# What's New in General Surgery: Burns and Metabolism

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Providers of burn care have learned and copied a great deal from the more established disciplines of trauma surgery and critical care surgery, but the continuing evolution of burn care has produced a substantial and growing body of burn-specific knowledge. This review will cover developments in the field of burn injury and burn care over the last 12 months. The care of patients with serious burn injury has improved in recent years to produce previously inconceivable survival and even quality of life. But this progress has come at the expense of tremendous resource consumption. In these times of cost-controlled healthcare, the number of burn units and burn beds continues to shrink. With most burn units operating at or near capacity, more patients are experiencing delays in transfer to regional centers and more surgeons are being called on to provide burn care.

### Delivery of burn care

In view of the limited number of specialty burn beds in this country; patients with smaller, uncomplicated burns should be cared for as outpatients or in community facilities. But the costly and scarce resources offered by regional burn units are often not being used effectively.[1] Referring physicians frequently overestimate the size of burns (averaging 75% larger than burn unit size estimates) and the need for aeromedical transport. In almost 10% of the patients, the cost of air transport exceeded the cost of hospitalization. Because it is not practical to teach every physician who may encounter a seriously burned patient the necessary assessment skills, the use of telemedicine may allow burn center physicians to visually assess patients and to participate in decision making. Such long range consults may make it possible to use regional burn center resources more efficiently. In this retrospective review, the authors identified 92 of 225 patients whose care might have been altered substantially by pretransport visual assessment by burn specialists. Such techniques have been adapted to off-site consultation in disaster situations and, more recently, to provide long range followup burn care for patients living a substantial distance from regional burn care facilities.[2]

Despite the impressive capabilities available to care for individual burn victims, nothing stresses the healthcare system like a mass casualty event resulting in a large number of burn injuries simultaneously. This was demonstrated most recently after The Station Nightclub fire in Rhode Island, in which 100 people were killed and 187 hospitalized. Mobilization of a Burn Specialty Team from the National Disaster Medical System (NDMS) was necessary to provide the required skilled manpower. McGregor[3] recently reviewed a number of major burn disasters with the goal of identifying lessons learned that could be applied to improve disaster preparedness. Simply identifying whether the fire occurred inside or outside allowed one to predict the type of resources likely to be needed. He also proposed an initial assessment team of burn specialists, working at a site remote from the scene, to guide the distribution of patients based on their injuries, to avoid overwhelming the limited number of burn specialty beds.

Amidst the current fears of large scale terrorist attacks, it is helpful to examine the extensive Israeli experience with such injuries incurred over the period from 2000 to 2002.[4] More than 1,000 victims of terrorist activity were analyzed, including 623 patients injured in explosions. In the group of patients injured by explosion, 91 patients (15%) sustained severe burn injury. Their management

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**Abbreviations and Acronyms**

BAL = bronchoalveolar lavage
DVT = deep vein thrombosis
HA = hydrofluoric acid
TBSA = total body surface area burned

was additionally complicated by the fact that 68% also suffered from nonburn injuries, either blunt or penetrating, that were not always apparent on initial presentation. Explosions also have the capability to cause secondary structure fires, as seen in the Bali night club bombing of 2002.[5] This explosion, and particularly the fire started by the explosion, completely overwhelmed the local healthcare system. This collapse of the infrastructure on Bali necessitated the long range evacuation, stabilization, and triage of a number of burned patients. After initial field care, many were airlifted to a tertiary hospital serving as an initial receiving facility, where they underwent resuscitation, assessment, and triage. After assessment, the most severely burned were secondarily air transported to regional burn specialty units around the country. This experience points out a pragmatic application of some of the lessons identified by McGregor[3] from previous fire disasters.

