ACUTE BURN CARE

Chapter 12

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Table of Contents

Introduction

The harsh cruelty of war, as witnessed by those who treat the wounded, would be intolerable if it were not for the belief that the art of medicine is advanced with each lesson learned. In order to pay proper respect to those who have suffered from their wounds, physicians must be dedicated to advancing and applying these lessons of combat casualty care (CCC) (Fig. 1).

Many of the lessons learned from Operation Enduring Freedom (OEF) in Afghanistan and Operation Iraqi Freedom (OIF) relate to problems that have existed as long as wars have been waged. Problems include: the remote and often austere environment in which the battle occurs; the presence, experience, and capability of CCC providers at each level of care; access to necessary supplies and

Figure 1. *Burn patients are frequently encountered in combat. This photograph demonstrates Iraqi burn patients on board the USNS Comfort hospital ship in 2003 in the Persian Gulf.*

equipment to implement care; the need to transport casualties expeditiously across dangerous terrain to a safe environment for further recovery; and the inevitability that innocents, too often children, will present among the wounded and require care.[1]

Children with severe burns are part of the reality of war, and their arrival at field hospitals should come as no surprise to anyone, least of all the surgeon. Care of pediatric burn patients should be anticipated.

Figure 2. *A host nation burn victim undergoing wound care at Balad AB, Iraq.*

The ultimate hope of all those associated with providing burn care is that prevention and safety programs will mitigate, if not minimize, thermal injury as a cause of mortality and morbidity. Unfortunately, military operations are often accompanied by sophisticated means of destroying the enemy, and explosives are often part of this equation. Despite methods of protection nearly as advanced as the weaponry, combatants on both sides are subject to the thermal effects of the tools of war. Such has been true for many decades, and recent events in Iraq and Afghanistan have proved to be no exception (Fig. 2).

Combat versus Civilian Burns

Analysis of burn injuries sustained in the civilian United States (US) population compared to those observed in combat zones reveals both similarities and differences. Severe burn injury occurs in approximately 5 to 10 percent of combat casualties.[2] Casualties may sustain thermal injuries from a variety of mechanisms, including the explosion of incendiary devices, as well as the secondary fires that occur as nearby combustible materials ignite. However, in the austere environment of the overseas military post, the hazards associated with everyday life, such as burning refuse or refueling operations, also contribute to injury.[3]

Whether the injury occurs in a combat or civilian environment, the severity of burn is generally determined by the intensity of the thermal energy to which the patient is exposed, the duration of exposure, and the total body surface area (TBSA) burned. The pattern of injury for military casualties is also related to the protective equipment worn at the time of burn. Unless specifically working in an environment associated with high-risk thermal or chemical exposure, such as firefighting, most civilians are wearing everyday clothing at the time of burn. By contrast, military personnel routinely wear durable uniforms; body armor provides additional protection to the torso. Despite efforts to improve protection against burn injury for combatants, the face and hands continue to be the least protected, resulting in significant numbers of burns to these areas (Fig. 3).[4]

Figure 3. *US soldier injured by a vehicle-borne improvised explosive device (IED) with fragmentation and burn injury to the face, torso, and extremities (following escharotomies). Note the escharotomy incision along the ulnar aspect of the hand has extended slightly deeper than intended through the fascia with protrusion of muscle.*

Burns involving the hands are common on the battlefield and are associated with devastating disability, making fire-resistant gloves essential gear for at-risk military personnel.

The civilian burn patient is generally assessed and treated near the place of injury by emergency medical services personnel. The patient is rapidly transferred by ground or air ambulance to the closest available medical facility, which may then transfer the patient to a regional burn center. The civilian patient is typically admitted to no more than two medical facilities during his or her hospital course. Although transport distances may be considerable for persons living in remote regions within the US, most civilian

burn patients can be transported from the site of injury to a definitive care facility within a few hours. In contrast, US military casualties are often transported to one or more intermediary facilities prior to final air evacuation over thousands of miles back to the US for definitive care.[5,6]

Triage is an important consideration in military burn care. North American Treaty Organization (NATO) triage criteria define the expectant category as including patients in whom there are signs of impending death, or in whom there are injuries requiring an expenditure of resources exceeding those available.[7] The latter subset of expectant category triaged patients may include patients with burns of greater than 85% TBSA.[8] Sound clinical judgment is required to appropriately allocate resources during times of excessive patient influx.

Figure 4. *US Army Burn Flight Team assists in rapid evacuation of severely burned combat casualties back to the US.*

Of note, young casualties with severe burns, even those with greater than 90% TBSA involvement may now survive to leave the hospital, provided rapid resuscitation and evacuation are available.[9] Even the most severely burned combat casualty will likely tolerate evacuation back to the US to receive care, with the support of family and friends at his or her bedside (Fig. 4). Providers are encouraged to contact US Army Institute of Surgical Research (USAISR) Burn Center staff at Brooke Army Medical Center for advice and assistance should survivability become a factor in decisions concerning continuation of care or evacuation. Providers are encouraged to call (210) 916-2876 or DSN (312) 429-2876 to contact the burn center attending surgeon. Consultation may also be initiated by sending an email message (burntrauma. consult@us.army.mil) to US Army Medical Department (AMEDD) burn consultants.

> Young casualties with severe burns, even those with greater than 90% TBSA involvement, will usually tolerate long-range evacuation provided adequate resuscitative support is available, making expectant status rare for US casualties.

The process of caring for burn patients in a combat zone can also be complicated by the presence of multiple open wounds sustained in a dirty environment, combined with hemorrhage related to the injury. Operative intervention for lifesaving treatment or stabilization of concurrent injuries is not uncommon before the combat casualty is evacuated out of the theater of operations. Associated nonthermal trauma is more common in combat than in non-combat burn injury patients.[6]

Initial Evaluation and Management

Perhaps the single most important lesson to learn when providing acute care for the burn casualty is to remember that burn patients are trauma patients. The visible nature of burn injury should not distract CCC

Figure 5. *Combat casualty care providers must resist becoming distracted by burn injuries and identify and manage immediately life-threatening injuries, which are often less visually graphic in nature (e.g., airway edema and obstruction).*

providers from the fact that the patient may have several other life-threatening injuries. This is particularly true when managing blast injury casualties (Fig. 5).[6,10,11]

> Burn casualties are trauma patients, and as such deserve a complete evaluation for associated injuries beyond burn. Treat the patient, not the burn.

Primary and Secondary Survey

Successful treatment of burn patients starts with a thorough primary and secondary survey of the patient. In a combat zone this often requires a combined strategy of airway and breathing evaluation and protection and hemorrhage control. It is very easy for the careprovider unaccustomed to severe burns to become fixated on the horrendous tissue damage, particularly that involving the face (Fig. 6). Combat casualty care providers must resist becoming distracted by burn injuries and identify and manage immediately life-threatening injuries, which are often less visually graphic in nature (e.g., airway edema and obstruction or internal hemorrhage from concurrent solid organ injury).

The initial management of the combat burn casualty proceeds in a stepwise process as outlined by the Advanced Trauma Life Support (ATLS) guidelines of the American College of Surgeons Committee on Trauma, modified for the special needs of the burn patient. The principles described in the Advanced

Figure 6. *This visually distracting and severe burn to a casualty's head and neck region poses a significant immediate risk to the airway.*

Burn Life Support (ABLS) curriculum sponsored by the American Burn Association (ABA) reflect these modifications.[12] As an important example, the two-liter bolus of lactated Ringer's solution described in ATLS is contraindicated in the hemodynamically stable burn patient, as this likely contributes to edema formation with no lasting benefit.

Patient Inspection and Decontamination

Despite many improvements in military clothing and equipment, including fire-resistant uniforms, military burn casualties need to be disrobed just like any other trauma patient in order to fully examine them and ensure that thermal or chemical tissue injury is stopped. Chemical burn injury can occur when a patient comes in contact with an acid, base, or toxic organic compound. The incidence of chemical burn injury in OEF and OIF has been very low.[11] Petroleum-based products are best removed with soap and water. Brush off any debris on a patient prior to irrigation.

White phosphorous is an incendiary munition that is also found in civilian products such as fertilizers, fireworks, and pesticides. While rarely encountered in OEF and OIF, white phosphorous exposure can result in severe, combined thermal and chemical injuries. White phosphorous is extremely volatile and can ignite spontaneously upon exposure to air. In addition, phosphoric acids form during combustion and cause further tissue injury.[13,14,15]

A Woods lamp can be used to identify embedded white phosphorous particles, which fluoresce under ultraviolet light. Treatment of patients with these embedded particles involves: (1) immediate debridement of visible debris; (2) copious irrigation; (3) coverage of exposed areas with saline or liquid-soaked gauze pads that must be kept wet; and (4) cardiac monitoring and serial measurement of serum electrolytes and calcium correction.[13,14] Profound hypocalcemia, hyperphosphatemia, and sudden death have been associated with white phosphorous chemical injury.[15]

Careproviders must take precautions to ensure that they do not sustain injuries in their attempt to clean and treat the casualty. Standard universal precautions (i.e., face mask, gloves, and gown protection) should be routinely practiced. The location in which patient decontamination is performed needs to be individualized based on the nature of the chemical exposure and characteristics of the care facility. Providers need to minimize secondary contamination of patient care areas. In the authors' experience, the combined thermal and chemical burn injuries most commonly encountered in OEF and OIF have not (thus far) routinely necessitated a separate area for patient decontamination.

> Identify the cause of the burn and ensure that the thermal or chemical tissue injury process is stopped. Careproviders should use standard universal precautions when caring for patients with possible chemical agent injury, and prevent secondary contamination of patient care areas.

