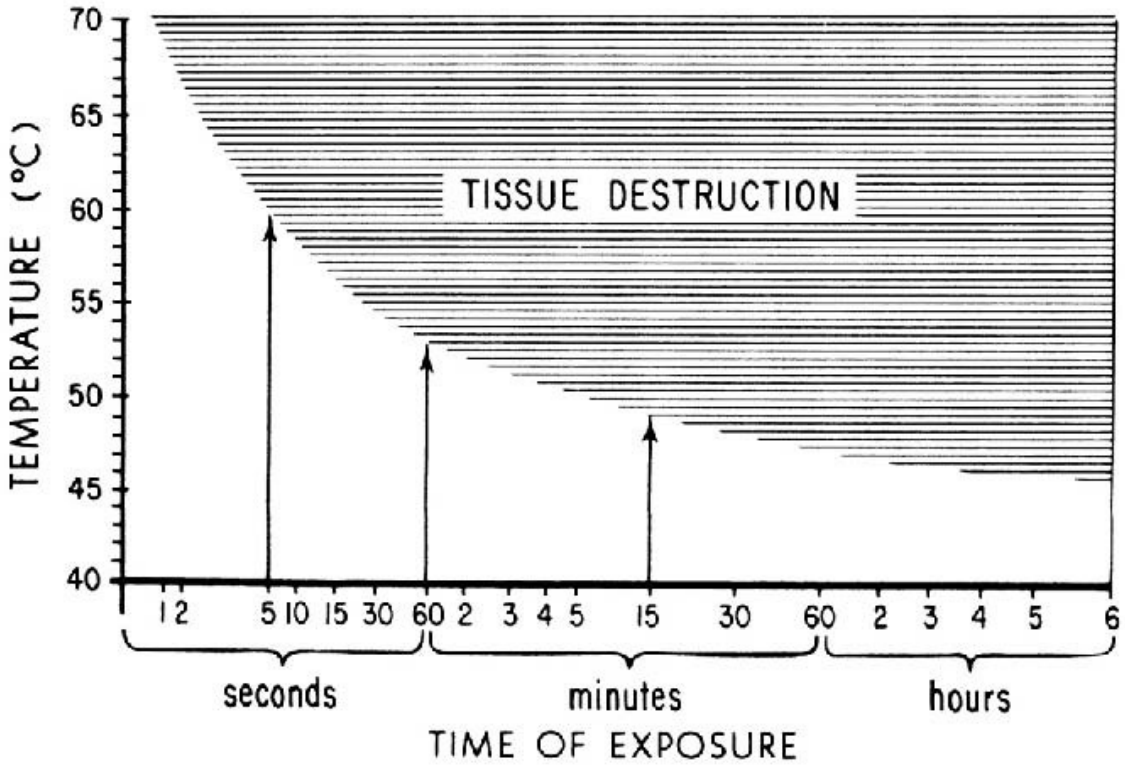
CHAPTER 8

THERMAL INJURIES

Thermal injuries from heat, chemical reactions, electricity, or cold can result in destruction of the skin and cause local and systemic effects. The management of the patient with a major thermal injury requires understanding of the pathophysiology, diagnosis, and treatment not only of the local skin injury, but also of the derangements that occur in hemodynamic, metabolic, nutritional, immunologic, and
psychologic homeostatic mechanisms.

