



## Chapter 142 – Electrical and lightning injuries

### Episode overview:

#### Core questions:

1. What is the relationship between current, voltage and resistance? How does this relate to potential for injury from electrical and lightning injuries?
2. What are the types of electrical injury? (based on type of current)
3. Differentiate between AC and DC current injuries.
4. List 4 types of electrical burns and 5 mechanisms of lightning injury
5. List 5 expected injury patterns for high-voltage and lightning injuries
6. List clinical findings (early and late) associated with electrical injuries.
7. List clinical findings associated with lightning exposure.
8. Describe the skin injuries associated with lightning and electricity.
9. Describe the modifications in field triage of multiple victims following a lightning strike.
10. Describe the prehospital management of electrical injuries
11. List 6 admission criteria for electrical/lightning injuries
12. List 6 complications of high-voltage injuries
13. Tips to avoid getting hit by lightning

#### WiseCracks

1. List six mechanisms of lightning injury.
2. ECG features
3. What is keraunoparalysis?
4. Describe the management of a pregnant patient (1st trimester and 2nd /3rd trimester) in the setting of electrical injury.
5. How are perioral electrical burns managed? List three early and three late complications.

#### Key concepts

Electrical current follows the path of least resistance, often neurovascular bundles. Deep tissue and organ damage is often much more extensive than would be indicated by examination of the overlying skin. **Appearances are deceiving!!**

- Testing is not indicated for victims of low-voltage electrical injuries who are asymptomatic or have minimal local symptoms and physical evidence of burn injury. These patients may be discharged home after evaluation.
- Testing is indicated for patients exposed to **high-voltage (>1000 Volts) sources and those with syncope, altered mentation, or any other neurologic abnormality, significant burns, entry and exit wounds, or significant ongoing symptoms.** Testing should include electrocardiography, complete blood count, basic chemistry panel, myoglobin and troponin level determination, and urinalysis. Additional testing is directed at suspected areas or injuries.
- Patients with electrocardiographic signs of cardiac injury or dysrhythmias, or with evidence of significant local injury, should be monitored for at least 6 hours in the ED, observation unit, or inpatient setting.



- The enormous current of a lightning strike may cause critical injury or death, or the current may be directed superficially over the patient to the ground, resulting in no injury or only superficial burns.
- Electrocardiography is indicated for all patients evaluated for lightning strike. Additional testing should be based on specific signs and symptoms.
- Lightning strike patients who present without symptoms or signs of injury, or with only minor first-degree burns, and with a normal ECG can be discharged home after evaluation. Patients who present with altered mentation or significant symptoms are evaluated in a manner similar to that used for victims of high-voltage electrical injury.
- **Lightning strike can cause fixed, dilated pupils in the absence of irreversible brain injury.**

## Rosen's In Perspective

This chapter discusses injuries from human-made electrical devices (high vs. low voltage; TASERS) as well as lightning injuries.

- *High-voltage injuries are impressively characterized by partial- to full-thickness skin burns, deep tissue destruction, and frequent cardiac or respiratory arrest. Low-voltage exposure causes less surface damage, but may be equally lethal, particularly in cases in which skin resistance is low.*
- Biggest groups at risk for electrical injuries
  - Young children/toddlers and middle aged men who are power line workers
  - Roughly 40 ppl per year die of lightning strikes in the USA (~10% of those who get struck by lightning)

## [1] What is the relationship between current, voltage and resistance? How does this relate to potential for injury from electrical and lightning injuries?

The first part of this question relates to Ohm's law:

*Current is the flow of electrons down an electrical gradient. It is measured in units of ampere. According to Ohm's law, current is directly proportional to the voltage of the source and inversely proportional to the resistance of the material through which it flows.*

