Burns: Military Options and Tactical Solutions

Steven J. Thomas, MD, George C. Kramer, PhD, and David N. Herndon, MD

Burn injury remains a constant source of morbidity and mortality in the military environment. The logistic constraints of combat casualty care can make it impossible to provide the large volumes of crystalloid typically used for burn resuscitation. Unlike penetrating trauma, the immediate and sustained fluid requirements necessary for resuscitation of thermal injury preclude the use of limited or hypotensive resuscitation. We examine the physiology, traditional resuscitation strategies, and rationales for the use of novel regimens in the resuscitation of thermal injury. Although strategies such as early use of colloids or hypertonic saline may not reduce morbidity or mortality when compared with large-volume infusions of lactated Ringer’s, they can be volume sparing for some hours and sustain life until more definitive therapy is initiated. An intriguing hypothesis is that oral resuscitation can effectively restore plasma volume after thermal injury. We present data from recent experiments of gastric and intestinal infusions of an oral rehydration solution in a porcine burn model that demonstrates restoration of plasma volumes and improvement in hemodynamic parameters associated with significant gastric emptying and intestinal absorption.

Key Words: Burn, Resuscitation, Pathophysiology, Treatments, Oral rehydration, Military trauma, Hypertonic saline.


It was soldiers saving soldiers. Soldiers putting out fires. Soldiers putting out fires on other soldiers; soldiers dragging soldiers out of fires; resuscitating; giving soldiers CPR; putting tourniquets on limbs that have been severed; putting out fires on their bodies, sometimes with their own hands. Anything they could do to care for their buddies that were most seriously injured, they were doing. They can’t do that without knowing how. They respond in a way that they would in combat.

Any military operation is fraught with the possibility of disaster. The opening paragraph described the actions of the medics and soldiers on March 23, 1994, at Pope Air Force Base. Two aircraft collided, creating a massive fireball that brought death and injury to more than 100 paratroopers. Nine were killed instantly and two more died en route to the hospital. Fifty-one casualties were treated and released, 25 were sent to intensive care units, 30 were sent to inpatient wards, and 13 were transferred to additional hospitals. Twenty-four soldiers died. The outcome of this incident could have been significantly worse had it not occurred on a military base, during daylight, with immediate medical support available and the availability of rapid evacuation to nearby hospitals.

One of the challenges in the new combat milieu will be the management of burn victims. Burns are a consistent cause of military mortality and morbidity. The overall mortality has remained approximately 4% of the total deaths from World War I to Desert Storm. The percentage of burn injury of all casualties ranges from 10% to 30%, depending on the type or nature of the conflict. The use of tanks, armored vehicles, aircraft, and battleships can increase the proportion of thermal injuries. Seventy percent of the tank casualties in the Yom Kippur War were burn, as were 34% of all naval casualties during the Falklands War. In Vietnam during the period 1965 to 1973, there were 13,047 burn injuries. Between March 1966 and July 1967, there were 445 patients with burns admitted to U.S. Army Hospitals in Vietnam. Most of those burn patients required no fluid at all. Those requiring fluid received approximately 4.5 L of blood and 5.8 L of intravenous (IV) fluids. Thirty-five percent of the burn patients returned to duty in Vietnam, 64% were evacuated, and 1% died. Half the burns were accidental (54%) and the rest (46%) were combat related. This example suggests that a large percentage of military burn injuries are accidental and not directly attributable to the combat environment.

Modern warfare is often fought in an urban environment with its own attendant risks, which are significantly different from those found on the conventional open battlefield. The increased lethality of the munitions used today deployed in a built-up environment can lead to high rates of blast injuries and burn injuries associated with fire. This can significantly increase the actual number of soldiers injured and inflict a large amount of collateral damage to a civilian population. In addition, these urban battles are often prolonged, as recently seen in Jenna, Palestine, where a running battle continued for over 4 days, preventing evacuation and making treatment of burn casualties a formidable task. Because of the nature of the military environment, their exists the possibility that a sud-
den, overwhelming, disastrous mass casualty situation can occur. Below are two illustrative examples.

**JULY 1967, THE USS FORRESTAL OFF THE COAST OF VIETNAM**

An A-4 Phantom fighter preparing for take-off accidentally launched a rocket into a fully armed and fueled A-4 Skyhawk. The heat detonated a 1,000-lb bomb, blowing a hole in the deck and igniting stored fuel. One hundred thirty-four crewman died in the ensuing firestorm. It is interesting to note that the 134 causalities from this one incident were almost three times the total number of sea-related combat deaths (n = 58) and 8% of the total Navy deaths during the Vietnam conflict (134 of 1,626).