Most surgeons will see combined burn and trauma injuries as a result of either motor vehicle crashes or assaults. The trauma and burn groups from Loyola recently reviewed their experience with such combined injuries.[6] The mortality, as expected, was higher than that from either injury alone. The effects of the nonburn trauma predominated in predicting outcomes in this series, but these were relatively small burns, averaging 21% body surface area. It was pointed out in the discussion of this article that had the burns been larger and the nonburn trauma Injury Severity Score lower, this effect would, in all probability, have been reversed, with the burn playing the major role in predicting outcomes. The severely burned trauma patient also presents some unique difficulties that may not be widely appreciated. CT scanning of the abdomen has become so routine as to be almost standard of care in many centers. Many surgeons may not realize that the abdominal CT scan of a resuscitated large burn may show intraabdominal fluid[7] as a result of the capillary leak phenomenon routinely seen in such burns. Clinical correlation, the use of attenuation coefficients, and repeat scanning may be necessary to differentiate blood or urine from edema fluid.

### Resuscitation and hemodynamics

The existence of mathematical formulae to guide burn resuscitation leads many to the erroneous conclusion that burn resuscitation is consistent and predictable. The US Army Institute of Surgical Research (home of the Brooke Formula for burn resuscitation) recently revisited the use of this formula in their clinical experience over a period of a decade.[8] Fluid requirements in the first 24 hours routinely exceeded calculated needs. Fluid requirements were generally greater for larger burns, but the expected close correlation between burn size, expressed as percentage of total body surface area burned (TBSA), and fluid requirement was not present. The patient's initial weight, the size of the burn, and the requirement for mechanical ventilation all contributed to a greater fluid requirement. The total fluid administered did not correlate with mortality. Size of burn, age, and worst base deficit in the first 24 hours were the predictors of mortality. Although the formulae may help in initial estimates of fluid requirements, the patient's response must guide the actual administration, as it should for any trauma patient.

With the ready availability of information from invasive cardiovascular monitoring, it seems logical to assume that better outcomes can be obtained using this information and resuscitating toward some more appropriate physiologic goal than just urine output. Holm and colleagues[9] recently randomized a group of major burn patients to resuscitation using the Parkland formula (4 mL/kg/%burn over the first 24 hours) compared with a comparable group of patients resuscitated using a pulmonary artery catheter to guide the fluid administration, with the goal of a cardiac index of $\geq 3.5$ L/min/m$^2$ and an intrathoracic blood volume index above 800 mL/m$^2$. Both groups were resuscitated with Ringer's lactate. The hemodynamically guided group, as expected, received substantially more fluid. But there were no differences in either the preload or cardiac output parameters. Both groups were found to be considerably intravascularly volume depleted. Ultimate morbidity and mortality did not differ between the groups. The authors concluded that increased crystalloid is incapable of restoring cardiac preload to baseline during the period of burn shock.

## Inhalation injury

The major predictor of morbidity and mortality after burn injury is the presence of inhalation injury. Deposition of mucus and fibrin in the airways has been identified as a major component of the resulting lung dysfunction. Early administration of aerosolized heparin and acetylcystine is intended to prevent the resulting plugs and obstructions, and appears capable of reducing the pulmonary dysfunction. But heparin will not dissolve a thrombus once it's formed, and many patients do not arrive at specialized burn centers for several hours after their injury. In an effort to clear the airways of clots already formed, the investigators at the Shrine Burn Unit in Galveston returned to their established sheep model of inhalation injury, and after a 4-hour delay, administered aerosolized tissue plasminogen activator.[10] In this experimental model, gas exchange, lung water, and pulmonary compliance all improved dramatically. There were no major bleeding problems and no changes in measured clotting times. This mode of therapy still must be tested in humans with burn and inhalation injury, but the preliminary experimental data are promising. The problem of airway obstruction produced by inhalation injury can also be attacked by efforts to prevent airway narrowing. After chlorine inhalation (relevant to smoke inhalation because of its release during the combustion of a number of plastics), the administration of the $\beta$-2 agonist terbutaline combined with the inhaled corticosteroid budesonide produced considerable improvement in lung function.[11] There are no data on whether combination of such approaches is synergistic.