Electrical injuries deserve special mention as they typically cause a disproportionate degree of underlying deep tissue injury relative to visible burn injury to the skin.[16,17] Electrical burns are most severe at the source of electrical contact (e.g., hands) and ground contact points (e.g., feet).[18] As such, careproviders should carefully evaluate electrical burn patients for systemic complications and specifically for rhabdomyolysis and compartment syndromes.[18]

Airway and Breathing Interventions

Patients with facial burns or large surface area burns who receive a large volume of resuscitation often develop progressive upper airway edema in the first 48 hours following injury. This makes delayed intubation difficult, if not impossible. This distortion of upper airway anatomy is a consequence of massive anasarca and occurs even in the absence of inhalation injury.[19] Early prophylactic intubation of patients with greater than 40% TBSA involvement or deep facial burns is recommended. Burn casualties, at risk for upper airway edema, who require long-range transport should have a definitive airway established prior to

Figure 7. *Fiberoptic laryngoscopy can be used to assess the upper airway for evidence of burn injury or edema.*
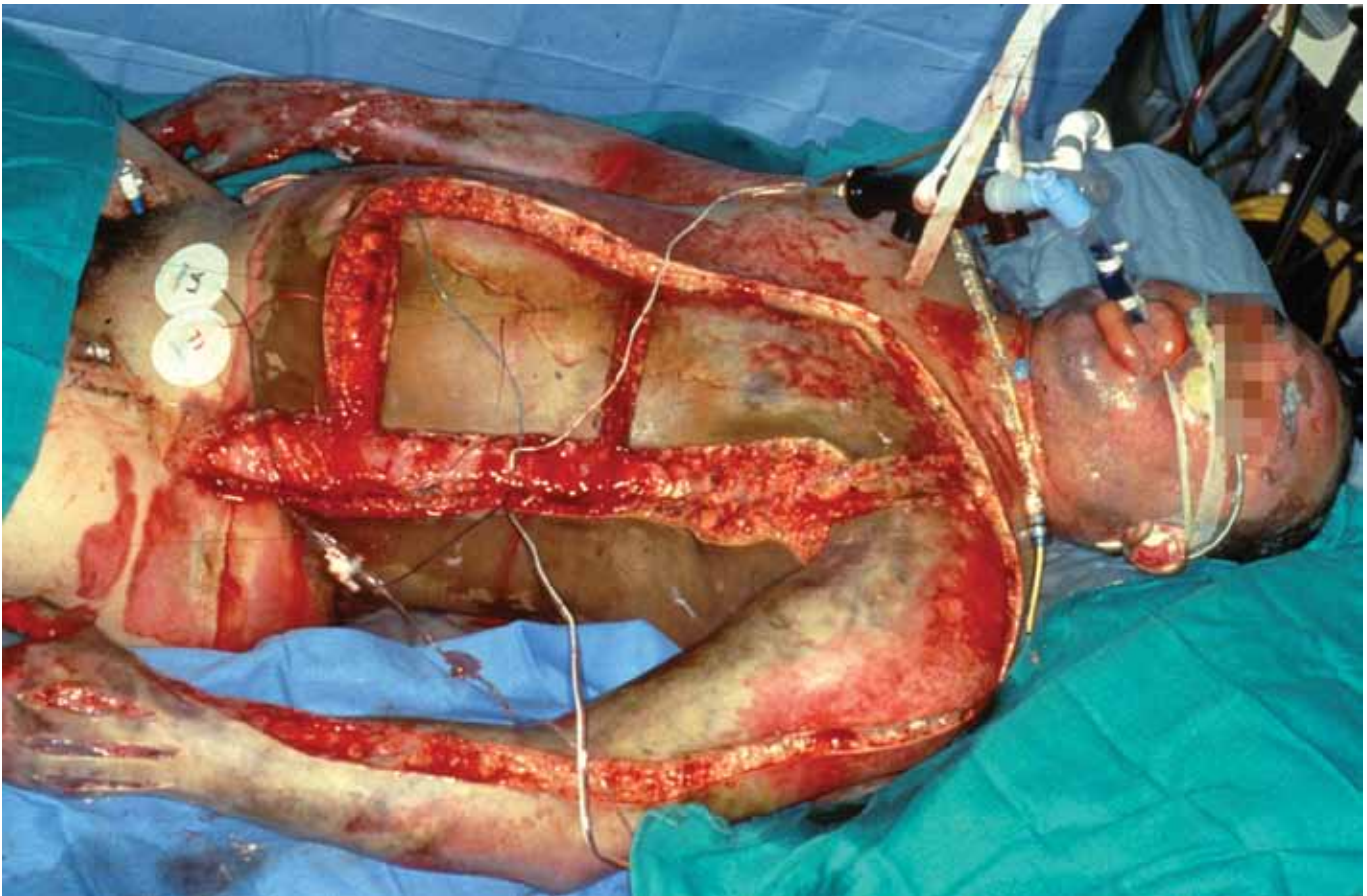
Figure 8. (Above) *Circumferential burns to the chest may impair effective ventilation and should be treated with thoracic escharotomy.*

Figure 9. (Right) *Effective chest excursion was achieved after thoracic escharotomy in this pediatric burn patient.*

movement between medical treatment facilities.[20] Inhalation injury is relatively uncommon, being diagnosed in approximately 10 percent of burn injuries.[21] Casualties with facial burns, large TBSA burn size, and those who are trapped within a burning vehicle or structure are those most at risk for inhalation injury.[21] Clinical findings such as stridor or production of carbonaceous sputum should increase suspicion of inhalation injury, but are by no means definitively diagnostic.[22] Fiberoptic laryngoscopy (if available) can be used to assess the upper airway for evidence of burn injury or edema in equivocal cases (Fig. 7). Patients suspected of suffering significant inhalation injury benefit from early airway protection by endotracheal intubation and subsequent support with mechanical ventilation.

As in the case of large burn size, the authors' experience is that it is better to err on the side of earlier rather than later intubation of patients with inhalation injury.[23]

> Treatment of life-threatening airway or breathing compromise and bleeding wounds takes priority over initial burn wound care. Prophylactic intubation of the patient with extensive burns or inhalation injury is advisable, especially if ongoing resuscitation is required. Protect the burn patient's airway and establish effective ventilation in preparation for aeromedical evacuation.

Patients with inhalation injury should be intubated with the largest size endotracheal tube possible. Sloughing of tissue from the friable airway following inhalation injury, coupled with blood and secretions, may quickly occlude an endotracheal or tracheostomy tube. Larger-sized endotracheal tubes will mitigate this process and facilitate subsequent interventions (e.g., bronchoscopy). Interval suctioning of the airway is important. The use of aerosolized heparin alternating with aerosolized *N*-acetylcysteine in burn patients with inhalational injury requiring ventilatory support has been shown to decrease the incidence of reintubation for progressive respiratory failure, decrease atelectasis, and reduce mortality in adults and children with massive burn and inhalation injury.[24,25] Fiberoptic bronchoscopy is also recommended to document extent of injury, as well as to remove large plugs under direct visualization.[20]

Patients who sustain circumferential burns of the chest, especially full-thickness burns resulting in a tight eschar, are at risk of respiratory impairment (Fig. 8). Effective chest excursion can be markedly impeded by thoracic eschar, resulting in hypercapnia, hypoxia, and respiratory arrest.[26] Such patients require thoracic escharotomy (Fig. 9).

> Circumferential burns involving the chest can impair ventilation and/or oxygenation due to reduced thoracic excursion. Thoracic escharotomy, performed at the bedside, can be a lifesaving intervention.

Comorbid Life-Threatening Injury Care

The purpose of the primary and secondary trauma survey is to rapidly assess a combat casualty and identify and mitigate imminent threats to life. Combat casualties, including those with burns, are most likely to die within the first 24 hours from exsanguination related to a penetrating wound.[27] Airway, breathing, and hemorrhage control must be addressed immediately in all casualties. Treatment of life-threatening airway or breathing compromise and bleeding wounds takes priority over initial burn wound care.

In addition to burn wounds, primary and secondary surveys of the casualty may reveal intraabdominal injuries as well as significant soft-tissue wounds and long-bone fractures, an observation noted among a large percentage of military burn casualties injured from explosions.[28] Military personnel may also sustain burn injuries while traveling in moving vehicles attacked with improvised explosive devices (IEDs), mandating evaluation for blunt trauma, as well as for penetrating injuries.

Burn Wound Evaluation and Patient Resuscitation

In a deployed environment, burn patients are routinely transported to the operating room not only for treatment of associated injuries, but also for debridement and dressing of all wounds. The operating room

provides the most sterile environment available for such interventions (Fig. 10). The presence of anesthesia staff to provide pain control and sedation during debridement and dressing changes makes the operating room an optimal location for these procedures.[10]

Estimating Depth of Burns

Burns are classically described as first-degree, second-degree (partial-thickness), or third-degree (full-thickness) in depth. First-degree burns affect a variable portion of the epidermis, feature erythema without extensive blistering, and heal within a few days. An example is a mild sunburn. For purposes of CCC (to include calculation of total burn size and fluid resuscitation needs), first-degree burns are

Figure 10. *The operating room provides the most sterile environment for debridement and dressing of burn wounds.*

of no consequence. Second-degree (partial-thickness) burns affect the entire thickness of the epidermis and a variable portion of the dermis. An example is a blistered scald burn. Because these burns spare the hair follicles and other epidermal analogs, they are capable of spontaneous healing. However, the healing time is highly variable. For this reason, second-degree burns are further subdivided into superficial second-degree burns (those that will heal with rapid reepithelialization and minimal scarring within 14 days) and deep second-degree burns (those that will heal after 14 days or more). Finally, third-degree (full-thickness) burns destroy the entire depth of the epidermis, dermis, and epidermal analogs. An example is a flame burn from gasoline, a house fire, or an IED. The burned skin may appear leathery, pale, or charred. These wounds are incapable of healing spontaneously, except by wound contraction, and almost always merit excision and

Degree of Burn	Depth of Wound	Wound Description
First	Epidermis	Pink or red, without blister formation; capillary refill and sensation intact
Second (partial-thickness)		
• Superficial partial-thickness	Epidermis, papillary layer of dermis	Blistering of skin, exposed dermis is red and moist; capillary refill and sensation intact, painful
• Deep partial-thickness	Epidermis, papillary and reticular layers of dermis	Blistering of skin, exposed dermis is pale, white to yellow; capillary refill is absent, pain sensation is diminished
Third (full-thickness)	All epidermal and dermal structures are destroyed	Charred, pearly white, or leathery appearance; capillary refill absent, insensate
Fourth	Epidermis, dermis, fat/ muscle/bone	Variable appearance; thrombosed blood vessels, insensate

Table 1. *Classification of burn depth.*

grafting. The term fourth-degree burns is sometimes used to describe burns that affect even deeper layers, such as fat, muscle, and/or bone (Table 1 and Fig. 11).