**APRIL 25, 1980, OPERATION “EAGLE-CLAW,” IRANIAN DESERT**

An RH-53 helicopter pilot, disoriented by dust, collided with a C-130. The site of impact was the C-130’s refueling compartment, creating a wall of flames, which immediately incinerated five of the C-130 flight crew. The radio operator on the lower deck was instantly engulfed by flames but was dragged from the aircraft by a Delta Force soldier. The situation worsened as hundreds of rounds of ammunition and antitank rockets began exploding. The two Marine helicopter pilots, although severely burned, managed to extricate themselves. The remaining casualties were evacuated by C-130 with a 3-hour flight time and Delta Force medics caring for them en route. Four severely burned soldiers were resuscitated and transported to stateside burn units.

There is often limited availability of fluids for the initial treatment of combat casualties, and casualty evacuation can be delayed hours and as much as days. Consequently, much discussion has centered on the role of limited or hypotensive resuscitation. It has been suggested that in many cases, limited resuscitation may be more effective than large-volume IV infusions. Hypotensive resuscitation may in fact be an acceptable treatment for penetrating torso injuries. However, its role is in no way suggested in the management of burn trauma. The massive fluid shifts and profound hypovolemia underscore the absolute requirement for fluid replacement. If left untreated, a full-thickness burn > 25% total body surface area (TBSA) will inevitably lead to burn shock.

“Burn injury is the greatest dysregulator of homeostasis of any injury and is not easily treated.” Hemorrhagic hypovolemia can often be effectively treated with limited resuscitation combined with the body’s own potent compensatory mechanisms. In contrast, burn shock is a complex interplay of microvascular dysfunction, inflammatory mediator release, and circulating depolarizing factors that result in massive fluid shifts from the vascular space into the interstitial and cellular space. Initially, the patient becomes hypovolemic with decreased plasma volume, decreased cardiac output, increased peripheral resistance, decreased urine output, and hemoconcentration. This is complicated by the development of edema both at the burn site and in nonburned tissue. The amount of edema is related to the volume and type of resuscitative fluids given. The edema is generated by diffuse increases in microvascular permeability and alterations in all the Starling forces.

**MORTALITY**

Major burn mortalities have decreased remarkably over the last 50 years (Table 1). Between 1942 and 1952, half of the children between the ages of 1 and 14 years with 50% TBSA burns were killed. Today, nearly half of the children with a 98% TBSA burn will survive if treated in a specialized burn treatment unit, whereas a 70% TBSA burn will kill 50% of the patients between the ages of 15 to 44, and a 50% TBSA burn will kill 50% of patients aged 50 to 64 years. However, even the mortality for the elderly has been markedly decreased by modern resuscitative regimens.

One of the primary reasons for this mortality decrease in major thermal burn is our increased understanding of how to resuscitate burn patients. Critical to this improvement is the early resuscitation of the patients. Other areas of improvement have been in the control of infection, support of the hypermetabolic responses to trauma, and early closure of the burn wound.

A recent article by Wolf et al. analyzed the mortality determinants in massive pediatric burns (> 80% TBSA) in 103 children. The major determinants of mortality in these patients were total body area surface burned, age, inhalation injury, time to resuscitation, and the amount of initial resuscitation fluids (Table 2). The amount and timing of fluid

| Table 1 Burn Mortality: The Percent TBSA that Produces LD₅₀ for Different Age Groups |
|---------------------------------|-----------|-----------|-----------|-----------|
| Age Groups (yr)                 | 0-14      | 15-44     | 45-64     | >65       |
| Bull and Fisher (1942-52)       | 49        | 46        | 24        | 10        |
| Bull (1967-70)                  | 64        | 56        | 40        | 17        |
| Curreri and Abston (1975-79)    | 77        | 63        | 38        | 23        |
| SBI/UTMB (1980-99)             | 98        | 70        | 46        | 19        |
| 2,164 patients                 | 1,524     | 450       | 127       | 63        |

<table>
<thead>
<tr>
<th>Table 2 En Route Variables</th>
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</thead>
<tbody>
<tr>
<td>Survivors (n = 69)</td>
</tr>
<tr>
<td>Nonsurvivors (n = 34)</td>
</tr>
<tr>
<td>Univariate p Value</td>
</tr>
<tr>
<td>Multivariate p Value</td>
</tr>
<tr>
<td>Time to IV Start (h)</td>
</tr>
<tr>
<td>Fluid in first 24 h (mL/m²burn/h)</td>
</tr>
<tr>
<td>Transport time (% &lt; 48 h)</td>
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</tbody>
</table>
Resuscitation are major contributors to mortality in massive burn. Wolf et al. found that the most significant contributor to mortality among the resuscitation requirements was not the type or volume of fluid given within the first 24 hours, but how soon after injury the fluid was started (Fig. 1). Early and prompt resuscitation of the patient can drastically reduce the mortality of a massively burned patient. This should certainly be the main concern of the military on the new urban battlefield, where delays in evacuation times of 2 to 9 hours are anticipated. During the “Black Hawk Down” firefight in Mogadishu, Somalia, the tactical situation resulted in a 14-hour evacuation time. Without prompt and adequate resuscitation, a burn victim in this scenario would convert from an otherwise survivable injury with limited morbidity into a virtually guaranteed fatality.