Fiberoptic bronchoscopy has long been the gold standard for diagnosis of inhalation injury, but it requires the availability of a skilled endoscopist, is invasive, and may worsen hypoxia or cause progression of airway obstruction. With the widespread availability of high resolution, high speed CT scanners, a virtual bronchoscopy technique has been developed to diagnose inhalation injury.[12] Ten burned patients with suspected inhalation injury were scanned. The authors were able to identify severe upper airway edema in 8 of the 10 patients. Virtual bronchoscopy was not compared with traditional bronchoscopy in this study, so no comments can be made about sensitivity or specificity versus the bronchoscope. The authors did not comment on the difficulties or risks of moving critically ill patients to the radiology suite, monitoring them, and protecting their airways during transport. It is unlikely that virtual bronchoscopy will replace flexible fiberoptic bronchoscopy in many burn units, but it may be useful in selected patients already going to CT scan for possible occult trauma.

Despite good early care, many patients with combined inhalation and burn injury progress to develop ARDS with the associated high morbidity and mortality. The optimal strategy for mechanical ventilation in these patients remains unknown. Recent trends have been toward lower tidal volumes and lower airway pressures. High frequency ventilation provides small tidal volumes and lower peak airway pressures, but has found little use outside of the pediatric ICU. Recently, the use of high frequency oscillatory ventilation was explored in a group of severely burned adult patients with ARDS.[13] All patients were switched from volume ventilation with positive end expiratory pressure to high frequency oscillatory ventilation, with immediate improvement in partial pressure of oxygen/fraction of inspired oxygen ratios and slower improvements in oxygen index. These patients were all heavily sedated and all were chemically paralyzed. The authors concluded that high frequency oscillatory ventilation is safe, effective, and can be used both in the ICU and in the operating room with at least short-term benefit in difficult to ventilate ARDS patients. The high frequency oscillatory technique has long been a mainstay of the management of small children with noncompliant lungs, but until recently, the ventilators were not powerful enough to routinely ventilate adult patients. It remains to be demonstrated whether the outcomes advantages found in pediatric patients will also be present in adults. The use of deep sedation and chemical paralysis, if necessary, will be a major drawback.

The timing and even the use of tracheostomy have long been controversial, particularly in children. Kadilak and associates[14] reviewed 98 intubated, burned children with an average age of 6.1 years, admitted to their hospital over a 9-year period. Patients were intubated orally for 82% of their ventilator days and nasally for the remaining 18%. Only 2 patients received tracheostomies for longterm management. Patients remained intubated for an average of 19.6 days. There were 5 unplanned extubations, and 13 tubes had to be changed electively for reasons such as leaking cuffs. Only 1 patient required reconstructive surgery for subglottic stenosis. The authors concluded that translaryngeal intubation is a safe and effective method of providing longterm ventilatory support. This study does not attempt to identify translaryngeal intubation as the optimal technique, only that it is safe and effective. Palmieri and coworkers[15] reached similar conclusions about early tracheostomy in severely burned children. Would tracheostomy have reduced the unplanned extubations and simplified the tube exchanges? What about longer term intubation? Without a direct comparison it is still impossible to conclude that one technique is superior.

## Wound management

The primary goal of burn care centers around closing the burn wound either by primary healing of partial thickness wounds or by autologous grafting of full thickness burns. The remainder of burn care consists of supporting the patient and preventing or treating complications. The faster the wound can be closed, the less the risk of infection, the less the patient's pain, and the shorter the hospitalization. Early excision and closure with autologous skin, allograft or cadaver skin, or skin substitutes has been accepted for the management of full thickness wounds for several years. Conventional wisdom has been that partial thickness wounds should be managed with a topical agent to prevent infection and the patient supported metabolically while the wound heals. In many cases this sequence fails to occur. This may be from erroneous assessment of burn depth initially or from conversion from partial to full thickness secondary to infection. But these same techniques of wound coverage can be applied to partial thickness wounds.[16] In one study, two groups of nonrandomized patients with partial thickness burns involving more than 40% TBSA were compared. One group of 13 patients was treated traditionally, as described. The second group of 16 patients was treated with operative debridement and coverage of the wound with meshed cadaver skin. The two groups did not differ in age or TBSA. The cadaver graft group had a markedly shorter hospital length of stay: 24 versus 40 days. There were three deaths in the traditional group and none in the allograft group. This is a small, nonrandomized group of patients, but if confirmed, will represent a major change in the management of large partial thickness burns.