Accurate burn classification is needed to identify which burns require skin grafting to accelerate healing, improve cosmetic results, and prevent contractures. Time to healing and scar development is retrospectively used to grade burns that were not initially excised and grafted. Partial-thickness burns that heal prior to 14 days are unlikely to scar, while those that take over 21 days to heal will likely scar and/or result in contractures (Fig. 12).

> Accurate estimation of a patient's burn size, expressed as the percentage of the TBSA burned, is the most important component in determining the severity of burn injury, and should be done in collaboration with consulting burn surgeons.

Clinical assessment of burn depth is fairly accurate for distinguishing first- and third-degree burns. Unfortunately, it is less accurate for determining which second-degree burns would benefit from immediate excision and grafting, and which will heal spontaneously within 14 days.[29,30] Expert burn surgeons are only 60 to 75 percent accurate in correctly classifying partial-thickness burn depth and recovery potential at time of initial injury.[30] To address this problem, a variety of standard (e.g., biopsy and histology) and advanced technologies (e.g., thermography, dye studies, laser Doppler imaging, noncontact high-frequency ultrasonography) have been used to assess tissue characteristics and/or perfusion as methods for determining burn depth.
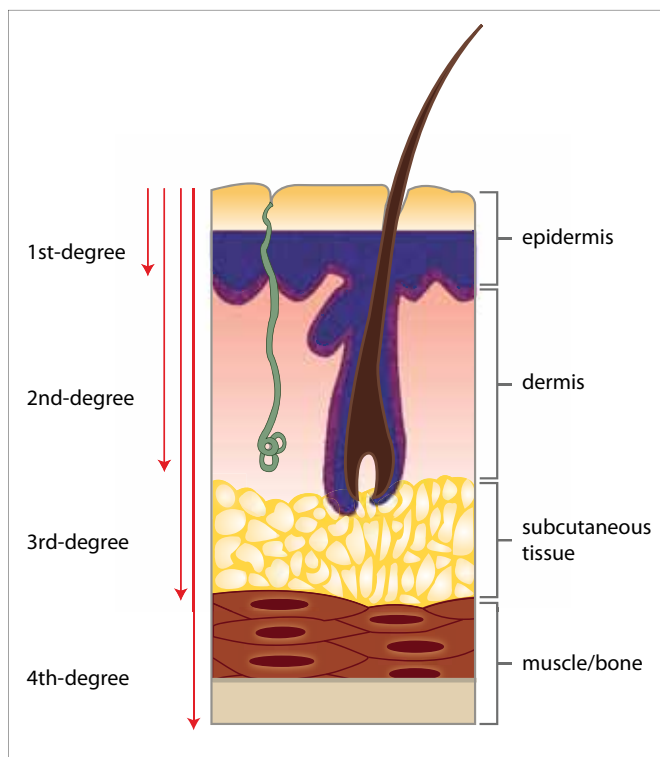

Figure 11. (Left) *Schematic cross section of skin anatomy demonstrating layers involved with differing burn depths.*

Figure 12. (Below) *A severe hand burn, now with scarring and contractures. Early excision and grafting, followed by timely splinting and rehabilitation, are essential to prevent outcomes like this in the treatment of burns of the hands and across major joints.*
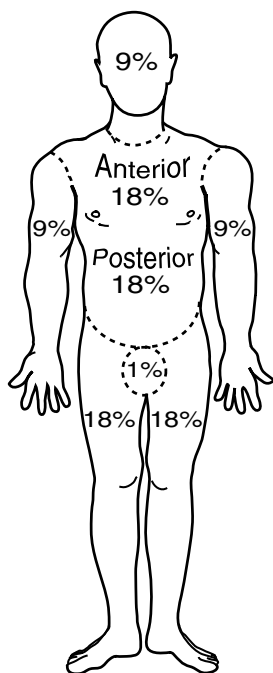
Figure 13. (Above) *Estimation of body surface area using the Rule of Nines is relatively inaccurate. Image courtesy of the Borden Institute, Office of The Surgeon General, Washington, DC.*
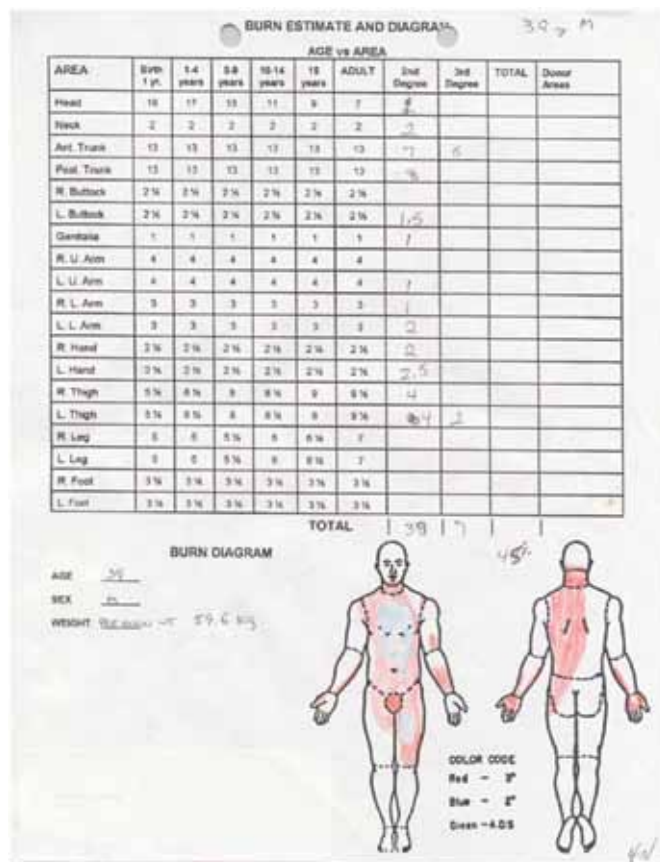
Figure 14. (Right) *Estimation of body surface area using a Lund-Browder chart is an accurate tool for assessing extent of burn injury.*

Combat casualty careproviders in OEF and OIF will need to make clinical assessments of burn depth in collaboration with consulting burn surgeons. Burns that do not heal within 14 days following injury are likely to benefit from excision and grafting, as well as from advanced rehabilitation, to ensure optimal cosmetic and functional outcomes.

Estimation of Burn Severity

Accurate estimation of a patient's burn size, expressed as the percentage of the TBSA burned, is the most important component in determining the severity of burn injury. Total body surface area burned is an important predictor of mortality (along with other factors including age, inhalation injury, and concurrent injuries). Total body surface area burned is the most important factor to consider when initiating burn resuscitation. The "Rule of Nines" is a commonly used, but relatively inaccurate, tool for estimating TBSA (Fig. 13).[31] The Lund-Browder chart is a more accurate (but more time-consuming) tool for assessing and documenting the extent of burn injury that takes into account differences in patient age (Fig. 14).[31]

Burn Location

As previously noted, circumferential burns (e.g., thorax and extremities) are at high risk for compromising tissue perfusion. Full-thickness and partial-thickness burns to critical areas such as the face, ears, hands, feet, perineum, and genitalia are also considered high-risk injuries and require burn specialist consultation. In addition, full-thickness or partial-thickness burns over joint areas need careful follow-up evaluation and management to prevent contractures.

Initial Fluid Resuscitation

Intravenous (IV) fluid resuscitation is typically required for all burn patients with greater than 20% TBSA involvement, and for some with greater than 10% TBSA involvement. Before any resuscitative fluids can be administered, IV access is required. Thermal burns often increase the difficulty of establishing and maintaining IV access. Problems include loss of normal landmarks, loss of skin pliability, and difficulty in penetrating the eschar with the catheter. Although it is preferable to establish IV access through unburned skin, access through burned skin is acceptable. When a peripheral IV catheter cannot be placed, central venous or intraosseous access should be obtained without delay.[32]

> It is acceptable to establish IV access through burned skin, if necessary. When a peripheral IV catheter cannot be placed, central venous or intraosseous access should be obtained without delay.

Once adequate IV access is established, the catheter must be secured. The routine use of adhesive tape or transparent dressings does not work over burned skin. Securing the IV catheter to skin (or eschar) with sutures or surgical staples is a very effective method (Fig. 15). Redundant access (i.e., at least two IV catheters) is essential prior to transporting the patient, especially during the critical phase of burn resuscitation.

