of recent conflicts are the unique factors surrounding the management of these injuries. These factors are due to the wound type and severity, injuries from the high-energy ballistic weapons used, the presence of embedded foreign material or fragments (such as soldier's clothing, dirt, and debris), initiation of antimicrobial agents, adequacy of initial wound debridement, immediate wound care, definitive surgical care, rehabilitative care, previous antimicrobial pressure, the presence of nosocomial pathogens (especially multidrug-resistant pathogens) at treatment facilities, unusual bacteria existing in the desert contaminating the wounds, and delayed definitive care despite incredibly fast triage time.[16,20]

Historically, burn wound infection has been and still is the most common cause of death in the thermally injured patient, particularly in the setting of delays in definitive surgical care.[1] In modern-day burn units, most burn-related deaths still result from septic shock, with bacteremia being a common infection.[64] The most frequently identified pathogens associated with bacteremia are *Staphylococcus aureus* and *Pseudomonas aeruginosa*.[64] Combat burn patients differ from civilian burn patients in the mechanisms of their injuries. Combat burn patients are commonly younger, have a longer time from injury to admission to a burn center, have a higher injury severity score, and have a higher incidence of inhalation injury.[11,64] Obviously, variability in the level of care available across the various levels in the evacuation process of military casualties can be expected to have some effect on the risk of burn wound infection in these patients.[1] Infections with other bacteria, particularly multidrug-resistant bacteria, have been described in numerous casualties.[64] The effect of multidrug-resistant bacteria and the potential lack of antimicrobial agents to adequately treat these infections are certainly a global threat, although in one study assessing bacteremia, including infections from multidrug-resistant bacteria, there was no difference in outcomes between those burned during combat operations versus those burned in the United States.[64]

Wounds sustained under battlefield conditions are considered to be contaminated, and their initial treatment should focus on decreasing this contamination and thus reducing the possibility of infection.[65] Moreover, with the current threat of terrorist attacks creating battlefield-like conditions in civilian mass-casualty situations, the importance of developing frontline measures to prevent wound infection and sepsis is clear.[65] Certainly, the ability to provide topical antimicrobial protection at or near the point of wounding has the potential to limit the morbidity and mortality of combat wounds. However, topical agents are effective only when applied after proper cleansing and debridement, which remain the mainstay of infectious prophylaxis in combat wounds unfortunately not possible on the field.[65] Regardless, burn wound care both at the time of initial

debridement and thereafter cannot be overemphasized. It should be directed at thoroughly removing devitalized tissue, debris, and previously placed topical antimicrobials.[1]

Caring for combat casualties, although important, has the potential to strain a facility's ability to provide ideal infection prophylaxis and treatment using in-theater assets. Traditional methods for prophylaxis and treatment of wound infections, such as dressing soaks and burn cream application, are time and resource consuming and are not suited for the conditions in modern field hospitals.[65] Despite experience with many topical antimicrobial agents and their proven efficacy in decreasing wound contamination and infection, combat medics and civilian first responders are not equipped with any such agents. This is, in part, the result of the fact that the most effective antimicrobials such as mafenide and silver sulfadiazine creams are too cumbersome for use in the field and are effective only when applied after proper cleansing and debridement.[65] Although direct application of mafenide solution has been strongly advocated as a potential technique to serve as a field-expedient topical antimicrobial for the initial care of combat wounds[65,66] and despite promising early results with some other products, there is yet no widely advocated topical therapy to be used readily on the field. The search for a safe and effective topical antimicrobial agent for battlefield and mass-casualty applications should continue. The logistical characteristics of candidate agents are important considerations. The ideal agent will be light and easily transported, reconstitutable with available water, resistant to extremes of environmental conditions, and simple enough to use that a casualty could apply it him/herself.[66]

Although data are inconclusive, early excision and grafting has become standard practice in most burn centers. This level of care, unfortunately, is typically not available for military personnel injured in forward operating areas until they arrive at the burn center.[1] Because operative burn surgery is labor- and resource-intensive, often requiring heavy consumption of blood products, US doctrine has routinely discouraged burn wound excision and grafting in combat zones. At the 28th CSH in Iraq, no effort was made to excise burn wounds by a specific day after injury.[46] Eschar often was allowed to separate and was then removed through debridement. Earlier excision was performed when the eschar seemed to compromise the patient. With the movement of the CSH to Ibn Sina Hospital in Baghdad and the deployment of experienced burn surgeons to that location in later months, earlier excision and grafting of the burn wound became standard practice in the care of Iraqis with major burns. This shift in emphasis reflects the importance of early excision in reducing hospital length of stay, as well as morbidity and mortality rates.[46]