A similar approach used a three-way randomization of a group of children with partial thickness burns to one of three treatment arms.[17] It compared the topical antimicrobial silver sulfadiazine with Biobrane or TransCyte, a bioengineered skin substitute. The primary study parameter was time to 90% reepithelialization or until conversion to full thickness and autografting. Time to reepithelialization was shorter with TransCyte (Smith & Nephew) versus Biobrane (Mylan Bertex Pharmaceuticals) versus silver sulfadiazine (7.5 versus 9.5 versus 11.2 days, respectively). The TransCyte group also required fewer autografting procedures. These two studies taken together strongly suggest that the traditional means of caring for large partial thickness burn wounds may no longer be the optimal care.

Partial thickness burn wounds tend to progress to full thickness wounds in the first 24 to 48 hours because of microvascular thrombosis. Efforts to prevent this progression with anticoagulants or antiplatlet agents have been unsuccessful. This additional tissue loss was prevented by early application of subatmospheric pressure with the VAC (Kinetics Concepts, Inc) device[18] in a small group of human bilateral hand burns. One hand was treated with topical antimicrobial cream and the other with the VAC. Much less edema and better preservation of blood flow were seen with the VAC. Although there is no objective evidence that tissue was preserved in this manner, the authors' clinical impression was that less tissue necrosis occurred and blood flow was definitely preserved.

## Infection and immunology

The major risk burn patients face in the course of their treatment is infection, whether from their open wounds, their lungs, or invasive devices such as catheters. This is, in part, from the loss of large portions of their mucocutaneous barriers. But the burn victim's ability to respond to microbiologic challenge is also seriously suppressed by the injury. A portion of the burn victim's increased risk of infection may be genetically predetermined. Patients with specific polymorphisms in the tumor necrosis factor and bacterial recognition genes are associated with a considerably higher incidence of sepsis than their burn injury alone would predict.[19] Although this propensity to infection cannot be corrected, early recognition might allow more aggressive treatment. The earlier use of antibiotics, administration of immunomodulators to correct the functional deficit, or just better isolation may be indicated in these patients. To date, this has not been studied.

Some aspects of the innate immune response can be manipulated in a therapeutic manner. Jeschke and colleagues,[20] recently compared two groups of burned children. Blood glucose was maintained between 120 and 180 mg/dL in both groups. One group required exogenous insulin to maintain this glucose level, the other group did not. The group receiving exogenous insulin had decreased levels of proinflammatory cytokines, increased levels of antiinflammatory cytokines, and decreased acute phase proteins. The children receiving insulin required less albumin administration to maintain comparable levels of serum albumin. The authors concluded that insulin acts directly to achieve these antiinflammatory effects and not simply through a lowered glucose. But the study was not designed to detect any change in incidence of infection, morbidity, or mortality. In conjunction with this study, the same group[21] randomized a group of burned children to receive either continuous infusion insulin to maintain glucose between 100 and 140 mg/dL or no treatment. The insulin infusion decreased acute phase protein levels after severe burn injury. The anabolic steroid oxandrolone has been shown to have similar effects to insulin on the acute phase proteins, albumin synthesis, and constitutive proteins[22] when begun on postoperative day 5. In addition to the acute effects of oxandrolone, longterm administration (for 1 year postburn) improved lean body mass, bone mineral content, and bone mineral density.[23] Not only did oxandrolone help to preserve lean body mass in burned children when started early, it accelerated the recovery of body weight and lean body mass lost in adult burn victims. Body mass restored by diet, exercise, and oxandrolone was maintained for at least 6 months after stopping the drug.[24]