The concept of limited or hypotensive resuscitation may have its place in the resuscitation of patients with penetrating trauma and perhaps even to some extent in blunt traumatic injury. However, our knowledge of burn shock and the data of Wolf et al. suggest that limited resuscitation has no place in the treatment of burns. It should be one of the highest priorities for the military to develop the logistic and treatment modalities to provide prompt and adequate resuscitation for the burn victim in all tactical environments.

**COMBAT MANAGEMENT OF THE THERMALLY INJURED PATIENT**

The key aspect of burn patient management is early and adequate resuscitation of the patient. The patient will rapidly become hypovolemic and fluid should be administered, ideally within the first minutes after the initial burn injury. The Parkland formula (4 mL/kg of lactated Ringer’s per percent TBSA burn injury) is the most widely used formula today for estimating the 24-hour fluid requirements for adults (Table 3). Current recommendations of the Advanced Burn Life Support advocate giving half of the fluids in the first 8 hours and the other half in the subsequent 16 hours after the burn. The greatest quantity of salt is given in the first 24 hours postburn; in the second 24 hours, more hypotonic solutions are often administered to replace the evaporative water loss. In practice, the Parkland formula is just an estimate of need, as the actual infusion rates are often greater and are adjusted to maintain an adequate urine output of 0.5 to 1 mL/kg/h. This presents a logistic nightmare for combat medics. If three

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**Table 3 Fluid Volume Estimates in the First 24 H for a 70-kg Man with a 40% Burn**

<table>
<thead>
<tr>
<th></th>
<th>Evans Formula</th>
<th>Brooke Formula</th>
<th>Parkland Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(24-h total = 7,000 mL, 48-h total = 12,400 mL, urine = 30–50 mL/h)</td>
<td>(24-h total = 7,000 mL, 48-h total = 12,400 mL, urine = 30–50 mL/h)</td>
<td>(24-h total = 11,200 mL, 48-h total = 14,000 mL, urine = 30–50 mL/h)</td>
</tr>
<tr>
<td>Colloid</td>
<td>1.0 mL/kg/% (2,800 mL)</td>
<td>0.5 mL/kg/% (1,400 mL)</td>
<td>None</td>
</tr>
<tr>
<td>Crystalloid</td>
<td>1.0 mL/kg/% (2,800 mL)</td>
<td>1.5 mL/kg/% (4,200 mL)</td>
<td>4.0 mL/kg/% (11,200 mL)</td>
</tr>
<tr>
<td>Free water</td>
<td>2,000 mL</td>
<td>2,000 mL</td>
<td>None</td>
</tr>
</tbody>
</table>

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soldiers suffer a 50% TBSA injury and evacuation is delayed for 8 hours, a total of 24 L (53 lb) of fluid is prescribed; a volume more than that is carried by a typical platoon of soldiers.

We advocate the use of more efficient volume expanders that can reduce the early requirement of fluids, if those fluids are shown to provide no deleterious effect on outcome. The generally accepted formulations to be considered are early use of colloids or hyperosmotic saline or their combination.

**Fluids that Reduce Volume Requirements**

The choice of fluids in burn resuscitation remains controversial. Colloids are not widely used as initial resuscitative fluids for burns. Because burn induces a diffuse increase in vascular permeability, it is argued that initial colloid replacement would not remain within the intervascular space and would further exacerbate fluid shifts and edema. One clinical study showed that although fluid requirements were decreased with colloid solutions, there were subsequent increases in lung water. This suggests that the use of colloids in the first 24 hours postinjury can lead to the later development of pulmonary edema. In contrast, many centers in Europe report excellent clinical results with the routine use of early colloid solutions as initial treatment. Early volume sparing has been reported with albumin, hetastarch, and dextran.

Even if colloid administration has no beneficial effect on outcome—if it simply lowers early volume needs—its use could be lifesaving for combat casualty care because corpsmen and soldiers can carry only limited resuscitative fluids. Although colloids for the initial management of burns may reduce early volume needs, further research is needed to establish the best infusion regimens for early colloid use in burns and their subsequent responses and outcomes.

