**Hyperthermia and Heat Illness**

**Presented by:**  
Eric Johnson, MD  
Emerg. Dept Director, Teton Hospital

**Epidemiology:** During 1979-1997, the most recent years for which data are available, an annual average of 381 deaths in the US were attributable to “excessive heat exposure” (see end for definition). For civilian population, avg. annual death rate of 0.02/100,000.

1995 was a disastrous year for heat-related fatalities with 1021 heat-related deaths. July heat wave in Chicago and Milwaukee was unprecedented.

- 89% occurred in permanent homes
- 57% male/ 43% female
- 67% age 60-89

1999 Chicago/Ohio heat wave data:
- 80 died
- 53% < 65 years
- Psych illness common.
- Most protective factor = working air conditioner.

2003 France Heat wave

**Definitions:**

- **Hyperthermia** is a rise in body temperature above the hypothalamic set point when heat-dissipating mechanisms are impaired (by drugs or disease) or overwhelmed by external or internal heat.
- **Heat Illness:** used to describe all adverse effects on the body of a raised core temperature (NOT FEVER)
- **Heat rash:** [miliaria rubra or prickly heat] rash caused by plugged sweat glands, retention of sweat and secondary inflammatory reaction
- **Heat edema:** self limited swelling of the feet and hands usually seen early with heat exposure
- **Heat cramps:** muscular cramps associated with exercise (usually post exercise) and secondary to relative hyponatremia.
- **Heat syncope:** fainting ascribed to the dilatation of peripheral blood vessels resulting from raised environmental temperature.
- **Heat exhaustion:** Is the result of water/salt depletion in the face of heat stress. Precursor of heat stroke.
- **Heat stroke:** complex clinical disorder characterized by:
  a) Core temperature rises above 40C [104-106°F]
  b) Central nervous system changes/abnormalities.
  c) Proposed: “**form of hyperthermia associated with a systemic inflammatory response leading to a syndrome of multi-organ dysfunction in which encephalopathy predominates**.”

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AP: Europe Heat Wave Killed Some 19,000  
The Guardian (UK) 9-26-2003 | Pamela Sampson
HEAT WAVE = Three or more days during which the air temperature is > 32.2C

Normal Response to Heat:
Narrow range of body temperature for “health”.
Balance between heat generated through metabolism and the external environment...

\[
\text{Heat Gain} = M \pm C \pm K \pm R \pm E
\]
M = metabolism
C = conduction
K = conduction
R = radiation
E = evaporation

Mechanisms of Heat Loss:
- Radiation: 65\% of heat loss
- Conduction: < 2\% [increases with water immersion]
- Convection: 10\% of heat loss
- Respiration: 5\%
- Evaporation: 30\% @ rest and up to 75\% with activity.
  Is the most effective means for dissipating heat, however, above 95\% humidity, evaporation no longer occurs.

Predisposing Factors:

Prolonged Exertion:
- athletes
- military
- outdoor work: e.g. crop workers with 0.39 avg annual death rate/100,000.

Poor muscle conditioning
Lack of Acclimation
Sleep deprivation
Poor living environment

Disease:
- CVD
- Dehydration
- Endocrine disorders: diabetes, thyrotoxicosis,
- Neuropathies
- Hypothalamic disease
- Skin Disorders: burns, scleroderma, CF
- Infections: malaria,
- Seizures

Extremes of AGE: very young and old

Medications and Drugs:
- anticholinergic agents: TCA’s, Phenothiazines
- Amphetamines and cocaine

In the 1995 Midwest Heat Wave, the most common comorbid conditions were: nervous disorders, endocrine disorders, respiratory ailments, and mental disorders.
- Alcohol
- Diuretics
- B-Blockers
- Alpha agonists

Other Factors:
- rapid change in humidity and temperature
- heavy and/or constrictive clothing

**Heat Stress to Heat Stroke: (see reference 24)**

**Exercise or Heat Exposure**

**HEAT STRESS**

- Acute phase Response
- Thermoregulatory response
- Heat Shock response

**Cutaneous Vasodilatation**

**Splanchnic Vasodilatation**

- Exaggerated Acute phase Response
- Release of Nitric oxide
- Production of reactive oxygen & nitrogen species
- Increased intestinal Permeability
  - Endotoxemia

**Thermoregulatory failure, Circulatory shock and HEAT STROKE**

**KNOWN CLINICAL EVIDENCE**

Putative pathways
Heat Exhaustion:
Early Recognition Important...may lead to heat stroke.
Clinical Picture:
Core temp 38-40°C [100.4-104°F]
Malaise, weakness, headache, anorexia, nausea, vomiting,
tachycardia, hypotension, profuse sweating.
Treatment:
Most respond to PO/IV hydration and eliminating heat stress

**Heat Stroke:**

<table>
<thead>
<tr>
<th>Classic</th>
<th>Exertional</th>
</tr>
</thead>
<tbody>
<tr>
<td>Affects elderly/debilitated</td>
<td>Young, healthy, un-acclimatized</td>
</tr>
<tr>
<td>Minimal physical activity</td>
<td>Usually strenuous activity</td>
</tr>
<tr>
<td>Perspiration minimal to absent</td>
<td>&gt; 50% sweating present</td>
</tr>
<tr>
<td>Sets in slowly</td>
<td>Develops rapidly</td>
</tr>
</tbody>
</table>

Clinical Picture:
Temp > 40°C [104°F]
Mental status changes: irritability, confusion, ataxia,
Seizures, coma
Tachycardia, tachypnea with resultant respiratory alkalosis
Ecchymosis, hematuria, hematemesis → clotting disorder—DIC

Lab/Diagnostic Studies:
- complete lab include LFT’s and clotting studies
- CXR
- ECG and enzymes
- ABG’s
- UA
- Lactic acid [significant elevation indicates poor prognosis in classic HS]

Treatment:

**HEAT STROKE:**

**** First priority is to start lowering core temperature***
(The best method is controversial)
Rapid Cooling associated with improved survival.

Pre-Hospital:
- Assess environment
- ABCDE’s...
- Remove unnecessary clothing
- Try cooling methods: mist body with lukewarm water
  Augment airflow over patient
Cover with cool, wet sheets
- Establish IV...fluid challenge
- Oxygen provided.

Hospital:
- ABCDE’s...intubate if needed
- IV access: studies show average volume given 1- 1.3 liters
- Measure core temperature
- Foley...measure I / O’s
- Immediate Cooling !!!!!!! Accurate diagnosis and duration of hyperthermia is main determinant of outcome. Studies seem to show that rapid cooling to below 39C within 30 minutes of presentation improves survival.

Mist method or Evaporative Cooling: Mecca Body Cooling Unit in which a fine mist of warm water [around 32*C] is blown over the patient suspended on a netting stretcher. Alternatively, sponge the naked patient with luke warm water while fanning with room air. Reported cooling rates of 0.31*C/minute. Alternative approaches have mist temps of 59*F and constant draft of air at 45*C [113*F]. “WET and WINDY Approach.

VS

Immersion Method: has worked in some studies with cooling rates reported of 0.15*C/minute. Difficult to manage patients. In studies with heatstroke, ice water cooling was twice as rapid in reducing core temperature as the evaporative spray method (0.20C/min compared to 0.11C/minute). In more than 200 patients with exertional heatstroke, immersion reduced temps to < 39C in 10-40 minutes-no patients died.¹

Peritoneal Lavage: reported to rapidly reduce temperature using 6*C lavage fluid.

Continue cooling until ~ 102*F
Give IV fluids: NS or D5WNS/1/2 NS
Try to minimize shivering/stop thermogenesis (which will only serve to raise the temp)
- Valium commonly used to minimize
If DIC: supportive care until clotting factors return to normal
DO NOT GIVE ANTIPYRETICS...

Complications:
- Worsening of underlying disease process, e.g. CAD
- Liver injury
- Acute renal failure [severe rhabdo seen]
- ARDS
- Blood coag problems---DIC
- Neuro injury

PREVENTION…
- If planning to work outside during “hot” weather, take 10-14 days to acclimate.
- Fluid intake critical!
- Salt intake is important, but salt tablets not recommended.
- Spend time in air-conditioned environment during heat waves.
- Taking cool baths can help.
- Don’t exercise during the hot part of day.
- Remember, fans not protective against heatstroke when temperatures 90°F and humidity exceeds 35%.
- Don’t leave age extremes in autos unattended.
- **Air conditioning the #1 protective factor!!!**

### Current Army Fluid Replacement Guidelines for Hot Weather Training:

<table>
<thead>
<tr>
<th>Heat Condition/Category</th>
<th>WBGIT Index (F)</th>
<th>Water Intake (qt/h)</th>
<th>Work-rest cycle (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>78-81.0</td>
<td>at least 0.5</td>
<td>continual</td>
</tr>
<tr>
<td>2</td>
<td>82-84.9</td>
<td>at least 0.5</td>
<td>50/10</td>
</tr>
<tr>
<td>3</td>
<td>85-87.9</td>
<td>at least 1</td>
<td>45/15</td>
</tr>
<tr>
<td>4</td>
<td>88-89.9</td>
<td>at least 1.5</td>
<td>30/30</td>
</tr>
<tr>
<td>5</td>
<td>90+</td>
<td>more than 2</td>
<td>20/40</td>
</tr>
</tbody>
</table>

Modified replacement Guidelines for Hot Weather Training (Avg Accl Soldier)

<table>
<thead>
<tr>
<th>Heat category</th>
<th>Easy Work</th>
<th>Moderate Work</th>
<th>Hard Work</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>W-R</td>
<td>Water Intake</td>
<td>W-R</td>
</tr>
<tr>
<td>1</td>
<td>NL</td>
<td>0.5</td>
<td>NL</td>
</tr>
<tr>
<td>2</td>
<td>NL</td>
<td>0.5</td>
<td>50/10</td>
</tr>
<tr>
<td>3</td>
<td>NL</td>
<td>0.75</td>
<td>40/20</td>
</tr>
<tr>
<td>4</td>
<td>NL</td>
<td>0.75</td>
<td>30/30</td>
</tr>
<tr>
<td>5</td>
<td>50/10</td>
<td>1</td>
<td>20/40</td>
</tr>
</tbody>
</table>

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**Current cooling method for Exertional Heatstroke at the US Marine Corps Training Base at Parris Island:**

a) An ice chest is constantly available during physical training. Dedicated tubs of water and ice are standing by.

b) In the field, the blouse and pants are removed from a patient who has collapsed from suspected heatstroke; shorts and T-shirt are left on. Rectal temperature is measured; if > 39.4°C, the patient is wet down, ice is packed around the groin and axillary areas, the patient is immediately transported to the clinic on a stretcher. Upon arrival, the stretcher is placed on top of the iced bathtub above the water and ice, with the carrying handles sticking out at both ends.

c) Mental status and other vital signs re assessed and blood is drawn for lab analyses.
d) 1 liter of NS is administered as a bolus.
e) Sheets are dipped into the tub’s icy water and are used to cover and drench the patient. Copious ice is added to the top of the sheet to cool the patient further, and the skin is massaged to improve skin blood flow. The sheets are frequently rewetted with icy water.
f) Concurrently the head is constantly irrigated with more ice water, and a fan is directed at the patient.
g) The patient is not routinely immersed in the ice water in case CPR is necessary. However if the rectal T is not reduced sufficiently, the patient is immersed directly into the ice water. With the above procedure, rectal T usually decreases to 39.5C within 15-0 minutes.