Beta adrenergic blockade has been shown to reduce the hypermetabolic response in burned children. In an effort to determine the effects of $\beta$-blockade in adult burn victims, patients who were taking $\beta$-blockers at the time of admission were compared with those started on $\beta$-blockade in the hospital, and these two groups were compared with a matched cohort of patients who never received $\beta$-blockers.[25] The group taking $\beta$-blockers on admission appeared to have a lower mortality, shorter healing times, shorter ICU and hospital lengths of stay, and lower incidence of wound infection. The group in whom $\beta$-blockers were started in the hospital had worse outcomes, but these patients were not well matched to the other two groups. The question of whether $\beta$-blockers have value in reducing the hypermetabolism in adult burned patients remains unanswered.

## Complications

Patients with critical burns are particularly subject to complications of both their injury and their treatment. These complications may threaten survival, prolong recovery, or simply make life miserable.

Pneumonia is a major cause of morbidity and mortality in the ICU and diagnosis is difficult at best. Clinical diagnosis, including physical findings, radiographic findings, and sputum examination frequently overdiagnoses pneumonia, leading to excessive antibiotic use and the associated complications. In medical and trauma ICUs there has been widespread acceptance of various means of bronchoscopically directed sampling of the lower airways to rapidly diagnose pneumonia and to limit unnecessary antibiotic use. The diagnosis of pneumonia in burned patients can be particularly difficult. Infiltrates may be from inhalation injury, atelectasis, ARDS, or pneumonia. There have been no data available on the use of quantitative microbiology and bronchoscopically directed sampling in burned patients. Burn physicians have been left to assume that results from other trauma patients apply to burned patients.

The group from Galveston has raised important questions about the interpretation of such bronchoalveolar lavage (BAL) results in burn victims.[26] They retrospectively reviewed a group of seriously burned children who underwent BAL during the course of excision and grafting of their burn wounds. The authors accepted colony counts of $\geq 10^3$ organisms as indicative of a positive BAL and compared these findings with routine chest x-ray. There are a number of problems with this study including small sample size, the reliance on routine chest radiograph as the gold standard, the failure to report the actual numbers of organisms obtained from the BAL, and so forth, but it raises one very important issue about the use of BAL in burned patients. In 80% of the patients diagnosed with smoke inhalation, there was a positive BAL even in the absence of any other indication of pneumonia. Inhalation injury produces a tracheobronchitis with mucosal erythema, ulceration, and hemorrhage. There is damage to the respiratory cilia, predisposing to local bacterial invasion. The authors speculated that this tracheobronchitis is the source of the positive BALs reported in this study. This question demands additonal study in a larger population of burned victims with inhalation injury before the techniques useful in other ICUs are accepted without question in the burn unit.

Rhabdomyolysis is not uncommon in the early period after a burn injury. It may result from compartment syndrome, electrical injury, or direct thermal injury to muscle. In the presence of the hypovolemia that commonly accompanies burn injury, myoglobin may be nephrotoxic through a variety of mechanisms. Standard treatment regimens include rapid volume replacement with crystalloid solutions and administration of mannitol and sodium bicarbonate. Unfortunately, there are very few clinical data available in any patient population that confirm that these treatments are either necessary or beneficial.

Brown and colleagues[27] reported on a large series of nonburn trauma patients with elevated creatine kinase levels as a surrogate for myoglobin. Although this was a retrospective study, they identified two comparable groups of patients, one of which received mannitol and bicarbonate, the second of which did not. They compared the incidence of renal insufficiency, requirement for dialysis, and mortality between the two groups. They were unable to show any benefit to the administration of mannitol and bicarbonate. Only at very high levels of creatine kinase did there appear to be an advantage to such treatment, and this did not reach statistical significance. Although this study raises questions about one of the dogmas of treating traumatic or thermal rhabdomyolysis, there are flaws in the study. There were no burn or electrical burn patients in the study. It was a retrospective study, so the bicarbonate and mannitol were not administered in a standard fashion or to achieve a standard urine output. Serum myoglobin levels were not measured. Although this study is not sufficiently convincing to justify complete abandonment of the use of mannitol and bicarbonate, it does suggest that this form of therapy not be pursued to the point of volume overload and hyperosmolality.