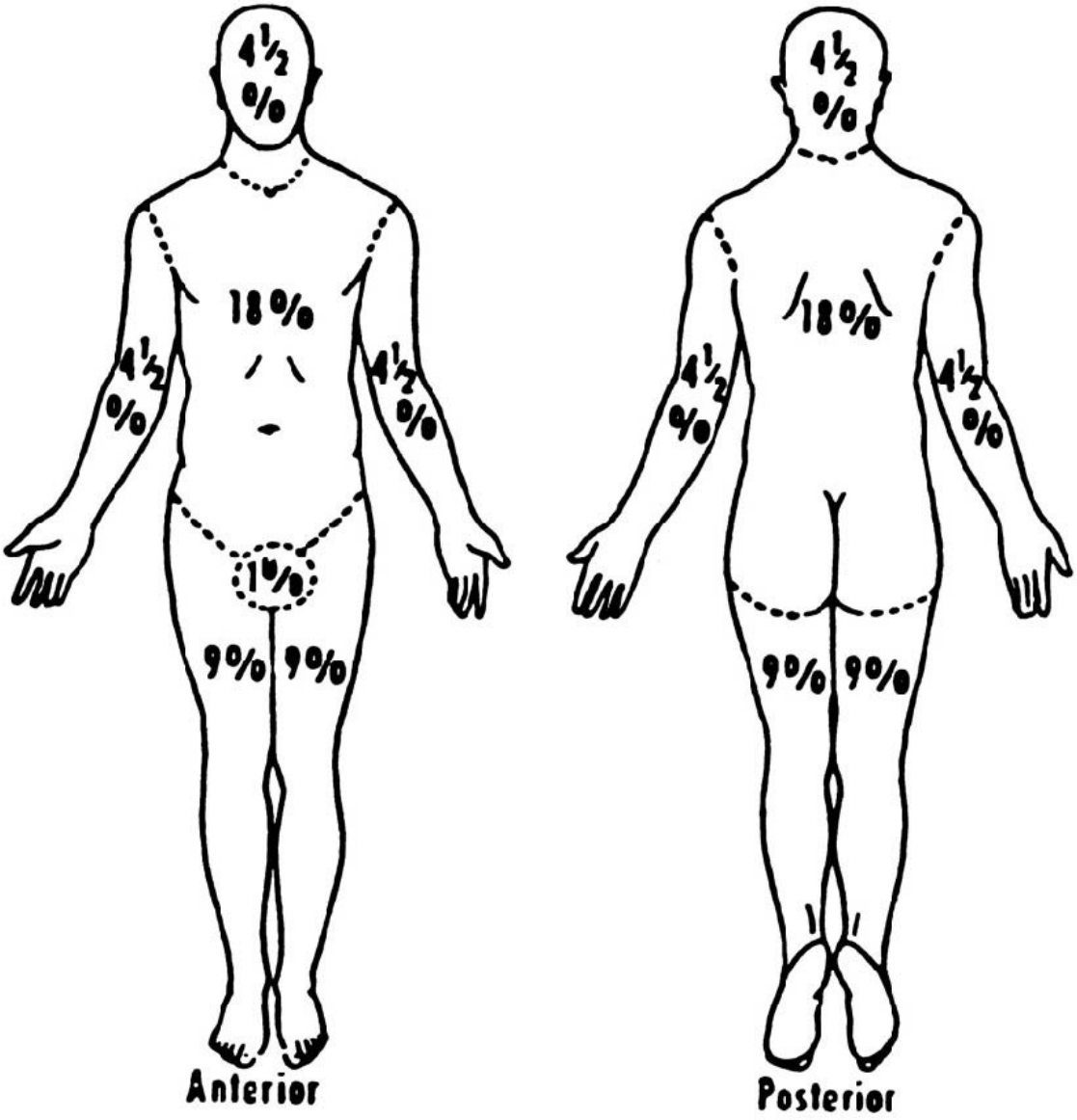
I. BURNS

A. Pathophysiology: Amount of tissue destruction is based on temperature (> 40° C) and time of exposure (Fig. 8-1)



(FIGURE 8-1)

B. Diagnosis and prognosis
   1. Burn size: % of total body surface area (TBSA) burned
      a. Rough estimate is based on rule of 9's (Fig. 8-2)
      b. Different charts are required for adults and children because of head-chest size discrepancy and limb differentials for ages birth to seven years (Fig. 8-3 and 8-4)

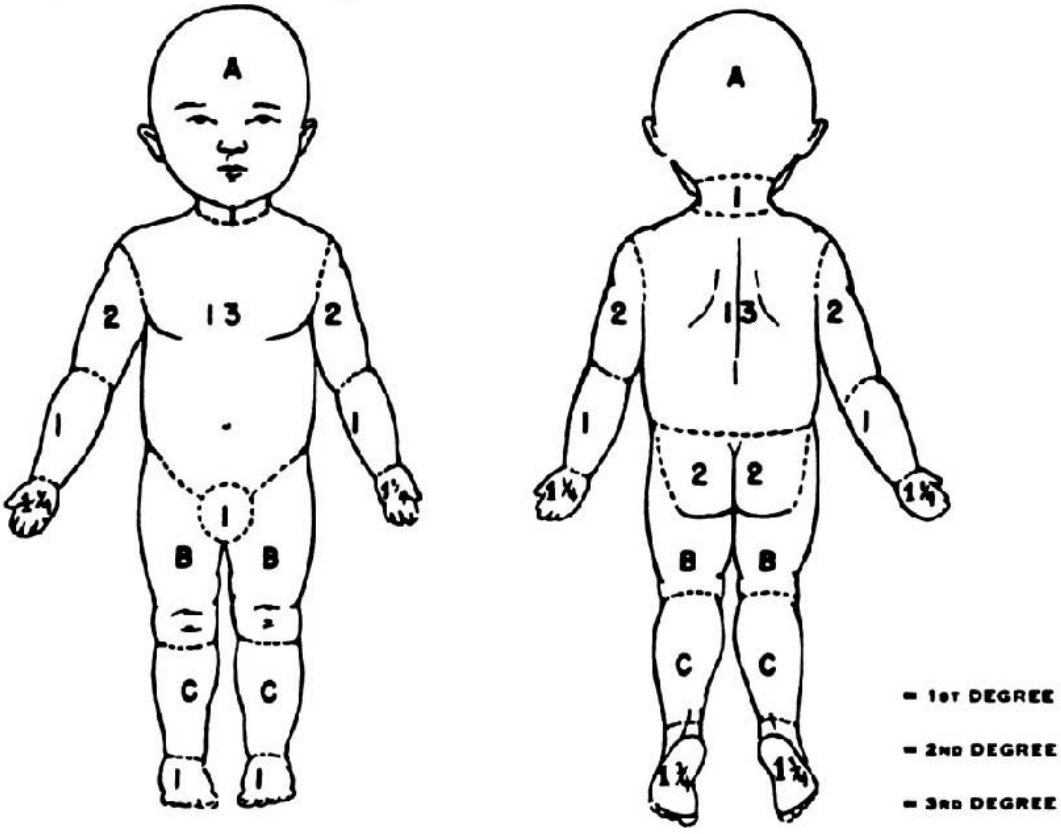


(FIGURE 8-2)