Hyperosmotic saline can rapidly restore plasma volume with smaller infused volumes and has been used by many centers for burn resuscitation. A meta-analysis of 10 clinical trials of 450 to 800 mOsm hypertonic saline solution was performed by Milner, who showed a 36% reduction in the first-24-hour fluid needs compared with the isotonic-treated patients. A small-volume formulation of 7.5% hypertonic saline/6% dextran 70 (HSD) is approved for clinical use in European countries for the initial treatment of trauma. Figure 2 shows plasma volume expansion of a small 4-mL/kg volume of HSD versus a large 25-mL/kg volume of lactated Ringer’s (LR) solution in 40% TBSA burn-injured sheep. The relative volume expansion after HSD infusion is 10 times that of LR. HSD has been shown by Elgjo et al. to rapidly improve hemodynamics and to have early volume-sparing (8–10 hours) effects in the resuscitation of burn injury. In sheep models of 40% TBSA burn, Elgjo et al. showed that volume requirements were reduced by 80% after an initial 30-minute infusion of 4 mL/kg HSD followed by lactated Ringer’s infused to maintain normal urine outputs. A rebound of fluid needs occurred at 8 to 10 hours postburn, suggesting no long-term volume sparing, as the total fluid requirements over a 48-hour period were the same when LR only was used.

Rapid infusion of HSD was initially recommended for the treatment of trauma and hemorrhagic hypovolemia, but more recent data suggest slower infusions are equally or more advantageous. With rapid 2-minute infusions of HSD, an initial hyperosmolarity and hypernatremia can be severe and can lead to cardiac arrhythmias and unnecessarily fast volume expansion after burn injury. In particular, burn resuscitation is a slow 24- to 48-hour process compared with the acute resuscitation of hemorrhagic blood loss. In studies of burn resuscitation using higher doses (8–10 mL/kg) and slower infusion rates (2–4 hours), prolonged volume expansion and reduced edema have been reported. Also, these infusion regimens can reduce or prevent the rebound of the fluid requirements seen with more rapid infusions.

Although a 4-mL/kg bolus infusion may be beneficial for hemorrhagic shock, a slower infusion rate at a higher dose may be the most efficacious infusion regimen for burn resuscitation. Short-term resuscitation needs could certainly be met with a small volume of hypertonic-hyperoncotic solution. In an evacuation center or staging area where large volumes are not available for hours, a slow administration of HSD may have distinct physiologic and logistic advantages.

Hypertonic resuscitation has been shown to be safe in hemorrhage and trauma with preexisting dehydration; however, there is a limit to the dose that can be safely administered. Huang et al. infused exceedingly high doses of various hypertonic saline solutions into burn-injured patients over 24 to 48 hours and found significantly increased renal failure and a higher mortality rate compared with isotonic fluids.
regimens. Although this study contrasts all previous studies of hypertonic resuscitation of burns, it suggests that very large doses or sustained infusion can be deleterious.

**Combined Injuries**

Combined injuries such as hemorrhage and burn injury occur in combat. We have few data on how best to treat these patients, but fluid needs will be increased, and standard endpoints such as urine output and blood pressure are likely to adequately guide therapy. A commonly encountered combined injury is burn and inhalation injury. In the military environment, a large percentage of injuries occur within closed spaces (e.g., buildings, tanks, or planes), which results in an increased frequency of concomitant inhalation injuries. Smoke inhalation injuries have been shown to require additional fluid, 2 mL/kg/4% TBSA burn, to maintain a urine output of 0.5 to 1.5 mL/kg/h. Underresuscitation of the burn patient exacerbates late pulmonary edema and increases the pulmonary failure rate. Initially after smoke injury, there is an increase in extravascular lung water, clinically manifested by a decrease in oxygenation occurring approximately 20 hours postinjury. During this period of time, the patient must be adequately resuscitated or the subsequent pulmonary edema will significantly worsen.

**ORAL FLUID REPLACEMENT IN THE BURN PATIENT**

One of the major problems when addressing the medical response to the combatant is the availability and portability of sterile replacement fluids. A packaged liter of LR solution weighs 2.3 lb and has a volume of 1,200 cm³. To resuscitate a 70-kg adult with a 40% TBSA burn would require approximately 6 L of IV fluid in the first 8 hours. Put another way, this would be approximately 14 lb of resuscitative fluids and 7,200 cm³ of space that an individual medic would have to carry, just for one patient. One strategy to reduce the amount of IV fluids would be the partial or complete use of fluid replacement with oral hydration.

The World Health Organization (WHO) has used oral rehydration solution (ORS) with tremendous success as a first-line therapy for severe diarrhea and cholera in children. These children have massive fluid losses and are volume contracted. When ORS packets are mixed with potable water, the resultant sodium/glucose/bicarbonate solution is readily absorbed by the intestine and restores normal hydration. Although the mechanism and composition of the fluid loss from secretory diarrhea are different from burn, both types of patients are significantly hypovolemic and can die without the administration of fluid. In theory, the large amounts of fluid replacement needed in thermal injury can be replaced in this manner. Fluids could be taken orally or administered by nasogastric tube (NGT), the placement of which could easily be performed by a medic with minimal skill levels.
important, and this includes the volume of the fluid ingested plus the volume of the gastric secretions. By giving repeated boluses of solution into the stomach, it should be possible to maintain a constant or nearly constant rate of gastric emptying.