Heat Wave: Three or more days of air temperatures greater than or equal to 90F (32.2C). The National Association of Medical Examiners definition from heat-related deaths includes exposure to high ambient temperature either causing the death or as substantially contributing to it, cases where the body temperature at time of collapse was greater than or equal to 105F (40.6C) and a history of exposure to high ambient temperature and the reasonable exclusion of other causes of Hyperthermia. Because death rates from other causes increase during heat waves, deaths classified as caused by Hyperthermia represent only a portion of heat-related death.

References:
The Heat Index:

Ambient temperature is not the only factor that plays a role in creating the potential for heat injuries, humidity is also important. Since our bodies rely on the evaporation of sweat as a major method of cooling, high humidity reduces our ability to cool the body, increasing the risk of heat illnesses. The Heat Index shows the relative effects of temperature and humidity (see Table 9.5).

<table>
<thead>
<tr>
<th>Relative Humidity</th>
<th>Environmental Temperature Fº (Cº)</th>
<th>Apparent Temperature Fº (Cº)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0%</td>
<td>64º(18) 69º(20) 73º(23) 78º(26) 83º(28) 87º(31) 91º(33) 95º(35) 99º(37) 103º(39) 107º(42)</td>
<td></td>
</tr>
<tr>
<td>10%</td>
<td>65º(18) 70º(21) 75º(24) 80º(27) 85º(29) 90º(33) 95º(35) 100º(38) 105º(41) 110º(44) 116º(47)</td>
<td></td>
</tr>
<tr>
<td>20%</td>
<td>66º(19) 72º(22) 77º(25) 82º(28) 87º(30) 93º(33) 99º(37) 105º(41) 112º(44) 120º(49) 130º(54)</td>
<td></td>
</tr>
<tr>
<td>30%</td>
<td>67º(19) 73º(23) 78º(26) 84º(29) 90º(33) 96º(36) 104º(40) 113º(45) 123º(51) 135º(57) 148º(64)</td>
<td></td>
</tr>
<tr>
<td>40%</td>
<td>68º(20) 74º(23) 79º(26) 86º(30) 93º(34) 101º(38) 110º(43) 123º(56) 137º(58) 151º(66)</td>
<td></td>
</tr>
<tr>
<td>50%</td>
<td>69º(20) 75º(24) 81º(27) 88º(31) 96º(36) 107º(42) 120º(49) 135º(57) 150º(66)</td>
<td></td>
</tr>
<tr>
<td>60%</td>
<td>70º(21) 76º(24) 82º(28) 90º(33) 100º(38) 114º(46) 132º(56) 149º(65)</td>
<td></td>
</tr>
<tr>
<td>70%</td>
<td>70º(21) 77º(25) 85º(29) 93º(34) 108º(41) 124º(51) 144º(62)</td>
<td></td>
</tr>
<tr>
<td>Apparent Temperature</td>
<td>Heat-stress risk with physical activity and/or prolonged exposure.</td>
<td></td>
</tr>
<tr>
<td>----------------------</td>
<td>---------------------------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>90°-104° (32-40)</td>
<td>Heat cramps or Heat Exhaustion possible</td>
<td></td>
</tr>
<tr>
<td>105°-130° (31-54)</td>
<td>Heat cramps or Heat Exhaustion likely.  Heat Stroke possible.</td>
<td></td>
</tr>
<tr>
<td>130° and up (54 and up)</td>
<td>Heat Stroke very likely.</td>
<td></td>
</tr>
</tbody>
</table>

**Caution:** This chart provides guidelines for assessing the potential severity of heat stress. Individual reactions to heat will vary. Heat illnesses can occur at lower temperature than indicated on this chart. Exposure to full sunshine can increase values up to 15° F.
5. Dehydration must be avoided not only because it hinders performance, but also because it can result in profound heat illness. Fluid replacement must be readily available. Student-athletes should be encouraged to drink as much and as frequently as comfort allows. They should drink one to two cups of water in the hour preceding practice or competition, and continue drinking during activity (every 15-20 minutes). For activity up to two hours in duration, most weight loss represents water loss, and that fluid loss should be replaced as soon as possible. Following activity, the student-athlete should rehydrate with a volume that exceeds the amount lost during the activity. A two-pound weight loss represents approximately one quart of fluid loss. Urine volume and color can be used to assess general hydration. If output is plentiful and the color is "pale yellow or straw colored" the student-athlete is not dehydrated.

Water and carbohydrate/electrolyte drinks are appropriate for exercise in heat. Carbohydrate/electrolyte drinks enhance fluid intake, and the electrolytes aid in the retention of fluid. In addition, the carbohydrates provide energy and help maintain immune and cognitive function.

6. By recording the body weight of each student-athlete before and after workout or practice, progressive dehydration or loss of body fluids can be detected, and the potential harmful effects of dehydration can be avoided. Those who lose five percent of their body weight or more over a period of several days should be evaluated medically and their activity restricted until rehydration has occurred.

7. Some student-athletes may be more susceptible to heat illness. Susceptible individuals include those with inadequate acclimatization or aerobic fitness, excess body fat, a history of heat illness, a febrile condition, inadequate rehydration, and those who regularly push themselves to capacity. Also, substances with a diuretic effect or that act as stimulants may increase risk of heat illness. These substances may be found in some prescription and over-the-counter drugs, nutritional supplements and foods.

Student-athletes should be informed of and monitored for signs of heat illness such as: cessation of sweating, weakness, cramping, rapid and weak pulse, pale or flushed skin, excessive fatigue, nausea, unsteadiness, disturbance of vision and incoherency. If heat illness is suspected, prompt emergency treatment is recommended. When training in hot and/or humid conditions, student-athletes should train with a partner or be under observation by a coach or athletic trainer.

First aid for heat illness

Heat exhaustion—Symptoms usually include profound weakness and exhaustion, and often dizziness, syncope, muscle cramps and nausea. Heat exhaustion is a form of shock due to depletion of body fluids. First aid should include rest in a cool, shaded environment. Fluids should be given orally. A physician should determine the need for electrolytes and additional medical care. Although rapid recovery is not unusual, student-athletes suffering from heat exhaustion should not be allowed to practice or compete for the remainder of that day.
Heatstroke—Heatstroke is a medical emergency. Medical care must be obtained at once; a delay in treatment can be fatal. This condition is characterized by a very high body temperature and usually (but not always) hot, dry skin, which indicates failure of the primary temperature-regulating mechanism (sweating), and possibly seizure or coma. First aid includes immediate cooling of the body without causing the student-athlete to shiver. Recommended methods for cooling include using ice, immersion in cold water, or wetting the body and fanning vigorously. Victims of heatstroke should be hospitalized and monitored carefully.

RISK FACTORS

Air temperature, humidity, and dehydration are common risk factors associated with heat illness. In addition, the following factors also put student-athletes at increased risk:

1. Nutritional supplements. Nutritional supplements may contain stimulants, such as ephedrine, ma huang or caffeine.* These substances can dehydrate the body and/or increase metabolism and heat production. They are of particular concern in people with underlying medical conditions such as hypertension, asthma and thyroid dysfunction.

2. Medication/drugs. Certain medications and drugs have similar effects. These substances may be ingested through over-the-counter or prescription medications or with food. Examples include antihistamines, decongestants, certain asthma medications, Ritalin, diuretics and alcohol.

3. Medical conditions. Examples include illness with fever, gastrointestinal illness or sickle cell trait.

4. Acclimatization/fitness level. Lack of acclimatization to the heat or poor conditioning.


*NOTE: Stimulant drugs such as amphetamines, ecstasy, ephedrine and caffeine are on the NCAA banned substance list and may be known by other names. A complete list of banned substances classes can be found on the NCAA Web site at www.ncaa.org/health-safety.
Hypothermia: “Out in the Cold”

Presented By: Eric Johnson, MD
Past President, WMS
ED Director, Teton Valley Hospital, Driggs ID

Objectives: At the completion of this discussion, participants will:
1) Understand basic definitions and classifications of hypothermia.
2) Review basic pathophysiology.
3) Be aware of treatment modalities and options.

Hypothermia is a medical condition for which health care providers need to be aware of. It is easily missed if not considered in the differential diagnosis and the management of patients is often complex and difficult. This subtle condition exists when the body’s core temperature falls below physiological minimums.

“This talk will mainly focus on Accidental Hypothermia”

A couple of cases:

“In February 1999, a 36 year old man with a history of binge drinking was found dead between parked cars in the parking area of a local Alaskan airport. He was last seen alive 18 hours earlier in an extremely intoxicated state. No evidence of injury or violence was noted. Environmental temperature was –20F to –25F. BA was 100mg/dl and urine alcohol level was 272mg/dl.”

“On May 20, 1999 at 1820h, an experienced female skier fell while skiing down a waterfall gully in Norway. She became wedged between rocks and overlying ice, and the space was continuously flooded by icy water. The woman struggled for 40 minutes and stopped moving at 1900. Rescue teams arrived at 1939 and air ambulance at 1956. She was intubated with CPR started. Arrived at hospital at 2110. Pharyngeal and rectal probes measured temp at 14.4°C. Underwent cardiopulmonary bypass and subsequent ECMO. Transferred to ICU after 9 hours of resuscitation. At 5-month follow-up after extensive hospitalization and rehab, she had partial pareses of the lower and upper extremities, which was improving. Mental function was excellent and she had resumed hiking and skiing.

