CHAPTER 24

THERMAL, ELECTRICAL AND CHEMICAL INJURIES

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Thermal injuries can result from exposure to heat, chemicals, electricity, or cold, and can result in destruction of the skin and cause local and systemic effects. The management of the patient with a major thermal injury requires an 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 (Figure 1).

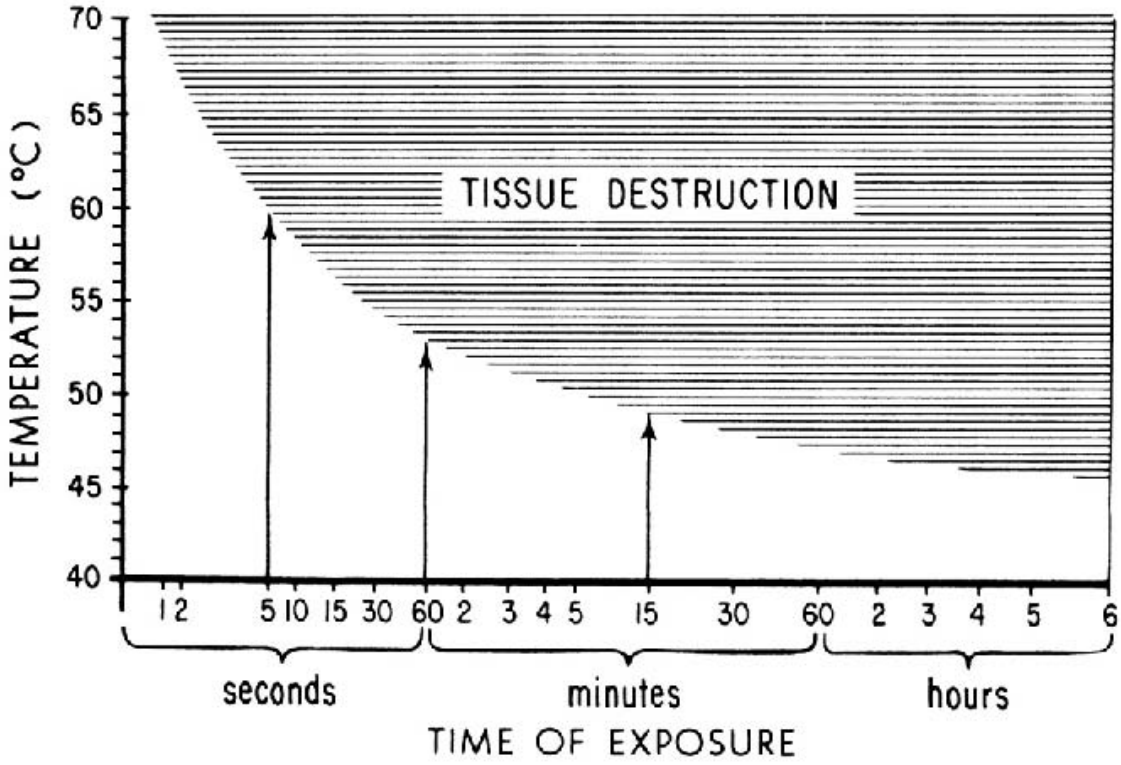


Figure 1. Tissue destruction based on temperature

B. Diagnosis and prognosis
    1. Burn size: % of total body surface area (TBSA) burned
        a. Rough estimate is based on rule of 9's (Figure 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 (Figures 3 and 4).
        c. Patient palm size can be used to estimate TBSA – palm is approximately 1% TBSA