**Composition of Oral Hydration Solutions**

The composition of the optimal oral replacement fluid has not been determined and will likely vary for different indications. The World Health Organization has had great success with their slightly hypertonic ORS solution containing glucose, sodium, chloride, and bicarbonate. It is easily formulated by adding WHO ORS powder packets to water (Table 4). Monafo used a 600-mOsm hypertonic lactated saline solution (HLSS) containing sodium, racemic DL-lactate, and chloride to orally resuscitate 10 burn injury patients. Powerade, Gatorade, and other related sports drinks are low in sodium (5–21 mmol/L) because they are designed to replace perspiration losses and to be palatable. It seems logical that a solution similar to LR or HLSS with the addition of glucose with an osmolarity range of 260 to 330 mOsm/L, given by drinking or infusion through an NGT tube, could rapidly be absorbed and provide the large volume and sodium necessary for burn resuscitation.

**Oral Resuscitation after Burn Injury**

Before the 1930s, a 200-mOsm solution of sodium chloride was used orally in conjunction with IV fluid in the management of burn shock. Moyer et al. administered a 200-mOsm solution enterally or intravenously to burned dogs. We have found only four references to oral resuscitation after burn injury, all of which suggest effectiveness (Table 5). Monafo, in a limited study of 10 patients, reported on resuscitation after major burn injuries using 600-mOsm HLSS in which patients were both orally and intravenously resuscitated. Monafo reported “it was discovered that HLSS solution (iced to be made palatable) was easily tolerated orally in significant amounts without apparent GI dysfunction.” He used HLSS to partially resuscitate four burn adults with 30% to 95% TBSA burns and three children with 22% to 58% TBSA burns. These severely injured patients had mostly full-thickness injuries. Patients received 10% to 60% of their fluid loading in the first 24 hours from oral fluids; a larger 60% to 90% of fluid loading in the second 24 hours was from oral delivery. One wonders how much ice and volume and dilution occurred in Monafo’s patients. This report shows that at least partial oral resuscitation of severe burns can be successful and that it can be accomplished with a hypertonic solution without glucose. It was not clear whether the solution was administered initially or after IV resuscitation was ongoing. Furthermore, from the data presented, it is not possible to compare the relative effectiveness of oral delivery versus intravenous infusion. To our knowledge, this study of oral resuscitation of large full-thickness burns with HLSS has never been followed up either clinically or experimentally.

El-Sonbaty recently reported good results with oral resuscitation of 20 children with 10% to 20% TBSA burns, using the WHO ORS. The depth of the burns was not presented, but we can assume that most of the patients did not present in burn shock, as the children’s mothers, under the supervision of a nurse, administered the oral hydration. The volume and rate of oral hydration with WHO ORS in this study was identical to the standard Parkland formula. El-Sonbaty reported that oral hydration was as effective as IV LR Ringer’s, also administered at the Parkland rate in 20 control patients. Again, there is no way to accurately compare relative vascular expansion or effectiveness of the two groups. Burn injuries of 10% to 20% TBSA do not necessarily induce hypovolemic shock. Patients in both groups devel-

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**Table 4** Selected Oral Hydration Solutions Compared to Intravenous Lactated Ringer’s

<table>
<thead>
<tr>
<th>Beverage</th>
<th>Carbohydrate (mmol/L)</th>
<th>Sodium (mmol/L)</th>
<th>Chloride (mmol/L)</th>
<th>Potassium (mmol/L)</th>
<th>Buffer (mmol/L)</th>
<th>Osmolality (mmol/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WHO ORS</td>
<td>111 (2.0)</td>
<td>90</td>
<td>80</td>
<td>20</td>
<td>30</td>
<td>331</td>
</tr>
<tr>
<td>Gatorade (Quaker Oats Co.)</td>
<td>250–333 (4.5–6)</td>
<td>20</td>
<td>20</td>
<td>3</td>
<td>3</td>
<td>280–380</td>
</tr>
<tr>
<td>Monafo HLSS (used PO and IV)</td>
<td>0</td>
<td>300</td>
<td>200</td>
<td>0</td>
<td>100</td>
<td>600</td>
</tr>
<tr>
<td>Jiang Burn Drink</td>
<td>252 (5.0)</td>
<td>48</td>
<td>28</td>
<td>0</td>
<td>20</td>
<td>347</td>
</tr>
<tr>
<td>Lactated Ringer’s</td>
<td>0</td>
<td>130</td>
<td>109</td>
<td>4</td>
<td>28</td>
<td>270</td>
</tr>
</tbody>
</table>

PO, orally.