- 1979-1998 a total of 13,970 deaths reported for an average death rate of 699 deaths/year.
- 49% > 65 years.
- Hypothermia deaths have been decreasing.

A. Definition

“Accidental Hypothermia” is defined as an unintentional decline in the core-temperature below 35°C [95°F].

Hypothermia can also be divided in severity based upon temperature:
* MILD 35°C – 32C [95 – 90F]
* MODERATE 32C – 28C [90 – 82F]
* SEVERE < 28C [82.4F]

“FIELD” Hypothermia is frequently divided into two groups:
- mild...above 32C [90F]
- severe...below 32C [90F]

Swiss Mountain Medicine Clinical Classification of Hypothermia
(does not require field core body temperature measurement-Durrer 2003)

Hypothermia I: patient alert, shivering (35 to 32°C, 95 to 89.6°F)
Hypothermia II: patient drowsy, non-shivering (32 to 28°C, 89.6 to 82.4°F)
Hypothermia III: patient unconscious (28 to 24°C, 82.4 to 75.2°F)
Hypothermia IV: patient not breathing (<24°C, <75.2°F)

B. Classification
Numerous classifications systems exist as noted below:
1. Accidental vs. Induced (controlled)
2. Primary vs. Secondary Accidental
   - Primary is an unintentional decrease in core temperature in normal, thermoregulatory-intact individuals (with significant cold exposure).
   - Secondary implies abnormal underlying disease process, which may predispose the individual to heat loss.
      - Decreased Heat Production
         Endocrinologic failure
         Insufficient fuel
         Neuromuscular physical exertion
      - Impaired Thermoregulation
         Peripheral failure
         CNS failure or neurologic abnormalities
      - Increased Heat Loss
         Induced vasodilatation
         Dermatologic causes
         Iatrogenic causes
         Environmental causes
   - Misc. Associated Clinical States
      e.g. trauma, pancreatitis, uremia, infections, etc.
3. Immersion vs. Submersion (cold water near-drowning)
4. Acute vs. Chronic [may also include a subacute category]

C. Normal Temperature Regulation
Man is a homeotherm, i.e. an organism through which many mechanisms is able to maintain a near constant body temperature despite environmental variation. It is known that the thermoregulatory center lies in the hypothalamus [preoptic anterior nuclei of the hypothalamus] and activation sets off a broad response through numerous physiologic events.

A simplified schematic of temperature regulation:

```
Cold Exposure
  ↓
Proprioceptors [skin and other cutaneous]
  ↓
Blood temperature
  ↓
Spino-thalamic
  ↓
Reflex vasoconstriction
```
Mechanisms by which we lose heat:

- **Radiation**... accounts for ~ 50-55% heat loss. Infants lose more due to increased surface area. Estimated an uncovered head can lose up to ½ of the body’s total heat at 4C [39F].
- **Conduction**... heat loss between objects—~15% of heat loss. In water, loss may increase by 20-25 times. With wet clothing, up to 5 times loss compared to dry.
- **Convection**... heat transfer by air/fluid of unequal temperature. ~10-15% loss, wind chill may contribute significantly.
- **Evaporation/Respiration**...~20-30% and affected by relative humidity and ambient temperature

D. Pathophysiology

As the body cools, a spectrum of events will occur with marked individual variation in the clinical picture seen along the decreasing temperature gradient. The primary effect of body cooling is a decrease in tissue metabolism and gradual inhibition of neural transmission and control. Initially, the body is in an “excitation” phase in an attempt to generate heat, however, as the temperature continues to decline, normal mechanisms begin to falter and the body enters an “adynamic or depression” of body systems.

1. Cardiovascular:
   a. From 35-32C[95-90F], an increase in HR, CO, BP.
   b. Below 32C[90F], all parameters begin to decrease with CO at 50% normal at 28C[82F] and 20% at 20C[68F]. There is a decrease in spontaneous depolarization in pacemaker cells with sinus bradycardia and atrial fib (secondary to atrial distension). Transmembrane resting potential decreases with increasing irritability below 28C[82F]; spontaneous V-fib may be seen along with asystole at temps below this (automaticity ceases in the range of 15-25C)
      - “J” or Osborn waves may be seen at the junction of the QRS and ST segment usually in leads II and V6. Can be observed at temps below 32C [90F] and can be helpful diagnostically, but not prognostic.

Osborn J waves (arrows) after the QRS followed by ventricular fibrillation secondary to jostling during an ambulance ride in a hypothermic patient (Danzl 2002).
2. Nervous System:
   After an initial increase, cerebral metabolism decreases 6-7% / degree C below 35°C [95°F]. Spectrum is from confusion and decreasing mentation to coma. Pupils commonly dilate at 30°C [86°F] with reflexes lost at 27°C [81°F]. EEG reported flat @ 20°C [68°F]. Protection of the CNS with deep hypothermia is interesting and highly variable. Dog studies at 20°C [68°F] showed cerebral oxygen consumption declined to 70% of measured normal values, CBF decreased 39% during hypothermia and cortical pO2 levels were noted to decrease only 10% at 20°C.

3. Respiratory:
   Again, an initial increase ‘till ~ 32°C [90°F], then a decrease in RR to ~ 7-15/min. at 30°C, 4-7/min in the mid 20’s. Decrease in ciliary function and gag reflex with increased likelihood of pneumonia and aspiration.

4. Gastrointestinal:
   a. Decreased motility with ileus common below 34°C [93.2°F].
   b. Decreased enzyme function (both exocrine and endocrine) of pancreas.
      Note: insulin not effective below 30°C

5. Renal:
   a. Decreased renal perfusion and glomerular filtration rate.
   b. “Cold induced diuresis” due to increased peripheral vascular resistance with fluid shifted to central core. Cold-water immersion increases urinary output 3.5 times with alcohol doubling that diuresis.

6. Heme:
   Due to fluid shift and diuresis, an increased viscosity (2x @ 20°C) and hemoconcentration noted. Cold inhibits the enzymatic reactions of the coagulation cascade, as well as platelet activity declines…may see cold induced thrombocytopenia.

7. Endocrine:
   Fairly well preserved with increased cortisol levels and thyroid usually normal (unless underlying disease) in accidental hypothermia.

8. Metabolic:
   Decreased metabolic function and oxygen consumption (~7% / C) such at ~30°C is 50% and at 20°C is 10%.
   Also, oxyhemoglobin curve shifts to the left, this decreasing the release of bound oxygen from the hemoglobin molecule at a lower partial pressure of oxygen.

9. Acid-Base:
a. When blood cools, arterial pH increases and partial pressure of carbon
dioxide falls. Metabolic causes of acidosis will be seen and most with
hypothermia will show an acidosis.
b. No safe predictors of electrolyte changes, however K+ should be
checked frequently as hypothermia can mask K+ induced changes in
the ECG. Hyperkalemia can be very dangerous in these patients.

E. CLINICAL MANAGEMENT AND TREATMENT

1. General Comments:
   a. One must think “hypothermia” in many cases before it is discovered…remember
to check core temp from more than one source.
   b. Clinical presentations may be highly variable based on pathophysiological
spectrum…core temperature should support clinical findings.
   c. Treat other injuries…don’t forget ABCDE’s.
   d. “No one is dead until warm and dead…unless they’re already dead”
   e. In general, avoid excess stimulation and handling for severe hypothermia…
   f. Get help and the team together…you may be working a long time and need lots of
resources!!!!
   g. Rapid rate of re-warming does not necessarily correlate with an increased survival
rate, except when cardiac arrest is present.

2. Pre- Hospital:
The principles are:
   a) Rescue safely.
   b) Prevent further heat loss (minimize core after-drop).
   c) Re-warm based upon conditions and equipment.
   d) Treat and handle gently.
   e) Transport to appropriate medical center.

There are many clinical examples of victims being rescued from a
cold stress (usually cold water immersion) in an apparently stable and
conscious condition only to experience “re-warming shock”, “post-rescue
collapse” or a coined by Golden, “circum-rescue collapse”. A case in 1980,
involving 16 Danish fishermen who were forced to abandon their fishing
vessel, is perhaps illustrative. These men were rescued after spending over
one hour in open water. During the rescue, they were able to climb aboard the
rescue vessel using a cargo net and were able to walk across the deck before
going below. All reportedly died of hypothermia.\(^1\) There are several
mechanisms which may contribute to re-warming shock: 1) the large after-
drop in core temperature, 2) collapse of arterial pressure; and 3) humoral
factors such as changes in pH that may stimulate ventricular fibrillation.

In general, care should be centered on rescue, examine, insulate and transport. Decision-making should be very conservative...take time to detect pulse and respirations. Try to obtain accurate history of events-helpful in choosing correct modality to re-warm. During pre-hospital transport, when ability to monitor and control physiologic parameters may be limited, a safe strategy would be to promote steady but moderate re-warming (~2C/hour).

3. Emergency Department/Hospital:

**ACTIVE VS PASSIVE REWARMING ?????**

a) Spontaneous Endogenous Re-warming or Passive Rewarming: best for the healthy patient with mild hypothermia.

b) Active Re-warming should be used when there is CV instability, temp < 32C, underlying disease states or passive rewarming has not been adequate.

   1) Active external re-warming or exogenous external re-warming:
      - Radiant heat
      - Hot water bottles or Heat Pac to heat loss areas.
      - Plumbed garments (rarely used)
      - Electric heating pads and blankets
      - Forced circulated hot air
      - Immersion in warm water: whole body vs. extremities.
        Vanggaard and Gjerloff\(^2\) proposed a simple re-warming Technique that supplies exogenous heat by immersing hands, forearms, feet, and lower legs in 44-45C water.
        - Negative pressure heating: not widely used.

        **CONS:** Can impede monitoring and resuscitation.
        Potential for dermal thermal injury.
        Potential for Core-After Drop: is a continuing decrease in core T after initiation of rewarming.
        **PROS:** May be useful in moderate hypothermia.
        Note: Then shivering is present, moderate exogenous re-warming in not any more efficient than shivering.