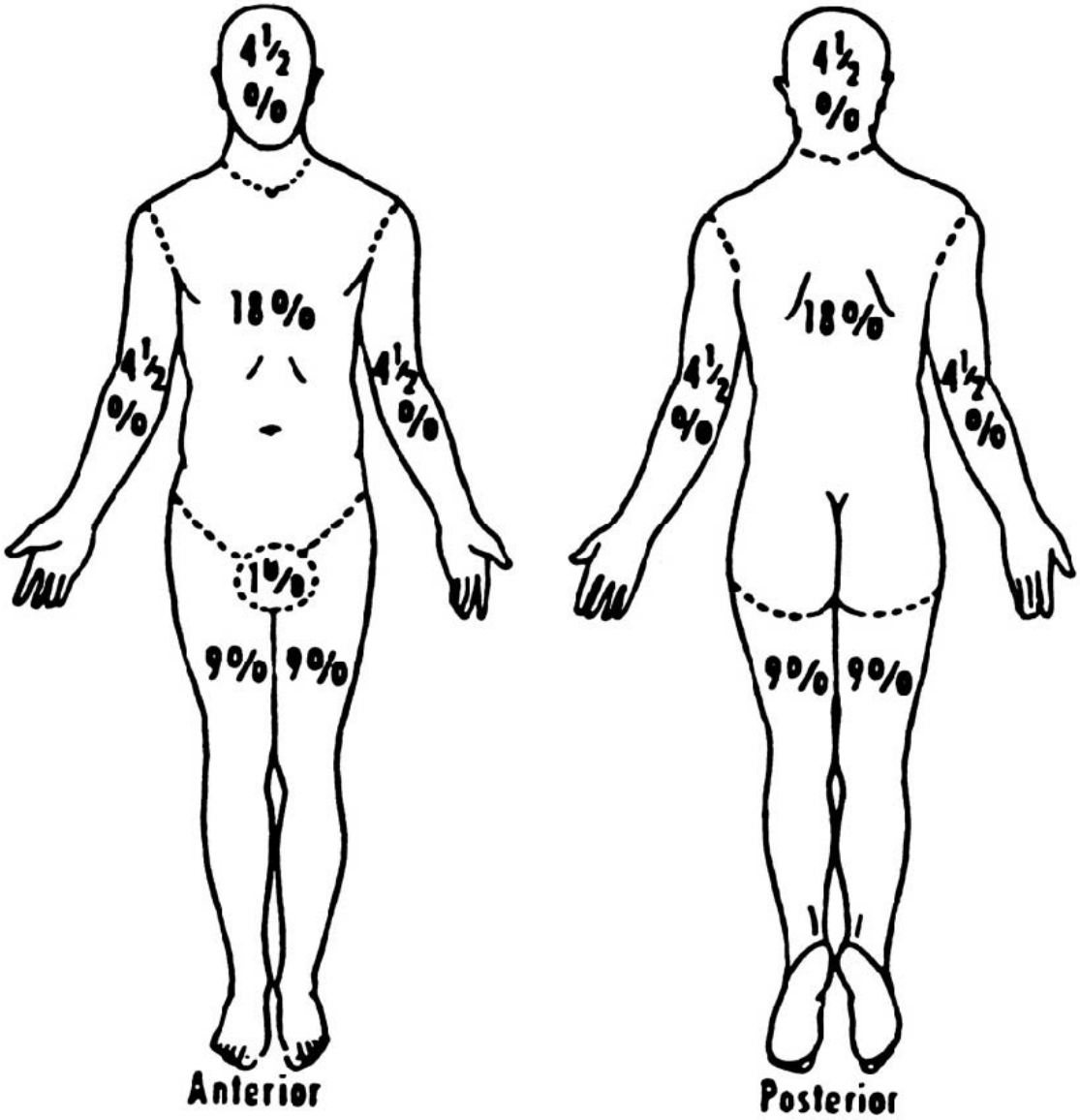