**Table 5** Oral Resuscitation of Burns

<table>
<thead>
<tr>
<th>Study</th>
<th>Subjects</th>
<th>TBSA (%)</th>
<th>Solution</th>
<th>mOsm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monafo⁴²</td>
<td>Adults and children (n = 9)</td>
<td>10–90</td>
<td>Hypertonic lactated saline</td>
<td>600</td>
</tr>
<tr>
<td>El-Sonbaty⁴³</td>
<td>Children (n = 10)</td>
<td>10–20</td>
<td>WHO ORS</td>
<td>331</td>
</tr>
<tr>
<td>Jiang⁴⁴</td>
<td>Anesthetized dogs (n = 7)</td>
<td>30</td>
<td>Glucose/NaCl/HCO₃ Burn Drink</td>
<td>347</td>
</tr>
<tr>
<td>Thomas (unpublished)</td>
<td>Anesthetized pigs (n = 5)</td>
<td>40</td>
<td>WHO ORS</td>
<td>331</td>
</tr>
</tbody>
</table>
oped hyponatremia (125–130 mEq/L) on day 5 postinjury, but otherwise had unremarkable outcomes. A comparison of oral hydration solutions versus IV solutions, shown in Table 4, suggests that hyponatremia may be a problem with most oral formulations and that oral resuscitation of burned patients may require a higher sodium concentration solution, such as that used by Monafo.

Jiang reported the only preclinical controlled study of oral resuscitation that we have found. Anesthetized dogs were inflicted with a 30% partial-thickness burn and then treated with a 347-mOsm “burn drink” of glucose NaCl and NaHCO₃ (Table 4). Total volume administered over 24 hours was the Parkland formula, 4 mL/kg/% TBSA burn. Controls were untreated burn and burns treated with a 1:10 dilution of the burn drink (35 mOsm). Controls were untreated burn and burns treated with a 1:10 dilution of the burn drink (35 mOsm). Impressive improvements in plasma volume, cardiac output, and urine output were shown for oral resuscitation, but only for the more concentrated 347-mOsm burn-drink group.

On the basis of these encouraging data, we have performed experiments in isoflurane-anesthetized pigs subjected to a full-thickness 40% TBSA burn injury and resuscitated with gastric or intestinal infusion of WHO ORS. Pigs have a GI system similar to humans. These studies in severe burns treated by GI resuscitation demonstrated that there could be significant gastric emptying, intestinal absorption, plasma volume expansion, diuresis, and hemodynamic improvements.

Intestinal absorption was measured with phenol red (32 mg/L) continuously infused and mixed with the WHO ORS into the proximal duodenum at the Parkland rate of 350 mL/h after a 40% TBSA burn injury in a 35-kg anesthetized pig. A triple-lumen intestinal feeding catheter was placed in the intestine though a small surgical opening in the stomach. Sampling from two distal intestinal sites, 5 and 25 cm distal to the infusion site, allowed the measurement of downstream concentration of phenol red and the calculation of fluid absorption. Figure 4 shows calculated intestinal absorption before and for 3 hours after burn injury. The average postburn absorption rate calculated per meter length of intestine was 83.3 mL/h, suggesting that it would take 4 m of intestinal length to fully absorb a volume equal to the Parkland rate. The duodenojejunile intestine in a 30- to 35-kg pig is approximately 5 to 6 m long. We measured plasma volume expansion and hemodynamic improvement after intestinal infusion. Baseline cardiac output of 5.1 L/min fell to 3.8 L/min at 60 minutes postinjury, but increased to 5.8 L/min after 2.5 hours. Base excess/deficit and lactate both show improvement with resuscitation (Fig. 5). Plasma volume (indocyanine green dilution) was decreased by burn injury and then increased after intestinal infusion by 6.3 mL/kg, a value equal to 18% of the intestinal dose of WHO ORS. Our previous studies of intravenous resuscitation of burn injury showed that only 10% to 15% of intravenous lactated Ringer’s solution typically remains in the circulation after burn injury; thus, enteral resuscitation may provide a level of volume expansion similar to that of IV infusion.

**Gastric Infusions**

We measured gastric emptying during gastric infusion of WHO ORS and vascular volume and hemodynamics in two studies. In the first study, we infused WHO ORS at a fixed rate of 10 mL/h (Parkland rate for 40% TBSA burn injury) for 90 minutes before and for 150 minutes starting at 30 minutes postinjury (Fig. 6). Gastric volume was measured every 30 minutes with additional small doses of concentrated phenol red using the method of George and Hunt. Figure 6 shows cumulative infused volume and cumulative gastric emptying. Gastric emptying is apparent both before and after burn, but at a rate approximately half that of the infused Parkland rate. Hemodynamics improved, but not to a level consistent with good resuscitation.