   2) Active internal re-warming or External Internal Re-warming:
      - Inhalation re-warming: (some benefits, but minimal thermal balance benefit)
      - Heated infusions
      - Gastric and colonic lavage
      - Mediastinal lavage: ED thoracotomy with internal cardiac massage and lavage reported in hypothermic arrested patients.\(^3\)

- Thoracic lavage
- Peritoneal lavage
- Extracorporeal lavage or cardiopulmonary bypass.

Preferred modality for treatment of the severely hypothermic patient with persistent non-perfusing cardiac rhythm.
- Diathermy (not widely used...experimental)

Extracorporeal re-warming remains the most efficient means of re-warming. Re-warming rates for the standard setup will raise core 1-2C every 3-5 minutes. Most centers use fem-fem. Studies are now ongoing for use of heparin-less bypass, especially important for the hypothermic trauma patient. Endovascular also increasing popularity.

NOTES:

- Drugs: Bretylium tosylate has been suggested as the most promising antiarrhythmic at low temps as it increases the ventricle threshold. 10mg/kg initial dose. No longer found. No good data on amiodorone.
- Ringer’s not recommended due to poor metabolism by the liver.
- Since NO large controlled studies exist, rigid treatment protocols should not be considered “standards”.
- Warming of fluids can be through standard blood warmers or whatever your hospital uses...microwave warming works well and NS takes about 2 minutes on high (try before you actually use). Careful with glucose solutions as it caramelizes at 60C [140F]. Mix thoroughly and use short tubing.
- IV’s, peritoneal lavage fluid at 40-42C [104-107F].
- Warmed, humidified air at 40-45C.
- Empirical anti-microbial therapy recommended for neonates, elderly, immuno-compromised. Cephalosporin plus an aminoglycoside has been recommended.
- In review of the literature, most successful defibrillations occurred at or slightly above 30C.

Where to take the Temperature???
- Tympanic with Diatek or First Temp—often poor. Aural can be OK but not readily available.
- Rectal temp- probe should be placed deep into rectum (10-15 cm)...easily placed in cold stool. Rectal lag often a problem.
- **Esophageal** — often-accurate measure of core.

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- Bladder probe.
- Oral- often worthless.

Labs: CBC, Chemistry profile, Coags, Amylase, ABG’s (not corrected), Type and cross, drug screen and blood alcohol, cardiac enzymes, cultures, possibly TFT’s. [NOTE: Preliminary interosseous studies on peds seem to show interosseous abg’s correlate well and may be helpful].

Radiologic: determined by clinical situation. C-spine, CXR, KUB often obtained. Other plain films as indicated as well as CT of Head and Belly.

ECG: obtained and closely monitored

Other: NG tube, Foley, Central line?

**Therapeutic Hypothermia:**

**Conclusions:** Therapeutic hypothermia is feasible and can be used safely and effectively outside a randomized clinical trial. The rate of adverse events was lower and the cooling rate was faster than in clinical trials published. (Crit Care Med 2007; 35:1041–1047)

In 2005, by the American Heart Association Guidelines for CPR and Emergency Cardiovascular Care, which included the following treatment recommendations [68,69]:

**Unconscious adult patients resuscitated after out-of-hospital cardiac arrest should be cooled to 32_C to 34_C (89.6_F–93.2_F) for 12 to 24 hours when the initial rhythm was ventricular fibrillation (Class I1a)** Similar therapy may be beneficial for patients with in-hospital cardiac arrest or out-of-hospital arrest associated with an initial rhythm other than ventricular fibrillation (Class I1b)


4. **Post – Resuscitative:**

All but the mildest hypothermia should be observed and treated in ICU setting until stable.

Complications:

- CV: hemodynamic instability, dysrthymias, MI or underlying disease.
- Pulm: pneumonia, aspiration, overload.
- GI: ileus, pancreatitis
- Heme: DIC, bleeding complications
- Neuro: paresthesias, numbness, loss of fine coordination, amnesia, confusion which slowly clears.
- Other: spesis, treatment complications, rhabdo, others.

**Myths of the COLD:**

a) Don’t rub snow on frostbite/

b) Alcohol makes you warmer.

c) You lose most of your heat through your head.
   a) 8-10% through head

d) You’ll die in cold water in 5-10”

e) Always stay with your boat if it overturns.
Chapter 11: 2005 WMS Practice Guidelines
HYPOTHERMIA

Recommendations are considered Category 1B, except were indicated 1A, by the WMS Panel of Expert Reviewers.

I. GENERAL INFORMATION

Hypothermia occurs when the body’s ability to generate and conserve heat is overcome by heat loss. Acute hypothermia presents with a sudden drop in body core temperature within a few hours. This is usually caused by immersion in cold water or a sudden drop in ambient temperature combined with wind and precipitation. Chronic hypothermia is the result of a gradual drop in body core temperature over several hours. Most chronic hypothermia deaths occur when the ambient temperature ranges from 30 to 50°F (-1 to 10°C). Hypothermia is almost always preventable by minimizing heat loss via conduction, convection, radiation, and evaporation. Prevention includes 1) proper choice and use of clothing and shelter, 2) avoidance of overexertion, 3) staying dry (a combination of proper clothing and avoidance of overexertion), 4) staying well-hydrated and 5) maintenance of adequate nutrition.

A. Mild Hypothermia: Hypothermia is considered mild if the core temperature is below 95°F (35°C) and above 90°F (32°C). In this temperature range, the thermoregulatory defense mechanisms, such as shivering, are generally unimpaired and operating maximally. Mild hypothermia often first manifests itself as loss of judgment and fine motor coordination. Shivering is often suppressed by physical activity, but by the time core temperature reaches 95°F (35°C), most patients are shivering vigorously. Uncontrollable shivering will be seen during further cooling to 90°F (32°C), except in some chronic exposure situations (>6-8 hours) where exhaustion and shivering fatigue may occur. Slurred speech, a stumbling gait and the development of ataxia are highly suggestive of hypothermia in a cold-exposed patient. It is important to note that most patients with mild hypothermia are fully able to rewarm themselves through shivering heat production, although they require protection from further heat loss in order to do so. The exception will be an exhausted patient who is unable to shiver.

B. Moderate-to-Severe Hypothermia: Hypothermia is considered moderate at core temperatures below 90°F (32°C) and above 82°F (28°C), and severe at core temperatures below 82°F (28°C).

As core temperature decreases below 82°F (28°C) (severe hypothermia), the heart is at risk of ventricular fibrillation either spontaneously due to low heart temperature, or as a reflex response to mechanical stimulation. The patient loses consciousness and pupils may be dilated and fixed. The torso will be cold to touch. The patient may be rigid and unresponsive, with non-palpable pulse and respirations, but not dead (the patient cannot be presumed dead unless these conditions persist after warming, or if obvious signs of fatal trauma are present).

II. GUIDELINES FOR FIELD TREATMENT

A) General Principles: The general principles of treatment apply for all cases of hypothermia. The patient must be gently removed from the cold exposure and remain in
a horizontal position. REMOVE WET CLOTHING CAREFULLY AND INSULATE THE PATIENT COMPLETELY (i.e., with one or even two sleeping bags), while maintaining an adequate exposure of the airways. This will minimize convective and conductive heat loss. A vapor barrier (i.e., plastic sheet, space blanket etc.) can be added to eliminate evaporative heat loss and PROTECT THE INSULATION FROM BECOMING WET. If wet clothing cannot be removed safely, place the vapor barrier between the clothing and insulation. If the patient is dry, the barrier could be placed outside the insulation.

B) Mild Hypothermia: A mildly hypothermic patient will normally be shivering vigorously and may be dehydrated. Administer fuel for shivering with warm high-energy drinks (non-alcohol) and foods, providing the patient is alert and can swallow without choking.

External heat sources, such as chemical or charcoal heat packs and hot water bottles can be used. For rewarming purposes, the heat should be applied preferentially to the chest and armpits. During winter transport heat should be applied to the soles of the feet to prevent frostbite (PROVIDED FROSTBITE IS NOT ALREADY PRESENT). Place the palms of the hands on the chest. Do not apply these heat sources directly to the patient's skin, but over a thin layer of clothing.

Exercise will generate heat but may also precipitate a significant drop in core temperature (afterdrop). If the patient is otherwise healthy and vigorously shivering, mild exercise may be initiated only after 45 to 60 minutes of shivering in an insulated environment. At this point the afterdrop should be reversed. However, if any deterioration in physical or mental condition occurs during exercise, it should stop immediately.

C) Moderate-to-Severe Hypothermia: Whether a patient is moderately or severely hypothermic, the clinical condition is serious: treatment is the same UNDER ALL CIRCUMSTANCES. The patient must be handled very gently and kept in the horizontal position. Because of the risk of inducing ventricular fibrillation, remove wet clothing and take care to minimize patient movement while performing other life-sustaining measures. Make arrangements to transfer the patient to medical facilities as soon as possible. Shivering will be weak, intermittent or nonexistent and the patient will not rewarm spontaneously. The condition may degenerate progressively. Application of moderate heat to the chest and armpits is indicated. Place external heat sources, such as heat packs etc., over a thin layer of clothing as indicated above.

Warmed and humidified supplemental oxygen may be administered. This is unlikely to significantly heat the body core; however, improvement in cardiovascular and mental function has been reported with this treatment likely due to rewarming of the brainstem via heat transfer form the upper airways.

Do not give a patient with impaired consciousness any warm drinks as this may cause burns and/or choking. Aggressive rewarming, such as warm water immersion, should never be attempted as this may cause ventricular fibrillation. Do not rub the extremities under any condition as rubbing produces little frictional heat, but damages the skin and underlying tissue (especially if it is frozen).

D) Cardiopulmonary Resuscitation: A cold, rigid, apparently pulseless and breathless patient is not necessarily a dead patient. A cold patient with no detectable pulse should not necessarily be given chest compressions. Apparent pulselessness may be caused by hypothermia and the resulting tissue rigidity in combination with a very slow heart rate. Under these conditions chest compressions may trigger ventricular fibrillation, and will not be effective in someone dead from the cold.

Check for breathing and pulse for a full minute, because vital signs in hypothermia may be present but very slow and faint. If you fail to detect cardiac activity or respiration, initiate rescue breathing immediately. This should continue for 3 minutes
as improved oxygenation may strengthen cardiac activity and make it detectable. The patient needs oxygen and there is no danger to the patient from rescue breathing. If bag and mask are used (with ambient air or compressed oxygen), care should be taken not to hyperventilate the patient as the heart is more susceptible to fibrillation during periods of hypocarbia. After 3 minutes of rescue breathing, another 60 seconds should be taken to detect cardiac activity and respiration. If the patient is still pulseless and breathless, chest compressions could be initiated.