Placement of a urinary catheter should be performed early during patient resuscitation, as urine output is an important indicator of the adequacy of resuscitative efforts. Burns to the genitalia and/or the perineal region are not contraindications to Foley catheter placement. The CCC provider may need to remove eschar on the glans penis to visualize the urethral meatus to enable placing the catheter. This simple intervention is far superior to placement of a suprapubic catheter and the complications associated with inadvertent violation of the peritoneal cavity.

Figure 15. *An IV catheter is secured to the skin using sutures.*

One of the most challenging and controversial aspects of burn care continues to be providing optimal resuscitation during the initial 24 to 48 hours following injury.[33] Severe burns lead to massive fluid shifts from the intravascular space to the interstitium in both burned and nonburned tissues. The hypovolemia caused by this shift and an increase in systemic vascular resistance leads to a reduction in cardiac output and decreased end-organ perfusion. Early volume replacement with crystalloid solutions to maintain adequate perfusion of vital organs reverses burn shock and can be lifesaving. Excessive fluid resuscitation, beyond the minimum required to maintain end-organ perfusion, exacerbates tissue edema, contributes to devastating complications such as abdominal compartment syndrome, and leads to increased mortality.[34]

Burn Flow Sheet Documentation

JTTS Burn Resuscitation Flow Sheet — Page 1

Date: [1]	Initial Treatment Facility: [2]					

Name	SSN	Pre-burn est. wt (kg)	Estimated fluid vol. pt should receive			
			% TBSA	1st 8 hrs	2nd 16th hrs	Est. Total 24 hrs
[3]	[4]	[5]	[6]	[7]	[8]	[9]

Date & Time of Injury	[10]	BAMC/ISR Burn Team DSN 312-429-2876

Flow chart columns: [11] Tx Site/Team | [12] HR from burn | [13] Local Time | [14a] Crystalloid (ml) / [14b] Colloid | [15] TOTAL | [16] UOP | [17] Base Deficit | [18] BP | [19] MAP (>55) / CVP | [20] Pressors (Vasopressin 0.02-0.04 u/min)

Rows: 1st, 2nd, 3rd, 4th, 5th, 6th, 7th, 8th, 9th, 10th, 11th, 12th

Total Fluids 1st 12 hrs: [21]

Rows: 13th, 14th, 15th, 16th, 17th, 18th, 19th, 20th, 21st, 22nd, 23rd, 24th

Total Fluids: [22]

[1] **Date**: Today's date

[2] **Initial Treatment Facility**: Where this form is initiated

[3] **Name**: Patient's name

[4] **SSN**: Patient's social security number

[5] **Weight (Kg)**: Estimated weight PRE-BURN "dry weight"

[6] **% TBSA**: Total body surface area burned

[7] **1st 8 Hrs**: ½ total calculated fluids per burn resuscitation formula (ABLS), given over 1st 8 hrs post-burn

[8] **2nd 16 Hrs**: Remaining ½ of the calculated fluids over the next 16 hrs

[9] **Estimated Total Fluids**: Total fluids calculated for the first 24 hrs post-burn injury

[10] **Time of Injury**: Time the patient burned, **NOT** the time patient arrived at the facility

[11] **Treatment (Tx) Site/Team**: Facility, CCATT or care team providing care at specified hour

[12] **Hour From Burn**: "1st" hour is the first hour post burn. For example: pt arrives @ facility 3 hrs post-burn. Clinicians will start their charting for the "4th" hour. Enter IVF & UOP totals from level I & II care, prior to arrival at the current facility, in the "3rd" hour row.

[13] **Local Time**: Current time being used by recorder

[14a] **Crystalloid (mL)**: Total crystalloid volume given over last hour (LR, NS, etc.)

[14b] **Colloid (mL)**: Total colloid volume given over the last hour (Albumin 5%-25%, blood products, Hespan, etc.) **Note when using Albumin**: With large resuscitations, start 5% Albumin at the 12 hour mark; with normal resuscitations, start at the 24 hour mark.

[15] **Total**: Total volume (crystalloid + colloid) for the hour

[16] **UOP**: Urine output for last hour

[17] **Base Deficit**: enter lab value, if avail. (indicates acidemia)

[18] **BP**: Systolic BP / Diastolic BP

[19] **MAP/CVP**: MAP and/or CVP if available.

[20] **Pressors**: Vasopressin, Levophed, etc., and rate/dose

[21] **12-hr Total**: Total IVF & UOP for 1st 12 hours post-burn

[22] **24-hr Total**: Total IVF & UOP for 1st 24 hours post-burn

Pre-burn Est. Wt (kg)	%TBSA	Fluid Volume ACTUALLY received		
		1st 8 hrs	2nd 16th hrs	24 hr Total
		[a]	[b]	[c]

Page 2 (24-48 hrs)

The guidelines for page 2 remain the same as for page 1, with the exception of the calculation table. On page 2, the values in [a] and [c] are the **actual** volumes delivered and recorded from page 1, blocks 21 & 22. [b] is the **actual** volume delivered from the 9th hour through the 24th hour. These values allow caregivers to re-calculate the mL/kg/% TBSA, and evaluate for over-resuscitation

Pre-burn Est. Wt (kg)	%TBSA	Fluid Volume ACTUALLY received		
		1st 24 hrs	2nd 24 hrs	48 hr Total
		[d]	[e]	[f]

Page 3 (48-72 hrs)

The guidelines for page 3 remain the same as for pages 1 & 2, with the exception of the calculation table. On page 3, the values in [d] and [e] are the **actual** 24 hour fluid totals recorded from pages 1 & 2. [f] is the **total** volume delivered over the first 48 hrs ([d] + [e]). Once again, these values allow caregivers to re-calculate the mL/kg/% TBSA, and evaluate for over-resuscitation

Figure 16. *The standardized Burn Flow Sheet has improved documentation, communication, and outcomes following battlefield burn resuscitation. Image courtesy of the Borden Institute, Office of The Surgeon General, Washington, DC.*

> Excessive fluid administration (over-resuscitation), beyond the minimum required to maintain end-organ perfusion, produces its own constellation of complications termed resuscitation morbidity. Resuscitation morbidity includes upper airway obstruction, pulmonary or cerebral edema, and compartment syndromes affecting the extremities and abdomen.

Patients presenting with concurrent injuries, which require fluid administration unrelated to burn treatment, complicate resuscitation of military burn casualties. Resuscitation is also made complex by virtue of multiple careproviders with varying backgrounds providing burn care during the patient's initial management and subsequent aeromedical evacuation and care. The implementation of a standardized Burn Resuscitation Flowsheet and Burn Resuscitation Guidelines (Fig. 16), by improving documentation and inter-echelon communication, has improved outcomes following battlefield burn resuscitation.[35,36]

Modified Brooke Formula

The current clinical practice guideline for resuscitation of the military burn casualty recommends initiating fluid resuscitation utilizing the modified Brooke Formula: lactated Ringer's solution totaling (2 ml x %TBSA burned x kilogram weight) divided over 24 hours, with half of the total amount administered during the first 8 hours following injury.[37] An abbreviated method of calculating the initial fluid resuscitation rate (only applicable to adults weighing over 40 kilograms) is to multiply the estimated %TBSA burned x 10. Coined the "Rule of Ten" at the USAISR (Chung KC, unpublished data 2009), this simple equation provides the initial hourly infusion rate for lactated Ringer's solution (Fig. 17).

Figure 17. (Above) *Ongoing resuscitation of a burn victim with lactated Ringer's infusion during critical care transport.*

Figure 18. (Right) *Patient monitoring during air evacuation.*

> *USAISR Rule of Ten for Burn Resuscitation of Adults:*
> %TBSA burned x 10 = Initial Hourly IV Fluid Infusion Rate

For children, body weight remains a critical consideration, and the modified Brooke Formula for children is used: (3 ml x %TBSA burned x kilogram weight) divided over 24 hours, with half of the total amount programmed for administration during the first eight hours following injury.[38] In addition, children require a maintenance fluid, which is not adjusted during resuscitation.

> *Modified Brooke Formula:*
> Lactated Ringer's total (2 ml x %TBSA burned x kilogram weight); first half infused in first eight hours
>
> *Modified Brooke Formula for Children:*
> Lactated Ringer's total (3 ml x %TBSA burned x kilogram weight); first half infused in first eight hours

These estimates, or any other burn resuscitation formulas, simply provide a point at which to start the resuscitation. Burn resuscitation must be closely monitored and adjusted based on clinical response and endpoints. Administer no more fluid than is necessary for end-organ perfusion as observed by adequate urine output, generally accepted as 30 to 50 ml per hour in adults, and 1 to 2 ml per kilogram per hour in children.[39] Intravenous fluid rates should be adjusted hourly, avoiding boluses of fluid and making incremental adjustments by 20 to 25 percent up or down, based on urine output. Current research and development efforts are underway to improve this process though the development of decision-assist software.[40]

> Optimal Burn Resuscitation:
>   Estimate → Initiate → Monitor → Adjust → Document
>   Repeat monitoring and adjustment process at hourly intervals to optimize resuscitation

Inadequate resuscitation can lead to ischemia of renal and mesenteric vascular beds and can worsen end-organ injury.[41,42] Excessive fluid administration (over-resuscitation) produces its own constellation of complications termed resuscitation morbidity. Resuscitation morbidity includes upper airway obstruction, pulmonary or cerebral edema, and compartment syndromes affecting the extremities and abdomen.[43]

Patient monitoring becomes more advanced as the patient is transported to better-resourced facilities (Fig. 18). Vital sign monitoring (assessment of pulses and manual measurement of blood pressure) rapidly advances as the patient is evacuated to higher levels of care, to include continuous electrocardiographic monitoring, pulse oximetry, and interval automated blood pressure measurements. Placement of arterial and central venous catheters provides continuous measurements of arterial and central venous pressures. An improving base deficit has also been identified as a helpful indicator of resuscitation efficacy.[44]

While central venous pressure, central venous saturation, and arterial base deficit are often followed during resuscitation, there are no accepted guidelines with respect to use of these variables as endpoints.[45] Adequate end-organ perfusion, manifested by a urine output of 30 to 50 ml per hour in adults (1 ml per kilogram per hour in children less than 30 kilograms), is the primary index of resuscitation adequacy used in burn patients.