Deep vein thrombosis (DVT) is difficult to diagnosis on clinical grounds in any patient population, but particularly so in burn patients in whom swollen extremities are common from injury, fluid resuscitation, sepsis, hypoalbuminemia, and so forth. Before readily available Doppler examinations, this difficulty led many clinicians to believe that DVT was rare in burn patients. But relying on clinical criteria to order the Doppler examination does not allow determination of the true incidence in the burn patient population. Wibbenmeyer and associates[28] examined 148 burned patients hospitalized longer than 3 days. Each patient had venous duplex examination on admission and at discharge. Nine patients (6.08%) were found to have venous thrombosis; in 8 of these the thrombosis was proximal. One of the two documented pulmonary emboli was fatal. Risk factors for DVT were the presence of a central line and the transfusion of more than 4 U of packed red blood cells. This prevalence of DVT is comparable with that of general surgical patients for whom DVT prophylaxis is widely recommended. The authors recommended that the issue of DVT prophylaxis in burned patients be evaluated. Fecher and coworkers[29] retrospectively reviewed a decade-long experience with clinically diagnosed DVT. They diagnosed DVT in 10 of 4,102 patients (0.25%) and diagnosed two nonfatal pulmonary emboli. They reported three deaths described only as not from thromboembolic disease. These authors routinely used subcutaneous heparin prophylaxis and reported no bleeding complications. The authors concluded that heparin prophylaxis is effective in the prevention of DVT in burn patients. Together these two articles provide evidence that DVT has a similar prevalence in burn and general surgery patients and that subcutaneous heparin is relatively safe. They do not provide evidence that subcutaneous heparin is effective in this patient population.

Pruritis may not be considered a burn complication because it is the expected but undesirable result of wound healing. The standard therapy, antihistamines, is often not successful in relieving the itching. A number of other modalities have been described including ice, hemorrhoid creams, and cannabinol. Hettrick and colleagues[30] reported moderate success in treating postburn pruritis with transcutaneous electrical nerve stimulation. Although not a cure, transcutaneous electrical nerve stimulation provides a noninvasive, patient controlled alternative for pruritis.

## Rehabilitation

Beyond survival, the goal in caring for burned patients is to return them to their preinjury status. The best of burn care often falls far short of this goal, but insurance companies, disability services, and lawyers routinely ask that this shortfall be quantitated. Many burn physicians are unfamiliar with the process of impairment ratings. Those familiar with the practice most frequently base their impairment rating on loss of range of motion, which can be easily measured. Costa and the groups from Seattle and Dallas[31] evaluated impairment based on whole person ratings, as directed by the AMA's guides. The skin rating is less objective and is broken into five classes ranging from 0 to 95% impairment. Classes are based on frequency of symptoms, ability to perform activities of daily living, and the need for medical treatment. The data from the Seattle unit were based on 139 patients studied predominantly at 2 years postinjury. The data from Dallas were based on 100 patients studied at an average of 12 months postinjury. The Seattle group averaged 17% impairment of the whole person compared with the Dallas group's average impairment of 19% of the whole person. The authors didn't establish that this impairment rating is accurate in any absolute sense or predictive of return to work, and so forth. But it does address the impairment from a major but subjective component of the burn patient's injury and demonstrates that consistent results can be obtained. The group from Uppsala[32] examined longterm outcomes of a group of burn patients injured on the job. At an average followup time of 9 years, 83% of the former patients were working, 10% were on sick leave or had a disability pension, and 7% were unemployed. Sixty percent of the unemployed reported moderate to severe pain compared with 18% of those working. Although these are the only longterm return to work data available, there is much information not available. There is no comparison to a nonburn injured cohort. It is impossible to evaluate the degree to which the burn injury impaired the victim's ability to advance in the workplace.