$$V = I R$$

*Hydraulic model*

But let's take a deeper dive and discuss the factors affecting electrical injury

**The degree of injury from electrical shock depends on multiple factors:**



## “Voltage Can Cause ARC’s”

- **Voltage**
  - Electrical potential difference between two points. See Joules law.
  - *Joule’s law, which describes the amount of thermal energy applied to tissues from electricity, is described by this formula:  $P I RT = 2$* 
    - *where  $I$  is the amperage,  $R$  is the resistance, and  $T$  is the duration (time) that the electricity is applied. As the formula indicates, voltage is not the only factor responsible for damage, but it is often the only property that is known in cases of electrical injury. As a result, injuries are conventionally classified as being caused by high- or low-voltage sources, with 1000 V as the dividing line. In the United States and Canada, household sources are low voltage, typically 120 or 240 V.*
- **Current pathway**
  - ***Internally, current follows the path of least resistance, and the degree of burns seen on the surface typically underestimates the damage occurring below the surface.***
  - **Limb paths cause more local tissue damage.**
  - *Transthoracic pathways (arm to arm) are more likely to generate arrhythmias and have higher mortality rates than vertical currents (leg to arm) or straddle pathways (leg to leg).*
- **Contact duration**
  - **Tissue damage is directly proportional to duration of exposure regardless of voltage level.**
  - *Exposure times greater than the length of one cardiac cycle tend to generate arrhythmias, likely in a manner analogous to the R-on-T phenomenon.*
- **Amperage**
  - **This is the electrical current or flow of electrons down a voltage gradient (amount of water moving through the pipe per second). Higher current transfers more energy, aka heat into the person, causing more injury.**
- **Resistance of the tissue**
  - ***Resistance is the degree to which a substance resists the flow of current;***
  - *Neurovascular tissue (high water content tissues) conduct well. Dry skin conducts very poorly. Current that is initially unable to pass through skin will create thermal energy and cause significant burns.*
- **Circuit type**
  - **AC vs. DC (AC is worst, more on this in question 3).**

Well there’s a formula for these principles...: (where’s Tristan when you need him?) – See Box 134.3 in Rosen’s 9<sup>th</sup> edition.

$$P = I^2RT$$
$$I = V/R$$

Current is the flow of electrons down an electrical gradient. It is measured in units of ampere.

**Resistance of body tissues (Box 134.4 in Rosen’s 9<sup>th</sup> edition):**

**Nerve (lowest) < Blood Vessels < Muscle < Skin < Tendon < Fat < Bone (highest)**



## [2] What are the types of electrical injury? (based on type of current)

- **Alternating current injury**
  - Including conducted energy weapon discharge
- **Direct current injury**
- **Lightning injury**

## [3] Differentiate between AC and DC current injuries.

Electrical sources create current that flows in one direction (direct current, DC) or alternates direction cyclically at varying frequencies (alternating current, AC).

The few systems that use DC include batteries, automobile electronics, and railroad tracks. Exposure to DC most frequently causes a single, strong, muscular contraction. This may throw the subject back from the source in a way that limits duration of exposure but can result in other injuries. Think blast/blunt trauma.

AC is more commonly used (eg, household currents) because it conveniently allows for an increase or decrease of power at transformers.

It is more dangerous than DC of similar voltage because amperage above the so-called let-go current will cause muscular tetanic contractions.

Because the flexor muscles of the upper extremities are stronger than extensor muscles, these contractions pull the victim closer to the source and result in prolonged exposure.

## [4] List 4 types of electrical burns and 5 mechanisms of lightning injury

**See Box 134.6 in Rosen's 9<sup>th</sup> edition for types of burns associated with electrical injury:**

- Entrance and exit site burns
- Arc burns, kissing burns
- Thermal burns
- Flash burns

*Most electrical injuries result in skin burns, which fall into one or more of four patterns: (see table)*

- *Usually the hand or wrist is affected*
- These burns are associated with much higher morbidity than similar appearing thermal burns
  - \*\*\*\*great amount of damage underneath the surface of skin\*\*\*\*



- *Burns at entrance and exit sites will typically have a punctate appearance, with central depression and necrosis surrounded by a hyperemic border.*

Types:

1. Entry and exit burns - direct contact
2. Arc or “kissing burns”
  - a. Kissing burns = *when electricity jumps from skin surface to skin surface, typically across flexed areas of the body. Temperatures may reach 3500°C (6332°F) and cause severe damage. Arc burns are usually noted across the volar forearm and elbow and along the inner arm and axilla.*
3. Thermal burns due to clothes catching on fire
4. Flash burns: *skin burns caused by brief, intense flashes of light, electrical current, or thermal radiation. Shock goes off nearby.*

*Cutaneous burns across the chest and upper abdomen hint at transthoracic current and a worse prognosis.*

Lightning injuries:

- Direct/contact strike
- Side flash / splash injury
- Stride injury

## **[5] List 5 expected injury patterns for high-voltage and lightning injuries**

High voltage:

Direct or arc injury patterns (burns / blunt trauma / cardio-respiratory arrest)

Lightning:

Injury occurs from the force of a strike, blunt trauma effects when the victim is thrown, the superheating of metallic objects in contact with the patient, blast-type effects and barotrauma, or shrapnel.

