0039–6109/96 $0.00 + .20

THE COMPLEXITIES OF MANAGING SEVERE BURNS WITH ASSOCIATED TRAUMA

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Major burn injury in association with polytrauma poses an unusual yet complex management problem. In the military environment it may account for as much as 24% of burn casualties,[78] whereas in civilian burn centers multiply injured patients represent less than 7% of burn admissions.[81] It has been reported that of those involved in an automobile fire, 36% have associated major trauma.[82] When a burn is associated with other trauma, mortality is directly related to whether there is single or multiple organ system involvement.[81]

Improvement in the outcome of non–thermal-injured trauma patients, associated with treatment in trauma centers,[4, 24] has moved public policy and practice toward the triage of such patients to specialized trauma center units. Similarly, isolated burn patients are usually managed in burn centers. As a result, few general/trauma surgeons care for major burns, and few individuals have substantial clinical experience in the management of the combined problems. These injuries require multidisciplinary care and may necessitate modification of preoperative, intraoperative, postoperative, and critical care management to effect optimal survival and functional potential.[24, 95] The success of coordinated treatment is realized through an effective triage, accurate and timely diagnosis, and precision in assignment of the surgical priorities.

Recent Data

The Los Angeles County and University of Southern California (LAC + USC) burn center has admitted 2914 major burn patients over the last 10 years.

The authors gratefully acknowledge Dr. Bruce Zawacki for his direction, guidance, and contribution to the development of a patient database and protocols for patient treatment, some of which are represented in this article.

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Table 1. LAC+USC BURN CENTER (1985–1995): 2914 ACUTE BURN ADMISSIONS

	Number	Percent Male	Percent Nonaccidental	Percent Job-related	Average Age	Percent Average TBSA	Percent Complications	Percent Mortality	LOS	LOS/TBSA
Associated trauma	132	81	41	11	32.6	20.0	21.2	13	23.9	1.20
with IT	26.5%				34.5	39.3	48.5	41	31.3	0.80
w/o IT					31.9	13.3	11.2	3	21.3	1.61
No trauma	2782	71	26	10	28.6	15.0	9.4	6	16.0	1.07
with IT	17%				35.4	33.1	28.0	23	26.4	0.80
w/o IT.					26.2	10.9	9.2	2	13.4	1.23

IT = inhalation trauma
LOS = length of stay in the hospital measured in days
TBSA = total body surface area

LAC+USC is a level one trauma center, so all multiple trauma patients with burn injury are admitted to the burn unit. These combined injuries account for nearly 5% of burn admissions. The overall mortality for this group is 13%, which is double that for burns without associated trauma (6%). The average burn size is 20%, compared with 15% for patients without multiple trauma. If one examines the subgroup of patients with inhalation injury, the differences are even more remarkable. The overall mortality for smoke inhalation with associated trauma is 41%, whereas in those without nonthermal injury (NTT) it is 23% (with average burn sizes of 39.3% and 33.1%, respectively). (The mortality for patients without an inhalation component is 3% with and 2% without NTT.) Clearly the combination of a major burn with smoke inhalation combined with multiple trauma accounts for most of the excess mortality and morbidity between the groups (Table 1).

These results are comparable to those of Purdue,[82] where the mortality for patients with combined injuries of NTT burns with inhalation trauma was 59%, with an average burn size of 55%; without inhalation trauma, mortality was 17%. In another large series this combination of injuries was associated with a 76% mortality.[81] Hence, it is clear that the burned multi-injured patient is at very high risk, even in experienced centers.

MECHANISM OF INJURY

Knowledge of the mechanism of injury is one key component in the judgment of the severity of injury and the likelihood of the specific associated injuries one must expect when planning an expeditious work-up. Motor vehicle accidents (MVA) (Table 2) account for the majority of the combined injuries,[82] followed by attempted escape from building fires, explosions, assaults, airplane crashes, and military wounds.

Entrapped MVA victims are exposed to both thermal and smoke injury and typically sustain deep burn injuries. This highly lethal environment results in a 25% to 50% mortality rate, with as many as 80% of these deaths occurring at the scene.[77, 82] Two distinct patterns of burn injury were noted in these patients. The first was reflected in patients who were trapped in or adjacent to the burning vehicle. These patients presented with facial and upper extremity burns, usually associated with an inhalation injury, as previously described. The second pattern was seen in patients who were thrown from their vehicles or who were able to flee from the wreckage. These patients had less severe burns of the torso and upper extremities without an associated inhalation injury.[81] Those who are able to leave the vehicle under their own power typically have less severe

Table 2. CAUSES OF OPEN FRACTURES AMONG CIVILIANS

Causes	Per Cent
Motorcycle accident	28
Motor vehicle accident	24
Falls	13
Pedestrian struck by car	12
Crush injuries of various causes	8
Firearms	2
Miscellaneous	13

From Browner BD, Jupiter JB, Levine AM, et al: Skeletal Trauma: Fractures, Dislocations, Ligamentous Injuries. Philadelphia, WB Saunders, 1992, p 312, *as modified from* Dellinger EP: Arch Surg 123:1320–1327, 1987; with permission.

polytrauma. However, this is not the case for those ejected from the car or motorcycle. Burns involving MCA or ejection are associated with severe multiple injuries.

Falls are a common cause of multiple trauma in structure fires.[95] These injuries are attended by a host of orthopedic and visceral injuries (intracranial trauma, spinal cord injury, long bone fractures, thoracic and/or intra-abdominal trauma) that may at first seem underwhelming and may be subtle compared with the associated and obvious burn injury. A careful history is important to help guide triage. It must be remembered that the median lethal dose for height in such a mechanism is about 40 feet, or four stories. Injuries to the spine are the most frequently overlooked. Respiratory difficulty may be mistaken for inhalation injury rather than the adult respiratory distress syndrome (ARDS) that can manifest early after a fall. Electrical injuries, particularly high voltage (>1000 volts), may cause both falls and tetanic fractures.[3] Access to high voltage is usually concomitant with heights, and falls result by way of involuntary movement or loss of consciousness from inadvertent electrical contact. Electrical injuries have occurred through a variety of mechanisms such as hang gliding, CB radio antenna placement, house painting with extended metal roller brushes, and digging into and inadvertent pruning of high voltage lines. In areas prone to thunder storms, lightning is not an infrequent offender. All of these injuries can be complicated by profound neurovascular injury in addition to massive orthopedic and soft tissue destruction, each having it attendant acuity, treatment, and morbidities.

Combat-associated burn injuries have a higher rate of associated trauma (24%)[78] than those experienced in the civilian population, although urban explosions are associated with a similar high incidence.[6] As in those injuries that occur in an industrial setting, chemical burn injury may be a confounding factor in their treatment and a safety issue for the medical staff and personnel.

INITIAL MANAGEMENT OF COMBINED INJURIES

The immediate management of a patient with multiple trauma and burns should focus upon ABCs of the Advanced Trauma Life Support[89] protocol, namely maintaining an airway, breathing, and circulation. To the uninitiated, the burn injury often seems the most urgent issue; however, the most immediate threat to life is asphyxia from airway obstruction due to swelling, unconsciousness, or foreign body. Impaired breathing from neurologic injury, sucking chest wound, or circumferential chest burn and circulatory collapse from exsanguination and/or acute hypovolemia related to the burn, tamponade, or tension pneumothorax must be corrected prior to focusing upon care of the burn wound.

Airway

Patients with multiple trauma are assumed to have a cervical spine injury until proven otherwise. The airway assessment and management must take this into account. During all attempts at airway inspection, bronchoscopy, or intubation, in-line cervical stabilization must be assured. A combative or confused patient may require mechanical or chemical restraints to avoid further injury. If the level of consciousness is such that the airway may not be protected or further injury is imminent, medical paralysis and intubation should be performed.

In managing an airway in a patient with a probable inhalation injury (Table 3) careful assessment must be made. The heat-associated upper airway edema of burn patients is often progressive over 24 to 36 hours but may be initially subtle. Those patients who require immediate operative intervention for abdominal, chest, or orthopedic injuries may have been intubated with only subtle findings of superglottic edema. However, by the end of the operation, these patients may develop severe pharyngeal edema which, with routine extubation, could end in disaster. Hence, any patient suspected of heat inhalation should be intubated and remain so until careful evaluation can be performed.

Cricothyroidotomy may be necessary to establish an airway in the acute setting in persons greater than 10 years old (contraindicated before 10 years of age). Indications for cricothyroidotomy include unsuccessful attempts at oral intubation and/or craniofacial trauma. Tracheostomy has no role in the acute setting.

Later, tracheostomy should be considered electively in those patients with head trauma requiring greater than 5 days of intubation, those with inhalation injury in which tracheal secretions or sloughing pose an obstruction risk, and those with facial trauma requiring any form of jaw fixation during fracture reduction. Burned patients who require tracheostomy should have early grafting of their necks if it is involved in the burn.

Breathing

Oxygen (100%) is administered via mask or endotracheal tube at the scene or on arrival to the emergency department (ED). Breathing is assessed for the adequacy of gas exchange by oxygenation measurement (O_2 saturation and/or absence of pallor or cyanosis), motion of the chest wall, and breath sounds. A

Table 3. INDICATIONS FOR INTUBATION: INHALATION TRAUMA

- Inadequate ventilation or oxygenation
  - Cyanosis
  - Agitation
  - Stupor or other signs of hypoxemia
- Unconsciousness, severe head injury, or to prevent aspiration
- Major multiple trauma in addition to the burn (e.g., flail chest)
- Signs of threatened airway obstruction or respiratory failure
  - Stridor
  - Hoarseness
  - Pharyngeal burns
  - Bronchospasm
  - Bronchorrhea
  - Wheezing
- Airway or pulmonary parenchymal injuries are likely with
  - Facial burns
  - Carbonaceous sputum
  - Carboxyhemoglobin greater than 15%
  - Fire in an enclosed space
  - History of unconsciousness
  - Presence of noxious fumes at the fire scene
  - Explosions
  - Immersion in acid, alkali, or hydrocarbons (kerosene)

blood gas analysis is mandatory in all patients with suspected smoke inhalation, to measure carboxyhemoglobin and methemoglobin as well as oxygen saturation. The current pulse oximeter monitors **cannot** differentiate hemoglobin bound with carbon monoxide (CO) from that bound with O_2 and report a normal saturation in the face of profound hypoxia due to CO. That is because O_2 saturation on the pulse oximeter is the sum of oxyhemoglobin, carboxyhemoglobin, and methemoglobin. The possibility of a hemopneumothorax, a sucking or flail chest wound, and/or misplacement of the endotracheal tube (absent CO_2 return or right mainstem intubation) must be considered and corrected. Extensive subcutaneous and/or mediastinal gas may result from a bronchial or tracheal injury, which can be diagnosed by bronchoscopy and may require immediate surgery.