Figure 7 shows data from an experiment with a gastric infusion rate increased to twice that of the Parkland rate. Cardiac output decreased after burn injury and increased after resuscitation. Blood hemoglobin shows hemoconcentration after burn injury and hemodilution during resuscitation, whereas urine output increased to Parkland target levels of 0.5 mL/kg/h or better after 2 to 3 hours of resuscitation. Both the tracer measurement of gastric emptying and the fluid content measurements of the stomach and intestine produced similar results; they showed that half of the gastric infusion left the stomach and nearly all of this volume was absorbed. Thus, a Parkland volume was administered to the circulation when WHO ORS was infused into the stomach at two times the Parkland rate. We have not performed studies with IV resuscitation in this model, but our experience with similar sheep models suggests that oral resuscitation may have a slower initial onset of hemodynamic effectiveness but that, after 3 to 4 hours, it can be similarly effective.
Burn Care in the Tactical Combat Situation

Butler et al. established stages of care for use in the special operations forces, which serves as an excellent framework for examining the tactical management of battlefield casualties. The stages of care described are as follows: (1) care under fire (the care rendered by the medic or buddy aid at the scene while the casualty is still under effective hostile fire); (2) tactical field care (care rendered by the medic or corpsman when the casualty is no longer under effective hostile fire; and (3) combat care evacuation (care occurring once the casualty has been picked up by an aircraft/vehicle/boat). The medical management of the casualty under these situations takes into consideration such factors as "enemy fire, medical equipment limitations, widely variable evacuation time, tactical considerations, and the unique problems entailed in transporting casualties that occur in special operations." Advanced Trauma Life Support was not designed for use in the combat environment. It was designed for hospital use under optimal conditions. The question that can be asked is, "Given these set of constraints, how should the medic manage the burned soldier?"

Stage 1: Care Under Fire

The first priority is to stop the burning process. In most cases, cold water will stop the burning process and reduce heat damage. However, with extensive burns, water cooling may cause hypothermia and should be avoided with large burns when its use will lower body temperature. Assuming that the soldier is conscious, the use of an oral rehydration fluid could be self-administered or given by combat lifesaver or buddy aid. The resuscitative process would begin even while under hostile fire. Mixed in a canteen, the ORS could be given almost immediately. In the unconscious patient, the thrust of care at this point would be to retrieve and return the

![Base Excess and Lactate](image)

![Infused WHO ORS and Gastric Emptying](image)
patient to a safe area as soon as the tactical situation allows. As in all tactical scenarios, the person rendering aid should continue to return fire, prevent further injury to the causality or injury to him- or herself, and attempt to bring the causality to a place of safety as soon as the tactical situation allows.

**Stage 2: Tactical Field Care**

If IV access is obtained and adequate lactated Ringer’s is available, standard Parkland resuscitation can be started. If not, hypertonic resuscitation and/or oral fluids should be considered. If we look at a 70-kg soldier with a 40% TBSA burn injury, using the Parkland formula as a guide, we find that the soldier will require 11,200 mL of fluid over the first 24 hours, the first half of that to be given over the first 8 hours.

In tactical situations where intravenous lines can be started, a 250-mL hypertonic saline could be administered over 2 to 4 hours to maintain initial plasma volume expansion. This could in essence “prime the system,” allowing time for oral absorption to occur, taking advantage of the delay from time of ingestion to effective intestinal absorption. The early saline infusion may prevent the decrement in intestinal absorption and motility resulting from splanchnic ischemia. Gastric emptying is optimal at gastric volumes between 600 and 800 mL. By continuing to give these fluids as a bolus at a rate of 4 mL/kg every 20 minutes, one can actually maintain a high rate of gastric emptying and satisfy fluid replacement requirements. The use of prepackaged solution packets, similar to those of the WHO ORS, would be simple and easy to use. Each soldier could actually carry some packets in his or her cargo pockets to be used for self-care or buddy aid.

We cannot overstate the fact that the primary determinant of mortality in thermal injury is the rapid and adequate replacement of fluids. The actual type of fluid administered is less likely to be a factor than how promptly fluid therapy is begun. As seen in the study by Wolf et al.15 of 103 children with >80% TBSA burn injuries, 69 children survived. Of the survivors, each had an intravenous line started in 0.6 ± 0.2 hours. In the 39 nonsurvivors, it took 2.2 ± 5 hours to get an intravenous line started (Fig. 1).17 The longer it takes to establish vascular access and administer fluids, the more likely it is that burn victims will die. In patients sustaining massive burn injuries that have a greater than 4-hour delay before fluid administration, the chances of surviving become practically zero.

Resuscitation should begin during tactical field care if at all possible. The longer the delay, the larger the patient’s initial volume deficits. After the initial ABCs, fluid must be administered either orally, by NGT, IV, or by a combination thereof. Some special operations teams “precannulate” before combat deployment, and have had excellent results. This is best suited for short-term, direct-action missions. This cannot be routinely recommended but, depending on the unit and/or mission, it is a viable option that facilitates rapid fluid replacement under duress.