### Chemical burns

Chemical burns present unique challenges. In addition to the direct skin loss, there is the potential for systemic toxic effects and the feeling often present in the treatment team that there should be some more specific intervention than simply irrigation with copious volumes of water. For a small subgroup of patients, more specific responses are needed and available. One of the chemicals with the potential to produce systemic toxicity and for which a specific response is available is hydrofluoric acid (HA).

Hydrofluoric acid was originally used only as an industrial solvent with the ability to dissolve glass and silica products. In recent years, its use has become more widespread; it is included in some rust removers and heavy duty detergents and cleansers. Hydrofluoric acid causes injury by two distinct mechanisms. First is the high concentration of hydrogen ions that produces a burn similar to those given by hydrochloric or sulfuric acids. The fluoride ions, however, are capable of penetrating tissues deeply and leading to a painful necrosis. This deep tissue necrosis occurs despite effective surface irrigation. The seriousness of HA injury depends on the concentration of the acid, the surface area exposed, and the duration of exposure. Weak solutions of HA may take hours to cause symptoms, often misleading both patient and physician into believing that irrigation and local wound care have taken care of the problem. The goal of therapy is to neutralize the fluoride ions with calcium ions. Although an uncommon injury, Hatzifotis and associates[33] reviewed their experience with 42 patients seen between 1977 and 1999. These authors presented an algorithm for the patient who presents with HA exposure. They recommended management of small cutaneous exposures with calcium gluconate in dimethyl sulfoxide (DMSO) after a minimum of 30 minutes of copious irrigation. If pain persists, other options include subcutaneous infiltration of calcium gluconate or regional infusion in a manner analogous to the Bier block. For exposures involving more than 5% TBSA, the potential exists for life-threatening systemic toxicity. Dünser and the group from Innsbruck[34] recently reviewed the critical care management of HA burns. They reviewed the electrolyte abnormalities and the risk of myocardial dysfunction and infarction, and various options for calcium and magnesium therapy.

The US Army Institute for Surgical Research recently reviewed their experience with chemical burns and, particularly, with white phosphorus burns.[35] The experience, generated over 51 years of operation, included 146 white phosphorus burns out of a total of 276 chemical burns. Outside of the white phosphorus experience, this series is comparable with a large civilian experience, but the phosphorus experience is unique and in the absence of another major conflict, will probably remain so. But, white phosphorus does occur in uses other than munitions and presents some specific challenges to the burn surgeon who may lack the military experience of dealing with this agent. White phosphorus ignites spontaneously if exposed to oxygen at a temperature of 86°F or higher. In wounds, white phosphorus will continue to oxidize until debrided, neutralized, or consumed. Wound irrigation with warm water facilitates conversion from solid to liquid, making it more difficult to locate and remove from a wound. Systemic effects include life-threatening hypocalcemia and hyperphosphatemia that can occur as early as 1 hour after injury. The authors recommended frequent monitoring of calcium and phosphorus levels for 48 to 72 hours after injury. Continuous vigorous water irrigation is probably optimal for initial management if possible. Immediate surgical debridement might be necessary to remove the particles of phosphorus. The embedded phosphorus is best identified by Wood's lamp, which will cause the particles to fluoresce. Copper sulfate should be avoided because of the risk of copper toxicity.

Burns associated with the manufacture of methamphetamine are the most recent type of chemical burn to present to burn units in large numbers. Several burn units have reviewed their experience with this new epidemic[36,37] with notable findings. The typical patient is a young man with flame burns involving the face and hands and a vague history of an explosion that they cannot or choose not to clearly explain. Only later is the complete history obtained from law enforcement, the family, or the media. Many of these patients require much higher than calculated fluid volumes to resuscitate. About half go through withdrawal characterized by agitation followed by hypersomnolence. Benzodiazepines are often required to manage the withdrawal. Costs for these patients are high and third party or even government reimbursement is limited, imposing a tremendous financial burden on burn unit hospitals.

In conclusion, burn care has made tremendous progress in caring for the typical burn patient, but more progress is needed at the extremes. The very young, the very old, and the very large burn still do not do well. There is also still a need for techniques that produce better functional and cosmetic results.

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