There are a number of advocates of hyperbaric oxygenation (HBO) for the treatment of CO inhalation poisoning[13, 41, 48, 49, 65] and burns.[93] The affinity of CO for hemoglobin is 200 times that of O_2. The elimination half-life of CO is about 4 hours on room air and about 45 to 60 minutes on 100% O_2 by mask. This is shortened to 30 minutes in HBO. However, even enthusiasts of HBO recognize that the benefits do not outweigh the risks in burn patients,[37, 39, 54, 70] and thus the addition of multiple trauma may exacerbate the risks. Without prospectively controlled studies of HBO in burn patients, its indications and efficacy remain anecdotal and its application remains experimental. The critically ill multi-injured patient may be particularly difficult to assess and treat in an HBO chamber.

Circulation/Resuscitation

Hypotension following trauma must be assumed to be from hemorrhage and/or hypovolemia until proven otherwise. Burn patients can become rapidly hypovolemic and hypothermic, thus confounding the assessment of volume loss due to hemorrhage. External hemorrhage is identified and controlled. The hypovolemic status of the trauma patient is usually assessed by observing a decreased level of consciousness, noting pale skin color, palpating thready pulses, noting tachycardia, and observing a narrowing of the pulse pressure. The pitfalls in this assessment arise from the inability to assess skin color or palpate pulses because of the burn injury and the change in sensorium and cardiac function that may accompany CO and cyanide (CN) inhalation.

The fluid requirements for the thermal component of the trauma are thought to be set by the initial injury: surface area and depth of burn and the presence or absence of inhalation injury. The traditional Brooke (2 mL/kg/dL with albumin) and Parkland (4 mL/kg/dL with *no* albumin) protocols are formulas that represent estimates of the patient's initial 24-hour fluid budget based on the percentage of body surface area involved with second- and third-degree burns and the patient's weight. We use a modification of the Brooke formula (Table 4) as our starting point for resuscitation but administer the patients "normal" daily maintenance fluid requirement enterally as tube feeding via a nasogastric tube (see ICU section for further refinement of fluid therapy and nutrition after initial stabilization). Some clinicians have recommended initiating burn resuscitation at 3 mL/kg/percent total body surface area (TBSA) in children[26] in addition to maintenance volume, but we find, as have others, that the addition of albumin and a lower total dose of fluid allow better tolerance of diet in children. The presence of inhalation injury generally increases the burn fluid budget requirement by 20% or more[9] over that estimated for the cutaneous

Table 4. INITIAL BUDGET* FOR ESTIMATING FLUID REQUIREMENTS DURING FIRST 48 HOURS AFTER BURN (PB)

Resuscitation fluid
Protenate or 5% albumin in isotonic saline: 0.5 to 1 mL/kg/% body surface area (TBSA) second- and third-degree burn
Ringer's lactate without dextrose: 1 to 1.5 mL/kg/% TBSA second- and third-degree burn
To a total of 2 mL/kg/% TBSA burn
One-half this volume usually suffices during the second 24 hours PB.
Maintenance fluid
1500 mL/m^2†
[This requirement is unchanged during the second 24 hours PB.]

*Modified from the Brooke formula

†For adults, the need for "maintenance fluid" is typically satisfied by nasogastric (NG) tube feedings during the first 48 hours PB. Similac is given to children <1 year of age, Pediasure to children >1 year and <7 years, and Nitrolan to all others. If not (as in cases of ileus), NG intake should be supplemented prn with IV 5% D&W. Infants and children weighing ≤ 25 kg require relatively more sodium than adults during the first 48 hours PB. In these infants and children, therefore, "maintenance fluid," whether given as IV 5% D&W or as NG tube feeding, is supplemented to become one-half normal in concentration with respect to sodium. This sodium supplementation is unnecessary after 48 hours PB.

injury. The initial weight of the patient should be recorded prior to massive fluid infusion so that an accurate estimate of nutritional and fluid requirements can be made.

The infusion of 2 to 3 liters of warmed lactated Ringer's solution is the recommended initial therapeutic and diagnostic maneuver in a hypovolemic trauma patient while evaluation of the cause of hypovolemia is performed. Failure to respond indicates ongoing massive fluid loss or hemorrhage; type-specific or O-negative blood may be required. The early use of clotting factors and platelets should be considered because of the consumptive coagulopathy induced by the burn. In the absence of ongoing external hemorrhage, in the combined injury patient with a negative chest radiogram or scant chest tube output, abdominal blood loss should be ruled out by diagnostic peritoneal lavage (DPL) in the ED. A hasty trip to the operating room for a nontherapeutic abdominal exploration, in an under-resuscitated burn patient, often leads to disaster.[81]

Cardiac tamponade may be diagnosed by B-mode ultrasonography. Tension pneumothorax must be suspected and should be treated rapidly by insertion of an 18-gauge needle into the pleural space, followed (whether positive or negative) by chest tubes. Spinal shock from a high cervical injury and metabolic poisoning (with CO and/or CN) from smoke inhalation must be in the differential diagnosis of those patients who appear unresponsive to the initial volume loading.

While the burned multi-injured patient is proceeding through the initial evaluation, we infuse an additional volume of 5% albumin at 200 to 400 mL/hr or Ringer's lactate, 500 mL/hr, to cover the burn losses until there is time for formal calculation of fluid requirements. If the patient is less than 5 years old, one can start at half those rates. If the burn is greater than 50% of the TBSA in an adult, this rate should be increased to 1 liter/hr. A Foley catheter should be inserted unless contraindicated.

The initial assessment of the adequacy of the fluid resuscitation effort requires monitoring of the patient's response to therapy using vital signs, electrocardiography, blood gases, acid/base status, peripheral perfusion, and urine output. However, for patients with extensive injuries and/or major burns and for those at the extremes of age, such monitoring may not be sensitive enough. Those patients benefit from early pulmonary arterial catheter monitoring.

Venous Access Considerations

One should use at least two large-bore intravenous catheters inserted percutaneously. Even if the only veins that are available are within the burn area, they should be used. When a venous cutdown is necessary, it should be placed as far distal on the extremity as possible to allow for line changes on the same vein by more proximal serial incisions. Occasionally in children, because of a paucity of cannulatable veins, it is necessary to use intraosseous fluid replacement through a needle inserted into the marrow of the tibia (18 gauge if <2 years of age, or a bone marrow biopsy needle if >2 years) (Fig. 1) until an intravenous line can be established. In adults in whom peripheral venous access is unavailable, the femoral site is preferable to the subclavian or internal jugular veins, in that order. It should be recognized that hip joint sepsis can result from venipuncture of the femoral vein in young children.

Disability

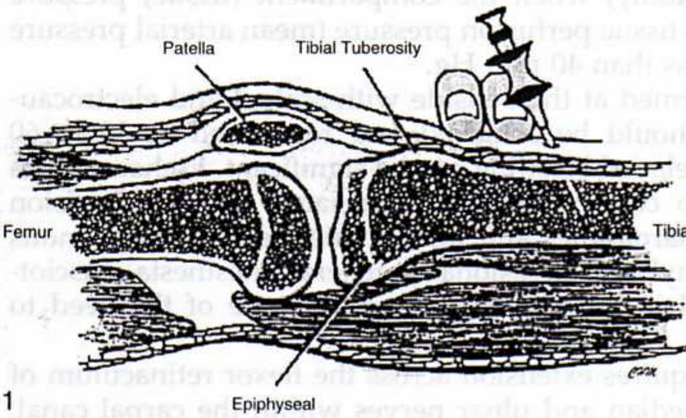
A rapid neurologic examination is performed after the ABCs are secured. Although an altered sensorium alerts one to head injury, hypoxia, or shock, the confounding factors of drugs and metabolic poisons from smoke must be considered. It is especially important to quickly identify and aggressively treat CO poisoning in a head-injured patient, as hypoxia may greatly worsen neurologic outcome.

Exposure/Cooling and the Environment

Patients are often brought to our ED in clothes or dressings saturated with water to "cool" the burn. This practice results in rapid hypothermia with its attendant cardiac and coagulation sequelae. Wet dressings are immediately removed in the ED and replaced with warm blankets. We have recommended to our EMT services not to wet the burn in the field, as cooling of the burn to reduce the zone of injury has been shown to be ineffective.[5, 44, 46, 64] After the ABCs are assured, full exposure of the patient is necessary for the secondary survey. Warm fluids (40°C) given through a Level One or equivalent large-volume fluid warmer is essential to maintain euthermia.

REASSESSMENT

The hallmark of good trauma care is assessment followed by reassessment, so that the dynamic physiologic state brought on by the injuries can be managed successfully. The addition of a burn and/or inhalation injury to this polytrauma environment requires additional surveillance to avoid such late problems as airway obstruction and limb ischemia.



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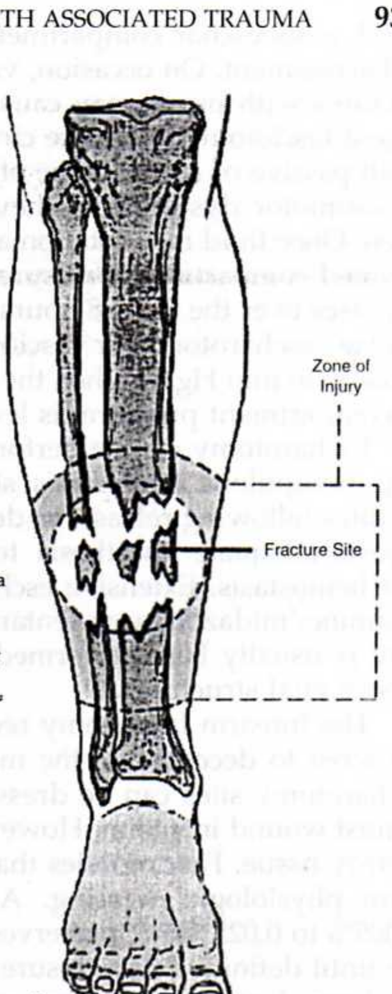

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Figure 1. The needle is inserted 2 cm distal to the tibial tuberosity on the medial aspect of the tibia. It is inserted in a caudal direction away from the joint space. (*From* Tintinalli JE, Krome RL, Ruiz E (eds): Emergency Medicine: A Comprehensive Study Guide, ed 3. New York, McGraw-Hill, 1992, p 170; with permission.)

Figure 2. The zone of injury, incorporating an area much greater than the fracture site. (*From* Browner BD, Jupiter JB, Levine AM, et al (eds): Skeletal Trauma: Fractures, Dislocations, Ligamentous Injuries. Philadelphia, WB Saunders, 1992, p 338.)

Inhalation Injury

Our protocol for smoke inhalation injury that is suspected on clinical or historic grounds is to perform bronchoscopy immediately in the ED or admitting area and then, if initially negative, every 6 hours for 24 hours following injury because the thermal component may manifest itself late. Supraglottic edema or erythema is a sign of heat inhalation trauma and requires immediate intubation to avoid airway obstruction. Transnasal fiberoptic examination of the pharynx and larynx is performed after spraying the nasal mucosa with a mixture of 4% lidocaine and 0.25% phenylephrine.