High voltage:

- Skin findings / burns (see Question 4)
- Cardiac
  - Arrest
    - Due to induced VF or asystole
  - Arrhythmias
    - Bradycardia, tachycardia. A fib, ectopy
- Respiratory arrest
  - Tetanic paralysis of thoracic respiratory muscles
    - Causing apnea
- CNS:
  - Direct injury to brainstem respiratory centres
  - Seizure disorder
  - Secondary vascular injury (stroke/CVT) from blood vessel injury
  - Vertigo



- *Delayed and chronic manifestations include ascending paralysis, transverse myelitis, and amyotrophic lateral sclerosis. Peripheral neuropathies are a common result, most often involving the median and ulnar nerves. Neuropsychiatric sequelae include anxiety, depression, mood lability, difficulty concentrating, and insomnia. These may become a persistent source of disability.*
- HEENT:
  - Early cataract formation
  - *vitreous and anterior chamber hemorrhages, retinal detachment, macular lacerations, and corneal or conjunctival burns.*
- Extremities
  - Vascular injury - thrombosis or aneurysm formation leading to tissue ischemia / necrosis
  - Muscle necrosis
  - Vascular / smooth muscle paralysis and DVT formation
  - Tissue edema
  - Compartment syndrome
  - Periosteal burns / necrosis
  - Fracture or dislocations from tetanic contractions or sudden myoclonic jerk at time of direct contact
- Viscera:
  - *muscle damage may result in significant myoglobinuria, subsequent renal failure, and life-threatening hyperkalemia.*
    - *These complications are more likely in patients who are hypotensive or volume-depleted.*
  - *Stress ulcers are a common gastrointestinal complication.*
  - *Uncommon but severe intra-abdominal injuries include a ruptured hollow viscus and necrosis of the pancreas or gallbladder. Pulmonary edema is rare. Although early deaths are due to respiratory and cardiac arrest, late deaths occur from sepsis, pneumonia, and renal failure.*

Lightning:

- Skin findings / burns / fern-like (Lichtenberg) figures (see question 8 below)
- CV system
  - Asystole (progressing to ischemic cardiac and cerebral injury if the respiratory centre has been reactivated)
    - VF
  - Myocardial contusion
  - ECG changes (see wisecracks)
- Resp system
  - Respiratory muscle paralysis
- CNS
  - *Apnea, due to effects on the medullary respiratory center, may persist for several hours.*
  - *Direct trauma may result in skull fractures, intracerebral and extracerebral hematomas and hemorrhages, cerebral edema, and elevated intracranial pressure. Leading to herniation and death. Cerebellar ataxia, peripheral nerve damage*
  - *transient loss of consciousness, amnesia for the event, and transient paresthesias and paralysis of the extremities.*
- Ears



- Rupture of TM due to shock wave / blast effect (expansion effect from air)
- Hearing loss, tinnitus, vertigo,
- Eyes
  - Immediate or delayed onset of cataracts
  - Paralysis of ciliary muscle
- Other injuries
  - Due to blunt trauma or blast injury

...we'll re-summarize this in the next question!