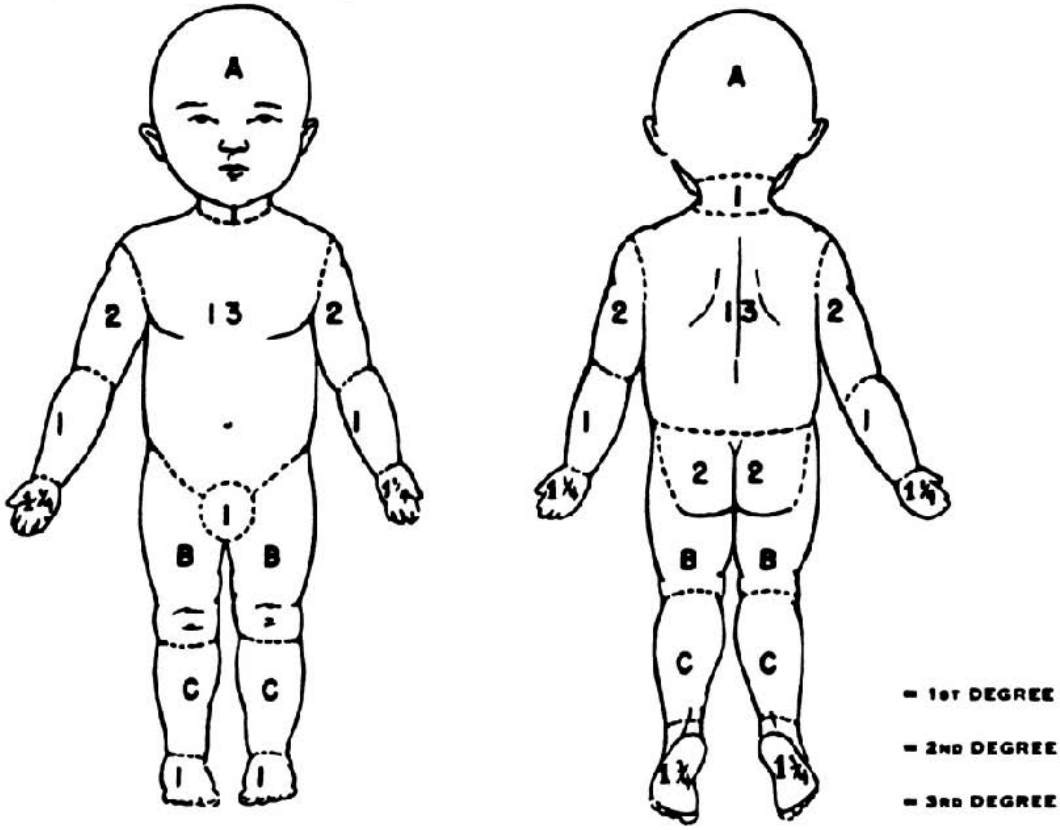