Compartment Syndromes/Limb Ischemia

The edema that develops under burns on extremities may produce a rise in interstitial tissue pressure of sufficient magnitude to cause, even if not circumferential, a subeschar compartment syndrome with the subsequent neurovascular embarrassment. On occasion, very deep thermal, high-voltage electrical, and/or fractures with burns may cause a muscle compartment syndrome and require urgent fasciotomy to restore circulation. The signs of ischemia may include pain (with passive or active range of motion), pallor, paresthesia, poikilothermia, and sensorimotor dysfunction; they must be acted upon promptly and reassessed often. Once fluid resuscitation and edema ensue, pulses may be lost owing to an elevated compartment pressure, but this is a late sign. Tissue edema commonly increases over the first 48 hours after injury. One should perform a compartment release (escharotomy or fasciotomy) when the compartment (tissue) pressure exceeds 30 mm Hg or when the tissue perfusion pressure (mean arterial pressure − compartment pressure) is less than 40 mm Hg.

Escharotomy can be performed at the bedside with scalpel and electrocautery. Scrupulous hemostasis should be achieved and reassessed at 30 to 60 minutes following release, as delayed bleeding can be significant. Escharotomies require adequate anesthesia to control the pain associated with the incision and hemostasis. Extensive escharotomies and fasciotomies require intravenous ketamine/midazolam or fentanyl and occasionally general anesthesia. Fasciotomy is usually best performed in the operating room because of the need to expose vital structures.

The forearm fasciotomy requires extension across the flexor retinaculum of the wrist to decompress the median and ulnar nerves within the carpal canal. Escharotomy sites can be dressed in sulfamylon-nystatin cream as prophylaxis against wound infection. However, the commercial cream tends to desiccate and destroy tissue. Fasciotomies that expose tendons, vessels, and/or nerves need a more physiologic dressing. Allograft irrigated with dilute Dakin's solution (0.005% to 0.025%)[42, 63] preserves tissue viability with superb antibacterial coverage until definitive flap closure can be performed.

Some key considerations must be noted. Inadequate resuscitation may lead to the mis-assessment of the vascular compromise as secondary to elevated compartment pressure because of the loss of pulses and/or Doppler flow. The presence of burns of the distal extremities interferes with the neurovascular assessment and monitoring of the resuscitation effort. This requires immediate attention with escharotomies if subeschar pressures are elevated. The eschar may act as a tourniquet with the effect of shunting blood centrally. Indicated or prophylactic escharotomy may further embarrass the patient's volume status, when the flow is restored to the extremities, if the patient is under-resuscitated.

Repeated pressure measurements are made in those burn injuries associated with a possible or a treated compartment syndrome. A Stryker pressure monitor is used every 6 hours during the first 24 hours following injury and then every 12 hours during the subsequent 24 hours, routinely and following every fasciotomy and/or escharotomy to ensure that an adequate release of the constriction has been effected. Although this extensive monitoring seemed excessive at first, it has resulted in the salvage of limbs whose initial releases were deemed adequate by postescharotomy pressure measurement. Brown et al[8] demonstrated this nicely in a survey of transferred patients in whom escharotomy was done at the outside facility and assessed on arrival to the burn unit.

SPECIFIC TRAUMA TYPES AND THEIR MANAGEMENT

Nonaccidental Trauma: Abuse and Assault

Nonaccidental trauma is defined as physical abuse, physical neglect, sexual molestation/abuse, and emotional maltreatment. The presence of multiple trauma must be assessed and worked up in an assault-provoked burn because of its moderate frequency in these patients, from 7% at LAC+USC to 16% elsewhere.[80] All patients admitted to the trauma and/or burn service with a clear history of assault or abuse and those with a questionable mechanism (an inconsistent or changing history by a caregiver) of injury should be evaluated by a physician in collaboration with the caregiving team for nonaccidental trauma regardless of the severity of the burn injury or the disposition of the patient.

The assessment of the burn injury for this purpose should note the location of a burn and its characteristics (e.g., shape, depth, margins). Scalding with a hot liquid is the most common type of abusive burn. Children and infirm adults are at highest risk because of their lack of ability to articulate a history. Young infants are typically scalded by immersion, whereas older children and adults are burned by having liquids thrown or poured on them. Symmetry, dependent location, and splash marks may indicate abuse in the child. Children instinctively withdraw from pain; therefore, burns that present with evidence of prolonged exposure are highly suspect. Other types of nonaccidental burn injuries may include contact with hot solids such as cigarettes, irons, heaters, and curling irons. Chemicals may be intentionally placed on a child to cause a burn, or a part of a child's body may be intentionally held over an open flame.

Skeletal survey in cases of suspected child abuse may reveal old fractures of ribs and long bones which may indicate previous suspicious injuries. Pelvic injuries are rare in children, and special attention should be paid to the ischiopubic rami, the most common site of these rare and indicative injuries.[1] Head CT is indicated in any patient with neurologic or developmental delay. Punctate hemorrhages or infarcts indicate "shaken baby syndrome" and are highly suspicious.

In California, as in many other states, health care practitioners are mandatory reporters of the disease known as nonaccidental trauma. We are responsible for understanding the reporting procedure of the laws in our region. Many of these laws have stiff penalties for those practitioners who fail to comply.

Orthopedic Injuries

Fractures are the most common nonthermal injury to complicate burns at our center and elsewhere, although the dominant mechanism of injury may differ.[95] Early surgical intervention in fracture management can be complicated by cardiovascular instability that can accompany massive fluid shifts in patients with large burns (Fig. 2). In general, however, the principles of fracture management conform to the standard principles of multiple trauma care, which include a systematic examination of all organ systems, initial immobilization of suspected fractures, cervical spine support of patients suffering MVA and electrical injuries, and the liberal use of DPL in evaluation of abdominal trauma.

Definitive fracture management, as without a burn, must take into account the amount and extent of the surrounding soft tissue damage. A vascular injury accompanying a fracture may be difficult to assess in the burned extremity, as are elevated compartment pressures. Upon arrival in the trauma/burn center, all of the cutaneous burn wounds are débrided and a careful assessment is made of extent and depth. An orthopedic consultation for fracture management should be procured early in the work-up.

The decision of how best to manage each fracture is made jointly by the burn/trauma surgeon and the orthopedist. For each patient therapeutic intervention is based on several considerations, including (1) the stability of the fracture and the need for its reduction and immobilization; (2) the access needed for burn wound hydrotherapy and dressing; (3) the requirements for the excision and grafting of the associated burn wounds; and (4) the most pivotal for a functional recovery, the effect of the management technique on the ability to institute aggressive physical therapy as soon as possible following the injury.

Fractures with overlying burns can complicate surgical reduction. Although fracture management varied, Wong et al[95] report that the only orthopedic complications that occurred were in the 15 of his 61 fracture patients who had associated overlying burns. Hardware placed through contaminated eschar may become infected and is, in general, contraindicated. The coexistence of a fracture and a burn in an extremity potentiates compartment compression and further tissue damage.[87] This may require escharotomy, fasciotomy, and occasional nerve tunnel (carpal) releases for effective management. Casts placed over burned skin can deepen the injury and/or lead to a septic wound by interfering with wound care.[26]

Prior to the modern burn treatment of early excision and grafting, fractures with overlying burn were managed primarily using skeletal traction while the surgeon waited for the burn eschar to separate. This was suboptimal because of the difficulty it caused with burn wound care, patient mobilization, and pin site infection.

In general, amenable extremity fractures at a distance from the burn wound are managed with reduction of the fracture and application of a cast. Choctaw et al[12] successfully used primary burn excision and grafting followed by a plaster cast to immobilize a closed extremity fracture with an overlying burn. However, this is an isolated and dated report, whereas internal and external fixation techniques have replaced casting when fracture instability or soft tissue injury complicates the picture.

Skeletal traction is used infrequently because of the immobility it produces. However, in a patient with large burns, a severe inhalation injury, or unstable cardiovascular status, fracture(s) may be initially treated with a traction splint or traction using Steinmann pins. Occasionally traction used in a lower extremity fracture, because of the suspension it provides the limb, may actually help provide access to the burn wound without compromising other aspects of patient care.

In the management of bone injuries located directly beneath an overlying burn, internal fixation surgery should be performed within 48 hours of the burn injury. The burn wound covering or adjacent to the fracture site is managed by early excision and grafting at the time of the orthopedic procedure or on the following day. Closed fractures and low-energy open fractures (Table 5A) may be stabilized internally on an elective basis, with respect to the burn injury, if they are not subjacent to an overlying burn. Satisfactory healing of the fractures and incisions without difficulty should be expected in these fracture types both with and without an adjacent burn.[87]

External fixation is the procedure of choice in managing high-energy open fractures (Table 5B) associated with significant soft tissue injury (e.g., type III tibia/fibula fractures). It can be used to stabilize fractures of the extremities that are in proximity to thermal injuries. The fixation pins can be placed through the cutaneous burn wound, but care should be taken to locate them outside of the kinetic zone of injury (Fig. 2). The pins are connected by means of a Hoffmann apparatus to provide stability across the fracture site. Routine wound care with early excision and grafting is used to manage the associated thermal injuries. However, as in the majority of cases without a burn, extensive débridement

Table 5. ENERGY OF EVENTS CAUSING SKELETAL TRAUMA

A. Energy Dissipated in Injuries

Injury	Dissipated Energy (ft-lbs)
Fall from a curb	100
Skiing injury	300–500
High-velocity gunshot wound	2,000
Automobile bumper collision at 20 mph	100,000

B. Classification of Open Fractures

Grade 1	Skin opening of 1 cm or less, quite clean, Most likely from inside to outside. Minimal muscle contusion, simple transverse or short oblique fractures.
Grade 2	Laceration more than 1 cm long, with extensive soft tissue damage, flaps, or avulsion. Minimal to moderate crushing component. Simple transverse or short oblique fractures with minimal comminution.
Grade 3	Extensive soft tissue damage including muscles, skin, and neurovascular structures. Often a high-velocity injury with a severe crushing component.
	3A Extensive soft tissue laceration, adequate bone coverage. Segmental fractures, gunshot injuries
	3B Extensive soft tissue injury with periosteal stripping and bone exposure often associated with massive contamination
	3C Vascular injury requiring repair

C. Classification of Closed Fractures with Soft Tissue Injuries

Grade 0	Minimal soft tissue damage. Indirect violence. Simple fracture patterns. Example: torsion fracture of the tibia in skiers.
Grade 1	Superficial abrasion or contusion caused by pressure from within. Mild to moderately severe fracture configuration. Example: Pronation fracture-dislocation of the ankle joint with soft tissue lesion over the medial malleolus.
Grade 2	Deep contaminated abrasion associated with localized skin or muscle contusion. Impending compartment syndrome. Severe fracture configuration. Example: Segmental "bumper" fracture of the tibia.
Grade 3	Extensive skin contusion or crush. Underlying muscle damage may be severe. Subcutaneous avulsion. Decompensated compartment syndrome. Associated major vascular injury. Severe or comminuted fracture configuration.