## **[6] List clinical findings (early and late) associated with electrical injuries.**

Early: go head to toe

- CNS
  - Apnea, LOC, amnesia, peripheral nerve damage/paralysis, keraunoparalysis
- Cardiovascular
  - Asystole (DC or lightning)
  - Dysrhythmias (VF post AC current)
  - Third spacing (burns)
  - Thrombosis or vasospasm (MI is very rare)
- Resp
  - Respiratory muscle (and centre) paralysis!
- GI
  - Pancreatitis, solid organ injury, hepatitis, rhabdo
- MSK
  - Fracture, dislocation, rhabdomyolysis, compartment syndrome
- Skin
  - Burns
  - \*\*\*low external injuries DOES NOT mean low internal injuries\*\*\*
  - Deep tissue burns

Late: go head to toe

- CNS:
  - Apnea, sequelae from direct cranial trauma, amnesia/LOC, seizures, cognitive dysfunction, anxiety, psychiatric effects
    - *depression, sleep disturbances, nightmares, nocturnal enuresis, and separation anxiety. Hysterical blindness, deafness, and muteness have been observed.*
  - *hypoxic encephalopathy, intracerebral hemorrhage, cerebral infarction, and spinal fractures*
- EENT
  - Cataracts



- CV
  - Thrombosis or vasospasm
    - Delayed arterial thrombosis as well as aneurysm formation and rupture have been reported following electrical injury and are due to medial coagulation and necrosis
  - Labial artery hemorrhage
- MSK
  - Compartment syndrome
- Skin
  - Wound infection / scarring / contractures
- Psych
  - Anxiety
  - Panic disorders
  - PTSD
  - Depression

**[7] List clinical findings associated with lightning exposure.**

See Box 134.8 in Rosen's 9<sup>th</sup> edition for findings suggestive of a lightning strike:

- **Clothing wet from rain**
- **Tears or disintegration of clothing**
- **Multiple victims**
- **Typical arborescent pattern of erythema or superficial linear or punctate burns**
- **Tympanic membrane injury**
- **Cataracts, especially in a younger patient**
- **Magnetization of metallic objects on the body or clothing**
- **Electrocardiographic changes**

Hx:

- Multi-casualty incident at an outdoor event (usually circa thunderstorm)

Px:

- Wet clothing with tears in it
- Lightning burn pattern on skin
- Tympanic membrane injury
- Cataracts

Tests:

- ECG changes
- Magnetic properties of metal objects on the patient



## [8] Describe the skin injuries associated with lightning and electricity.

We discussed the skin findings associated with electrical injury in question 4:

Types:

1. Entry and exit burns - direct contact
2. Arc or “kissing burns”
  - a. Kissing burns = *when electricity jumps from skin surface to skin surface, typically across flexed areas of the body. Temperatures may reach 3500°C (6332°F) and cause severe damage. Arc burns are usually noted across the volar forearm and elbow and along the inner arm and axilla.*
3. Thermal burns due to clothes catching on fire
4. Flash burns: *skin burns caused by brief, intense flashes of light, electrical current, or thermal radiation.*

*Cutaneous burns across the chest and upper abdomen hint at transthoracic current and a worse prognosis.*

When it comes to lightning - less than 5% are deep skin burns and instead most skin findings are from flashover effects.

*current preferentially flows over the integument rather than through it (following the path of least resistance). The result is the arborescent or fern like patterns of erythematous streaks (typically first-degree burns) that have been termed Lichtenberg figures*

**See Fig. 134.4 in Rosen’s 9<sup>th</sup> edition.**

***Deeper burns may occur at the direct point of contact or wherever metal is involved (due to superheating), such as with a belt buckle or jewelry. Clothing may catch on fire, resulting in thermal burns. Unlike conventional high-voltage electrical exposures, exit wounds are not seen, and the overall effects are much less severe.***

## [9] Describe the modifications in field triage of multiple victims following a lightning strike.

*.... the initial arrhythmia is asystole. At some point, the intrinsic pacemaker activity of the heart brings about a resumption of cardiac activity. However, if the respiratory center has not been reactivated, hypoxia follows, and the cardiac rhythm will deteriorate into ventricular fibrillation..*

***This may explain reports of successful resuscitation and full recovery of lightning strike victims after being apneic and pulseless for 15 minutes and following resuscitations lasting up to 8 hours. This observation has led to the practice of treating the apparent dead first at the scene of a multiple-victim lightning strike because early resuscitative efforts may prevent death.***