Use of prophylactic systemic antibiotics is now well accepted in a wide variety of settings, including the performance of many surgical procedures. However, the role of antibiotics at the time of injury on the battlefield is debated because there are no convincing data supporting that immediate antimicrobial therapy effectively prevents wound infections. Currently, there are differences in implementation of antibiotics at the time of injury on the battlefield with the British military using relatively narrow-spectrum agents, typically penicillin with a β-lactamase agent, similar to agents recommended by the International Committee of the Red Cross at the time of initial surgical evaluation.[63,67] The US military, at least for those unable to receive surgical care in a rapid manner, has proposed broader spectrum agents.[15,63,68] Given the concern of antimicrobial resistance with broad-spectrum therapy, narrow-spectrum antibiotic therapy might be of greater long-term benefit, but this remains to be answered.[63]

Antibiotic prophylaxis has been examined in burn surgery. Use of systemic antibiotics for prophylaxis of subsequent burn wound infection has not been proved effective. In fact, early use of antibiotics such as penicillin and erythromycin aimed at controlling outbreaks of *Streptococcus* have been anecdotally observed to be associated with an increase in infections caused by multidrug-resistant staphylococci.[1] Few studies have supported the use of prophylactic antibiotics during acute burn surgery,[1] and antibiotics seem to be of no value in the prophylaxis of wound infections accompanying surgery for small to moderate burns.[1] Routine systemic antimicrobial prophylaxis in the burned patient is not indicated for rapid or delayed evacuation, and there are insufficient data to recommend for or against its use in patients with concomitant inhalation injury. In the event that a burn patient experiences concomitant traumatic penetrating injury or fracture, antibiotic prophylaxis should be administered as recommended for that injury.[1] It is crucial to note that systemic antibiotic therapy is clearly indicated in the surgical treatment of infected burn wounds, and this may necessitate empiric treatment of many patients with large open wounds and evidence of infection.[1]

Guidelines have recently been developed for managing and preventing infectious complications of combat-related injuries and infections associated with burns in the combat casualty. These guidelines were published recently and disseminated to all health care providers in the combat zones.[44] Burns should be debrided early, typically at the initial presentation to the surgeon at levels II and III or within the first 24 hours because the eschar serves as a major source of subsequent infections. The role of topical antimicrobial therapy is clear for burn patients. For full-thickness burn wounds, mafenide acetate every morning and silver sulfadiazine every evening is recommended. Silver sulfadiazine once daily is acceptable for partial thickness burns or for burns of limited extent. When twice-daily dressing changes are impossible, once-per-day changes will still provide significant benefit. It is essential to thoroughly debride and cleanse the wound at each dressing change using chlorhexidine gluconate (4%). For partial-thickness burns, biobrane is adequate for simple coverage of clean wounds. For burns of limited extent (eg, <30% total body surface area), silver-impregnated dressings are adequate.[44] Unless there is gross evidence of infection at subsequent debridements, wound cultures do not adequately predict subsequent infections or infecting pathogens. Wound cultures may lead to unnecessary courses of broad-spectrum antibiotics and are thus highly discouraged.[44]

COMMUNICATION AND EARLY CONSULTATION

Early communication between the provider initiating transfer of the burn patient and the provider at the receiving burn center is valuable when the health care professional providing the initial care does not have extensive or recent experience caring for severe burns or the burn casualty requires a lengthy evacuation process.[6] The value of early telephone communication and e-mail between providers along the evacuation route cannot be overemphasized. Both aid in the timely discussion of the burn patients and management along the continuum of care. The capability of the Internet to electronically transmit photographs or video of the burn casualty, often in real time, has become an invaluable resource, especially for primary care providers in remote areas.[6,13] An electronic consultation system speeds access to care as key medical information is sent from theater hospitals back to the burn center.[13]