BURN SHEET

NAME _____ AGE _____ NUMBER _____

BURN RECORD. AGES — BIRTH — 7 ½ DATE OF OBSERVATION _____



RELATIVE PERCENTAGES OF AREAS AFFECTED BY GROWTH

	AREA	AGE 0	1	5
A	½ OF HEAD	9 ½	8 ½	6 ½
B	½ OF ONE THIGH	2 ¾	3 ¼	4
C	½ OF ONE LEG	2 ½	2 ½	2 ¾

% BURN BY AREAS

PROBABLE 3RD° BURN: HEAD_____ NECK_____ BODY_____ UP ARM_____ FOREARM_____ HANDS_____ GENITALS_____ BUTTOCKS_____ THIGHS_____ LEGS_____ FEET_____

TOTAL BURN: HEAD_____ NECK_____ BODY_____ UP. ARM_____ FOREARM_____ HANDS_____ GENITALS_____ BUTTOCKS_____ THIGHS_____ LEGS_____ FEET_____

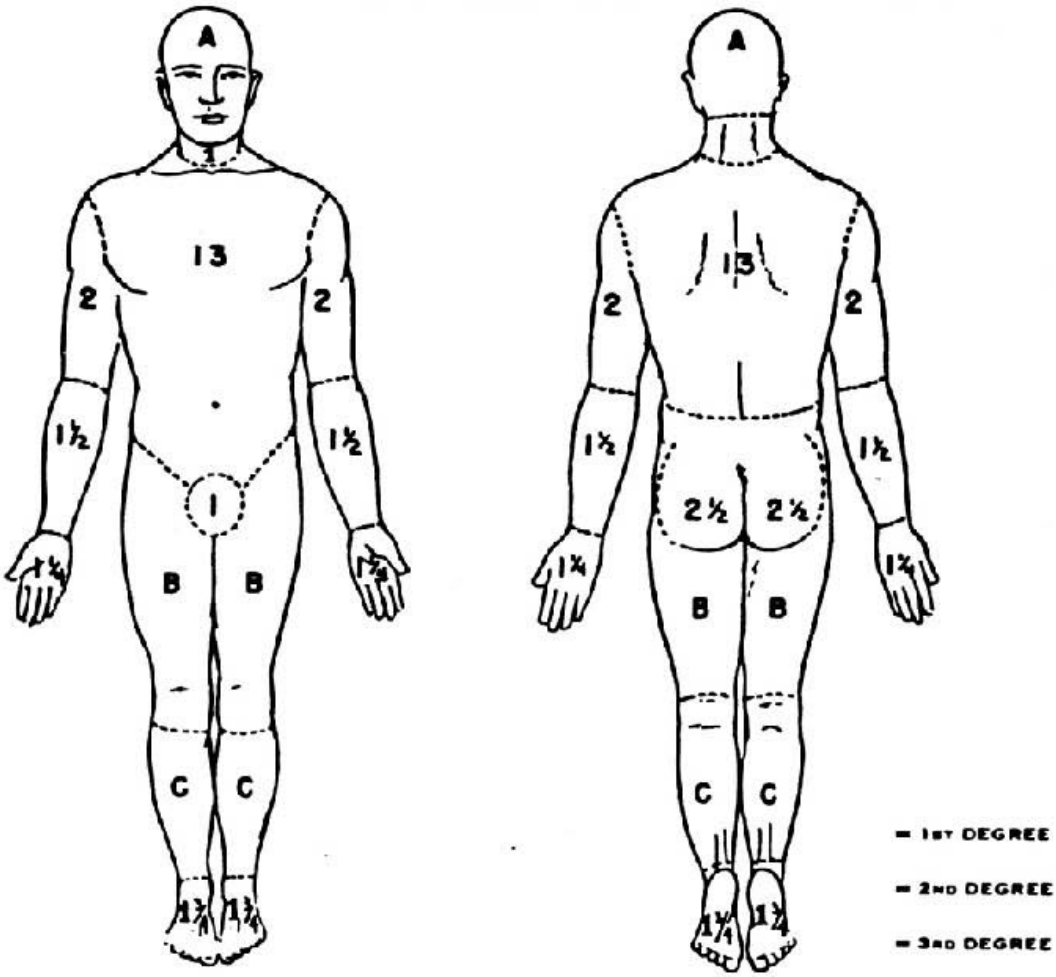
SUM OF ALL AREAS _____ PROBABLY 3RD° _____ TOTAL BURN _____

(FIGURE 8-3)