## [10] Describe the prehospital management of electrical injuries

- Ensure scene safety
  - **\*\*have the power company turn off the power to the line before rescuing anyone!\*\***
- Ensure PPE
- Rapid triage for most critical victims (are there any other injured?)
- ACLS care for anyone unresponsive
  - “Reverse triage”
    - Priority are those people with no respiratory effort (respiratory muscle paralysis can last minutes)
    - **PATIENTS WITHOUT SIGNS OF LIFE ARE TREATED FIRST**
  - Cardiac monitoring and treatment of arrhythmias
  - Volume resuscitation
- Rapid transport to the nearest hospital

### **A COUPLE OTHER HOSPITAL MANAGEMENT PRINCIPLES:**

- Serum CK-MB measurements and ECG changes are poor measures of myocardial injury following electrical trauma; cardiac telemetry will more accurately assess for arrhythmias and autonomic dysfunction
- Parkland and similar formulas used for fluid resuscitation following thermal burns should not be used in victims of electrical injuries, since surface burns may grossly underestimate the extent of injury.
- Follow-up with ophthalmology is prudent to watch to delayed cataract formation

## [11] List 6 admission criteria for electrical/lightning injuries

- **History of high voltage injury or lightning strike**
- **Altered mental status / neuro deficits**
- **Respiratory weakness / paralysis**
- **Cardiac injury / contusion / dysrhythmia / ischemia**
- **Hypotension**
  - **Third spacing**
- **Extensive thermal burns or circumferential burns**
- **Rhabdomyolysis**
- **Compartment syndrome**
- **Blunt traumatic injuries**
- **Extremity thrombosis or vasospasm**
- **Deep pediatric oral burns (for hydration)**
- **Pregnant patients**



## [12] List 6 complications of high-voltage injuries

- Neuro-psychiatric sequelae
- Blunt trauma (anywhere!)
- Cardio-pulmonary arrest
- Thermal burns (anywhere!)
- Tetanic muscle contractions (leading to fractures, compartment syndrome)
- Rhabdomyolysis

## [13] Tips to avoid getting hit by lightning

See Box 134.5 in Rosen's 9<sup>th</sup> edition for tips to avoid lightning strikes

Squat!

## Wisecracks

### 1) List six mechanisms of lightning injury.

- Conduction injuries
  - Direct strike
  - Contact strike (hits something the person is holding on to or touching)
  - Side flash or splash injury
  - Streamer (hits the ground and then travels through the patient)
    - May cause the "stride voltage injury"
- Flash / arc burns (current doesn't enter the body)
- Blast injury
  - Barotrauma
  - Shrapnel
  - Blunt trauma

### 2) List the ECG changes seen with lightning strikes (5).

See Box 134.7 in Rosen's 9<sup>th</sup> edition for electrocardiographic changes seen with lightning strikes.

- ST elevation
- QT interval prolongation
- Atrial fibrillation
- Inverted or flattened T waves
- Myocardial infarction pattern without cardiac sequelae



### 3) What is keraunoparalysis?

#### A finding in lightning strike victims:

*Charcot, in 1889, described the phenomenon termed keraunoparalysis, with the victim of a strike awakening to find himself or herself on the ground, unable to move the limbs.*

*This flaccid paralysis, which is usually accompanied by marked vasomotor changes that result in extremities that appear blue, mottled, and pulseless, may persist up to 24 hours. The lower extremities are more commonly involved, and the typical pattern is recovery over minutes to days.*

### 4) Describe the management of a pregnant patient (1st trimester and 2nd /3rd trimester) in the setting of electrical injury.

*For obstetric patients, the overall risk to the fetus is small, but a spontaneous abortion can occur. Secondary trauma may lead to placental abruption.*

Obstetric consultation and fetal monitoring are essential.

### 5) How are perioral electrical burns managed? List three early and three late complications.

*Toddlers and young children sustain orofacial injuries after chewing or sucking on electrical cords or from lingual contact with sockets.*

*Full-thickness burns may be sustained on the mucous membranes and lips, with destruction to the tongue and teeth as well. Injuries to the oral commissure produce cosmetic difficulties and, more significantly, the well-recognized complication of delayed labial artery bleeding, typically occurring 2 days after injury, when the resultant eschar separates from the wound.*

#### Early:

- Thermal burn with soft tissue swelling
- Dehydration
- Airway compromise

#### Late:

- Perioral scarring
- Dental loss

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- AVN of the bone
- DELAYED labial artery bleeding