Figure 2. TBSA burn based on rule of 9's.

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_____

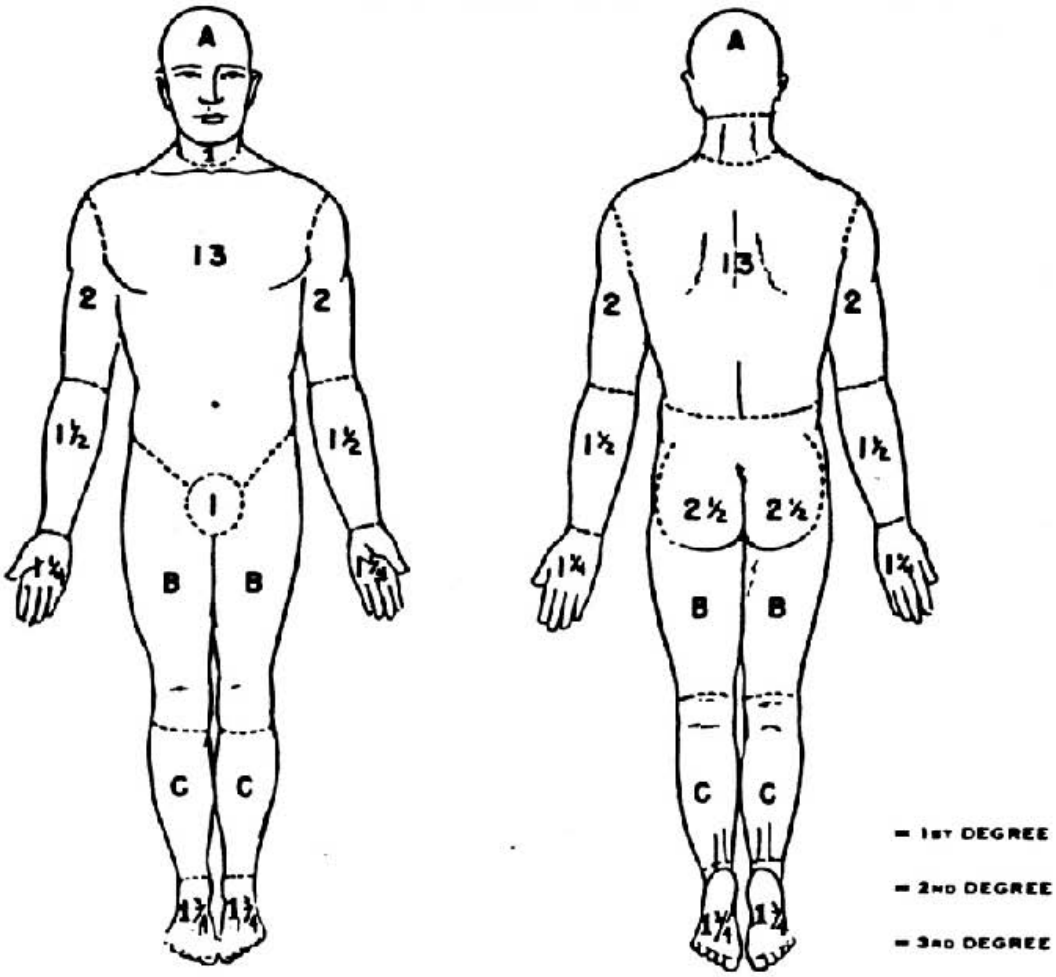
SUM OF ALL AREAS _____ PROBABLY 3RD° _____ TOTAL BURN _____

Figure 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 4

2. Age: burns at the extremes of age carry a greater morbidity and mortality
3. Depth: may be difficult to assess initially as injury can evolve and deepen over 24-48 hours
    a. Type and temperature of etiologic agent, and time of exposure helpful
    b. Classification (Figure 5 and Table 1)
        i. First degree: superficial - erythema but no skin breaks, similar to a sunburn
        ii. Second degree: blisters present, 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 in appearance
        iv. Fourth degree: muscle, bone affected
    c. Zones of injury
        i. Coagulation (central): tissues undergo necrosis and are irreparably damaged
        ii. Stasis (intermediate): vasoconstriction and ischemia (can improve or worsen, depending on treatment)
        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 and/or transfer to a burn center (See Table 2)
5. Inhalation injury: beware of burns occurring in enclosed spaces, singed nasal/facial hair, carbon particles in pharynx, hoarseness, conjunctivitis - patients may not initially have any signs of airway compromise, so must have high index of suspicion.
6. Associated injuries, e.g. fractures - depending on circumstances surrounding burn, patients may require full trauma workup