Do not initiate chest compressions in a patient who has been submerged in cold water for more than 1 hour; has a core temperature of less than 10° C; has obvious fatal injuries; is frozen (e.g. ice formation in the airway); has a chest wall that is so stiff that compressions are impossible; or if the rescuers are exhausted or in danger.


Defibrillation is rarely effective if the core temperature is below 30° C.

In the patient who is not breathing and has no pulse, the clinical decisions are based on access to transportation:

• If transportation is available within 3 hours, begin ventilation (intubate if possible), protect from further cooling, and do not start chest compressions. Wait for the rescue crew. Starting chest compressions might precipitate ventricular fibrillation in a patient who actually has a weak pulse which is difficult to detect, but which might be providing adequate perfusion. If chest compressions cause ventricular fibrillation, perfusion will be lost.

• If transportation is not available within 3 hours begin ventilation (intubate of possible), start chest compressions and perform for up to 30 minutes while attempting to rewarm the patient. If this is unsuccessful in restoring spontaneous circulation, discontinue CPR.

• CPR, while litter bearing, is not effective and should not be attempted.

III. GUIDELINES FOR EVACUATION

If a patient with mild hypothermia is adequately rewarmed, with a return to normal mental status, there is no need for evacuation. Take care to prevent a recurrence. Monitor the patient while walking with him/her to the nearest location where treatment is practical. Patients who do not respond to rewarming, or who obviously have moderateto-severe hypothermia, must be insulated for maximum heat retention, provided with moderate heat source(s), and be evacuated as soon as possible. Evacuation of such a patient must be as gentle as possible to prevent ventricular fibrillation. Package the person so that rescue personnel are able to examine the patient periodically. Every 15 minutes during transport check the patient for 1) vital signs, 2) burning of the skin underneath heat sources and 3) circulation in the feet to examine for frostbite, unless this examination increases heat loss in which case be judicious in monitoring as often as
ALGORITHM:

Rescue & Examine

YES

Responsive

NO

Respirations ? (take your time)

YES

Assume cardiac output

NO

Ventilate 3 minutes & recheck Pulse for 60 seconds. Institute BLS

Pulse for 60 seconds.

Institute BLS

IV Access if able

Thiamine, Glucose, Narcan if Indicated.

Cardiac Monitor

Nonarrest Rhythm: SB, Afib

Arrest Rhythm: VF, asystole

Central pulse ?

YES

NO (?)

Heat desirable

Heat optional

Spontaneous re-warming

Insulate/Vapor barrier/Fuel

Gentle handle

Evacuate

To Hospital

CPR

If transport < 3 hours, intubate if able and do not start. If > 3 hours, CPR x 30 minutes, if not effective- STOP

Insulate, IV D5NS, O2

Cardiac monitor

Gentle handle

Evacuate

Yes

NO
HOSPITAL

Perfusing Rhythm present?

YES

- Core T>32°C
  - Passive or External rewarm

- T<32°C
  - Use active core rewarm alone or with AER

NO

Extracorporeal rewarming option?

- yes
  - Rewarm to >32°C
  - During CPR Use all methods of ACR + AER available

- NO
  - T<32°C
  - Use active core rewarm alone or with AER
Objectives:
1. Understand the physics involved in lightning and risk factors for human harm.
2. Discuss pathophysiology of lightning injuries and learn pathognomonic signs.
3. Learn the immediate care protocols as well as strategies for definitive treatment of lightning injury.
4. Discuss prevention strategies.

Introduction:
Why discuss the topic of lightning injuries? This question is one I hope to be able to answer clearly by the end of my review, but for me, the answer lies in Prevention. Once struck, one is propelled upon a course of multiple outcomes, some of which we can impact, and others in which little can seemingly be done. It is important to understand risk factors for lightning development, consequences, medical treatment and most importantly, how not to be a victim.

Recommended reading: “A match to the heart” by Gretel Ehrlich
Published originally by Pantheon Books, 1994.

“Development” and Physics of Lightning:
From the beginnings of time, to Aristotle who proposed that lightning was burning wind, to Benjamin Franklin who proved via a kite that lightning was electrical, and through today’s technology, lightning remains a fascinating object of awe and study. In his book Understanding Lightning, Dr. Martin Uman of the University of Florida pondered the possibility, suggested by others, that “it may well have been lightning in the primordial soup covering the earth several billion years ago that produced the complex molecules from which life eventually evolved...Thus, we may be indebted to lightning for the presence of life on earth.”

Lightning remains a universal concern. With over 2000 thunderstorms in progress above the earth’s surface at any one time, this means approximately 8 million strikes each day or about a hundred cloud to ground lightning discharges each second. As the particles within a cloud (called hydrometeors) grow and interact, some become charged possibly through collisions. It is thought that the smaller particles tend to acquire positive charge, while the larger particles acquire more negative charge. These particles tend to separate under the influences of updrafts and gravity until the upper portion of the cloud acquires a net positive charge and the lower portion of the cloud becomes negatively charged. This separation of charge produces enormous electrical potential both within the cloud and between the cloud and ground. This can amount to millions of volts, and eventually the electrical resistance in the air breaks down and a flash begins. Lightning, then, is an electrical discharge between positive and negative regions of a thunderstorm.

A lightning flash is composed of a series of strokes with an average of about four. The length and duration of each lightning stroke vary, but typically average about 30 microseconds. (The average peak power per stroke is about $10^{12}$ watts.)

The facts:
a. Travels as fast as 100,000 miles a second.
b. Up to ~ 50,000 degrees F
c. Channels longer than 10 miles have been observed. Case reports of “a bolt from the blue” where one may be struck on an apparently clear day.¹
d. Lasts ~ .01 - .0001 of a second
e. Potentials often as high as 10 million to 100 million volts.
f. Current up to 50,000 + amps.

DESCRIPTION OF LIGHTNING DISCHARGE PROCESSES
With the initial breakdown of the air in a region of strong electric fields, a streamer may begin to propagate downward toward the Earth. It moves in discrete steps of about 50 meters each and is called a stepped leader. As it grows, it creates an ionized path depositing charge along the channel, and as the stepped leader nears the Earth, a large potential difference is generated between the end of the leader and the Earth. Typically, a streamer is launched from the Earth and intercepts the descending stepped leader just before it reaches the ground. Once a connecting path is achieved, a return stroke flies up the already ionized path at close to the speed of light. This return stroke releases tremendous energy, bright light and thunder. Occasionally, where a thunderstorm grows over a tall Earth grounded object, such as a radio antenna, an upward leader may propagate from the object toward the cloud. This "ground-to-cloud" flash generally transfers a net positive charge to Earth and is characterized by upward pointing branches. The initial breakdown and propagation are similar for intra-cloud lightning, but the discharge generally occurs between regions of opposite charge. Nevertheless, tremendous energy, bright light, and thunder are still produced by intra-cloud lightning.

Electricity is defined as the flow of electrons between points of high potential (concentration) to low potential. The volume or actual number of electrons that flow is the current and is measured in amperes (I). Voltage, as measured in volts (V), is the electromotive force that drives electrons across the potential difference. Resistance describes the hindrance to the flow of electrons and is measured in ohms (R). Ohm's law describes the relationship: I = V / R ...current is directly proportional to voltage and inversely related to resistance. The transformation of electrical energy into heat is what causes most of the harmful effects and is described through Joule's law: \[ \text{Heat} = k(I) \times R \times T \]

Heat generated is directly proportional to the amount of current, tissue resistance and the duration of contact.

Epidemiology:
NOAA data of the estimated number of lightning deaths from 1940-1973 is larger than the number caused by tornadoes, floods and hurricanes. Since 1973, lightning is reported to have killed an average of 67 people a year, second only to 146 flash-flood/flood-related deaths. In 2003, 44 deaths were reported. Tornadoes rank third and hurricanes fourth with 17 deaths per year. Lightning is consistently one of the top three causes of deaths/year with flash floods, winter weather and temperature extremes exchanging places from year to year. The number of people injured by lightning averages more than 2.5 times the number of lightning-related deaths. Recent data from the National Weather Service show that lightning casualty statistics are underreported by at least 28% and 42% for injuries. Hence, lightning kills about 100+ people [US] a year and injuries 400 more; the actual number of injuries is probably much larger.

Risk times and places:

¹ see end of syllabus for case report
a. 92% of casualties occurred between May and Sept, peak in July.

b. 73% of casualties occurred in the afternoon [noon-7pm].

c. Nat Center for Health Stats (NCHS): highest number of deaths in Florida and Texas.

d. From population normalized data, Wyoming has the highest lightning casualty rate [0.196/100,000 inhabitants, followed by New Mexico, than Arkansas and Florida [0.120/100,000]. This data changes frequently...

Who and what activities:

1. NCHS from ‘68-’85 shows the highest mortality risk from age 10-19(men < 40) and are predominantly males.

2. From Colorado data, 66% of incidents had only one casualty; with max number of casualties in an incident were 12.

3. Data from Colo., more people were casualties during recreation (52%), than during employment (25%). In Florida, employment was 38% and recreation 32%.

4. More people in Colorado were lightning victims near or at the summit of a mountain ridge (18%) and the vicinity of trees (16%). In Florida, a location close to water was the most common (25%), followed by trees (22%) and transportation (10%).

5. Analyses for Colorado and Florida show a high number of victims on a golf course, however, the golf-related frequency is equaled or exceeded by several other activities and locations.

6. Military data from ’98-’01 showed 142 lightning strikes caused 350 service member injuries and one death.

   - 374 deaths...annualized rate of 0.23 deaths/ million persons.
   - 75% (286) were reported in the South and Midwest with Florida and Texas the highest.
   - 1 in every 4 deaths was work related (129) with agriculture and construction the highest numbers reported.

In October 1997, NOAA published findings of some 35 years of USA lightning statistics...the report highlights are summarized below:

1) Location:
   - 40% unreported
   - 27% open fields and recreation areas
   - 14% under trees
   - 8% water-related
   - 5% golf/golf under trees
   - 3% heavy equipment and machinery related
   - 2.4% telephone related (not cell phone).