The recent establishment of the Joint Patient Tracking Application System, a secure Web-based software utility, has also enhanced the provision of care. The system allows a near real-time picture of patient movement and allows authorized users the ability to view reports and see what is occurring as care is being delivered along the evacuation route.[13,17] Addition of new burn-related treatment recommendations to this system has been a tremendous

asset in improving continuity of care and optimizing real-time communication across the echelons of care. It also provides dissemination of recommendations and guidelines across all levels of care.[17] Weekly videoteleconferences between field operating theaters and major burn center facilities also enhance care by providing rapid performance improvement.[13]

TERROR-RELATED BURN INJURIES

Though terrorism is not a recently recognized threat, terror attacks have changed in the past decade. A gradual shift in the nature of terror attacks has occurred throughout the world, and ,today we witness a larger proportion of attacks performed by suicide bombers equipped with explosives rather than random shooting inevitably resulting in a combination of blast injuries, penetrating injuries, and thermal injuries among victims.[6,44,69,70] This type of injury is very similar to injuries seen in present-day wars.[6] However, the creation of new explosives with the addition of common items such as fuel, cooking gas cylinders, and other volatile materials in terrorists' bombs has further increased the severity of burns caused by terrorist attacks in the last few decades.[6] Although some have claimed that a connection between the surge in violence and the severity of the injuries or in-hospital mortality was not established,[70] it was recently demonstrated that, among terror attack patients with burns, mortality is almost double that of patients who have burns not related to a terror attack.[70] The most probable reason for the increased mortality rate of terror attack–related burns victims compared with other burns victims is the existence of multidimensional injuries such as shrapnel and blast injuries.[70]

Burns are at present common form of injury among terror-attack victims and contribute about 9% of all terror related trauma.[44] In many aspects, patients with burns inflicted by a terrorist act compose a highly selected group, when compared with other burn patients.[6,44] The main difference between war and terrorist attacks is in the targeted population—soldiers in the former, civilians in the latter[6]—and the ethnic background of the victims, which is intentionally selected.[69] Civilians are less protected compared with soldiers and therefore are more susceptible. Moreover, the fact that acts of terrorism harm the very old and the very young confronts the medical system with a case-mix that is utterly different from the one expected in war,[6] although the major age predilection of terror victims remains the productive years (as a result of the public settings in which the attacks take place).[69] Furthermore, terrorist attacks are usually perpetrated in highly populated areas and therefore near medical centers,[6] which makes evacuation of victims a less complex operation. Nevertheless, both in war and in a terrorist attack, there are usually multiple casualties within a very short time. This puts a much heavier load than usual on the medical system, which is used to coping with only a few cases of accidental burns at any given time in peacetime.[6]

Analysis of the medical management of patients who sustained burn injury after terrorist attacks reveals, however, several potential barriers to the provision of optimal care even in the most advanced setups.[71] In addition to the lack of adequate systems to facilitate either primary or secondary triage of burn victims to specialized burn care facilities, failure of communications systems was found to be most often widespread. This failure not only hinders the sharing of information between responders in the field but also prevents effective coordination and planning by and among hospital receiving units.[71–73] This certainly requires improvement in current standards of emergency preparedness as the threat of terrorist attacks is not likely to decrease soon. Moreover, the shift in the manifestation of terror around the world necessitates a change in response toward these kinds of attacks, so that teams are well prepared for all stages of treatment, including acute care and long-term care, both medical and nonmedical. This is to ensure that the best treatment to victims is given while avoiding long-term increase in the consumption of resources.[70] It must be also recognized that burns, being a common form of terror-related injury, burn care facilities, and personnel should be prioritized in terror-stricken areas.[44]

TREATMENT OUTCOME OF WAR-RELATED BURN INJURIES

In a recently published study comparing civilian burns and combat burns from Operation Iraqi Freedom and Operation Enduring Freedom, mortality was found to be similar between civilians and military personnel injured in combat zones when treated at the same center (Brooke Army Medical Center in San Antonio, TX, the home of the US Army Institute of Surgical Research Burn Center—level V). This was still true despite higher incidences of other injuries, inhalation injury, and longer times to definitive care for combat-related burn injuries even when adjusted for age of patients.[18]