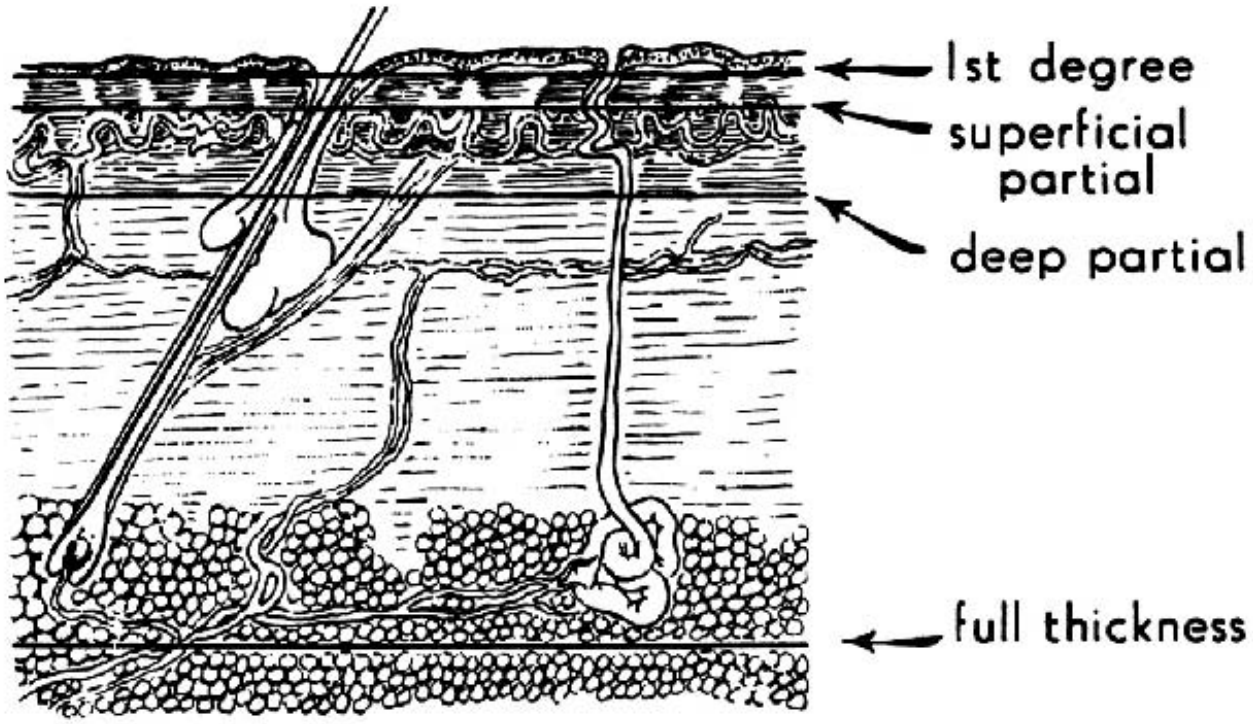


Figure 5. Classification of burns by depth

Degree	Depth	Layers Involved	Features	Healing Time	Management
First	Superficial	Epidermis only	Pink, red, brisk capillary refill, painful	<7 days	Symptomatic
Second	Superficial partial-thickness	Epidermis, papillary (upper) dermis	Pink, red, moist, edematous, brisk capillary refill, very painful	Variable 10-28 days	Daily wound care, debride sloughed skin
	Deep partial-thickness	Epidermis, reticular (lower) dermis	White, pink, red, dry, no blanching, reduced sensation		Daily wound care, surgical excision and resurfacing
Third	Full thickness	Epidermis, entire dermis	White, brown, dry, leathery, no blanching, insensate	>21 days	Surgical excision and resurfacing
Fourth	Full thickness	Epidermis, entire dermis, fat, fascia, muscle, bone	Exposed deep tissue	N/A	Amputation, complex reconstruction

Table 1. Description and features of burns based on depth

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, presence of inhalation injury (Figure 6)
9. Circumferential burns: can restrict blood flow to extremity, respiratory excursion of chest and may require escharotomies
10. Certain criteria are used to make the determination regarding whether transfer to a burn is necessary (Table 2)