BURN SHEET

NAME _____ AGE _____ NUMBER _____

BURN RECORD. AGES 7 TO ADULT. DATE OF OBSERVATION _____



RELATIVE PERCENTAGES OF AREAS AFFECTED BY GROWTH

AREA	AGE 10	15	ADULT
A ½ OF HEAD	5½	4½	3½
B ½ OF ONE THIGH	4¼	4½	4¾
C ½ OF ONE LEG	3	3¼	3½

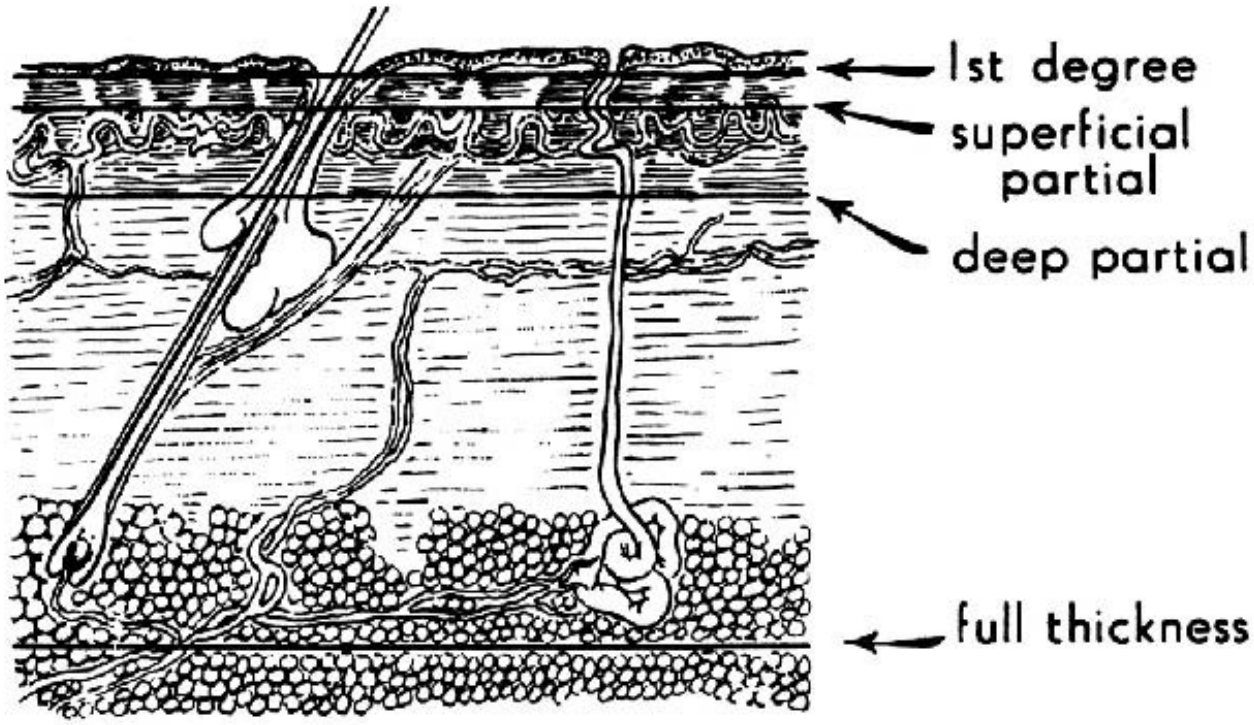
% BURN BY AREAS

PROBABLE 3RD° BURN: HEAD_____ NECK_____ BODY_____ UP. ARM_____ FOREARM_____ HANDS _____
GENITALS_____ BUTTOCKS_____ THIGHS_____ LEGS_____ FEET _____

TOTAL BURN: HEAD_____ NECK_____ BODY_____ UP. ARM_____ FOREARM_____ HANDS _____
GENITALS_____ BUTTOCKS_____ THIGHS_____ LEGS_____ FEET _____

(FIGURE 8-4)

2. Age: burns at the extremes of age carry a greater morbidity and mortality
3. Depth: difficult to assess initially (injury can evolve over 24-48 hours)
    a. History of etiologic agent and time of exposure helpful
    b. Classification (Fig. 8-5)
        i. First degree: erythema but no skin breaks
        ii. Second degree: blisters, red and painful
            (a) Superficial partial-thickness, involves epidermis and upper dermis
            (b) Deep partial-thickness, involves deeper dermis
        iii. Third degree: full-thickness-insensate, charred or leathery
        iv. Fourth degree: muscle, bone
    c. Zones of injury
        i. Coagulation (central): necrotic, irreparably injured
        ii. Stasis (intermediate): vasoconstriction and ischemia (can improve or worsen)
        iii. Hyperemia (peripheral): heals without scarring
4. Location: face and neck, hands, feet, and perineum may cause special problems and warrant careful attention; often necessitate hospitalization/burn center
5. Inhalation injury: beware of closed quarters burn, burned nasal hair, carbon particles in pharynx, hoarseness, conjunctivitis
6. Associated injuries, e.g. fractures