In the recent Iraqi and Afghani conflicts, many injuries have been from explosions, which generate high amounts of heat in a flame ball as well as blast overpressure and penetrating fragments. Most other injuries have been due to munitions and road side bombs. Conversely, in the civilian population, burns were often due to other causes such as scalds with hot liquids and contact burns. Although flame burns were frequent in this group, they were generally not associated with explosions. These differing causes of burn have differing propensities to induce full-thickness wounds. The areas of the body burned were also different between the 2 populations. Chest, upper arm, and thigh burns were more common in civilians, and head and hand burns were more common in the military.[18] All patients were treated similarly after arrival at the burn center with early total excision of the burn wound, modern critical care techniques, and aggressive rehabilitation. In this analysis, it was shown that results such as mortality and gross function after discharge did not differ between civilian and military despite group dissimilarities for age (higher in the civilian group), full-thickness burn (higher in the military group), inhalation injury (higher in the military group), and associated nonburn injuries (higher in the military group). When age was controlled by excluding all civilian subjects outside the range of age for the military group (18–58 y), any perceptible differences further diminished in size.[18]

In another study from the same burn center, it was concluded that in a military population, length of hospitalization, TBSA, and the presence of inhalation injury were most strongly associated with a failure to return to duty. Being able to associate burn factors of civilian return to work with military personnel return to duty was, however, unsettled.[74] In neither military nor civilian populations was the presence of a hand burn found as a dominant factor.[16]

CONCLUSIONS

Historically, major wars help change medical treatment protocols and even define new subspecialty surgical fields. During the American Civil War in the 1860s, physicians perfected limb amputation skills as a means of avoiding life-threatening infection. During World War I, with trench warfare (with soldiers' faces rising out of the trench first), surgeons established principles for *craniofacial injuries*, which later defined the subspecialty of craniofacial surgery. During World War II, treatment protocols for hand burns were created to treat British fighter pilots who were instructed to land their burning planes no matter what. During the Vietnam War, surgeons perfected the repair of major vascular injuries, which helped establish the field of vascular surgery. We are still learning lessons from the injuries from the war in Iraq.[16] Anyway, from planning to execution, providing critical care services in the field is demanding

work.[40] In addition to the serious and significant problems encountered in the management of burn injuries during the ongoing military conflicts,[22] unfortunately, the field of combined injury remains relatively unfamiliar to burn surgeons.[23]

Management of combat casualties with severe burns and associated traumatic injuries requires a coordinated interaction of surgical, critical care, and evacuation assets. These patients present enormous challenges to the entire medical system as a result of the severity of injury combined with the great distance required for transport to definitive care.[10] Such management must be derived from skills and data collected in past conflicts and civilian trauma and from information and experience obtained during ongoing conflicts.[44] Combat-related burns, unfortunately, are increasing in frequency, size, and severity.[9] Survival of the critically injured burn trauma patient depends on many factors, including timely access to facilities able to provide expert care.[15] A recent analysis of changes in mortality by burn size indicates that, indeed, burn-related mortality has improved significantly since the Vietnam conflict perhaps because of more rapid and safe evacuation, early excision and grafting, and better critical care techniques.[18] The occurrence of invasive burn wound infection has also decreased with the widespread use of early excision and grafting, topical antimicrobials, and the implementation of strict infection control measures in most centers. However, the unique and often austere environment encountered in the combat zone raises the issue of how best to prevent infection in injured military personnel. Wound care and the use of prophylactic, topical antimicrobials should occur as soon as possible in the evacuation process; however, use of systemic antimicrobials should be avoided during the evacuation process to minimize selective pressure for resistant organisms.[1]

Military burns have a broad effect that ranges from individual patients to the overall status of military operations.[9] The chaos created by an ongoing military conflict or a catastrophic event impedes decision making and effective treatment of patients. This requires a paradigm shift from the application of unlimited resources to the allocation of care, with limited resources, for the greatest good for the greatest number of patients.[42] Training and preparation are essential to remain effective during crises. Disaster triage and crisis management represent a tactical art that incorporates clinical skills, didactic information, communication ability, leadership, and decision making. Planning, rehearsing, and exercising various scenarios encourage the flexibility, adaptability, and innovation required in combat situations as well as in disaster settings.[42] Unique in military medicine are highly motivated patients who reap benefits from the surgeon's constant exposure to complex battle injuries.[16] In addition to practicing established concepts from previous military conflicts, new technology for the advancement of trauma care must be continuously applied[27] to help bring order to the chaos of overwhelming catastrophic events.[42]

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