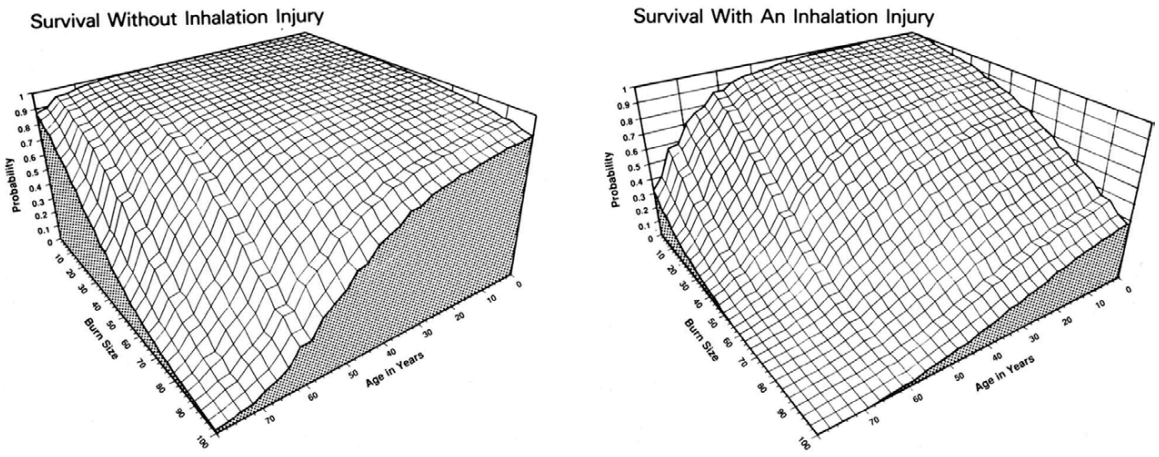


Figure 6

Burn Center Referral Criteria (ABA Guidelines)
1. Partial thickness burns greater than 10% total body surface area (TBSA) in patients <10 yr or >50 yr 2. Partial-thickness burns greater than 20% total body surface area in all patients. 3. Burns that involve the face, hands, feet, genitalia, perineum, or major joints. 4. Third degree burns in any age group. 5. Electrical burns, including lightning injury. 6. Chemical burns. 7. Inhalation injury. 8. Burn injury in patients with preexisting medical disorders that could complicate management, prolong recovery, or affect mortality. 9. Any patient with burns and concomitant trauma (such as fractures) in which the burn injury poses the greatest risk of morbidity or mortality. 10. Burned children in hospitals without qualified personnel or equipment for the care of children. 11. Burn injury in patients who will require special social, emotional, or rehabilitative intervention.

Table 2. Burn Center referral guidelines

C. Treatment plan
   1. History and physical exam
      a. In pediatric burns where the history does not correlate with the burn injury, consider the possibility of child abuse – contact social work and/or follow hospital-specific protocols.
   2. Relieve respiratory distress - escharotomies and/or intubation – see below.
   3. Prevent and/or treat burn shock – fluid resuscitation with large bore IV (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. Thromboembolic prophylaxis
8. Baseline laboratory studies (i.e. CBC, comprehensive metabolic panel, U/A, chest x-ray, EKG, cross-match, arterial blood gases, and carboxyhemoglobin)
9. Cleanse, debride, and treat the burn wounds

D. Respiratory involvement
   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 escharotomies (cutting into the eschar to relieve constriction)
      b. Carbon monoxide poisoning
         i. May be present immediately or have a delayed presentation; high level of suspicion if patient exposed to smoke in an enclosed space
         ii. Diagnosed by carboxyhemoglobin levels measured in arterial blood gas
         iii. Important to remember that patients with a history of smoking may have baseline elevated carboxyhemoglobin
         iv. Initial Rx is displacement of CO by 100% O_2 by facemask
         v. Hyperbaric oxygen treatment may be of value, but is often not practical in many locations
      c. Smoke inhalation leading to pulmonary injury
         i. Insidious in onset (18-36 hours)
         ii. Due to incomplete products of combustion, not heat (direct thermal injury to lungs occurs only secondary to steam burns)
         iii. Causes chemical injury to alveolar basement membrane and subsequent 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 and infection – mucosal barrier of respiratory tract is damaged
         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)
         vii. Monitor respiratory and mental status – be aware of hoarseness, wheezing, stridor. If any concerns about current or future airway involvement, best to intubate patient prior to excessive airway edema