2) Gender of Victims: 84% male; 16% female

3) Months of most incidents: June 21%; July 30%; August 22%

4) Days of week of most incidents: Sun/Wed/Sat

5) Time of Day: 2-6pm

6) Number of Victims: one-91%; two or more- 9%.

7) Deaths by state: FL, MI, TX, NY, and TN

8) Injuries by state: FL, MI, PA, NC, and NY.


- 1318 deaths due to lightning
- Greatest number: FL, TX.
- Highest Rates: NM, AZ, AK, MS.
**Pathophysiology:**

Lightning injury may occur by one of several mechanisms:

a. Direct strike.
b. Contact...person in direct contact with an object carrying current.
c. “Splash” or side flash...lightning jumps from its primary strike.
d. Ground current...lightning current spreading through the ground.
e. Blunt trauma...injury caused from shock waves produced by expansion and implosion of surrounding air.

**Factors of Determining Electrical Injury:**

- type of circuit
- resistance of tissues
- amperage and voltage
- current pathway
- duration
- environmental factors

**Resistance of Body Tissues:**

- Least: nerves-blood-mucous membranes-muscle
- Intermediate: dry skin
- Most: tendon-fat-bone

High temperature and electromechanical forces are the primary causes of human injury, and the extent of injury depends upon the factors noted above. Probably the most important difference between lightning and high-voltage electrical injuries is the duration of exposure to the current. Lightning causes a massive current but of a very short duration, the study and mathematics of this makes predicting injuries difficult and is not well advanced.

Lightning current may flow internally for an incredibly short time, causing a “short circuit” of electrical systems but it seldom causes significant burns or tissue destruction. Cardiac and respiratory arrest, neurologic damage and autonomic instability are more common seen. Lightning will tend to cause asystole rather than V-fib.

**Clinical Manifestations [Keraunopathology]:**

In this section, I wish to briefly review manifestations of lightning injuries with regards to body systems, and discuss acute treatment in the following section.

**A. Cardiac and vascular:** Immediate cardiac arrest is the most common cause of death after a direct strike, this in effect, a “celestial” counter-shock as lightning is high voltage, large impulse and of short duration. Asystole is commonly seen, but V-fib may occur. Spontaneous conversion to NSR may occur and may be common. ST-T wave changes may occur, along with prolonged QT, enzyme levels may elevate, but true myocardial infarction is noted to be rare. In a review of “CV Effects of Lightning Strikes” by Lichtenberg, important differences were seen with re: to the type of strike. Direct strike resulted in a high incidence of life-threatening pericardial effusion or severe global cardiac dysfunction. Splash injuries manifested CK-MB release but had normal echos and no ECG evidence of injury. Ground strikes had only non-specific ECG changes. Injury as assessed by CK-MB release was seen in 75% of direct hit victims, 66% of splash and 12% of ground strike. Late sequelae was limited to a single case of recurrent pericarditis.

Autonomic instability with unexplained hypertension and peripheral vasospasm may occur, but usually will resolve over hours. Keraunoparalysis is an intense vascular spasm, which results in loss of pulses, mottling and absent sensation in an extremity...thought due to sympathetic nervous system instability and again usually resolves spontaneously.
B. **Respiratory:** At the time of a strike, concomitant respiratory arrest may occur due to paralysis of the brainstem respiratory center, and this may outlast cardiac arrest. If timely ventilation assistance is not provided, secondary hypoxic cardiac arrest will occur...the duration of apnea rather than the duration of asystole appears to be the critical factor in mortality.

C. **Cutaneous:** The skin manifestations of lightning strikes are varied and usually superficial secondary to “flashover”...deep burns are reported to occur in less than 5% of cases. Manifestations include:

1. Punctate burns appear like small cigarette burns, may be clustered and may/ may not requiring grafting
2. Linear burns are partial thickness and tend to occur over areas of moisture such as axilla and groin.
3. Feathering burns are not true burns but a feming pattern seen due to electron showering over the skin. These are also known as Lichtenberg figures, and resolve within hours. Reported by Georg Lichtenberg in 1777, they appear over the skin within one hour of the strike and may last 24-36 hours. Thought now to be fractal patterns caused by positive charges over the skin.
4. Thermal burns result from ignition of clothing or heating of metallic objects such as jewelry or belts.

D. **Neurologic:** The nervous system is especially vulnerable to effects of lightning, both central and peripheral. Up to two-thirds of seriously injured patients have keraunoparalysis (KP) on presentation, with cold, pulseless extremities and mottling. KP is a transient paralytic state and lasts for minutes to hours. Massive stimulation of the autonomic nervous system is thought responsible. Many patients will have LOC and then appear confused with anterograde amnesia for days. CNS injuries are the most common with cerebral infarction, hypoxic encephalopathy, basal ganglial degeneration and intracranial hematoma seen. Peripheral nerve lesions can be seen but are reported to be less common. Autonomic nervous system complications occur with hypertension the most common, but cases of hypotension have also been reported. Four categories for neurologic complications have been proposed:

1. Immediate and transient symptoms.
   a. Nearly 75% of patients with lightning strike have a brief LOC and 80% have brief limb weakness and paresthesias. Headache may be present.
   b. Keraunoparalysis with Lichtenberg figures seen.

2. Prolonged or permanent (damage to CNS)
   a. Post hypoxic-ischemic encephalopathy.
      i. Most common secondary to cardiac or respiratory arrest.
   b. Cerebral infarction (rare).
   c. Intracranial hemorrhages.
      Susceptible locations are the basal ganglia and brainstem.
   d. Cerebellar syndromes (uncommon).
   e. Myelopathy
      i. Spinal cord injuries result in paralysis, chronic pain, pressure ulcers, autonomic dysfunction.
   f. Peripheral nerve lesions.
   g. Autonomic nervous system disorders include cardiac dysrythmias and cold temperature insensitivity in that these folks can tolerate cold weather without need for warm clothing. Thought to be an issue in the hypothalamus.
   h. Behavior and neuropsychiatric problems.

3. Delayed neurologic syndromes.
   a. Include motor neuron disease and movement disorders. ALS, parkinsonism, focal dystonia and tics are reported. Chronic epilepsy is rarely seen.
4. Secondary or lightning-linked complications. Usually related to the trauma, blast effect or falling.

E. Renal: Renal problems are reported but rare as compared to high voltage electrical injuries. Failure secondary to hypoperfusion and myoglobinuria [usually secondary to blunt trauma] can occur.

F. Ophthalmic: Cataracts are noted with other electrical injuries but are less common in lightning injuries. Macular edema and cataracts are the most common. Reviews of a variety of neuro-opthalmologic complications are rare, but injuries to the entire axis have been noted such as retinal detachments, optic nerve injury and even blindness.

G. Otologic: Tympanic membrane rupture is most commonly reported, but other otologic problems such as transient vertigo, sensorineural hearing loss, conductive deafness, tinnitus, basilar skull fracture, avulsion of the mastoid bone, burns to the external auditory canal, and peripheral facial nerve palsy have been noted.

H. Musculoskeletal: Numerous types of fractures and dislocations have been reported, probably most common due to blunt trauma or severe spasm. Muscle compartment syndromes are also reported but in general are rare. Physeal injuries in children have been reported. In review from a referral clinic, a number of disc disruptions were found, thought secondary to the severe muscle contractions and possible trauma.

I. Blunt trauma: Any organ system may be injured secondary to being thrown by the secondary concussion.. all patients should be stabilized and evaluated accordingly.

J. Psychiatric: “Post-electric” shock syndrome is a disorder of cognitive and psychologic disturbances following lightning or electrical injury. Cognitive complaints and deficits resemble those in mild to moderate traumatic brain injury, and psychologic disturbances range from specific phobias to major depression. Multiple somatic complaints are often noted. Chronic pain syndromes may develop which may also lead to long-standing depression with its associated risks. Patients who have not recovered from initial effects after 3 months are at risk for long-term sequelae and disability. A larger support group called the Lightning Strike and Electric Shock Survivors, Int. Inc. exists.

K. Pregnancy: In a review of 11 pregnant women who survived lightning strike, there were 5 cases of fetal death in utero, abortion, stillbirth or neonatal death. The only fetal autopsy revealed pulmonary interstitial hemorrhage. Latest review now totals 13 cases with 0% maternal mortality and 50% fetal mortality [38].

TREATMENT:

If the lightning strike is not witnessed, it is difficult and confusing at times to clarify the diagnosis. Differential diagnoses include trauma and assault, MI, CVA, seizure, subarachnoid hemorrhage and the differential that is used for unconsciousness in emergency medicine. The presence of typical burn patterns, keraunonparalysis, outdoor location with thunderstorm present and/or tympanic rupture may be clues.

The major cause of death in lightning injuries is cardiopulmonary arrest (~10%). Quick initial assessment and treatment needs to be instituted ASAP. Most lightning strikes involve single victims, however groups are sometimes involved. “Reverse triage” is applied to multiple victims of lightning injuries; i.e. victims who appear clinically dead following the strike should be treated before other victims who show signs of life.

At the Scene:

Initial assessment and “reverse” triage if needed.
Aggressive ABC’s with CPR if needed.
Standard ACLS with good ventilation.
Be aware of potential for blunt trauma injuries.
(C-spine and backboard)

Consider other environmental injuries...hypothermia

Transport

Note: lightning strike victims seldom have significant underlying tissue destruction, and in contrast to other electrical injuries, fluid loading is NOT necessary and may be harmful.

Emergency Department Management:
- History may be poor or difficult to obtain
- ABCD and E
- Cardiac monitoring and ECG
- Lab: routine enzymes, CBC, chemistries, UA
- Xray: plain films pm, CT, others as needed.
- MRI scanning reported helpful.
- Fluid restriction may be of benefit.
- Most require admission
- Meds: High Dose steroid use has been useful in blindness secondary to lightning strike.

Follow-up:
- Depending on injuries, subspecialty F/U or close primary care F/U may be needed. Psychiatric problems, eye or ear problems or long-term autonomic/neuro problems will require close following. Rehab may be indicated.

PREVENTION:

NO absolute safe place from lightning!!!

For group activities, develop a lightning action plan.

Know Risk Factors..see above in epidemiology.

Learn about thunderstorms and the three stages:

1. growth
2. maturity
3. dissipation

Be weather wise and weather alert...watch the sky.