The delivery of fluids via intraosseous (IO) injection seems ideally suited to this environment and has been recommended for combat casualty care.50 When there are delays because of difficulties establishing intravenous lines, IO needles would provide rapid access, and are easy to insert after minimal training. Most importantly, during the chaos that occurs in combat, the IO technique is not likely to be forgotten and requires minimal technical skills to perform. In the burn patient, intravenous access can be extremely difficult to obtain secondary to edema and eschar.49 Two new IO devices for adults have recently been introduced (Pyng Medical and...
WaisMed) and may facilitate the utility of IO access. Animal research has suggested acute resuscitation efficacy with IO delivery of hypertonic saline dextran; however, a recent report suggests that soft tissue and bone necrosis can develop 2 to 4 days after treatment.\textsuperscript{51,52}

Along with the other discussants, we recommend as an initial resuscitative fluid the use of HSD administered at a slow rate of 2 mL/kg/h. This will expand the plasma volume and initially stabilize the patient. We also advocate that each soldier carry one 250-mL 7.5\% hypertonic saline-dextran intravenous packet in his cargo pocket. This accomplishes two things: first, it decreases the load the medic must carry; second, it makes the provision of fluid replacement that much easier if fluids do not have to be located before use. It is in the field that the massive fluid losses must be replaced with or without an NGT placement. Continuous oral replacement should be considered. An initial 500- to 600-mL bolus, approximately a canteen with one packet of rehydrating solutes, followed by bolus feedings of 2 to 4 mL/kg every 20 minutes should maximize gastric emptying. This could theoretically meet the patient’s ongoing resuscitative needs and could be administered by virtually anyone, freeing up the medic for other patient management. The ideal fluid replacement “drink” for burn shock is yet unknown but should be investigated. Once established, such a formulation could be stored in small, lightweight, individual packets. The individual soldier should carry these as well.

We are suggesting the use of new solutions and oral therapy for the management of burn injury in an environment where long delays in evacuation may occur, but these concepts require further research regarding their efficacy and safety before they can be fully implemented. At present, we still must rely on intravenous therapeutics to maintain thermally injured patients.

**Stage 3: Combat Casualty Evacuation Care**

Care at this level depends somewhat on the level of care provider accompanying the evacuation vehicle (physician, nurse, physician assistant, or medic). Resuscitation must continue. A definitive airway may be needed. A full secondary survey can begin at this time. Advanced Trauma Life Support protocols should begin here. Burn dressings need to be applied. Escharotomies should be performed as necessary.

**CONCLUSIONS AND FUTURE DIRECTIONS**

The optimal resuscitative regimen has yet to be developed for combat casualty care of burn injuries. Substantial animal research into the use of colloids and hypertonic solutions and studies of their use by many burn centers have demonstrated early volume-sparing effects. HSD has been shown to safely reduce volume requirements and reduce mortality in penetrating trauma.\textsuperscript{53,54} HSD is in clinical use in Europe and should be considered for use by NATO medics to generate data on the military use of HSD. There is also evidence that HSD optimizes burn outcomes compared with large volumes of isotonic crystalloids. However, the key question is, are the clinical outcomes better or equivalent with hypertonic or colloid solutions or their combination compared with isotonic fluids when early volume must be limited? The answer awaits actual use in military operations, as controlled trials are likely to be impossible to perform.

Further evaluations on the safety of IO infusion of HSD are needed, and until then can only be recommended for isotonic fluids. Theoretically, oral replacement may provide an alternative for the combat situation. However, the theory needs to be tested in controlled animal trials to evaluate its effectiveness. Our preliminary data, along with those of Jiang,\textsuperscript{44} suggest that oral replacement can be effective in restoring plasma volume and maintaining hemodynamic stability. Oral fluids have traditionally been contraindicated before surgical stress and for patients in hemorrhagic shock, burn shock, or trauma. It is likely that oral hydration solutions will never be recommended for abdominal or thoracic trauma. However, in burn injuries, there should be no direct compromise of the GI tract. However, the only studies we know of (Table 5) suggest that oral resuscitation can be used to resuscitate burn shock in animals and humans. These studies need to be followed up to fully evaluate the mechanisms, efficacy, and any deleterious effects. Different oral resuscitation regimens and formulations need to be compared in moderately and severely burned models.

We suggest that 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. Furthermore, there may be advantages to early intestinal or enteral resuscitation even if it can only be performed in hospitals. Although early enteral feeding has been traditionally avoided in burn patients, it has recently been demonstrated to be safe and effective for nutrition when started immediately with hospital care of patients with large burns or used before, during, and immediately after surgery of burned patients.\textsuperscript{55,56} It is possible that the gut will benefit from early enteral resuscitation, particularly when specific nutrients are included in formulations. Oral resuscitation may increase intestinal blood flow and result in better maintenance of gut barrier integrity.

**REFERENCES**

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