While hemodynamic variables (e.g., hypotension) are helpful in identifying uncompensated shock, they inadequately detect hypoperfusion in compensated shock states. Patients with compensated shock may appear normotensive, yet still suffer from regional hypoperfusion, as evidenced by progressive metabolic acidosis. Current methods for assessing the adequacy of fluid resuscitation in critically ill patients are suboptimal. While much emphasis has been placed on defining markers of global perfusion adequacy (e.g., base deficits), future efforts will likely involve better defining markers of regional perfusion adequacy (e.g., gastric intramucosal pH monitoring) and endpoints for resuscitation.

> Adequate end-organ perfusion, manifested by a urine output of 30 to 50 ml per hour in adults (1 ml per kilogram per hour in children less than 30 kilograms), is the primary index of resuscitation adequacy used in burn patients.

Complications of Burn Injury

Abdominal Compartment Syndrome

Patients with significant burns are at risk for developing abdominal compartment syndrome. This risk increases with the volume of fluid infused over the first 24 hours following burn injury. Infusion of fluid volumes exceeding 250 ml per kilogram within the first 24 hours following injury is particularly hazardous.[46] Thus, initiation of serial measurements of the bladder pressure may be prudent as soon as a patient, during the first 24 hours post-burn, receives greater than 200 ml per kilogram of fluid infusion. Other risk factors for abdominal compartment syndrome include extensive TBSA involvement and full-thickness burn size, aggressive fluid resuscitation in the early resuscitative period, and deep or circumferential burns to the abdomen and thorax.[47]

Figure 19. *This image illustrates an open abdomen following decompressive laparotomy for abdominal compartment syndrome.*

> If abdominal compartment syndrome develops, a decompressive laparotomy will likely be required.

If intraabdominal hypertension occurs (i.e., bladder pressure greater than 25 mm Hg): (1) escharotomies of any eschar involving the abdominal wall are warranted; (2) every effort should be made to reduce the fluid infusion rate; and (3) bedside placement of a peritoneal drain should be considered to remove ascites.[46,48,49] If these methods fail to reduce bladder pressure and if the patient develops abdominal compartment syndrome (e.g., intraabdominal hypertension with rising airway pressures, cardiovascular collapse, and/or oliguria despite adequate preload), a decompressive laparotomy will likely be required (Fig. 19).[50] Because the open abdomen becomes heavily contaminated and may be impossible to close, decompressive laparotomy is a high-risk procedure in burn patients.[46,49,50] In the authors' experience, such an intervention is associated with a mortality exceeding 80 percent. Techniques proposed to reduce the fluid infusion rate in patients with intraabdominal hypertension include early use of colloid and use of hypertonic crystalloid solutions.[51,52,53]

> Both over-resuscitation and under-resuscitation of burn patients must be avoided; each invokes unique morbidity.

Traumatic Rhabdomyolysis

Patients with traumatic rhabdomyolysis are at risk of acute kidney injury and acute tubular necrosis.[54] These patients present with gross myoglobinuria, which can be distinguished from hematuria by a urinalysis that is dipstick positive for blood but microscopically negative for red blood cells. The diagnosis is further supported by documenting elevated levels of serum creatine phosphokinase (CPK). Once diagnosed, rhabdomyolysis is treated with an increase in the intravenous fluid rate in order to achieve a target urine output of 1 ml per kilogram per hour (i.e., commonly 75 to 100 ml per hour in adults), to clear the tubules of myoglobin. In addition, urgent fasciotomy and/or debridement of necrotic muscles may be required to eliminate sources of ongoing pigment release (tissue injury). If these measures fail to produce a gradual clearing of pigment from the urine (as determined by visual inspection over several hours) or a decline in the serum CPK level, then infusion of mannitol and/or administration of bicarbonate to alkalinize the urine should be considered.[18,54,55] The efficacy of mannitol and bicarbonate therapy for rhabdomyolysis remains controversial.[56,57,58,59]

Electrolyte Disturbances

Burn patients may present with a variety of electrolyte disturbances. Patients with massive tissue destruction, such as those with traumatic rhabdomyolysis, are at risk for hyperkalemia. Loss of the evaporative barrier to water loss leads to very large insensible water losses and thus to hypernatremia. This mandates intravascular volume replacement with hypotonic intravenous (such as D5W) and/or oral solutions, beginning about 48 hours post-burn.[60] The amount of these losses can be roughly estimated by the formula, daily water requirement = (1 ml x TBSA burned x weight in kilograms). However, patients are also at risk of hyponatremia because of abnormalities in the thirst mechanism and in some cases the syndrome of inappropriate secretion of antidiuretic hormone (SIADH).[61]

The rate of serum sodium correction depends on the severity of symptoms and rate at which the derangement developed (acute versus chronic).[62] The treatment of acute (less than 48 hours duration) hyper- and hyponatremia associated with burn injury involves correcting intravascular volume deficits and correcting hyper- or hypotonicity. The serum sodium should be corrected at an initial rate of 1 mEq per liter per hour. Serial serum electrolyte measurements should be performed every one to two hours during initial treatment phases. The correction of chronic sodium disturbances (greater than 48 hours duration) should be at a rate not to exceed 0.5 mEq per liter per hour.[63] Serum sodium correction is performed more rapidly if a neurological complication, such as ongoing seizure activity, is attributed to sodium derangement.

The predictive accuracy of formulas for serum sodium and intravascular volume repletion is limited.[64] Lindner et al. studied the predictive accuracy of formulaic approaches to serum sodium correction and found that individual patient variability of response to treatment dictates such formulas should only be used as a guide. Serial measurements of serum sodium are recommended to ensure appropriate treatment. Finally, burn patients may develop severe hypophosphatemia during the first three to five days post-burn, most likely reflecting the tremendous increase in metabolic demand that occurs during this period.[65] Thus, serum electrolytes must be monitored frequently (minimum of twice daily) in patients with major burns.

Figure 20. (Left) *With circumferential burns, elevation of the burned extremity and frequent evaluation are extremely important.*

Figure 21. (Bottom Left and Bottom Right) *Extremity escharotomies following circumferential burns.*

Escharotomy and Fasciotomy

Circumferential burns of the extremities and torso are prone to the compressive effect of eschar. Fluid resuscitation can rapidly exacerbate such compression through increased tissue edema, with resultant vascular obstruction, ischemia, and limb loss.[26] This most commonly occurs in the setting of circumferential full-thickness burns, but does on occasion occur with deep partial-thickness burns, or noncircumferential burns. Elevation of burned extremities well above the level of the heart is a simple but critically important intervention that will minimize tissue edema in the initial 48 hours following burn injury. Elevate burned limbs and evaluate them hourly during patient resuscitation (Fig. 20). This can be done with pillows and blankets, or better yet, with slings constructed of surgical netting hung from IV poles. When this fails to maintain adequate distal blood flow, escharotomy (a longitudinal incision through the burned skin) is required (Fig. 21).

> Elevation of burned extremities well above the level of the heart is a simple but critically important intervention that will minimize tissue edema in the initial 48 hours following burn injury.

Progressive diminution of pulsatile arterial flow by Doppler flowmetry is the primary indication for escharotomy. Other indications include cyanosis of distal unburned skin, impaired capillary refill, or progressive neurological deficits.[66] Such neurologic deficits include paresthesias progressing to hypesthesia or loss of motor function. In addition, early escharotomy should be considered for any patient with deep,

Figure 22. (Left) *Hand escharotomies. Burned skin is incised to the subcutaneous level, providing decompression while avoiding deeper structures.*

Figure 23. (Below) *Compartment syndrome is unusual following thermal injury. Unlike circumferential eschar, which is treated with escharotomy, a true compartment syndrome requires fasciotomy as demonstrated here.*

circumferential extremity burns who is being evacuated between military medical treatment facilities on the battlefield.

Escharotomy is considered to be a relatively urgent procedure and can be performed at the bedside, using sharp incision with a knife or electrocautery device. Regardless of the technique used, escharotomies should be performed in the most sterile environment possible. The burned skin is incised down to the subcutaneous level, providing decompression through the incision sites.[26] Escharotomies are generally performed on the lateral and medial aspects of the limbs, avoiding any underlying neurovascular structures, and without entering the deep (investing) fascia (Fig. 22). Pain control during this procedure should be managed with titrated doses of intravenous narcotics or ketamine. Once the escharotomy has been completed, neurovascular examination is serially repeated to verify effectiveness.

Early escharotomy should be considered for patients with circumferential, deep burns involving the extremities, especially in anticipation of long-range aeromedical transport.

Except in cases involving high-voltage electrical injury, fractures deep to the burn, or vascular injury to the limb, fasciotomies of burned extremities are rarely required.[2,67] If compartment syndrome is suspected in a circumferentially burned limb, escharotomies should be performed, and the patient reevaluated (to include neurovascular exam and measurement of intracompartmental pressures).

> Fasciotomies are performed only when clinical findings indicate intracompartmental hypertension (compartment syndrome). They should not be performed prophylactically, solely on the basis of circumferential burns.

