Objectives

- Understand lightning and electrical injury presentation in various settings
- Review the behavior of electricity and its victims
- Discuss the mechanism and patterns of injury associated with different types of electrical injury
- Review triage, treatment, and management pitfalls of electrical injury
Rate of Injury

- Electrical injury accounts for 1000 deaths annually in the US
  - No reporting requirement for electrocution
  - Severe reporting bias

- Lightning deaths estimated at 50 to 300 deaths annually in the US
  - Non-fatal strike rate likely 4-5 times higher
Age relevance

- **Children:**
  - Floor/receptacle level, explore with mouth/fingers/shape sorting activities
- **Adolescents/Teens/Early Adulthood:**
  - Risk taking behavior, chemical impairment
- **Adults:**
  - Occupational risk, outdoor activities
Electricity in the US

- War between currents:
  - AC: Westinghouse
  - DC: Edison

- 1880s:
  - Samuel W. Smith staggers onto AC (first death in US)
  - Edison’s associate develops electric chair
  - Adopted as humane alternative to hanging
  - Kemmeler first execution by chair- ‘better with an axe’
Physics: a Review

- **Current: AC vs. DC**
  - AC three times more lethal than DC
  - Spasm vs. tetany
  - Entry/exit vs. source contact/ground contact

- **Resistance: resists flow of electricity**
  - Moisture content and physical properties
  - Higher resistance creates more heat
  - Bone, tendon, fat >> muscle, vessels, nerves
    - Skin varies with sweat/moisture, callous, etc.
Physics: a Review

- **Amperage**: amount of energy that flows through an object
  - True measure of lethality
  - Responsible for heat generation
  - Nearly impossible to predict accurately

- **Voltage**: measure of potential between two points
  - Think of it as potential energy
Physics: a Review

- **Duration of contact:**
  - Similar to impulse
  - Time that current flows through tissues
  - Longer is worse

- **Pathway:**
  - “Path of least resistance”
  - Resistance increases as coagulation and carbonization occurs—pathway changes
Physics: a Review

- **Lightning:**
  - Properties of both AC and DC and neither
  - Single, unidirectional discharge of a massive current impulse
  - We frankly do not understand the complete physical properties and physiologic effects of lightning strikes yet!
  - Prevailing theory:
    - “Negative leader and positive streamer”
Formulas for Injury

- **Ohm’s Law**
  - \[ I = \frac{V}{R} \]
  - Current (Amps) = \( \text{Potential (Volts) / Resistance (Ohms)} \)

- **Joule’s Law**
  - \[ P = I^2Rt \]
  - Heat (Joules) = \( \text{Current (Amps)}^2 \times \text{Resistance (Ohms)} \times \text{Time (sec)} \)
# Tissue as a conductor

<table>
<thead>
<tr>
<th>TISSUE</th>
<th>RESISTANCE (Ω/CM²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mucous membranes</td>
<td>100</td>
</tr>
<tr>
<td>Vascular areas</td>
<td></td>
</tr>
<tr>
<td>Volar arm, inner thigh</td>
<td>300–10,000</td>
</tr>
<tr>
<td>Wet skin</td>
<td></td>
</tr>
<tr>
<td>Bathtub</td>
<td>1,200–1,500</td>
</tr>
<tr>
<td>Sweat</td>
<td>2,500</td>
</tr>
<tr>
<td>Other skin</td>
<td>10,000–40,000</td>
</tr>
<tr>
<td>Sole of foot</td>
<td>100,000–200,000</td>
</tr>
<tr>
<td>Heavily calloused palm</td>
<td>1–2 million</td>
</tr>
</tbody>
</table>
## Effect of Amperage (@60Hz)

<table>
<thead>
<tr>
<th>PHYSICAL EFFECT</th>
<th>CURRENT (mA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tingling sensation</td>
<td>1–4</td>
</tr>
<tr>
<td>Let-go current</td>
<td></td>
</tr>
<tr>
<td>Children</td>
<td>4</td>
</tr>
<tr>
<td>Women</td>
<td>7</td>
</tr>
<tr>
<td>Men</td>
<td>9</td>
</tr>
<tr>
<td>Freezing to circuit</td>
<td>10–20</td>
</tr>
<tr>
<td>Respiratory arrest from thoracic muscle tetany</td>
<td>20–50</td>
</tr>
<tr>
<td>Ventricular fibrillation</td>
<td>60–120</td>
</tr>
</tbody>
</table>
People as circuits

1 second exposure to 120V:

- Mucous Membrane (100 Ohm)
  - 1.2 Amps
  - 144 Joules
- Volar Arm (300)
  - 0.4 Amps
  - 48 Joules
- Calloused Skin (1 M)
  - 0.00012 Amps
  - 0.0144 Joules
People as circuits

- 1 second exposure to 110kV:
  - Volar Arm (300)
    - 367 Amps
    - 40,000+ kJoules
  - Calloused Skin (1 M)
    - 9 Amps
    - 82,000+ kJoules
Electrical Injury