(FIGURE 8-5)

7. Co-morbid factors, e.g. pre-existing cardiovascular, respiratory, renal and metabolic diseases; seizure disorders, alcoholism, drug abuse
8. Prognosis: best determined by burn size (TBSA) and age of patient, inhalation injury
9. Circumferential burns: can restrict blood flow to extremity, respiratory excursion of chest and may require escharotomy

C. Categorization of burns is used to make treatment decisions and to decide if treatment in a burn center is necessary (Table 8-1, Table 8-2)

Categorization of burns (American Burn Association)

	Major Burn	**Moderate Burn**	**Minor Burn**
Size - Partial thickness	> 25% adults > 20% children	15-25% adults 10-20% children	< 15% adults < 10% children
Size - Full thickness	> 10%	2-10%	< 2%
Primary areas	major burn if involved	not involved	not involved
Inhalation injury	major burn if present or suspected	not suspected	not suspected
Associated injury	major burn if present	not present	not present
Co-morbid factors	poor risk patients make burn major	patient relatively good risk	not present
Miscellaneous	electrical injuries		
Treatment environment	usually specialized burn care facility	general hospital with designated team	often managed as out-patient

(Table 8-1)

Burns That Dictate Patient Admission to a Hospital or Burn Center

- 2° and 3° burns greater than 10% of BSA in patients under 10 or over 50 years of age
- 2° and 3° burns greater than 20% BSA in any age group
- 2° and 3° burns posing a serious threat of functional or cosmetic impairment, e.g. the face, hands, feet, genitalia, perineum, and about major joints)
- 3° burns greater than 5% BSA in any age
- Electrical burns including lightning
- Chemical burns posing a serious threat of functional or cosmetic impairment
- Inhalation injury
- Burns associated with major trauma

Table 8-2

D. Treatment plan
   1. History and physical exam
   2. Relieve respiratory distress - escharotomy and/or intubation
   3. Prevent and/or treat burn shock – IV – large bore needle (x2)
   4. Monitor resuscitation - Foley catheter and hourly urine output
   5. Treat ileus and nausea - N.G. tube if > 20% TBSA burn or intubated
   6. Tetanus prophylaxis
   7. Baseline laboratory studies (i.e. CBC, comprehensive metabolic panel, U/A, chest x-ray, EKG, cross- match, arterial blood gases, and carboxyhemoglobin)
   8. Cleanse, debride, and treat the burn wound

E. Respiratory distress
   1. Three major causes of respiratory distress in the burned patient:
      a. Unyielding burn eschar encircling chest
         i. Distress may be apparent immediately
         ii. Requires escharotomy (cutting into the eschar to relieve constriction)
      b. Carbon monoxide poisoning
         i. May be present immediately or later
         ii. Diagnosed by carboxyhemoglobin levels measured in arterial blood gas
         iii. Initial Rx is displacement of CO by 100% O_2 by facemask
         iv. Hyperbaric oxygen treatment may be of value
      c. Smoke inhalation leading to pulmonary injury
         i. Insidious in onset (18-36 hours)
         ii. Due to incomplete products of combustion, not heat
         iii. Causes chemical injury to alveolar basement membrane and pulmonary edema
         iv. Initial Rx is humidified O_2 but intubation and respiratory support may be required

v. Secondary bacterial infection of the initial chemical injury leads to progressive pulmonary insufficiency
vi. Severe inhalation injury alone or in combination with thermal injury carries a grave prognosis
vii. Three stages of presentation have been described:
(a) Acute pulmonary insufficiency (immediately postburn to 48 hours)
(b) Pulmonary edema (48-72 hours)
(c) Bronchopneumonia (25 days)
viii. Monitor respiratory and mental status – be aware of hoarseness, wheezing, stridor

F. Burn shock
1. Massive amounts of fluid, electrolytes, and protein are lost from circulation almost immediately after burning (Table 8-3)

Burn or Associated Condition Dictating Extra Fluid Administration

- Underestimation of the %TBSA burn
- Burn greater than 80%TBSA
- Associated traumatic injury
- Electrical burn
- Associated inhalation injury
- Delayed start of resuscitation
- 4° burn
- Administration of osmotic diuretics
- Pediatric burns

Table 8-3

2. Systemic response occurs if > 20% TBSA burn, resulting in a hypermetabolic state and capillary leak
3. Resuscitation requires replacement of sodium ions and water to restore plasma volume and cardiac output
a. Many formulas have been reported to achieve resuscitation
i. This can be given by prescribing 4cc Ringer's lactate/Kg/%TBSA burn over the first 24 hours (Baxter or Parkland Hospital formula)
ii. 1/2 of the first 24-hour fluid requirement should be given in the first eight hours postburn and the remaining 1/2 over the next 16 hours

b. A plasma volume gap may remain – change to colloid after 24-30 hours postburn by administering plasma or 5% albumin 0.35-0.5cc/Kg/% TBSA burn over 24 hours; plasmapheresis may help
c. After 30 hours D5W can be given at a rate to maintain a normal serum sodium