A from Browner BD, Jupiter JB, Levine AM, et al: Skeletal Trauma: Fractures, Dislocations, Ligamentous Injuries. Philadelphia, WB Saunders, 1992, p 312–314; *B from* same source as *A*, as modified from Bone L, et al: J Bone Joint Surg 71A:336–340, 1989; *and C from* same source as *A*, as modified from Chapman MW (ed): Operative Orthopedics, vol 1. Philadelphia, JB Lippincott, 1988, pp 161–172; with permission.

followed by local muscle flaps and/or free tissue transfer is usually required to manage the soft tissue and bone losses surrounding the fracture.[19, 29, 94]

In summary, the timely management of fractures is warranted because unstable orthopedic injuries are major contributors to patient morbidity. Realize that early excision and grafting of the burn wound with internal and/or external fixation of the fracture permit optimal mobilization and wound care.[81] A multidisciplinary team approach is used to prioritize these therapeutic interventions for the best functional outcome. Antibiotic coverage appropriate to the orthopedic injury is given. A prolonged orthopedic procedure and subsequent large burn procedure are best done on separate days. One can apply this method to progressively larger burn wounds that require multiple excisions, such that, with the use of flaps and biologic dressings, one can achieve an early functional wound coverage with timely fracture fixation.

Thoracic Injuries

Life-threatening injuries of the thorax associated with blunt or penetrating trauma in conjunction with a burn are managed as if the burn did not exist. These injuries are usually apparent at the time of the primary and secondary surveys done in the ED and require prompt action. Chest tubes are placed through normal skin, if available, to reduce the risk of empyema.[79] Chest tubes placed through burned skin are removed at the time of early excision and grafting and replaced through a grafted area. Thoracotomies for management of parenchymal or chest wall hemorrhage are less prone to dehiscence than are sternal incisions. Rib cartilage and bone subjected to thermal injury should be débrided at the time of thoracotomy or early excision and covered with a muscle flap, usually the latissimus dorsi. Burns over a median sternotomy should be excised (if full or deep partial thickness) and skin grafted at the time of initial surgery. If there is insufficient subcutaneous tissue for adequate coverage of the sternal split or fracture, pectoralis flaps can be rotated to provide vascular soft tissue coverage for skin grafting.

Consideration should be given to chest wall compliance, which may be severely decreased by the presence of an overlying burn, even if it is not totally circumferential. Escharotomies may be required to obtain an adequate tidal volume without excessive airway pressures.

Pulmonary contusion may accompany inhalation injury and/or a severe burn. Here one might err in giving the patient the minimal volume possible so as not to exacerbate the lung injury. However, it is well established that an under-resuscitation of the burn-injured individual actually increases lung water accumulation[43] and pulmonary edema,[96] which increase morbidity and mortality.

Abdominal Injuries

Significance

In our center, about 4.5% of combined injury patients have a significant abdominal injury. This seems to be a relatively stable phenomenon over the last 20 years in civilian burn centers in the United States, with a 5% rate of significant abdominal trauma reported in the last large series of patients reviewed.[82] An older series representative of the differences seen with war injuries reported that 20% of their multiple trauma burn patients had abdominal injuries that required emergent surgical intervention.[78] In addition, many burn patients manifest abdominal signs consistent with gastrointestinal,[68] biliary,[33] and pancreatic[86] inflammation during the acute and convalescent phases of their care. Most of these patients require surgery for these conditions or for long-term enteral access.[33]

Diagnosis of Acute Injury

The diagnosis of intra-abdominal blunt injury requires emergent celiotomy and is complicated by the burn injury. In a patient with a large burn injury, the abdominal examination is often unreliable. In addition, the hematocrit changes and the vital signs are as likely caused by the burn and the resuscitation it requires as by an intra-abdominal hemorrhage. This situation requires a confirmatory test(s) to decide two things: (1) if an abdominal operation is likely to help the patient and (2) the priority of exploration when multiple body cavities are involved in the injury contributing to shock.

The choice of which one or which combination of the three most reliable tests—DPL, CT, or ultrasonography—depends largely on the comfort of the physician, the acuity of the patient, and evidence of previous abdominal surgery. In the only prospective randomized study in which all three modalities were used in the ancillary diagnosis of blunt abdominal trauma, the three were found to be nearly equal in sensitivity, specificity, and accuracy, and were complementary in reducing the incidence of missed injuries.[52] In our center, in the quasi-stable patient or the patient who is being taken to surgery emergently for an extra-abdominal injury, we rely heavily on DPL to assess the need for exploration. In the otherwise stable patient, CT is our workhorse and is followed by DPL or celiotomy for equivocal findings. We are currently using ultrasonography to aid in the diagnosis of acute cardiac tamponade in both penetrating and blunt injury patients. However, as our familiarity has increased so has our reliance on ultrasonography for the assessment of intra-abdominal fluid. Ultrasonography, like physical examination, can be applied serially by the skilled surgeon or ED physician to increase its overall diagnostic accuracy with respect to significant abdominal injury.[52]

In no other patient population does a nontherapeutic celiotomy for trauma have a higher cost-benefit ratio, while at the same time no other missed injury has a more devastating outcome for the patient. The tenuousness of the large burn patient during the resuscitation, coupled with the life-saving efficacy of early enteral nutrition, must be on the minds of all those responsible for the acute operative management of these patients. Once the decision for exploration is made, closure and maintenance of abdominal wall continuity must be considered. Abdominal wall dehiscence in burn patients is frequent, secondary to a long-lasting (>4 weeks) healing diathesis, whether or not the burn was traversed by the abdominal incision.[33] As a result, several guidelines are offered:

1. Paramedian incisions should be avoided because of their higher incidence of dehiscence.[33]
2. Consideration should be given to temporary prosthetic closure in the face of massive bowel edema (we use a filet 3 liter IV bag) to avoid the use of retention sutures.
3. Closed technique for DPL should be used in the major burn patient.
4. Buried retention sutures should be used when the abdomen can be closed.

Abdominal Complications of Burns

Abdominal sepsis following a burn is also difficult to diagnosis and can be attributed to missed injury (bowel, pancreas, liver), acalculous cholecystitis, pancreatitis, ischemic bowel, and intra-abdominal abscess. DPL has a reported diagnostic accuracy of 94% in thermally injured patients, with negligible complications related to the DPL. This procedure safely and reliably discriminated between patients needing urgent celiotomy[68] while avoiding the stability and transport issues involved with CT scan. If intra-abdominal abscess is suspected, CT can be both diagnostic and therapeutic (catheter drainage), often obviating re-exploration in this setting.

As survival has increased for large burns, so has the incidence of rare complications of this injury. The risk factors for pancreatitis developing in the thermally injured patient are, in order of importance, inhalation injury, associated trauma, and the need for escharotomy. This places combined injury patients at higher risk for pancreatitis to complicate their recovery. Burn patients with pancreatitis have increased mortality and length of stay. Those patients with high pancreatic enzyme elevations and greater than 50% TBSA burn have about a 43% risk of pancreatic pseudocyst or abscess development.[86] A high index of suspicion and routine inclusion of serum pancreatic enzyme analysis in the sepsis work-up aid in the early diagnosis and salvage of these patients.

Vascular Injuries

The acute assessment of vascular injury is further complicated by the systemic and local impact of the burn injury. Angiography remains the gold standard in the diagnosis of vascular lesions. Sensitive noninvasive tests such as duplex/Doppler ultrasound scanning and ankle-brachial index (ABI) are used to screen likely patients and allow a more selective application of angiography if there is a surgical need for its specificity. Problems can arise with the ABI screening when inadequate resuscitation or compartment syndrome complicates the postinjury period. Adequate resuscitation and escharotomy must be assured before ABI can be interpreted. Angiography in the face of hypovolemia may lead to acute tubular necrosis and renal failure.

Both hollow viscus and burn injury connote a high risk for infection with vascular repair and/or reconstruction procedures. Problems with contamination of grafts, both autologous and synthetic, confer a high morbidity and mortality. Evans et al[30] have extended the lessons learned in treating bone infection with muscle flaps to the problem of vascular graft infection with surprising success. One should consider the further extension of this philosophy to the immediate prophylactic use of a muscle flap to cover contaminated grafts, in conjunction with a bactericidal topical treatment such as dilute Dakin's solution (0.005% to 0.025%) prior to closure. Electrical injuries of the extremities, particularly the wrists, present a situation in which an acute flap and revascularization may be required to preserve limb function. Here one could use a free flap that also serves as the vascular reconstruction, such as the contralateral radial forearm flap with the radial artery as the flow-through conduit. Extra-anatomic bypass remains an option only if the route is not within the zone of injury.

Neurologic Trauma

The putatively unstable cervical spine injury can be temporarily immobilized by means of a rigid cervical collar until the cervical spine work-up is complete. True unstable cervical fractures are best treated with the application of traction/stabilization via halo or tongs. Pins are placed through the burn if necessary, followed by meticulous pin site care and early excision.

The neurosurgical approach to an intracranial lesion may require transversing burned tissue. Full-thickness scalp and bone débridement is carried out at the time of the neurosurgical procedure if they are nonviable from the burn injury. Closure of the defect requires a watertight seal of the dura; tensor fascia lata or rectus fascia is a suitable dural substitute. Dura and bone flaps need an overlying vascular tissue to allow them to heal. Pericranial, scalp, and free fascial or muscle flaps can be used to bring robust vascular tissue to cover the operative closure. Muscle should never be in direct contact with the cerebral parenchyma, as this is known to create a potential epileptic focus. Bleeding bone and fascia granulate and can be closed with autograft skin. Esthetic concerns are secondary to a functional closure of the wound. Revision options, however, should be planned at the time of the original procedure so that no unnecessary reconstructive bridges are burned in effecting early closure.

After resuscitation and decompression of space-occupying lesions, the reduction of intracranial hypertension and maintenance of cerebral perfusion pressure (CPP) are key elements in the prevention of secondary brain injury.[83] Intracranial pressure (ICP) monitors are used on all patients with closed head injury and a Glasgow coma score less than 8 and in selected patients who require an emergent neurosurgical procedure. Ideally, the ICP monitor should be placed through unburned scalp. However, the acuity of the closed head trauma patient demands ICP monitoring for at least 48 hours after injury, and burned scalp is used if nothing else is available. Using a bolt or fiberoptic type of monitor rather than a true venticulostomy tube allows a greater choice of placement sites and lower morbidity. Prophylactic antibiotics are given with all ICP monitoring. The antibiotics given for this purpose are tailored to their ability to cross the blood-brain barrier and their coverage of the "usual" gram-positive and gram-negative organisms isolated in the burn unit. ICP and CPP management is discussed in the intensive care unit (ICU) section.