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

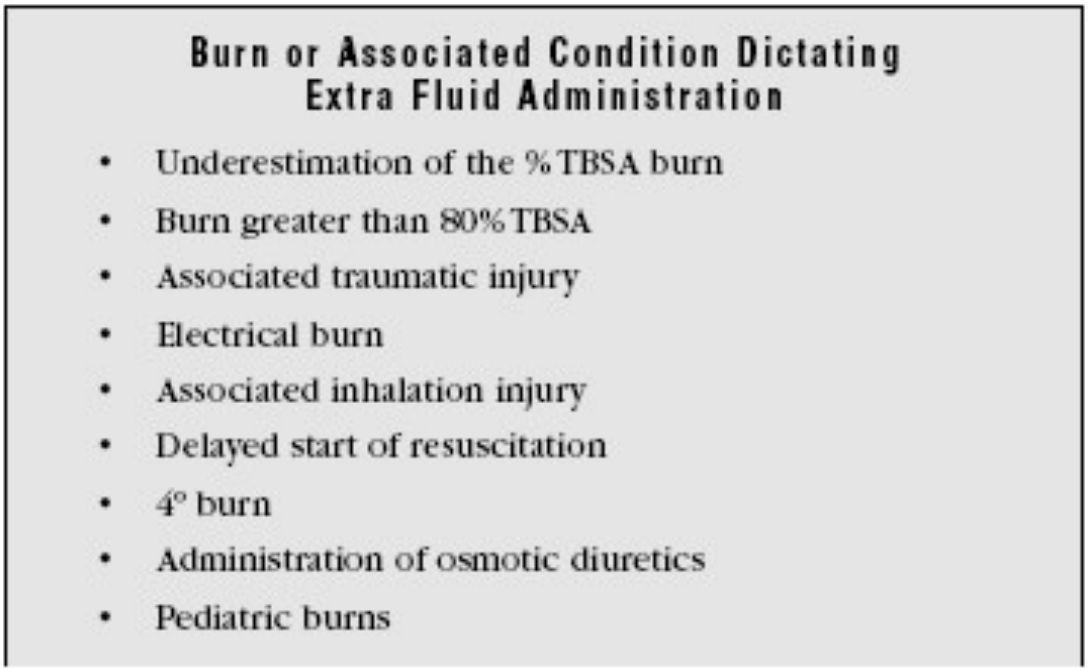


Table 3. Burn shock

2. Systemic inflammatory response occurs if > 20% TBSA burn in adults, >30% TBSA in children, and >15% TBSA in elderly - results in a hypermetabolic state and increased capillary permeability - causing
3. Resuscitation requires replacement of sodium ions and water to restore plasma volume and cardiac output – initiate if adult burns >15-20% TBSA and pediatric burns >10% TBSA
    a. Many formulas have been reported to achieve resuscitation – these serve only as a guide for initial IVF– must also monitor UOP to appropriately titrate rate
        i. Parkland formula: 2-4cc Ringer's lactate/Kg/%TBSA burn over the first 24 hours
        ii. 1/2 of the 24-hour fluid requirement should be given in the first eight hours postburn and the remaining 1/2 over the next 16 hours
        iii. Remember to factor in any fluid boluses patient may have received either in ED or at OSH when performing calculations
    b. Administration of colloid during or after resuscitation can vary from burn center to burn center
    c. Children – should receive maintenance fluids (weight-based 5% dextrose in half-normal saline), as well as resuscitative fluids

F. Monitoring resuscitation
    1. Urine output 0.5-1cc/kg/hr in adults and 1cc/Kg/hr in children < age 12
    2. A clear sensorium, pulse < 140/min, BP >90/60 mmHg, HCO_3 > 18meq/L, cardiac output > 3.5 L/min/M^2

3. CVP in acute major burns is unreliable – use if myocardial disease, age > 65, inhalation injury, fluid requirements > 150% of expected

G. 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

H. Treatment of the burn wound
   1. Wound closure by the patient's own skin (autograft) 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 at least 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 resistant organisms)
   3. Necrotic tissues or any burned tissue not expected to heal within 2-3 weeks may be removed by any of several techniques
      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, as well as the neck for possible tracheostomy placement
   5. Once healed, pressure with elastic support/compression garments is usually necessary to reduce hypertrophic scarring
   6. Physical therapy/occupational therapy - important adjunct in burn care, helps prevent contractures, especially for burns that cross joint surfaces

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

c. Myoglobinuria associated with compartment syndrome

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 5. Burn wound infection risk factors

2. Gastrointestinal bleeding
   a. Curling's ulcer: gastric ulcer that results from large TBSA burn due to decreased plasma volume - causing ischemia of gastric mucosa. 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 global 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. Overresuscitation
   a. If IVF rate remains elevated despite adequate UOP, increased risk for
      i. Abdominal compartment syndrome
      ii. Extremity compartment syndrome
6. 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
   e. Contractures may require future revision and reconstructive procedures months to years after original burn injury.

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. Alkali burns may be more severe due to ability to deeply penetrate tissues
    b. Fluid resuscitation needs often underestimated
    c. 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/other powders 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 intra-arterial infusion in affected extremities
    c. Serial EKG and BMP monitoring of patients - may become hypocalcemic
    d. Pulmonary edema may occur if subjected to fumes
    e. Monitor effectiveness of treatment by frequent pain assessment – if treatment is working, pain should decrease
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, current does not run through patient's body
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 – need serial EKG monitoring
2. Renal
a. High risk of renal failure due to hemoglobin and myoglobin deposits in renal tubules – important to see if myoglobinuria is present
i. Requires higher IVF/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. Musculoskeletal
a. Tetanic muscle contractions may be strong enough to fracture bones, especially spine
b. Although there may be minimal external damage, have a high suspicion for compartment syndrome in extremities
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 whirlpool 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 (similar to electrical injuries)

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