G. Monitoring resuscitation
1. Urine output 30-55cc/hr in adults and 1.2cc/Kg/hr in children < age 12
2. A clear sensorium, pulse < 120/min, HCO_3 > 18meq/L, cardiac output > 3.1 L/M^2
3. Monitor for nomothermia, blood pressure (mean arterial pressure > 60 in adults)
4. CVP in acute major burns is unreliable – use if myocardial disease, age > 65, inhalation injury, fluid requirements > 150% of expected

H. Metabolic considerations
1. Increased metabolic demands in patients with burn injury (hypermetabolic state)
2. High carbohydrate/high protein diet – dietician and tube feeds as needed
3. Early feeding (start at 12 hours) – prevents mucosal atrophy, ulceration, bacterial translocation in gut
4. Measure prealbumin to determine nutritional status

I. Treatment of the burn wound (Table 8-4)
1. Wound closure by the patient's own skin is the ultimate goal of treatment
a. By spontaneous healing
b. Autograft
c. Allograft
d. Xenograft
e. Artificial skin
f. Cultured epithelial cells
2. Specific treatment of the burn wound differs from one burn center to another
a. The most commonly employed topical antibacterials are silver sulfadiazine (Silvadene®) and mafenide acetate (Sulfamylon®)
b. Dressing changes 1x/day with soap and water – no need to scrub or remove blisters
c. Status of burn wound bacterial colonization and effectiveness of topical antibacterial treatment can be monitored by biopsies of wound for quantitative and qualitative bacteriology
d. Systemic antibiotic therapy only used for sepsis, not prophylactically (breeds
e. resistant organisms)

Sample Orders

For a 70 Kg 40 year old patient with a 40% flame burn:

1. Admit to ICU portion of burn center
2. Strict bedrest with head elevated 45°
3. Maintain elevation of burned extremities
4. Vital signs: pulse, BP respiration q 15 min, temperature q 2 h
5. Check circulation of extremities (capillary refill or Doppler) q 30 min
6. 100% O_2 face mask
7. Infuse Ringer's lactate at 700cc for first hour, then reassess
8. Measure urinary output by Foley catheter to closed drainage
9. Notify physician of first hour's urine output (must be 30-50cc: 1.2-1.5cc in pediatric patient)
10. N.P.O.
11. N.G. tube to intermittent low suction
12. Measure pH of gastric content q 2 h — stress ulcer prophylaxis (e.g. Zantac)
13. Morphine sulfate 4 mg intravenously q 2-3 hr prn pain - no intramuscular narcotics (unreliable absorption)
14. Tetanus toxoid 0.5cc IM (if patient previously immunized)
15. Send blood for Hct., glucose, BUN, cross match 2 units, electrolytes
16. Urine for U.A. and culture
17. Chest x-ray
18. EKG
19. Arterial blood gases q 6 h and prn
20. Cleanse wounds with Betadine solution, debride all blisters, map injury on Lund-Browder chart, and photograph wounds
21. Apply silver sulfadiazine to all wounds with sterile gloved hand (use reverse isolation technique when burn wounds are exposed)
22. Dress wounds with burn gauze and surgifix
23. Splint extremities as per physical therapist
24. Change all dressings, cleanse wounds, and reapply topical antibacterial q 8 h or q 12 h
25. Bronchoscopy — If inhalation injury suspected

Table 8-4

3. Necrotic tissues may be removed by any of several techniques (may take 5-7 days to declare):
    a. Formal excision
    b. Tangential (layered) debridement
    c. Enzymatic debridement
    d. Hydrotherapy - a useful adjunct
4. Autografts should be applied to priority areas first, such as the hands, face and important joints
5. Once healed, pressure is usually necessary with elastic supports to minimize hypertrophic scarring
6. Physical therapy - important adjunct in burn care

J. Complications: can occur in every physiologic system or secondary to burn injury (Table 8-5)
1. Renal failure
    a. From hypovolemia
    b. Beware of nephrotoxic antibiotics in the burn patient

Risk Factors in Burn Wound Infection

I. PATIENT FACTORS
- A. Extent of burn > 30% of body surface
- B. Depth of burn: full-thickness vs. partial-thickness
- C. Age of patient (very young or very old at higher risk)
- D. Pre-existing disease
- E. Wound dryness
- F. Wound temperature
- G. Secondary impairment of blood flow to wound
- H. Acidosis

II. MICROBIAL FACTORS
- A. Density >10^5 organisms per gram of tissue
- B. Motility
- C. Metabolic products
    1. Endotoxin
    2. Exotoxins
    3. Permeability factors
    4. Other factors
- D. Antimicrobial resistance