Inhalation Trauma

Significance

Exposure to the particulate and gaseous products of incomplete combustion (smoke) imparts the most lethal injury associated with a burn trauma. Mortality attributed to fire-related inhalation injury ranges from 30% to 90%.[17] In one autopsy study, 70% of burn victims dying within 12 hours of admission had inhalation injury.[97] Although some investigators have measured up to 50 different compounds[2] in the blood of fatally smoke-exposed individuals, these can be classified into three broad chemical constituents: asphyxiants, systemic toxins, and irritants.

Clinically there is synergistic effect between the inhalation trauma and the burn, which has its greatest effect in those burn injuries associated with a mortality of 40% to 60%. Thirty-eight percent of all patients with inhalation trauma develop pneumonia, compared with only 8% in those patients without an inhalation component. This increases to 48% with moderate to severe inhalation injury as diagnosed by bronchoscopy. Overall, inhalation trauma alone has been reported to result in an increase of 20% in mortality. The addition of pneumonia to the parenchymal insult increases mortality by 60%.[15] In our burn center patient experience, the addition of multiple trauma to this population doubled the mortality of an inhalation injury.

Mechanism of Inhalation Trauma

The inhalation injury can be thought of as a *three-hit model* of injury based on the pathophysiology of the injury and its anatomic distribution. The first is a thermal component related to the deposition of heat in the upper airway by inhaled hot gases and particles. A thermal airway injury is rarely manifest below the vocal cords owing to the efficient heat exchange that the filtering and humidification mechanisms of the upper areodigestive tract provide. However, at extreme temperatures or in high heat capacity environments such as steam (approximately 4000 times the heat-carrying capacity of dry air[17]), direct thermal tracheal burns are seen. The second is the inhalation of CO and hydrogen cyanide (HCN), systemic toxins that bind hemoglobin and cytochromes. CO has 200 times the affinity for hemoglobin that O_2 does and shifts the dissociation curve to the left. This combined effect of CO severely limits O_2 delivery to the tissues. Both CO and HCN bind to cytochromes in the mitochondria and inhibit the utilization of O_2, resulting in anaerobic metabolism, and are responsible for the early deaths from asphyxiation. Exposure to asphyxiants such as CO and HCN is the most common cause of early mortality at the scene following smoke inhalation. Many of these patients succumbing to early deaths have little or no thermal injury! The third is a chemical burn component related to the corrosive gases and chemical irritants adsorbed to the minute carbonaceous particles (≤ 5 μ) that are deposited well below the cords into the tracheobronchial tree. These particles elute their contents over time into the trachea, bronchioles, and alveoli, causing a pernicious chemical burn. This chemical injury is thought to be propagated by free radical intermediates.[21, 47] One early manifestation of the chemical component is injury to the type II pneumocytes, resulting in depletion of surfactant and resultant alveolar collapse.

Diagnosis

A history of the event causing the burn and the trauma is essential to assessing the risk of inhalation injury (see Table 3) and its proper management. The diagnosis of a smoke inhalation injury is made more complex in the presence of multiple trauma. Patients with head trauma and a clouded sensorium obscure the physical findings associated with CO poisoning. Further, the thermal and asphyxiant components manifest early after injury, whereas the chemical injury may take several days to become apparent.[17] Bronchoscopic reassessment of all patients suspected of inhalation injury should continue for 48 hours after injury. A low or progressively falling PaO_2/FiO_2 ratio (less than 300 suggests pulmonary dysfunction) should prompt bronchoscopic evaluation and a low threshold for intubation. Stridor and noisy breath sounds are late signs suggestive of inspiratory obstruction and require emergency institution of orotracheal or nasotracheal intubation. In a critical upper airway obstruction, a single attempt should be made to pass an orotracheal or nasotracheal tube. If the attempt is unsuccessful, one should not make further attempts to intubate using muscle relaxers but should instead perform an immediate cricothyroidotomy.

Some authors have correlated serum calcitonin levels with the presence, degree, and prognosis of inhalation injury.[72, 76] Elevated calcitonin levels may persist for years after the injury,[71] even in asymptomatic patients. Despite the high sensitivity of this test for inhalation injury, it remains investigational and is not available in most centers for the acute diagnosis.

Treatment Methods

Ventilation. All patients should be placed on a high-frequency percussive ventilator (HFPV)—Percussionator VDR-4 (Bird Space Technology, Sandpoint, Idaho) (Fig. 3), as it is currently the only treatment method proven in humans to lower the morbidity and mortality of an inhalation injury.[84] Prophylactic use of HFPV in patients with inhalation injury resulted in a lower morbidity and mortality for patients.[18, 84] A study comparing two methods of high-frequency ventilation and one method of conventional ventilation demonstrated decreased

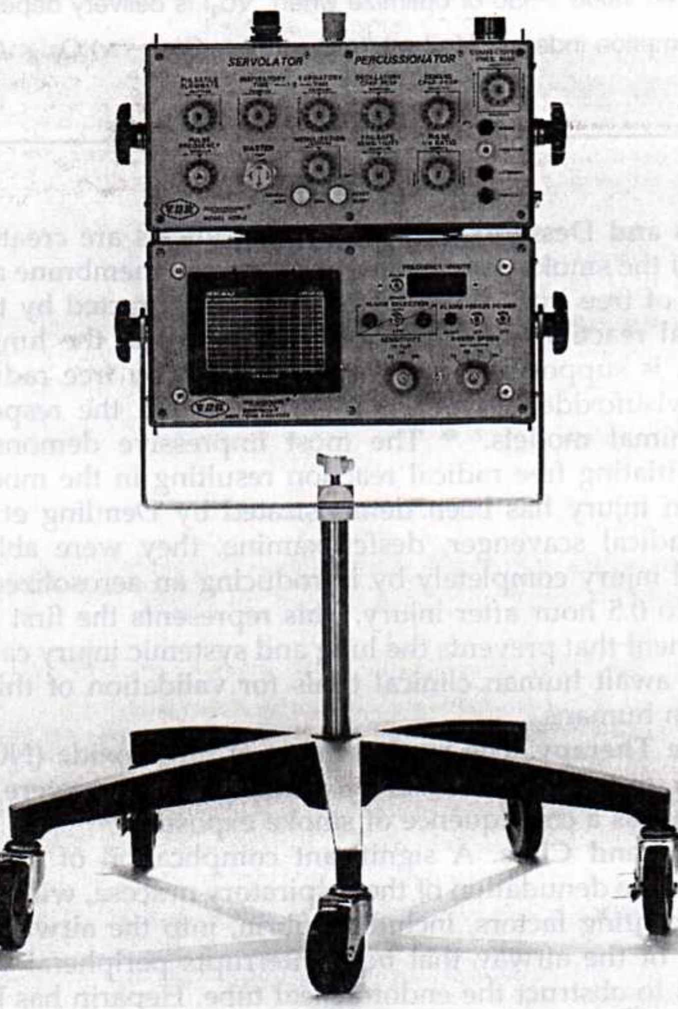

Figure 3. The Percussionator (Bird Space Technology, Sandpoint, ID), a high-frequency percussive ventilator. (Courtesy of Percussionaire Corporation, Sandpoint, ID.)

pulmonary damage in primates with inhalation injury treated with HFPV.[14] HFPV helped prevent pneumonia and reduced the mortality from the pneumonias that did occur.[84] In ARDS, HFPV improves intrapulmonary shunt (Qsp/Qt) with a significantly lower peak inspiratory pressure and slight lower pulmonary end-expiratory pressure (PEEP) and airway pressure (mean),[23, 45] resulting in reduced barotrauma.

Patients are initially treated with 100% O_2 for presumed CO and CN inhalation and circulatory shock. PEEP and oscillatory continuous positive airway pressure to total 10 to 12 cm H_2O are used with FiO_2 sufficient to maintain arterial oxygenation between 70 and 100 mm Hg once the asphyxiants have been cleared. Best PEEP is chosen to maximize SvO_2.

Prophylactic steroids or antibiotics are inappropriate for the treatment of inhalation injury. An indwelling arterial cannula should be inserted to monitor blood pressure and to facilitate frequent monitoring of blood gases. A Swan-Ganz catheter is used to measure pulmonary wedge pressure, cardiac output, stroke work index, pulmonary vascular resistance, O_2 delivery and consumption (Table 6), and PvO_2.

Table 6. OXYGEN DELIVERY AND CONSUMPTION

O_2 delivery index = Do_2 I mL/(min · m²) = $CaO_2 \times CI \times 10$
Normal value = 520–720
Preferred value >550 or optimize when Vo_2I is delivery dependent
O_2 consumption index = Vo_2I mL/(min · m²) = $C(a - v) O_2 \times CI \times 10$
Normal value = 110–140
Preferred value >170–200

O_2 Radicals and Desferoxamine. Oxygen radicals are created de novo by the interaction of the smoke constituents with the cell membrane and accelerated by the presence of free iron. White blood cells are attracted by the products of these free radical reactions and inflict further injury to the lung parenchyma. This mechanism is supported by experiments done by free radical scavengers such as dimethylsufoxide (DMSO), which modulated the response to smoke inhalation in animal models.[7, 46] The most impressive demonstration of the control of the initiating free radical reaction resulting in the modulation of the smoke inhalation injury has been demonstrated by Demling et al.[25] Using an iron and free radical scavenger, desferoxamine, they were able to eliminate the parenchymal injury completely by introducing an aerosolized starch-linked preparation up to 0.5 hour after injury. This represents the first pharmacologic postinjury treatment that prevents the lung and systemic injury caused by smoke inhalation.[51] We await human clinical trials for validation of this exciting life-saving therapy in humans.

Nitric Oxide Therapy. The modest effect of nitric oxide (NO) on the lung vascular smooth muscle appears to be limited by the severe inflammatory changes that occur as a consequence of smoke exposure.[73, 75]

Transudation and Clots. A significant complication of smoke inhalation injury arises from the denudation of the respiratory mucosa, with the subsequent transudation of clotting factors, including fibrin, into the airways. These products form a cast of the airway that both interrupts peripheral ventilation and can be dislodged to obstruct the endotracheal tube. Heparin has been shown to decrease these endobronchial fibrin cast formations, with resulting improvement in oxygenation and reductions in barotrauma and pulmonary edema in an ovine model of severe smoke inhalation injury. Heparin, however, does not reduce oxygen free radical activity after smoke inhalation injury.[21] Further, by inhibiting clot formation one can eliminate fibrin degradation products that are thought to contribute to the development of shock lung.[34] Heparin may be given either intravenously or as an inhaled aerosol to have its clinical effect, but its systemic use must be weighed against the risk of bleeding. Our anecdotal experience, as well as that of others, is that the aerosol reduces the tenacity and frequency of clots in patients with smoke inhalation. Blood rheology may also contribute significantly to the pathophysiology of inhalation injury. The improvement of pulmonary function following treatment with pentoxifylline suggests that this agent may be useful in the management of smoke inhalation injury.[74]

Electrical Injury

Electrical injuries account for 3% to 12% of burn admissions,[52a, 87a] with a mortality of 3% to 15%. The cutaneous manifestations of electrical burns are usually far less than the internal destruction caused by the current flow. Block et al[4a] demonstrated that the damage inflicted by current flow is not one of joule heating but rather that of the electroporation of the cell membrane with subsequent rupture. The injury to soft tissue, particularly muscle, manifests itself clinically as rhadomyolysis and compartment syndrome. The release of myoglobin damages the kidney, therefore requiring supernormal resuscitation fluid volume and osmotic diuretics.