- Electrothermal heating is a result of current passing through the victim.
- Other tissue burns can occur from:
  - Arcing: 2500° C
  - Flames from ignited clothing
  - Flash from current dispersing over skin
Injury Patterns

- Head and Neck:
  - Common point of entry
  - Cataracts in 6%
    - Initially present or delayed up to several months
  - Oral lesions
    - Infant/toddler concern
    - Delayed bleeding
  - Head and Cervical Spine Injury
    - Falls and being thrown from source
Injury Patterns

- Cardiovascular
  - Cardiac Arrest
    - V-fib or asystole
  - EKG changes
    - Tachycardia, ST elevation, QT prolongation
    - PVC, A-fib, Bundle branch blocks
  - Vascular injury
    - Temporary spasm, thrombosis, delayed rupture
22 yo male farmer after brief contact with 240V electrical source.
Injury Patterns

- Neurologic
  - Neuronal loss of conductivity
  - Brain is commonly injured:
    - Loss of consciousness, disruption of respiratory center
  - Peripheral nerves may suffer immediate myelin sheath injury or delayed dysfunction from edema or compartment syndrome
    - Paralysis, neuropathy
Injury Patterns

- Musculoskeletal
  - Spasm or tetany
    - Loss of muscles of respiration
  - Ischemia from vascular injury
  - Muscle necrosis
  - Compartment syndrome
  - Fractures and dislocation
    - Spasm or from secondary trauma
Injury Patterns

- Skin
  - Most severe at source and ground contact points
    - Common sites are head/hands and feet
  - Kissing burns along flexor creases
  - Usually full thickness, appearing gray with central necrosis
  - NOT predictive of underlying tissue damage
Little on Lightning

- Temperature “hotter than the surface of the sun”
  - AC arc 2500° C
- 100 million volts
- 100 strikes per second worldwide
- 50 strikes per square mile in the US every year
- No reported death in VA since 2009
- 12 yo male, ballfield, Fredericksburg
Lightning Strike Prevention

- **Stay indoors**
  - Open shelters are not as safe

- **If caught outside**
  - Avoid trees, partial shelter
  - Safer in low lying area/ditch in crouched position

- **Wait 30 minutes after thunder or lightning ends**
Lightning Strikes

- Direct Strike
- Contact: Victim touching struck object
- Side Flash/Splash: Jumps to victim from struck object
- Step voltage: Both feet on ground where current dissipating
Additional Injury Patterns

- Head and Neck
  - Direct strikes may enter orifices
  - Tympanic rupture is common
  - Ossicle chain or mastoid disruption
    - Permanent hearing loss possible
  - Myriad of eye injuries
    - Dilated pupil does not predict death
Additional Injury Patterns

- **Cardiovascular**
  - Arrest with asystole more common
  - Cardiac enzymes often elevated
  - Hypertension

- **Neurologic**
  - Keraunoparalysis
  - LOC, confusion, anterograde amnesia
  - Peripheral neuropathy +/- atrophy
Additional Injury Patterns

- **Skin**
  - Deep burns in less than 5%
  - Thermal burns
    - Sweat lines from steam production
    - Additional burns if clothing ignites
  - Lichtenburg figures (feathering)
    - Electron shower passing over external skin
Prehospital Management

- Secure the scene
  - Prevent additional victims
    - Look out for “number one”
  - Ensure power sources removed
    - “Not my job!”
  - Lightning CAN (and does) strike twice
    - Vehicle safest refuge (Faraday cage)
    - Squatting onto balls of feet safest position if lightning eminent
Prehospital Management

- Triage Considerations
  - Potential for multiple victims
  - Change of routine triage
    - Those without spontaneous respiration or pulse should be treated first
Initial Resuscitation

- Combination of Cardiac and Trauma Care
  - ACLS and ATLS/ITLS apply
  - Treat similarly to crush injury as TBSA will likely underestimate total tissue damage
  - 20 ml/kg IVF bolus for hypotension and guide further fluid administration by vital signs and clinical status
Continued Management

- History of electrical source and duration
- Fluid administration
  - Guided by urine output
    - 0.5-1.0 ml/kg/hr if *no* heme present
    - 1.0-1.5 ml/kg/hr if heme present
- EKG and cardiac monitoring
  - High voltage exposure
  - Any cardiopulmonary complaint
Continued Management

- **Head CT**
  - Initial AMS or any change in MS during care

- **Labs**
  - CBC, Chem Panel, UA
  - Evaluate for myoglobinuria and rhabdomyolysis

- **Tetanus status**
  - Wounds are tetanus prone
Disposition

- **Burn Center Transfer**
  - Burns meeting ABA/ACS criteria
  - High voltage/Lightning injury

- **Admission**
  - Cardiac arrest, dysrhythmia, abnl EKG
  - Hx of cardiac disease or high risk
  - LOC, Chest pain, Hypoxia
  - Conductive injury or other severe injury
Summary

- Physics of electrical conduction dictate injury, but difficult to predict based on history or skin exam.

- Burn injury is often greatest at source and ground contacts. Underlying injury must be investigated.

- Common lightning presentations are often transient. Triage must focus on those in cardiovascular collapse.
Thank You

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