Flash to Bang Method

A study in Florida found the mean distance between successive strikes from the same storm to be about 2-3 miles. Since each storm and flash varies, if you are within 2-3 miles of a flash, the next flash could be at your location. When you see a flash, count the seconds to the initial bang of the thunder, and then divide the number of seconds by 5 to give you the distance in miles from you to the lightning. For safety purposes, a flash-bang time longer than 10-15 seconds is recommended. The “30-30” rule is helpful...if less than 30 seconds from flash to thunder, one should seek shelter, and not venture out until 30 minutes of silence (no thunder). This rule is being phased out by NOAA.

Although the flash and resulting thunder occur at essentially the same time, light travels at 186,000 miles in a second, almost a million times the speed of sound. Sound travels at the relatively snail pace of one-fifth of a mile in the same time. Thus the flash, if not obscured by clouds, is seen before the thunder is heard. By counting the seconds between the flash and the thunder and dividing by 5, an estimate of the distance to the strike (in miles) can be made.

Lightning detection equipment is available.

If Lightning Nearby:
1. Seek shelter in a safe building and stay away from windows telephones, other electrical or conductive devices.
2. Remain or go inside a vehicle and avoid metal contact.
3. Avoid open fields if possible.
4. Do not be the highest object.
5. Avoid contact with metal objects.
6. Avoid high terrain or bodies of water if able.
7. Avoid taking refuge under isolated trees or other isolated tall objects.

Indications of imminent lightning:
May hear crackling noise or smell ozone
Hair may stand on end
Objects may take on a “blue” glow…St Elmo’s fire
If any of the above: leave or crouch on the balls of your feet with head down, don’t touch ground with hands. (Lightning Safety Position)

In the Mountains:
◆ Mountaineering maxim: “on by noon, off by two”
◆ Move off ridges, summits; avoid drainages and shallow caves
◆ In a group, separate (if possible and feasible) from one another…~ 10-15 ft.
◆ Avoid rappelling when lightning imminent (current can follow ropes, especially if wet.
◆ Remove metal objects if strike imminent (ski poles, ice axe, crampons, etc)
◆ Insulate yourself from ground current by crouching on a coiled rope, pack or ensolite pad
◆ Recommend helmet NOT be removed as may be protective if blunt trauma involved.

**Boating and Lightning**

Being on board a boat during a thunderstorm poses an immediate danger to the crew, whether or not there's a lightning protection system. If you're not able to leave the boat for land-based shelter when thunderstorms roll through, safety precautions should be taken immediately by the crew to minimize personal danger.

- Discontinue any outdoor activities and move below.
- Avoid any activities that might provide a connection between your body and the water, even something as seemingly minor as fishing.
- Stay low in your boat and move as close to the center of it as possible.
• Disconnect all electronics immediately, especially the VHF or any other radio connected to an antenna and, if possible, lower or remove any antennas.

• Discontinue use of any telephone, including mobile phones.

• Avoid contact with any piece of equipment that is bonded to the lightning protection system, and especially avoid contact with two components simultaneously.

• If your boat is struck, your body can become a path for electrical current. Stay away from all metal objects, whether or not they're bonded to the system.

• Sailors should not go near the spar's compression post if it is deck-stepped, and stay away from the spar itself if it is keel-stepped. Remember that the mast is the main conductive path.

• If your boat is struck, immediately check the seacocks and thru-hull fittings to be sure they're still intact. Always have wooden plugs on hand in a variety of sizes that fit your boat's seacocks.

Even though the odds are in your favor that your boat may never be hit by lightning, if it happens it can have devastating effects. Don't take a chance, protect yourself. If you are in a small boat and close to shore when a thunderstorm approaches, get in and off the water immediately. Better yet, don't go out if thunderstorms are predicted. But what if you are miles offshore and a storm pops up? Hopefully, you have prepared in advance.

The voltages involved in lightning are so high that even materials that would normally be considered non-conductive become conductors, including the human body. The voltages are so massive that if they start to travel through a boat's structure - say through its mast - then meet with high resistance (for instance, the hull skin) the current discharge, in its attempt to reach ground, may simply blow a hole in the non-conductive barrier. The safety conscious Captain should make sure that his vessel is properly protected. Reference should be made in detail to the standards for lightning protection as set forth by the American Boat and Yacht Council (ABYC) and the job should be performed by a licensed marine electrician.

In theory, a lightning protection system is used to create what is know as a "Faraday's cage," so called after the late nineteenth-century scientist Michael Faraday. The principle of a Faraday's cage is to provide a surrounding, well-grounded, metal structure, in which all of parts are bonded together and carry the same electrical potential. Such a "cage" attracts and carries any lightning strike to ground much like lightning rods on buildings. In other words, you need to provide an unobstructed way for the lightning to dissipate its energy to ground (the water surrounding you). Faraday himself risked his own life to prove this theory. The additional benefit of a lightning protection system is that it tends to bleed off any charge build-up in the general vicinity, possibly averting a lightning strike in the first place.
So how does a lightning protection system work? In a boat, the "cage" is formed by bonding together, with heavy conductors, the vessel's mast and all other major metal masses. A marine electrician must tie in the engines, stoves, air conditioning compressors, railings, arches etc. with a low resistance wire which would ultimately provide a conductive path to ground (the water) usually via the engine and propeller shaft, keel bolts, or better yet, a separate external ground plate at least 1 square foot in dimension. It is important that you ensure that your crew fall within the protection of the "cage," something not always feasible when the vessel is not built of steel or aluminum. On fiberglass or wooden boats it is advantageous to have a mast or other conductive metal protrusion extending well above the vessel, creating what is known as a "cone" or zone of protection.

It is generally accepted that this cone of protection extends 45 degrees, all around, from the tip of the metal protrusion. This means that if the aluminum mast of the average sailing vessel is properly bonded to the vessel's other major metal masses and is given a direct, low-resistance conductive path to ground, the entire boat should fall within the protected zone. If the vessel has a wooden or composite mast, a marine electrician can achieve the same effect by installing a 6 to 12 inch metal spike at the top and running a heavy conductor down the mast and as directly as possible to ground, usually through the engine and propeller shaft.

Again, refer to the ABYC standards and have a professional marine electrician install your lightning protection. **This is not a do-it-yourself project.**

**While on the water, stay alert...**

- Check NOAA Weather Radio for latest warnings and forecasts.
- Watch for signs of approaching storms:
  - dark, threatening clouds that may foretell a squall or thunderstorm
  - a steady increase in wind or sea
  - lightning flashes.
- An increase in wind opposite in direction to a strong tidal current may lead to steep waves capable of broaching a boat.
- Heavy static on your AM radio may be an indication of nearby thunderstorm activity.
- If a thunderstorm is approaching, head for shore if possible. Get out of your boat and away from the water. Find shelter immediately.
- If a thunderstorm catches you while afloat, remember that gusty winds and lightning pose a threat to safety.
  - put on your personal flotation device and prepare for rough seas.
  - stay below deck if possible.
  - keep away from metal objects that are not grounded to the boat's protection system.
  - don't touch more than one grounded object at the same time (or you may become a shortcut for electrical surges passing through the protection system).
Radio Tips

If you have a VHF transceiver with built-in NOAA Weather Radio channels, use them. If your VHF radio is not equipped with weather channels, you may want to buy a VHF weather radio—they’re readily available. Keep in mind, however, broadcast reception varies with the location of you and the transmitter, the quality of the radio, and any obstructions. A broad, average range is 20 to 40 miles. If you venture beyond that range, you should consider buying a good quality HF single sideband transceiver to add to your VHF. It may be more expensive, but it is worth it to be able to get the information that may save your life and property.

Weather Information Broadcasts*

<table>
<thead>
<tr>
<th>Source</th>
<th>Frequencies</th>
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<tbody>
<tr>
<td>NOAA Weather Radio</td>
<td>162.400 MHz</td>
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<tr>
<td>(continuous broadcasts)</td>
<td>162.425 MHz</td>
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<td>162.450 MHz</td>
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<tr>
<td>Coast Guard Marine Information Stations</td>
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<td>Time and Frequency</td>
<td>10 MHz</td>
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<tr>
<td>Stations WWV and WWVH</td>
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Commercial AM and FM Radio Stations


3. Video "Lightning and Sailboats" - This 23 minute video from the NLSI Lightning Video Library describes lightning on the water and provides "how to" methods to install lightning protection systems for sailboats. Information also applies to powerboats. Comes with 24 page descriptive booklet. Cost $79.00, incl. shipping in USA. To order, tel NLSI at 303-666-8817.

NOTE: To provide adequate protection, the entire circuit from the top of the mast to the “Water” ground should have a minimum conductivity equivalent to a No. 8 AWG copper conductor. If a copper cable is used, the individual strands should be no less than No.17 AWG. Copper metal or strips should
be No.20 AWG. Major metal components aboard the boat, within 6 feet of the lightning conductor, should be interconnected with the lightning protective system with a conductor at least equal to No. 8 AWG copper. It is preferable to ground the engine directly to the ground plate rather than to an intermediate point in the lightning protection system.

**Q. Is a lightning protection system required to be installed in a boat?**

A. No, but if one is installed it should comply with E-4, Lightning Protection. This standard provides guidance on the proper size of conductors, the types of components to be connected to the system, and the method of discharging the lightning currents into the water.

**CONCLUSION:**

As thunderstorms and lightning are common weather entities for anybody, and almost everywhere, it behooves us to think about potential problems and knowledge of unique treatment aspects that may occur with these problems. As always, the final key is PREVENTION and avoidance.

**References:**

Books:

Magazines:

Individual Articles:

A Bolt from the Blue

At approximately 11AM MDT on Sunday, Sept 18th, 1994, a 51 year old male mountain bikers was watching a rugby match near Vail, CO. He was struck by lightning to the side of his head, on a day with “blue sky” and no apparent storms in the vicinity. Subsequent analysis using GEOS imagery and data from the National Lightning Detection Network, it was determined that he was struck by a single bolt emitted from a storm 16km or 10 miles away. Neurlogy 1997; 48:683-686.
Chapter 14: WMS PRACTICE GUIDELINES
LIGHTNING INJURIES

Recommendations are considered Category 1B by the WMS Panel of Expert Reviewers

I. GENERAL INFORMATION
One bolt of lightning may generate 300,000 amps and 2 billion volts— an awesome power capable of great destructive force. A single strike often injures or kills more than one person. Lightning injures or kills in one of four ways: 1) direct strike, 2) splash after striking a nearby object, 3) ground current, 4) trauma from the blast of exploding air or, 5) direct contact with an object carrying current. Lightning causes serious injury or death in about one-third of its victims and permanent sequelae of some sort in about two-thirds of survivors. The factors related to a fatal outcome include immediate cardiopulmonary arrest, acute neurologic and/or traumatic injuries or leg or head burns. Because any electrical current takes the shortest path between contact points, multiple organ systems may be injured. The duration of a lightning strike is so brief (less than one millisecond) that it may not penetrate, but “flash over” the patient’s skin.