Table 8-5

2. Gastrointestinal bleeding
    a. More likely in burns over 40% TBSA
    b. Usually remains subclinical
    c. Antacids and H_2 blockers
    d. Increased risk with burn wound sepsis
3. Burn wound sepsis
    a. Monitored by tissue biopsy - qualitative and quantitative
    b. Must keep bacterial count < 10^5 bacteria/gm of tissue
    c. Clinically suspect sepsis with
        i. Sudden onset of hyper or hypothermia
        ii. Unexpected congestive heart failure or pulmonary edema
        iii. Development of the acute respiratory distress syndrome
        iv. Ileus occurring after 48 hours postburn
        v. Mental status change
        vi. Azotemia
        vii. Thrombocytopenia
        viii. Hypofibrinogenemia
        ix. Hyper or hypoglycemia is especially suspect if burn > 40% TBSA
        x. Blood cultures may be positive but in many cases are not
4. Progressive pulmonary insufficiency
    a. Can occur after:
        i. Smoke inhalation
        ii. Pneumonia
        iii. Cardiac decompensation
        iv. Sepsis from any cause
    b. Produces:
        i. Hypoxemia
        ii. Hypocarbia
        iii. Pulmonary shunting
        iv. Acidosis
5. Wound contracture and hypertrophic scarring
    a. Largely preventable
    b. Active range of motion of involved and adjacent joints is encouraged to prevent joint contractures from the outset
        i. Splints and passive range of motion are used if active range of motion is unable to be performed, e.g. elbow and knee are kept in extension and MCP joints of fingers in flexion
        ii. Limb elevation and range of motion are useful for reducing edema and maintaining movement
    c. Timely wound closure with adequate amounts of skin should largely eliminate these problems
    d. Continued postoperative splinting and elastic pressure supports are of value in the remodeling of collagen with prevention of hypertrophic scars

II. CHEMICAL BURNS

A. Pathophysiology
   1. Tissue damage secondary to a chemical depends on:
      a. Nature of agent
      b. Concentration of the agent
      c. Quantity of the agent
      d. Length of time the agent is in contact with tissue
      e. Degree of tissue penetration
      f. Mechanism of action

B. Diagnosis
   1. Chemical burns are deeper than initially appear and may progress with time
      a. Fluid resuscitation needs often underestimated
      b. Watch for renal/liver/pulmonary damage

C. Treatment
   1. Initial treatment is dilution of the chemical with tap water
      a. Copious irrigation for 30 minutes
      b. Exception – cement/concrete/powdered lye should be brushed off dry
   2. Special attention to eyes – after copious irrigation with saline, consult ophthalmologist
   3. After 12 hours initial dilution, local care of the wound with debridement, topical antibacterials, and eventual wound closure is same as for thermal burn

D. Of particular note are:
   1. Gasoline
      a. Excretion by lung
      b. May cause large skin burn, if immersed
      c. Watch for atelectasis, pulmonary infiltrates; surfactant is inhibited
   2. Phenol
      a. Dull, gray color to skin, may turn black
      b. Urine may appear smoky in color
      c. Spray water on burn surface
      d. Wipe with polyethylene glycol
      e. Direct renal toxicity
   3. Hydrofluoric acid
      a. Irrigate copiously with water
      b. Subcutaneous injections of 10% calcium gluconate, or intraarterial infusion in extremities
      c. Monitor EKG of patients - may become hypocalcemic
      d. Pulmonary edema may occur if subjected to fumes
   4. White phosphorous burn
      a. Do not allow to desiccate - may ignite
      b. Each particle must be removed mechanically
      c. Copper sulfate (2%) may counteract to make phosphorous more visible (turns black in color)
      d. Watch for EKG changes (Q - T interval and S - T and T wave changes)
      e. May cause hemoglobinemia and renal failure

III. ELECTRICAL INJURIES

A. Pathophysiology
   1. Effects of passage of electric current through the body depend on:
      a. Type of circuit
      b. Voltage of circuit
      c. Resistance offered by body
      d. Amperage of current flowing through tissue
      e. Pathway of current through the body
      f. Duration of contact
   2. Tissue resistance to electrical current increases from nerve (least resistant) to vessel to muscle to skin to tendon to fat to bone

B. Diagnosis
   1. Types of injury
      a. Arc injury: localized injury caused by intense heat
      b. Injury due to current
         i. Due to heat generated as current flows through tissue
            (a) Injury more severe in tissue with high resistance (i.e. bones)
            (b) Vessels thrombose as current passes rapidly along them
         ii. Effect of current may not be immediately seen

C. Special effects of electrical injury
   1. Cardiopulmonary
      a. Anoxia and ventricular fibrillation may cause immediate death
      b. Early and delayed rhythm abnormalities can occur
      c. EKG changes may occur some time after the burn in a delayed fashion
   2. Renal
      a. High risk of renal failure due to hemoglobin and myoglobin deposits in renal tubules
         i. Requires higher urine flow (75cc/hr in adults)
         ii. Must alkalinize urine to keep hemoglobin and myoglobin in more soluble state
         iii. Mannitol may be useful to clear heavy protein load
   3. Fractures:
      a. Tetanic muscle contractions may be strong enough to fracture bones, especially spine
   4. Spinal Cord Damage
      a. Can occur secondary to fracture or demyelinating effecting of current
   5. Abdominal effects
      a. Intraperitoneal damage can occur to G.I. tract secondary to current
   6. Vascular effects
      a. Vessel thrombosis progresses with time
      b. Delayed rupture of major vessels can occur
   7. Cataract formation - late complication
   8. Seizures