Prophylactic use of drugs that effectively cover the pores, such as dextran, may avert the soft tissue sequelae in these injuries. However, once the diagnosis of compartment syndrome is established, release and débridement are the initial surgical treatments. The use of cadaver skin and irrigation with nondestructive antibiotic solutions (Dakin's) as interim wound treatments allows preservation of vital structures such as nerves and tendons.

One should not use Sulfamylon cream as a dressing for these open wounds, as it causes desiccation and destruction of tissue. One should never débride nerves even if they appear damaged, as recovery of their function is the rule rather than the exception. The incidence of immediate neurologic findings in electrical burns ranges between 25% and 67%, with loss of consciousness being the most frequent finding (as high as 45%). Loss of consciousness usually resolves prior to admission in 79%.[11] As with all burn injuries, rehabilitation therapy must be given as early as possible after the injury so that patients may return to their normal place in society.[40]

CRITICAL CARE ISSUES AND ICU MANAGEMENT

Individual Optimization of Resuscitation

Individualization of the resuscitative regimen has been recognized as essential for a successful outcome for burn and trauma patients. Although the "formulas" for fluid therapy draw on different clinical and experimental results and philosophies to define their starting points, they all are titrated by an iterative process tied to vital signs and urine output. Given the mind-boggling combinations of injuries and the elegant simplicity of this iterative solution, which saves lives, one can appreciate the tenacity with which practitioners hold to its contribution. But can we do better? If we are correct in our starting point, then perhaps changing to more physiologically global endpoints would allow further refinement and improvement in outcome.

In a person with a 50% BSA burn, the cardiac output drops to 50% of the preburn level by 1 minute after burn and to 33% of the preburn level by 1 hour after burn. Because this fall in cardiac output is so rapid after a large burn and is attributed primarily to a transudation hypovolemia, a very high priority is given to the establishment of intravenous access for fluid replacement. A confounding issue, however, is that a decrease in cardiac contractility has been known to occur following burn and is attributed to a putative circulating myocardial depressive factor.[26] Recently, cardiac ultrasound investigation of burn and trauma victims has isolated this effect as a profound depression of left ventricular (LV) diastolic function that occurs following thermal injury but not following multiple trauma.[50] Further, the underresuscitation of a burn and associated smoke inhalation result in more serious pulmonary dysfunction and lung water accumulation.[26, 96] If one considers the tremendous fluid shifts, the cardiac and pulmonary dysfunction, and the attendant hypermetabolic state as manifestations in the continuum of a burn-induced systemic inflammatory response syndrome (BI-SIRS), then optimization of oxygen delivery and consumption may have a role in guiding initial resuscitative treatment. It is no surprise, then, in retrospect, that urine output and near-normal vital signs may not be reliable monitors of adequate burn resuscitation[27] or reciprocally that Swan-Ganz–monitored patients who survived their major burn averaged 48% more fluid than their Parkland burn budget estimated, whereas nonsurvivors averaged 25% more with no difference in urine output between the groups.[88] Schiller et al[88] have gone one step further, however, in that they have demonstrated for their patient population a reduced mortality, from 48% to 10%, in comparable groups of severe burn patients by optimizing to supernormal indices.

Therefore, virtually all severe burns (Table 7) and most moderate burns require Swan-Ganz monitoring for optimal fluid resuscitation.[27] Although urine output is helpful in the ED or admitting area, it is a rather inexact method for judging the adequacy of fluid therapy. It is our experience that deep scald burns, burns with inhalation injury, and burns associated with trauma can require up to 300% the estimated fluid requirement prescribed by the Brooks and Parkland formulas.

Optimization of VO_2I and DO_2I (see Table 6) requires a Swan-Ganz catheter, although the indices can be measured using indirect calorimetry in patients without a Swan-Ganz monitor. Fluids are given to increase the cardiac index and blood is given to increase oxygen-carrying capacity and to provide a delivery (DO_2I) that allows a venous oxygen saturation greater than 65%. In general, hypovolemia is corrected (pulmonary artery wedge pressure >10 and central venous pressure >5) prior to starting inotropes; however, a renal dose of dopamine (3 μg/min) can be started after the initial bolus to assist in splanchnic

Table 7. CLASSIFICATION OF BURNS ACCORDING TO RISK*

Minor burns

Total burn area† of <15% BSA‡ (<10% in children <10 years or adults >40 years)
Third-degree burns of <2% BSA
Usually receive outpatient care§

Moderate burns

Total burn area of 15%–40% BSA (10%–30% in children or adults >40 years)
Third-degree burns of 2%–10% BSA
Burns to hands, face, feet, eyes, ears, or perineum which are a functional or cosmetic risk to the patient
Selected minor burns in poor-risk patients (age <5 or >60 years, having intercurrent diseases such as diabetes and heart disease) **usually receive ward care, although patients who do or might require escharotomies for circumferential burns, or those with burns of 25% to 40% may be best cared for in the ICU, at least for a few days.**

Critical burns

Total burn area of >40% BSA (>30% BSA in children)
Third-degree burns of >10% BSA.
Burns associated with actual or possible inhalation injury or with high-voltage electrical injury, fracture, or other major trauma
Selected moderate burns in poor-risk patients (age <5 or >60 years, having intercurrent diseases such as diabetes and heart failure) **receive ICU care.**

**Data from* Specific optimal criteria for hospital resources for care of patients with burn injury. American Burn Association, April, 1976; and Hospital and prehospital resources for optimal care of patients with burn injury. J Burn Care Rehabil 11:98–104, 1990.

†Areas of first-degree burn are not included in total burn area.

‡BSA = body surface area.

§Even if relatively small and of minimal risk, patients with third-degree burns that are likely to eventually require grafting should be admitted to ward care for consideration of prompt excision and skin grafting.

perfusion. Low-dose dopamine is also extremely useful in decreasing the fluid requirements in spinal shock associated with a high cord injury.

The use of dopamine and blood in acute burn resuscitation has had its detractors in public forums and in the literature,[35, 37] yet their arguments are usually based on the "potential" problems and lack optimization goals for oxygen delivery and consumption. We contend that the side effects of any therapy which attend the desired response should determine its clinical utility. One can mitigate the undesirable effects of inotropes by using them after adequate blood volume has been established. One must remember that transfusion may carry a risk aside from the transmission of disease. Although a relationship exists between the number of transfusions received and infectious morbidity, which is independent of age or burn size, no significant relationship exists between number of transfusions and burn mortality.

Special Fluid Therapy

Experimental evidence comparing crystalloid (LR) and hypertonic solutions (HLR) with and without protein colloid showed that the optimal composition of a burn resuscitation fluid, with respect to tissue edema, total fluid requirement, and cardiac function, is LR and albumin.[10] In extremely large burns (>70%), our resuscitation fluid composition after the first 6 to 8 hours following burn favors albumin.

Matsuda et al used sodium ascorbate in an isomolar effusion (154 mmol Na^{+1}) instead of LR and albumin in animals[59–61] and humans (personal communication, 1995), with the result of reducing the fluid volume required for resuscitation by greater than a factor of than 2 to 4. The mechanism is assumed to be inhibition of the leak[58] (and thereby protein loss) by downregulation of the O_2^{-2} and OH^{-1} free radical pathways.[62] This therapy must continue for at least 8 hours to maintain adequate hemodynamic stability in the presence of a reduced resuscitation fluid volume.[90] In a recent abstract, Tanaka et al[91] showed that high-dose vitamin C (sodium ascorbate) given at 4 grams/hr/60 kg as a 130-mEq (25 mg/mL) solution significantly reduces the required fluid volume needed to resuscitate burn patients with severe burns (>30% TBSA) from 6.1 to 2.7 mL/% burn/kg with equivalent blood pressure, heart rate, arterial pH, base excess, central venous pressure, and urinary output. The retained fluid per percent of burn was also significantly reduced from 4.5 to 1.9 mL/kg/% burn, which represents a substantial reduction in the edema formation side effect of resuscitation.

Sepsis Management

Invasive Monitoring and Intravenous Line Change Protocols

All lines placed in the ED or operating room are removed or are changed over a wire within 24 hours after admission because of the high contamination rate (>15%).[31] We currently change lines over a wire every second day, with a new site every eighth day; however, this may be excessive, especially through nonburned skin.[20] A more reasonable protocol is to change the site only if the catheter site is purulent or erythematous or if the catheter is culture positive from a previous change. Otherwise one should change the catheter over a wire only when catheter sepsis is suspected on clinical grounds. Routine changes are avoided, as are the costs and the preventable mechanical and infectious complications associated with them.[20] We culture every catheter tip removed but obtain blood cultures only for fevers greater than 102°F or for multiple soft signs of sepsis. A positive catheter sepsis is counted when both the line and the blood are positive for the same organism.

Nutrition

Enteral feeding is second only to proper fluid management in improving the survival and reducing septic complications of a major burn. It is of such high priority that it should be considered part of the resuscitation regimen. A nasogastric tube should be placed upon admission, and after adequate degassing of the stomach tube, feeding should be started. An 80 to 100 : 1 calorie to nitrogen ratio formula with omega-3,6 fatty acids, glutamine, and fiber is desirable and has been shown to reduce translocation and septic complications.[55] Mainous et al[55] demonstrated the safety and efficacy of immediate enteral feeding in patients with major thermal injury and found this practice to be applicable to a wide variety of other critically ill patients.

Feeding jejunostomy tubes should be used in all abdominal trauma patients unless an absolute contraindication is present. These patients had not been thought to be candidates for enteral nutrition because of unfounded fears related to the presence of ileus or fresh gastrointestinal anastomosis. Gastric residuals are measured every 4 hours and feedings are withheld when they exceed 150 mL. Persistent residuals early in treatment require motility enhancement by the graded use of metoclopramide, cisapride, or intravenous erythromycin, in that order. Residuals later in the course of treatment are similarly treated, but it must be remembered that intolerance to feeding may be the harbinger of a septic event. Prophylaxis for ulcer appears to be unnecessary in patients fed via gastric tube (our unpublished data), but it is required in patients fed below the pylorus.[16]

Matsuda et al[57] advocate that resting energy expenditure (REE) be measured at regular intervals in individuals with open burn wounds greater than 10% BSA in order to adjust nutritional support appropriately. Milner et al[66] demonstrated that the REE remains significantly elevated long into the rehabilitation phase, with the REE returning to normal values 100 to 150 days after burn in patients with smaller burns (20% to 40%) and as long as 250 days after injury in those with larger burns (> 75%).