A delay in performing a clinically indicated escharotomy, or an inadequately performed escharotomy, may lead to a true compartment syndrome mandating fasciotomy (Fig. 23).[67] In addition, massive fluid resuscitation can result in a compartment syndrome in a normal (unburned) limb.[68] In the authors' experience, the regions most sensitive to post-burn compartment syndrome are the anterior lower leg and the forearm. Fasciotomies of the thigh and upper arm as part of post-burn management are rarely indicated. Post-burn compartment syndromes of the hand do occur, and are best managed by a surgeon with appropriate expertise (e.g., hand plastic surgeon).[69,70]

External fixation is generally the preferred treatment option for combat casualties with major burns and underlying extremity fractures, as these wounds are assumed to be contaminated.[71] Although the presence of nonviable tissue at the pin sites is far from ideal, alternative treatment options are even less attractive. The use of external fixation does not contribute to an increase in compartment pressures and it allows for ease of monitoring of tissue edema and viability during burn resuscitation.[72] Internal fixation may be considered in selected cases, provided there are clear advantages over external fixation and the operation can be performed before the wound becomes heavily colonized (i.e., within the first one to two days post-burn).[72]

> External fixation is generally the preferred treatment option for combat casualties with major burns and underlying extremity fractures, as these wounds are assumed to be contaminated.

Initial Wound Care

When considering the acute management of the burn wound, it is crucial to remember that the skin is intimately linked at a physiologic level to the function of every other organ system. Generally speaking, the larger the burn wound, the greater the adverse effect on each of those systems. The sooner the burn wound is addressed, the sooner the patient can commence recovery. A thorough and continuous assessment of the burn and its healing status are paramount.

The term 'wound care' includes multiple activities often performed in a progressive manner from point of injury through initial hospital resuscitation, wound management, and rehabilitation. From the perspective of the first responder, the primary activities related to wound care involve halting the burning process and protecting the skin from further injury. In some cases, this may mean quite literally extinguishing the fire, or more often, simply removing any residual clothing or equipment that may be retaining heat, thereby furthering the insult to the tissue.

Cleansing and debridement of the burned skin follow as the next logical step in care of the burn wound. This action may include cleaning of the patient's skin with a disinfectant soap and warm water. For patients with burns related to possible chemical exposure, irrigating the skin with copious amounts of water is crucial. Brush off debris before irrigation as the damaging effects of certain chemical agents can be compounded with irrigation.

Initial debridement of patients with large surface area burns is best performed in a clean, warm operating room with anesthesia support, resuscitation capability, adequate lighting, and appropriate dressing materials. In the combat environment, this means formal debridement may have to be delayed until the patient is evacuated to a Level III Combat Support Hospital (CSH). Casualties with partial-thickness burns often demonstrate blisters as the epidermis separates from the dermis and fluid (similar in composition to plasma) fills the void (Fig. 24). In the field, it is recommended that blisters be left intact until such time as formal wound care, in a clean environment, can be performed.[73] A clean, dry bed sheet will usually provide adequate protection of the blistered skin.

Figure 24. *Partial-thickness burns demonstrate fluid-filled blisters that should be left intact until formal wound care is performed. Image courtesy of Robert H. Demling, MD, Harvard Medical School.*

The choice of topical burn dressings and when to apply them is based on several factors: materials on-hand, provider preference, adjacent wounds, and the anticipated time and distance between successive medical facilities. Providers in the field should simply cover burns with a clean, dry dressing and avoid applying any topical ointments, including burn creams, to the wounds.[73] This approach eliminates the need for careproviders to later have to remove creams when patients present at the next facility in the evacuation chain. The use of a silver-impregnated dressing such as Silverlon®, Acticoat®, or SilverSeal® as the initial dressing is a reasonable alternative, since these materials are relatively easy to apply, provide a topical antimicrobial effect, and do not impede the subsequent examination and debridement process.[74]

> Providers in the field should simply cover burns with a clean, dry dressing and avoid applying any topical ointments, including burn creams, to the wounds.

Once the burns have been formally cleansed and debrided, dressing the wound in a silver-impregnated dressing covered by layer of gauze provides a clean, protective milieu that utilizes the silver ion as the antimicrobial agent.[74] This dressing is effective for many hours to several days. This eliminates the need for twice daily reapplication of topical creams such as Silvadene® or Sulfamylon®.[75,76] However, we caution that silver dressings do not take the place of meticulous care when wounds are contaminated or infected. Thus, burn patients with such wounds will continue to require once or twice daily dressing changes, cleansing with chlorhexidene gluconate, and reapplication of topical antimicrobial creams.

Burns sustained in combat often involve adjacent areas of open soft-tissue wounds that result from direct tissue loss, degloving injuries, or surgical debridement. Wounds of this nature are left open for serial debridement and until definitive coverage or closure can be performed.

Patient Exposure and Hypothermia

Just as it is very important to completely expose the burn patient during the initial assessment, it is also crucial to remember that burn casualties are predisposed to hypothermia. Burn patients with large surface

area burns can quickly become hypothermic due to loss of normal skin thermoregulatory function.[77] Hypothermia is even more likely in the burn patient who also has severe trauma and blood loss. Burn patients are prone to hypothermia during multiple phases of care, including operating room wound debridement, routine dressing changes, and transport.

> Burn patients with large surface area burns, especially those with traumatic injuries resulting in blood loss, can quickly become hypothermic due to loss of normal skin thermoregulatory function.

Because of this high risk of hypothermia, the burn casualty in the prehospital setting should be kept warm and dry (e.g., covered with a clean sheet and a warm blanket). Use of hypothermia prevention kits is recommended during all phases of transport. Do not wet the patient and do not apply wet sheets. The operating room should be kept as warm as possible for the casualty. Warmed intravenous fluids should be used during the resuscitation process. Research is ongoing to further evaluate the feasibility of internal warming using specialized venous catheters during the early phases of resuscitation of the military casualty.

Pain Control

The severity of pain reported by burn casualties varies greatly. This variability is due, in part, to the extent that pain receptors are affected, the presence of concurrent injuries, and subjective components related to pain.

> The judicious administration of intravenous narcotics is generally effective in controlling pain for the burn patient. Indiscriminate dosing of narcotics may cause adverse consequences such as hypotension and respiratory depression.

Intermittent dosing of intravenous morphine or fentanyl is effective for controlling background burn injury pain. The addition of IV ketamine (0.25 to 1.0 mg per kilogram) provides very effective analgesia (disassociative sedation at higher doses) during dressing changes and other painful procedures.[78] More recently, the use of oral transmucosal fentanyl citrate (Actiq®, Cephalon Inc., Fraser, PA) has been used for acute pain management in combat.[79] Sedation using a benzodiazepine in small doses decreases anxiety and is an important adjunct to pain control. The routine use of continuous infusions of these drugs in CCC settings is discouraged unless the patient can be closely monitored to ensure optimal pain control, sedation, and immediate detection of adverse effects (e.g., respiratory depression and hypotension).

Advanced Burn Wound Care

Wound Excision

The surgical process of sharply excising burned skin (excision) and replacing it with autologous skin (grafting) is based on sound principles of general surgical wound management. Expediting this process has been shown to decrease mortality and morbidity in US burn centers.[80,81] The process of excision and grafting requires a substantial commitment of resources (personnel, supplies, and hospital support services). Excision and grafting are ideally postponed until the casualty arrives at a Level V care facility such as a burn center that is fully staffed and equipped to complete all phases of care, including rehabilitation.

Figure 25. (Left) *Treatment of host nation patients may require surgeons to provide definitive burn care with excision and grafting.*

Figure 26. (Below) *Placement of a negative-pressure wound dressing on the lower extremities following excision and grafting is one way to achieve postoperative splinting of freshly grafted wounds.*

Early (in-theater) excision and grafting are not recommended for any patient who can be evacuated to a designated burn center within one to two weeks of burn injury. To intentionally excise the burned skin, without a means of covering the exposed tissue bed, invites unnecessary contamination and may ultimately impede definitive wound closure. Similarly, to proceed with skin grafting prior to arrival at the burn center would place the fresh grafts at undue risk for shear force injury and loss during the transport process.

On the other hand, experiences in the current conflicts in Afghanistan and Iraq have provided numerous examples of the need for forward-deployed surgeons to perform excision and grafting of burn patients who cannot be evacuated.[1] This primarily involves host nation patients whose only hope of recovery often rests with the facility at which they initially present (Fig. 25). As a consequence, staff at deployed military hospitals should be prepared to provide definitive burn care.

> Early (in-theater) excision and grafting are not recommended for any patient who can be evacuated to a designated burn center within one to two weeks of burn injury. However, forward-deployed surgeons should be familiar with this procedure for treatment of those who cannot be evacuated or host nationals.