D. Treatment
   1. CPR if necessary
   2. Fluids - usually large amounts

a. No formula is accurate because injury is more extensive than can be predicted by skin damage
b. Alkalinize with $NaHCO_3$, if myoglobinuria or hemoglobinuria present

3. Monitoring
   a. CVP or pulmonary wedge pressure helpful since total capillary leak does not occur as it does in a in thermal burn
   b. Maintain urine output at 75-100cc/hr until all myoglobin and/or hemoglobin disappears from urine
4. Wound Management
   a. Topical agent with good penetrating ability is needed [i.e. silver sulfadiazine (Silvadene®) or mafenide acetate (Sulfamylon®)]
   b. Debride non-viable tissue early and repeat as necessary (every 48 hrs) to prevent sepsis
   c. Major amputations frequently required
   d. Technicium-99 stannous pyrophosphate scintigraphy may be useful to evaluate muscle damage
5. Treat associated injuries (e.g. fractures)

IV. COLD INJURIES

The two conditions of thermal injury due to cold are local injury (frostbite) and systemic injury (hypothermia)

A. Frostbite
   1. Pathophysiology
      a. Formation of ice crystals in tissue fluid
         i. Usually in areas which lose heat rapidly (e.g. extremities)
      b. Anything which increases heat loss from the body such as wind velocity, or decreases tissue perfusion, such as tight clothing, predisposes the patient to frostbite
      c. Ability of various tissues to withstand cold injury is inversely proportional to their water content
   2. Treatment
      a. The key to successful treatment is rapid rewarming in a 40° C water bath
         i. Admission to hospital usually required
            (a) Tetanus prophylaxis
            (b) Wound management
            (c) Physical therapy
               (i) Maintenance of range of motion important
               (ii) Daily whirpool and exercise
            (d) Sympathectomy, anti-coagulants, and early amputation of questionable value in controlled studies
         ii. Usually wait until complete demarcation before proceeding with amputations. Non-viable portions of extremities will often autoamputate with good cosmetic and functional results.

B. Hypothermia
   1. Diagnosis
      a. Core temperature < 34° C

b. Symptoms and signs mimic many other diseases
c. High level of suspicion necessary during cold injury season

2. Treatment
   a. Must be rapid to prevent death
   b. Monitor EKG, CVP, and arterial blood gases and pH during warming and resuscitation, maintain urine output of 50cc/hr
   c. Begin Ringer's lactate with 1 ampule $NaHCO_3$
   d. Oral airway or endotracheal tube if necessary
   e. Rapidly rewarm in 40° C hydrotherapy tank (requires 1-2 hours to maintain body temperature at 37°C)
   f. Treat arrhythmias with IV Lidocaine or Amiodarone drip if necessary
   g. Evaluate and treat any accompanying disease states

V. LIGHTNING INJURIES

A. Cutaneous effects - lightning strikes may cause cutaneous burn wounds
   1. Contact burns from clothing on fire or contact with hot metal (i.e. zippers, etc)
   2. Entry and exit burns are usually small, may be partial or full thickness
   3. Lightning burns are not the same as electrical burns – don't get deep tissue injury

B. May have temporary ischemic effects on extremity - pallor or neurologic deficits. Spontaneous recovery after a few hours is the rule - probably due to local vasoconstriction

C. Systemic effects can occur such as arrhythmias, cataracts, CNS symptoms

CHAPTER 8 - BIBLIOGRAPHY

THERMAL INJURIES

1. Gallagher J.J., Wolf S.E., and Herndon D.N. Burns. In: Sabiston's Textbook of Surgery, 18th edition, eds. Townsend C.M., Beauchamp R.D., Evers B.M., et al. Philadelphia: Saunders, 2007.

2. Gibran N. Burns. In: Greenfield's Surgery Scientific Principles and Practice, 5th edition, eds. Mulholland M.W., Lillemoe K.D., Doherty G.M., et al. Philadelphia: Lippincott Williams and Wilkins, 2010.

3. Gibran, N.S. and Heimbach, D.M. Current status of burn wound pathophysiology. Clin Plast Surg. 2000; 27:11-22.

4. Grunwald T.B. and Garner W.L. Acute Burns. Plast Reconstr Surg. 2008; 121: 311e-319e.

5. Klein M.B., Nathens A.B., Emerson D., et al. An analysis of the long-distance transport of burn patients to a regional burn center. J Burn Care Res. 2007; 28:49- 55.

6. Matthews, M.S. and Fahey, A.L. Plastic surgical considerations in lightning injuries. Ann Plast Surg. 1997; 39:561-5.

7. van Zuijlen, P.P. et al. Dermal substitution in acute burns and reconstructive surgery: a subjective and objective long-term follow-up. Plast Reconstr Surg. 2001; 108: 1938-46.