Prophylactic Antibiotics

Burn patients, multiple trauma patients, and patients undergoing major surgical operations often suffer from acquired immunologic deficits that predispose them to life-threatening sepsis.[69] Burn wounds are sterile for about 48 hours after burn and thereafter become colonized. The routine use of prophylactic antibiotics in burn patients is limited to topical wound care, and this practice had made life-threatening wound sepsis a rare event. We supplement our topicals (silver sulfadiazine and Sulfamylon) with nystatin powder, which has reduced the *Aspergillus* infection rate in our units. Prophylactic intravenous antibiotics for burn wound care are used only perioperatively and are limited to the first 48 to 72 hours after operation unless another indication is present (Table 8). Our usual regimen is intravenous cefazolin for burns less than 25% and amikacin, vancomycin, and fluconazole for patients with greater than 25% burn or extremes of age. Topical nystatin use was associated with a decrease in

Table 8. INDICATIONS FOR INTRAVENOUS PROPHYLACTIC ANTIBIOTICS IN BURN PATIENTS

Sexually transmitted disease risk
Orthopedic injury or surgery
Neurosurgery or injury with elevated intracranial pressure and/or cerebrospinal fluid leak
Abdominal surgery
Chest surgery or chest tube placement
Perioperative burn surgery

fungemias and acquisition of yeasts in burn wounds, but with an increase in colonization and fungemias caused by nystatin-resistant, amphotericin B–susceptible *Candida rugosa*.[28] This led to a policy of perioperative use of fluconazole, 400 mg per day for no greater than 72 hours. The perioperative use of fluconazole has reduced the rate of fungemias on our unit.

Presumptive Infection Management

The diagnosis of an infection requiring treatment is difficult in burn patients because they routinely have SIRS in response to the burn injury, which manifests high fevers and elevated white blood cell counts. While the diagnostic work-up proceeds, typically one waits for two signs of generic and systemic infection prior to starting parenteral antibiotics therapeutically, for example, ileus and confusion, confusion and leukopenia, leukopenia and glucose intolerance, or high fever and confusion. In the very old and especially the very young, the index of suspicion must be higher and parenteral antibiotics must be started before waiting for a second sign of sepsis.

Bronchoalveolar lavage (BAL) is a cost-effective way to diagnose nosocomial pneumonia in surgical ICU patients.[22] It requires the cooperation of the microbiology laboratory to provide quantitative cultures on the washings. Croce et al[21a] have shown that this method can distinguish between nosocomial pneumonia and SIRS, thus eliminating the costs of treatment and morbidities.

Respiratory Management

All patients including children with a documented inhalation injury are started on the volumetric diffusive respiration (VDR) percussive ventilator on admission to the burn unit. Our initial settings are a respiratory rate of 15, PEEP total of 10 to 12 cm H_2O, peak inspiratory pressure (PIP) of 18 to 20 cm H_2O, inspiratory-expiratory ratio of 1:1, and high frequency rate of 500 subtidal volumes/min, or about 8 Hertz. The endotracheal tube cuff pressure is adjusted to create a small leak to aid in the egress of carbonaceous secretions. The cuff pressure is measured and recorded at frequent intervals. Adequate humidification is key to the safe use of ventilators, especially in high-flow conditions in which dry gases may precipitate concretions that obstruct the tube. The Concha humidifier and the Bird Injectron used together seem to provide an adequate solution to this problem in our burn patients.

Volutrauma and barotrauma probably contribute as much to the development of ARDS as does the underlying disease process. In an effort to avoid this additional insult to the patient, we try to limit the PIP to less than 40 cm H_2O on conventional ventilators. The mechanics of the VDR-HFPV are such that the actual intratracheal airway pressure is about two thirds of the value read on the machine, such that we become concerned with the measured airway pressures on this ventilator at about 55 cm H_2O. In volume ventilators, we use 5 mL/kg tidal volumes and adjust the respiratory rate to meet the minute volume, which maintains the desired Pa_{CO_2} level.

Gattinoni et al,[32] using a CT scanner, showed that the fluid accumulation of acute lung injury and ARDS is not distributed evenly, as one would suspect from the "white out" on the chest radiograph, but is greatest in the most dependent areas. Further, they demonstrated that with prone positioning of the patient the fluid moves to the most dependent area, now anterior, in about 6 hours. The best ventilation and lowest shunt for the patient occur when the patient is turned and prior to the fluid redistribution. Additionally, it should be realized that the lowest total lung capacity, residual volume, and reserve volume are realized with the patient in the supine position, and conversely the best values are achieved in the prone position.

Tracheostomy offers many advantages in the care of the intubated patient, and we are very aggressive in our trauma patients with respect to early tracheostomy. The benefits enjoyed in trauma patents, although also realized in burn patients with inhalation injury, are attended by rather significant complications in the latter group. The 30% incidence of complications (ulceration and tracheitis)—20% at less than 5 days, 45% at greater than 5 days[67]—in tracheotomized burn patients with inhalation trauma has led some authors to assert that an endotracheal tube is the preferred airway management long term.[43] Endotracheal tube complications are rare (subglottic stenosis, vocal cord damage, and nasal cartilage necrosis). If, however, the patient has significant sloughing of the mucosa, tracheostomy may be life-saving in the management of obstruction by simply removing and replacing the inner cannula.

The future of severe lung injury management lies in the management of the primary insult, either by removing the offending substances (VDR-HFPV), by quenching the free radical reactions (deferoxamine and vitamin C), or by downregulating the white cell response to injury. The use of intracellular adhesion molecule receptor binders, steroids, interleukins, and the like inflicts a global downregulation that may contribute to morbidity and mortality. Local white blood cell downregulation in the lung may be possible from an unlikely compound that may also be useful in the treatment of the ventilatory problem. Perfluorocarbons used as the oxygen carrier for liquid ventilation (full and partial) and blood substitutes are inhibitors of white blood cells in the lung and have been shown to obviate lung destruction in animal models.

Deep Venous Thrombosis and Pulmonary Embolism Prophylaxis

Some retrospective studies in burn patients suggest that the incidences of deep venous thrombosis (DVT) and pulmonary embolism (PE) are too low to justify the attendant complications of prophylaxis with low-dose heparin and leg squeezers.[85] True prospective studies are lacking, and evidence indicates that the incidence of thrombotic events may be as high as approximately 20% in high-risk trauma patients (our unpublished data).

Our practice for all burn and severe trauma patients is to use leg squeezers and to use heparin every 12 hours either by subcutaneous 5000 U bolus or slow intravenous infusion at 1 U/kg/hr unless a contraindication to heparin exists (e.g., intracranial bleeding). Those patients at high risk of DVT/PE (Table 9)

Table 9. RISK FACTORS FOR DEEP VENOUS THROMBOSIS AND PULMONARY THROMBOEMBOLISM

Trauma, especially lower-extremity fractures	Estrogen therapy
Burns	Advanced age
Immobilization	Antithrombin III, protein C, protein S deficiency
Neurologic injury	Malignancy
Sepsis	Inflammatory bowel disease
Prior history of thromboembolism	Paroxysmal nocturnal dyspnea
Hemoglobinuria	Nephrotic syndrome
Congestive heart failure	Lupus syndrome
Stroke	Lupus anticoagulant
Obesity, especially morbid obesity	Myeloproliferative disorder
Pregnancy	Abnormal plasminogen activity

who have a potential bleeding risk factor or have failed intravenous heparin therapy are treated with percutaneous caval filters or caval clipping at the time of exploratory celiotomy.

Pain Management

Pain management is an extremely important and difficult problem in burn[56] and multiply-injured patients.[53] Specific skeletal injuries of the thorax and lower extremities[92] may be well managed by an indwelling epidural catheter. However, the polytraumatized burn patient on a ventilator may require something more akin to general anesthesia with paralysis, amnestics, and opiates given by continuous drip.

Pain assessment is the key to good pain management. We use three different pain scales (Table 10), depending on the patient's ability to participate in his or her own care. Whenever possible, the management of pain should given over to the patient. Two of the management tools we use are visual analog scales, four poker chips for children, and a linear scale of 1 to 10 for adults. In preverbal patients less than 3 years of age and in patients with impaired mental status, we use an observer pain scale to titrate medication for pain. After the initial

Table 10. OBSERVER PAIN SCALE SCORE FOR NONCOMMUNICATIVE OR INTUBATED PATIENTS

Points	0	1	2
Vital signs EIR, BP, and/or RR	Baseline	>20% above baseline	>30% above baseline
Communication vocal (nonvocal)	0 (compliant)	Consolable cry (compliant with coaxing)	Moan/scream (resisting)
Facial expression	Relaxed	Tense	Twisted or grimacing
Posture	Neutral	Tense and/or extremities drawn up	Back arched and/or extended extremities
Agitation	Mild	Moderate	Severe

Total pain score: Severe = 7 to 10; moderate = 4 to 6; mild = 1 to 3 pain assessment, which must take into account the patient's present pain level and the anticipated pain associated with a procedure or dressing change, the patient is treated following the pain protocol (Fig. 4) in one of three regimens. Frequent reassessment via the pain assessment algorithm allows for quick titration to ensure pain comfort and built-in steps to wean the patient.

As with any therapy assessment, consideration of the underlying disease process and premorbid conditions allows for the safe and effective administration of pain-relieving drugs (Table 11). Paralyzing agents can have a prolonged effect when combined with aminoglycoside therapy because the latter interacts with the muscle end-plate. We have had patients remain paralyzed for days to weeks after discontinuing the paralyzing agent. Thermal injuries may induce an inflammatory cascade that results in alterations of nerve function. We have observed sustained clonus in patients treated with fentanyl which has resolved as the patient recovers. Pain management needs to continue throughout the rehabilitation phase so that the patient can participate in function-restoring

PAIN ASSESSMENT ALGORITHM (q3–6 hours)

The patient's pain is assessed using one of the three assessment scales listed. The timing of this assessment is to correlate with the expected plateau of action of the given analgesic, usually every 3–6 hours.

If the patient's pain level is unchanged as indicated by the "Ø" symbol, the dose of the current medication is increased and the pain reassessed.

If the pain has increased with maximal dosage of the current medication indicated by the " + " symbol, then the patient is moved to the next level of analgesic treatment.

If the pain has decreased to the "Mild Pain" or "A" level with the given medication indicated by the " ↓ " symbol, then the dose is maintained at the current level with continuous reassessment indicated by the "Maintain" loop. If 3 days of maintenance have been given, consider going to the next lowest level regimen or halving the maintenance dose.

If there is no change in the patient's pain level after *three* augmentations or there is an acute change in pain level not associated with a procedure:

Assess the wound to rule out

- Neurocirculatory compromise
- Hematoma
- Infection

Then increase pain medicines to next higher level's regimen.

Painful procedures should be anticipated by augmenting to the next higher pain level regimen to cover the expected discomfort.