Unlike US military casualties who are usually evacuated to medical treatment facilities within hours of injury, host nation casualties often present several days to weeks after injury. The surgeon must assess such patients with respect to wound contamination, determine whether an infection is present, and decide whether autografting would be prudent. Host nation patients presenting in a delayed fashion with invasive burn wound infections pose special management challenges (see Infection Control). A viable option for treatment of dirty or contaminated burns is to excise the wound to healthy-appearing tissue and to perform scheduled dressing changes using negative-pressure wound therapy (NPWT) until the bed appears optimal for grafting (Fig. 26).[82] Placement of allograft (cadaver skin, with or without NPWT) as a temporary

Figure 27. *The technique of tangential excision can be rapidly accomplished with a large hand dermatome. Note the potential for massive blood loss associated with this operation.*

measure to prime the wound bed is an option, if available.[83] Gammagraft® (Promethean LifeSciences, Inc., Pittsburgh, PA), an irradiated allograft product with a long shelf-life, may be considered when no other source of allograft exists.[1]

Tangential Excision
Dermal burns are excised with multiple tangential passes of a manual dermatome (such as a Blair, Humby, Brown, Braithewaite, Watson, or Goulian-Weck instrument) until viable tissue is reached (Fig. 27). This method of tangential excision allows maximum preservation of viable dermis and subcutaneous fat. This leads to better long-term results in the quality of the healed grafts and improved mobility and range of motion for the patient. Regardless of the instrument used, the key is to remove only that which is deemed nonviable and to preserve that which may heal. Areas requiring intricate or delicate work, such as the hand and fingers, are best approached using small instruments like the Goulian dermatome, with shallow penetration and multiple passes.[84]

Fascial Excision
Subdermal burns extending well into the subcutaneous tissue, and those that are heavily colonized or

Figure 28. *Excision to fascia of deep burns of the lower extremity at a Level III facility. Excision to fascia is indicated for deep third-degree burns and infected burns. A marked step-off will be created by this soft-tissue defect.*

infected, are often best excised primarily to the level of the investing fascia (Fig. 28). Excision to this level can proceed rapidly using a knife, scissors, or electrocautery device. Fascial excision often results in less overall blood loss compared to tangential excision, as excision proceeds in a rapid manner along the fascial planes, removing all eschar with the underlying subcutaneous tissue. This process can result in the removal of a significant amount of tissue, especially in obese patients, with marked step-offs and associated soft-tissue defects.[85]

Engraftment of autograft onto fascia is often better than when grafting onto subcutaneous tissue, thereby speeding wound closure. The undesirable aspects of fascial excision and grafting include: (1) inferior cosmetic appearance, (2) increased edema in distal extremities due to the loss of venous and lymph vessels, and (3) decreased sensation and inferior functional results.[86] Each of these factors must be considered when deciding which technique to use when removing burned tissue.

Areas that have been adequately debrided show brisk punctate bleeding in healthy-appearing dermis. Poor bleeding in grayish-colored dermis indicates inadequate debridement, requiring deeper excision. As

debridement progresses deeper into and through the dermis, more fat appears and capillary bleeding gives way to flow from larger arterioles and veins. The total amount of blood loss from extensive excision may be massive, and the surgical team must endeavor to monitor the wound bed for excessive bleeding and temper the pace of excision to address hemostasis.[85]

> Effective excision of burned skin uncovers the underlying vascular bed. The surgeon must monitor the pace and extent of surgical excision to ensure hemostasis is achieved.

Hemostasis in the debrided wound bed is routinely obtained using pinpoint electrocautery. Repetitive dabbing of the excised wound bed with a dry gauze sponge is an effort in futility. Instead, a bulb syringe can be used to irrigate blood off of the field during electrocautery. Compressive dressings soaked in dilute (1:100,000 or 0.01 mg per milliliter) epinephrine placed on the exposed capillary bed are effective adjunctive methods of achieving hemostasis (Fig. 29).[85] A nonadherent, perforated, polyester-film material such as TELFA™ (Kendall Brands, Covidien Inc., Mansfield, MA) can be used with the epinephrine-soaked gauze to help prevent clot dislodgment from the wound surface when the gauze is removed. Local pressure and the use of temporary elastic bandages can improve hemostasis. Recombinant human thrombin or fibrin sealants can also be used.[87,88]

Figure 29. *Compressive dressings soaked in dilute epinephrine placed on the exposed capillary bed are effective hemostatic adjuncts.*

Whether utilizing tangential or fascial techniques to excise burned skin, blood loss can be significantly reduced with the use of pneumatic tourniquets in conjunction with temporary exanguination of the extremity. Since bleeding from the wound bed cannot be utilized as an indicator of tissue viability when using tourniquets, the operating surgeon must possess experiential knowledge of the desired appearance of the wound bed to avoid unnecessary or inadequate depth of excision. Regardless of which debridement option the surgeon chooses, he or she must be prepared for the blood loss associated with excision of burns. Two to six units of packed red blood cells should be typed and crossed for the patient in anticipation of excisions involving greater than 10% TBSA. Estimation of blood loss is difficult even for experienced burn care teams. It is recommended that less experienced teams limit their excisions to less than 10% TBSA at a time, or two hours in duration.

> Two to six units of packed red blood cells should be typed and crossed for the patient in anticipation of excisions involving greater than 10% TBSA.

Skin Grafting

Coverage of open wounds, following either excision of burns or debridement of injured soft-tissue, can be accomplished using autograft, allograft, or biosynthetic products. Ultimate wound closure involves use of

autologous tissue, either in the form of split- or full-thickness grafts or flaps.

Harvesting of Skin

An autograft in the form of a split-thickness skin graft (STSG) is routinely harvested at a depth of between 0.006 to 0.012 inches using either a manual, or more commonly, a powered dermatome. The advantages of using powered dermatomes are uniformity and speed in the harvesting process. Use of dilute (1:1,000,000) epinephrine in lactated Ringer's solution injected by clysis into the subcutaneous space aids in hemostasis and assists in "leveling" of the operative field prior to harvesting (Fig. 30).[89] The use of a 60-ml syringe coupled to a 18- to 16-gauge needle works satisfactorily for the clysis procedure, and can be performed fairly rapidly even for a large surface area.

Figure 30. *Subdermal clysis aids in hemostasis and "leveling" of the operative field prior to skin harvesting.*

The selection of donor site dressing is largely a matter of operator preference.[85] Xeroform® gauze is commonly available, even in the deployed military environment, and has proven to be effective. Donor sites generally heal in about 10 to 14 days and may be reharvested multiple times once healed.

> Survival of the combat burn casualty is linked to wound closure, and the surgeon must exploit all possible donor sites to facilitate coverage. The scalp is an excellent donor site and should not be overlooked.

A STSG may be placed on the wound bed as either a sheet graft or meshed graft (Figs. 31 and 32). Typically, a properly placed STSG is adherent to the wound bed in three to five days and is durable enough for fairly aggressive cleansing after about seven days. Cleansing of the healing graft is important, especially when debris fills the interstices, impeding wound closure.

Excellent functional outcomes with STSG coverage can be achieved with early and progressive rehabilitation and through close communication between the surgeon, wound care team, and rehabilitation team to determine a safe and effective rehabilitation plan. Rehabilitation efforts involving grafted areas should be minimized during the first three days following graft placement. Mobilization activities such as transfers can be performed during this time if the area of grafting can be safely protected from shear forces. As the STSG matures, rehabilitation activities may be advanced, but every consideration must be given to protection of the healing graft until durable adherence is confirmed, usually around postoperative day seven.

Areas of burn graft in which an optimal functional or cosmetic result is desirable should be covered with thick unmeshed STSGs (Fig. 33).[90] Examples of areas best served by sheet grafting versus meshed skin grafting include the face, neck, and dorsum of the hand. Availability of adequate donor sites affects how much grafting can be accomplished using sheet grafts.[91]

Figure 31. *Harvesting of a split-thickness skin graft at a depth of 10/1,000 inch is facilitated by subdermal clysis with a solution of epinephrine (concentration 1:1,000,000) in lactated Ringer's, injected using a 60-milliliter syringe and an 18-gauge needle. Harvesting is performed by use of an air or electric-powered dermatome. Xeroform gauze is stapled into place, followed by a dry gauze dressing and a compressive wrap such as an Ace® bandage or surgical netting (depending on location).*

Meshed Skin Grafts

Meshing of skin allows for greater graft coverage from available donor sites, improves conformity of the graft, and provides a route of escape for serous fluid beneath the graft. Instrumentation used to reproducibly mesh skin comprises a mechanical device that allows the surgeon to expand the skin in ratios between 1:1 and 6:1. As the expansion ratio increases, the cosmetic quality of the skin decreases, and the healing time increases. A meshing ratio of 3:1 or less is employed for most circumstances due to the friability and prolonged healing associated with wider expansion.[91] There are times, however, when donor sites are so limited as to demand that ratios of 4:1 or higher are used. Using a "sandwich" technique in which widely meshed autograft is covered with sheet allograft serves to protect the underlying tissue bed during prolonged healing.[91]

There are several different types of meshing devices available to the surgeon (Fig. 34). Some devices utilize a flat carrier upon which the skin is placed prior to being passed through the cutting blades. Another version of this device utilizes carriers with fine ridges, which work with the mesher blades to create the desired

Figure 32. *Placement of meshed split-thickness skin graft on the lower extremity following excision to fascia, performed at a Level III facility. Excision and grafting at hospitals in the combat zone are generally not performed, except in cases of host national casualties who do not have other treatment options.*

Figure 33. *Unmeshed split-thickness skin grafts should be used in areas where optimal function or cosmetic result is desirable.*

Figure 34. *Meshing of the skin allows for greater graft coverage, improved conformity of the graft, and drainage of serous fluid.*

pattern. A third type uses no carrier, requiring only that the skin be fed through the cutting rollers in a uniform manner.

> Regardless of the type of mesher utilized, it is imperative that both the surgeon and the operating room technician know how to use the meshing device prior to starting the case to avoid wasting any valuable donor autograft.

Full-Thickness Skin Grafts

The most common alternative to the STSG is a full-thickness skin graft (FTSG). The main advantages of using the FTSG are durability of the healed wound, minimal contracture, and cosmesis.[90] The disadvantages of using a FTSG include loss of valuable donor site and necessity for excellent vascularization for graft survival. The technique of harvesting a FTSG involves sharply incising the skin into the subcutaneous layer, then preparing the FTSG by removing as much of the subcutaneous tissue as possible from the dermis. Donor sites for a FTSG may be closed primarily or covered with a STSG. Most FTSGs heal in 10 to 14 days.[91]

Regardless of the type of graft used, protection of the graft with proper limb splinting and positioning is essential.[85] Mobilization activities such as transfers and ambulation can be performed within the first few days after grafting, provided that the graft site can be safely protected. Excellent functional outcomes with FTSG coverage can be achieved with early and progressive rehabilitation and through close communication between the surgeon, wound care team, and rehabilitation therapists.