Although lightning strikes are unpredictable, there are ways to reduce the chance of injury. During an electrical storm: 1) avoid open areas where you are one of the tallest objects, 2) do not seek shelter under a single tree or bush or rock that stands in an open area, 3) avoid extremes of high or low ground, 4) avoid contact with metal objects, 5) seek shelter deep in a dry cave, staying away from the sides and roof, 6) seek shelter among trees or bushes or rocks of uniform size, 7) if boating, attempt to get to shore, waves and shore-line permitting, 8) squat with your feet close together or sit in a compact position on a non-conductive material, such as a foam pad or rope coil, and 9) spread out a group but stay close enough to maintain visual contact with each other.

II. GUIDELINES FOR ASSESSMENT
Victims of lightning strikes are not electrically charged and pose no threat to rescuers. Patients typically fall into one of three categories: 1) minimally injured, requiring little immediate care other than psychological support, although they must receive a thorough examination when time allows, 2) seriously injured, often initially unconscious, requiring immediate attention to airway and obvious injuries, including appropriate stabilization for possible head and spine injuries, and 3) maximally injured, in cardiopulmonary arrest. Initiate rescue breathing and chest compressions (CPR) immediately on all pulseless, breathless victims of lightning strike. Following a severe electrical shock, respiratory paralysis may persist long after cardiac activity returns. Rescuers must be prepared to provide prolonged rescue breathing, but no more than 30 minutes of chest compressions. If there are multiple victims, institute reverse triage principles, i.e., treat seemingly dead
victims first.
Therapy for increased intracranial pressure (see Traumatic Brain Injury and Spinal Injury) may be necessary. For conscious patients capable of safely tolerating oral fluids, hydrate appropriate to safeguard against the rarely encountered but possible rhabdomyolysis.

Promptly investigate the hypotensive patient for major hemorrhage, spinal shock, or fluid loss from burns. Internal burns of muscles may result in extensive fluid loss, out of proportion to the external burns. Burns requiring Burn Center therapy are rarely a requirement. Test vision and evaluate hearing. Tetanus immunization must be current. Evacuate all patients surviving a lightning strike for definitive medical evaluation and treatment. These patients have a potential for immediate and delayed sequelae, including neurological, renal, cardiac, and muscular dysfunction.

Lightning and Boating…from cdc.gov.

**LIGHTNING PROTECTION SYSTEM**

The major components of a lightning protection system for a boat are an air terminal, main conductor, and a ground plate. Secondary components are secondary conductors, lightning arrestors, lightning protective gaps, and connectors (see Figure 5).

The mast, if constructed of conductive material, a conductor securely fastened to the mast and extending six inches above the mast and terminating in a receiving point, or a radio antenna can serve as the air terminal. The main conductor carries the electrical current to the ground. Flexible, insulated compact-stranded, concentric-lay-stranded or solid copper ribbon (20-gauge minimum) should be used as the main conductor. The ground plate, and that portion of the conductor in contact with the water, should be copper, monel or navel bronze. Other metals are too corrosive. The secondary conductors ground major metal components of the boat to the main conductor. However, the engine should be grounded directly to the ground plate. Lightning arrestors and lightning protective gaps are used to protect radios and other electronic equipment which are subject to electrical surges. The connectors must be able to carry as much electrical current as other components of the system. Further, the connections must be secure and noncorrosive. On a large power boat or sailboat, a properly designed and grounded antenna could provide a cone of protection. Presently, however, the vast majority of the radio antenna is totally unsuitable for lightning protection. This is also true of the wires feeding the antenna. If the antenna is not properly grounded, it may result in injury or death and cause considerable property damage. Sailboats with portable masts, or those with the mast mounted on the cabin roof, are particularly vulnerable as they are usually the least protected as far as grounding or bonding is concerned.
Ideally, an effective ground plate should be installed on the outside of all boats when the hulls are constructed. Unfortunately, this is not often done. Such a ground plate would help manufacturers design safer lightning protection systems for the boats.

**LIGHTNING PROTECTION CODE**

The National Fire Protection Association, Lightning Protection Code, suggests a number of ways in which the boater can protect his boat and minimize damage if the boat is struck or is in the vicinity of a lightning strike. These suggestions are summarized below:

A lightning protective mast will generally divert a direct lightning strike within a cone-shaped radius two times the height of the mast. Therefore, the mast must be of sufficient height to place all parts of the boat within this cone-shaped zone of protection (see Figure 6).

The path from the top of the mast to the “water” ground should be essentially straight. Any bends in the conductor should have a minimum radius of eight inches (see Figure 7).

To provide adequate protection, the entire circuit from the top of the mast to the “water” ground should have a minimum conductivity equivalent to a No. 8 AWG copper conductor. If a copper cable is used, the individual strands should be no less than No. 17 AWG. Copper metal or strips should be a minimum of No. 20 AWG.

Major metal components aboard the boat, within six feet of the lightning conductor, should be interconnected with the lightning protective system with a conductor at least equal to No. 8 AWG copper. It is preferable to ground the engine directly to the ground plate rather than to an intermediate point in the lightning protection system.

If the boat’s mast is not of a lightning protective design, the associated lightning or grounding connector should be essentially straight, securely fastened to the mast, extended at least 6 inches above the mast and terminate in a sharp receiving point.

The radio antenna may serve as a lightning protective mast, provided it and all the grounding conductors have a conductivity equivalent to No. 8 AWG copper and is equipped with lightning arrestors, lightning protective gaps, or means for grounding during electrical storms. Most antennas do not meet these requirements. The height of the antenna must be sufficient to provide the cone-shaped zone of protection.

Antennas with loading coils are considered to end at a point immediately below the loading coil unless this coil is provided with a protective device for by-passing the lightning current. Nonconducting antenna masts with spirally wrapped conductors are not suitable for lightning protection purposes. Never tie down a whip-type antenna during a storm if it is a part of the lightning protection system. However, antennas and other protruding devices, not part of the lightning protection system, should be tied down or removed during a storm.
All materials used in a lightning protective system should be corrosion-resistant. Copper, either compact-stranded, concentric-lay-stranded or ribbon, is resistant to corrosion.
The "water" ground connection may be any submerged metal surface with an area of at least one square foot. Metallic propellers, rudders or hull will be adequate.
On sailboats, all masts, shrouds, stays, preventors, sail tracks and continuous metallic tracks on the mast or boom should be interconnected (bonded) and grounded.
Small boats can be protected with a portable lightning protection system. This would consist of a mast of sufficient height to provide the cone of protection connected by a flexible copper cable to a submerged ground plate of at least one square foot. When lightning conditions are observed in the distance, the mast is mounted near the bow and the ground plate dropped overboard. The connecting copper cable should be fully extended and as straight as possible. The boaters should stay low in the middle or aft portion of the boat.

WHEN CAUGHT IN A STORM
Thunderstorms in Florida and over its coastal waters are frequently unpredictable. Even with the best weather reports, along with constant and accurate observations of climatic conditions, boaters can still be caught in open waters in a thunderstorm. Then, with or without a lightning protective system, it is critical to take additional safety precautions to protect the boat's personnel.
These precautions during a thunderstorm are:
Stay in the center of the cabin if the boat is so designed. If no enclosure (cabin) is available, stay low in the boat. Don't be a "stand-up human" lightning mast!
Keep arms and legs in the boat. Do not dangle them in the water.
Discontinue fishing, water skiing, scuba diving, swimming or other water activities when there is lightning or even when weather conditions look threatening. The first lightning strike can be a mile or more in front of an approaching thunderstorm cloud.
Disconnect and do not use or touch the major electronic equipment, including the radio, throughout the duration of the storm.
Lower, remove or tie down the radio antenna and other protruding devices if they are not part of the lightning protection system.
To the degree possible, avoid making contact with any portion of the boat connected to the lightning protection system. Never be in contact with two components connected to the system at the same time. Example: The gear levers and spotlight handle are both connected to the system. Should you have a hand on both when lightning strikes, the possibility of electrical current passing through your body from hand to hand is great. The path of the electrical current would be directly through your heart--a very deadly path!
It would be desirable to have individuals aboard who are competent in cardiopulmonary resuscitation (CPR) and first aid. Many individuals struck by lightning or exposed to excessive electrical current can be saved with prompt and proper artificial respiration and/or CPR. There is no danger in touching persons after they have been struck by lightning.

If a boat has been, or is suspected of having been, struck by lightning, check out the electrical system and the compasses to insure that no damage has occurred.

A few of the latest articles:

1) **Implantable cardioverter defibrillators save lives from lightning-related electrocution too!**

2) **Guillain-Barré syndrome after lightning strike.**

3) **Hit by lightning out of the blue**
   Duppel H - *Dtsch Med Wochenschr* - 01-JUN-2009; 134(23): 1214-7. A group of six hikers were hit by lightning out of the blue sky. The biggest harm was done to a 29-year-old man (size: 190 cm) while walking along a high spruce. He experienced a seizure with consecutive sinus tachycardia and hypertensive dysregulation. One year later he still complained about reduced physical strength. The other five hikers had less severe injuries. INVESTIGATIONS: Burns were detectable in five of six patients. Elevated creatine kinase and myoglobin were indicative for myolysis. Renal parameters were normal. DIAGNOSIS, THERAPY AND COURSE: All patients were treated with intravenous fluid and electrolyte substitution during transport to hospital. Two patients were additionally treated with metoprolol. CONCLUSION: Cardiac arrhythmias, usually tachycardia, myolysis, and seizures require early treatment with beta blockers, sufficient fluid supply, and antiepileptics. In patients with cardiac arrest after a lightning injury immediate cardiac resuscitation is crucial.

4) **Lightning injury: a review.**