TESTS
VAS 1–10 (>14 years and verbally responsive)
OPS 1–10 (verbally unresponsive or <4 years)
Poker Chip Test (children 4–14)

Figure 4 *See legend on opposite page*

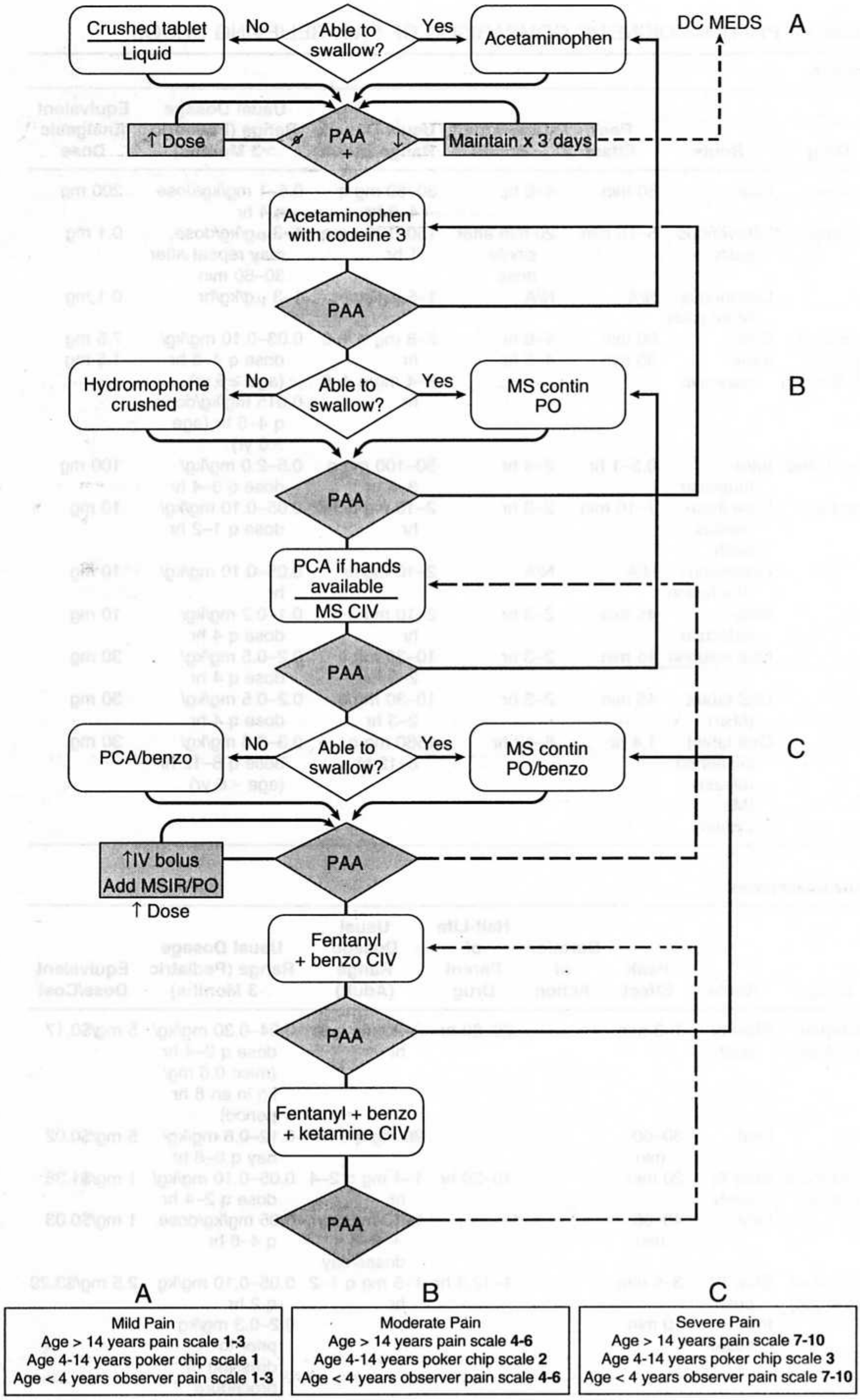

Figure 4. Pain management algorithm. PAA = pain assessment algorithm; PCA = patient-controlled anesthesia; MS = morphine sulfate; CIV = continuous intravenous infusion.

Table 11. PHARMACOKINETIC COMPARISON OF PAIN-RELIEVING DRUGS

Opioids

Drug	Route	Peak Effect	Duration of Action	Usual Dosage Range (Adult)	Usual Dosage Range (Pediatric >3 Months)	Equivalent Analgesic Dose
Codeine	Oral	60 min	4–6 hr	30–60 mg q 4–6 hr	0.5–1 mg/kg/dose q 4 hr	200 mg
Fentanyl	Intravenous push	5–15 min	20 min after single dose	150–100 μg q 1 hr	1–3 μg/kg/dose, may repeat after 30–60 min	0.1 mg
	Continuous IV infusion	N/A	N/A	1–5 μg/kg/hr	1–3 μg/kg/hr	0.1 mg
Hydromorphone (Dilaudid)	Oral Intramuscular	60 min 30 min	4–6 hr 4–5 hr	2–8 mg q 4–6 hr 2–4 mg q 4–6 hr	0.03–0.10 mg/kg/dose q 4–6 hr (age ≥6 yr) 0.015 mg/kg/dose q 4–6 hr (age ≥6 yr)	7.5 mg 1.5 mg
Meperidine	Intramuscular	0.5–1 hr	2–4 hr	50–100 mg q 3–4 hr	0.5–2.0 mg/kg/dose q 3–4 hr	100 mg
Morphine	Slow intravenous push	7–10 min	2–3 hr	2–10 mg q 1–2 hr	0.05–0.10 mg/kg/dose q 1–2 hr	10 mg
	Continuous IV infusion	N/A	N/A	2–10 mg/hr	0.05–0.10 mg/kg/hr	10 mg
	Intramuscular	45 min	2–3 hr	2–10 mg q 4 hr	0.1–0.2 mg/kg/dose q 4 hr	10 mg
	Oral solution	45 min	2–3 hr	10–30 mg q 2–3 hr	0.2–0.5 mg/kg/dose q 4 hr	30 mg
	Oral tablet (Msir)	45 min	2–3 hr	10–30 mg q 2–3 hr	0.2–0.5 mg/kg/dose q 4 hr	30 mg
	Oral tablet sustained release (Ms Contin)	1.4 hr	8–12 hr	1560 mg q 8–12 hr	0.3–0.6 mg/kg/dose q 8–12 hr (age <6 yr)	30 mg

Benzodiazepines

Drug	Route	Peak Effect	Duration of Action	Half-Life of Parent Drug	Usual Dosage Range (Adult)	Usual Dosage Range (Pediatric >3 Months)	Equivalent Dose/Cost
Diazepam (Valium)*	Slow IV push	1–3 min		20–80 hr	2–20 mg q 6 hr	0.04–0.30 mg/kg/dose q 2–4 hr (max: 0.6 mg/kg in an 8 hr period)	5 mg/$0.17
	Oral	30–60 min			20 mg q 6 hr	0.12–0.8 mg/kg/day q 6–8 hr	5 mg/$0.02
Lorazepam (Ativan)	Slow IV push	20 min		10–20 hr	1–4 mg q 2–4 hr	0.05–0.10 mg/kg/dose q 2–4 hr	1 mg/$1.38
	Oral	40–60 min			1–10 mg/day + 2–3 doses/day	0.05 mg/kg/dose q 4–8 hr	1 mg/$0.03
Midazolam (Versed)	Slow IV push	3–5 min		1–12.3 hr	1–5 mg q 1–2 hr	0.05–0.10 mg/kg q 2 hr	2.5 mg/$3.29
	Intranasal	10 min				0.2–0.3 mg/kg prior to dressing or procedure	

Table continued on opposite page

Table 11. PHARMACOKINETIC COMPARISON OF PAIN-RELIEVING DRUGS *(Continued)*

Miscellaneous agents

Drug	Route	Usual Dosage Range (Adult)	Usual Dosage Range (Pediatric >3 Months)
Acetaminophen	Oral, nasogastric tube, per rectum	325–6600 mg q 4 hr	10–15 mg/kg/dose q 4–6 hr
Hydroxyzine	Oral, nasogastric tube, intramuscular	2150 mg q 6 hr	1 mg/kg/dose q 6–8 hr
Ketamine†	Slow IV push, intramuscular	1.4 m dose q 1–2 hr	1–3 mg/kg/dose q 1–2 hr

Reversal agents

Drug	Route	Onset	Usual Dosage Range (Adult)
Flumazenil (Romazicon)‡	Intravenous	1–2 min mg q 1 min (max: 1 mg total dose)	Not recommended for age <18 yr by manufacturer
Naloxone (Narcan)‡	Venous	1–2 min 0.1–0.2 mg q 2–3 min to effect	0.005–0.010 mgll(g O 2–3 min to effect)

*Use with caution in geriatric patient or hepatic disease.

†Use with a benzodiazepine to prevent emergence reactions.

‡Caution: Withdrawal syndrome may be precipitated; above dosages are initial dosages for partial reversal.

Slow intravenous push to be given over 1 to 2 minutes or longer.

therapy and anticipate a comfortable recovery for reconstructive procedures. Pain management can be greatly enhanced by attention to the psychological state of the patient, as depression is all too frequent in the gravely ill. Supplementation of pain management protocols with antidepressants and talk therapy has yielded surprising results.

Team Approach

Our burn team consists of residents, attending physicians, fellows, nurses, a social worker, a pharmacist, and physical and occupational therapists who make rounds as a group each day. In addition, we have multidisciplinary meetings and staff meetings to manage the complexities in the care of these patients. Through this process each member of the team is informed and empowered to effect patient care.

Rehabilitation of the burn and trauma patient starts on the day of injury and requires team dedication to the areas of greatest morbidity early in the planning of surgical priorities and physical therapy. Intensive care rehabilitation is performed by the team of therapists and starts with an evaluation on admission which is integrated with the ICU and surgical treatments.

The greatest cost of burn and trauma care is not the acute hospitalization but rather the loss of productive years of the patient, the costs of chronic rehabilitation or convalescent care, and the financial support needed secondary to morbidity and mortality of the injury. One must, after the life-saving maneuvers, prioritize the functional outcome of the head, neck, and hands, which are the greatest impediments to a return to an independent and productive life. Indicators for a successful functional outcome and optimal surgical management to reach that goal are now being developed.

SUMMARY

A high incidence of severe inhalation injuries can be expected in the combined injury patient. The initial management remains attention to the ATLS priorities of airway, breathing, and circulation, with prompt and safe transfer to a regional center of excellence. The treatment of either the burn or the associated injuries may be compromised by their combined presence, and a team approach is essential to their optimal management. Circulatory management goals based on oxygen consumption and delivery allow greater understanding and control of the physiologic demands placed on the patient by the disease process. The management of inhalation injury and ARDS is at an exciting turning point in history, and we now have in hand and use many techniques that allow salvage of these mortal conditions. Pain management is essential to humane care and requires frequent assessment and patient control to be effective. Rehabilitation of the burn and trauma patient starts on the day of injury and requires team dedication to the areas of greatest morbidity early in the planning of surgical priorities and physical therapy.

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