Engraftment

Meticulous wound management during the immediate postoperative period is vital to graft viability and patient survival due to the importance of burn wound closure. Movement of the graft or shear is the principal cause of graft failure; infection is the second.[92,93] Securing the graft to the wound bed is important because unintended motion disrupts neovascularization, leading to death of the graft.

> Movement of the graft or shear is the principal cause of graft failure; infection is the second.

To minimize the possibility of movement, grafts are typically secured with staples or sutures. Surgical staples are quickly applied and relatively easy to remove. Advantages of sewing the grafts in place include more precise placement and the ability to use absorbable suture, eliminating the need for later removal. Suturing generally takes considerably longer than stapling. Adhesives such as fibrin glue may be used to supplement adherence, especially in areas with irregular contours.[87] When using biological glue, it is important to ensure that any dressing applied over the graft does not adhere to wound.

Splints incorporated into the final dressing help maintain the desired limb position and help prevent graft loss due to shear, especially over joints. The use of negative-pressure wound dressings has increased in popularity due to their effectiveness in promoting engraftment and protection against shear, provided that negative pressure is maintained. At the first dressing change, the nonadherent dressing can be left in place, provided there are no signs of infection. This layer is removed over the course of the next two to three days as the graft interstices close. Removal of the dressing in contact with the graft is facilitated by soaking the dressing with 5% solution of Sulfamyalon® or saline prior to removal.

Infection Control

Despite many advances in burn care, local infection related to unhealed burn wounds can lead to systemic illness and death.[94] Measures to prevent burn wound infection include meticulous wound care. This includes effective topical antimicrobial therapy, removing all nonviable tissue (tissue debridement), and timely excision and grafting when indicated. Contact precautions, including isolation in private rooms, should be liberally employed in the treatment of burn patients. The use of gloves and gowns when in contact with the burn patient assists in minimizing nosocomial spread of infection. Meticulous and regular use of antimicrobial hand cleanser should be the rule for all providers caring for burn patients.[95]

> Measures to prevent burn wound infection include topical antimicrobial therapy, tissue debridement, and timely excision and grafting when indicated. The use of prophylactic antibiotics in burn patients is not recommended except perioperatively.

Burns should be considered contaminated wounds, and casualties should have their tetanus immunization status updated accordingly. The use of prophylactic antibiotics in burn patients is not recommended except perioperatively (in association with excision and grafting procedures).[96] A rim of mildly erythematous tissue often surrounds healing burns, but extension of the erythema more than two centimeters past the wound margin implies cellulitis, which should be treated with antibiotics aimed at beta-hemolytic streptococcal and staphylococcal infections (Fig. 35).[97] Such gram-positive infections are highly responsive to therapy.[95]

Figure 35. *Streptococcal cellulitis in a burn patient.*

By contrast, when burn patients demonstrate systemic evidence of sepsis, particularly when coupled with color changes in the wound, an invasive gram-negative burn wound infection should be suspected and treated aggressively (Fig. 36). In the absence of effective topical antimicrobial therapy, the risk of gram-negative wound infection is a function of burn size (i.e., patients with larger burns are more likely to present with and die from such infections).[98] These patients require: (1) aggressive resuscitation (early goal-directed therapy treatment for sepsis); (2) topical therapy with mafenide acetate cream (Sulfamylon®); (3) treatment with antibiotics effective against gram-negative organisms (the authors currently use imipenem-cilastatin, and amikacin, to cover multiple-drug-resistant *Pseudomonas* spp. and *Klebsiella pneumoniae*); (4) prompt infection source control by excision to fascia; (5) a scheduled second-look operation; and (6) subsequent grafting.[95] In addition, post-excision topical use of 5% Sulfamylon® solution, or of dilute Dakin's solution (0.025% sodium hypochlorite), may be used to combat gram-negative colonization.[99]

Metabolic and Nutritional Considerations

Burn patients demonstrate extraordinary increases in metabolic rate, as a function of burn size.[100,101] There are several important consequences of this. Patients demonstrate a persistent tachycardia that makes heart

Figure 36. *Host nationals may present with sepsis due to infected burn wounds several days after injury. In this photograph, subeschar bacterial proliferation and suppuration have occurred. After resuscitation, this patient's burns were excised primarily to fascia.*

rate a poor indicator of both effective resuscitation and suspected sepsis. Elevated core temperature is also common. Therefore, the usual definitions of fever need to be adjusted upwards, accepting core temperature values of up to 38.5°C before antipyretics are given.[102,103] The massive caloric requirements engendered by this hypermetabolic state cannot be met by oral alimentation alone. Therefore, patients with burns totaling greater than 30% TBSA require Dobhoff or nasogastric tube feeding. Early enteral nutrition is encouraged, provided the patient is not hemodynamically unstable or requiring pharmacological support with vasopressor agents.[104] Immediate post-burn administration of acid-suppressive medications (proton-pump inhibitors, H_2-blockers, or antacids) is critical for preventing gastroduodenal ulceration (Curling's ulcer).[105,106,107,108]

Aeromedical Transport and Definitive Care

All military burn casualties who require the level of care offered by a burn center are transferred to the USAISR Burn Center at Brooke Army Medical Center in San Antonio, Texas (Fig. 37). The ability to safely transport burn casualties across long distances, while continuing resuscitation, allows rapid transfer of patients to facilities capable of providing definitive care. This capability facilitates the overall process of burn care for combat casualties as it enables early excision and grafting and early rehabilitation therapy. Evacuation policies regarding burn casualties are similar to guidelines published by the American Burn Association (ABA) for burn center admission criteria. Both are based on the severity of burn injury, the presence of inhalation injury, and other associated injuries (Table 2).[109]

Critically injured burn casualties, typically those with large surface area burns and/or inhalation injury, are transported to the burn center by one of the US Army's Burn Flight Teams. Each team consists of a general surgeon, a registered nurse, a licensed vocational nurse, a respiratory therapist, and an operations officer, each of whom work daily in the intensive care units of the burn center.[110] Burn casualties not requiring Burn Flight Team support, but with one or more other critical problems of lesser severity, are transported by a US Air Force Critical Care Air Transport Team (CCATT). The CCATT crews consist of a physician, registered nurse, and respiratory technician, each trained in the management of critically ill patients in flight.[111,112,113]

For patients requiring mechanical ventilation during flight, the choice of ventilator and ventilator mode during transport is based on the patient's severity of injury, pulmonary status, and response to ventilatory support. Patients with inhalation injury may require significant ventilatory support beyond the capabilities of conventional ventilators

Figure 37. *Staff at the USAISR Burn Center take a call from a referring hospital. Early and frequent communication between the referring medical treatment facility and the burn center are absolutely essential to successful transfer of a patient with severe thermal injury.*

BURN CENTER REFERRAL CRITERIA
A burn center may treat adults, children, or both.   **Burn injuries that should be referred to a burn center include the following:**   1. Partial-thickness burns of greater than 10% of the total body surface area   2. Burns that involve the face, hands, feet, genitalia, perineum, or major joints   3. Third-degree burns in any age group   4. Electrical burns, including lightning injury   5. Chemical burns   6. Inhalation injury   7. Burn injury in patients with preexisting medical disorders that could complicate management, prolong recovery, or affect mortality   8. Any patients with burns and concomitant trauma (such as fractures) in which the burn injury poses the greatest risk of morbidity or mortality. In complex cases, if the trauma poses the greater immediate risk, the patient's condition may be stabilized initially in a trauma center before transfer to a burn center. Physician judgment will be necessary in such situations and should be in concert with the regional medical control plan and triage protocols.   9. Burned children in hospitals without qualified personnel or equipment for the care of children   10. Burn injury in patients who will require special social, emotional, or rehabilitative intervention

Table 2. *Evacuation policies surrounding burn casualties mirror ABA burn center admission criteria.*[109]

used for evacuation. Extensive use of the Volumetric Diffusive Respiration ventilator (VDR-4®) by the USAISR Burn Center to treat patients with inhalation injury and other severe pulmonary problems led to extensive use of the VDR-4® in patient transport.[20] The TXP® pressure-controlled ventilator is also used in the evacuation of patients because of its simplicity, compact size, and effectiveness in this patient population.[114] Both the VDR® and TXP® are powered by compressed air or oxygen, have no electrical requirements, and are approved for use on all military aircraft.

As with the interfacility transfer of any critically ill or injured patient, communication between the sending and accepting physician is essential for optimal continuity of care. Staff at the USAISR Burn Center is available 24 hours per day, seven days per week, to respond to questions and to facilitate evacuation of seriously injured burn casualties.

Providers are encouraged to call (210) 916-2876 to contact the burn center attending surgeon, or DSN (312) 429-2876 if commercial access is not available. Consultation may also be initiated by sending an email message to US Army Medical Department burn consultants (burntrauma.consult@us.army.mil).

Summary

Critical elements of caring for burn patients in a combat environment are: (1) careful titration of fluid resuscitation (neither too much, nor too little) during a burn shock period that lasts at least 48 hours; (2) awareness of the risks of over-resuscitation and prompt recognition and management of such complications (e.g., abdominal and extremity compartment syndromes); (3) strategically-timed aeromedical evacuation,

which balances the need for close monitoring and hemodynamic stability during the burn shock period against the need for early excision of large burns in a dedicated burn center; and (4) recognition of the scope and burden of civilian burn care during combat (e.g., definitive surgical care that includes excision and grafting of burned children and adults).

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