

MEDICINE LECTURE

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Electrical & Lightning Injuries



Background

Electrical injuries, although relatively uncommon, are inevitably encountered by most emergency physicians. Adult electrical injuries usually occur in an occupational setting, whereas children are primarily injured in the household setting. The spectrum of electrical injury is very broad, ranging from minimal injury to severe multiorgan involvement, with both occult and delayed complications, to death.

Presentation

Electrical injuries can present with a variety of problems, including cardiac or respiratory arrest, coma, blunt trauma, and severe burns of several types. It is important to establish the type of exposure (high or low voltage), duration of contact, and falls or other trauma.

outline

- **Physics of injury**
- **Mechanisms of Injury**
- **Associated Injuries**
- **Management**
- **Prognosis**

Physics of injury

Electro thermal Heating Formulas

- $P = (I^2)Rt$ and $(I = V/R)$
- P thermal power (heat), in Joules
- I current, in amperes
- R resistance, in ohms
- t time, in seconds
- V potential, in volts

Factors Determining Electrical Injury

- **Type of circuit**
- **Resistance of tissues**
- **Amperage**
- **Duration**
- **Voltage**
- **Pathway of current**

Type of Circuit:

- **One of the factors affecting the nature and severity of electrical injury is the type of circuit involved, either direct current (DC) or alternating current (AC).**
- **High-voltage DC contact tends to cause a single muscle spasm, often throwing the victim from the source. This results in a shorter duration of exposure but increases the likelihood of traumatic blunt injury. Brief contact with a DC source can also result in disturbances in cardiac rhythm, depending on the phase of the cardiac cycle affected,**

- **AC exposure to the same voltage tends to be three times more dangerous than DC. Continuous muscle contraction, or tetany, can occur when the muscle fibers are stimulated at between 40 and 110 times per second.**

Resistance

- Resistance is the tendency of a material to resist the flow of electric current; it is specific for a given tissue, depending on its moisture content, temperature, and other physical properties.
- The higher the resistance of a tissue to the flow of current, the greater the potential for transformation of electrical energy to thermal energy.
- Nerves, muscle and blood vessels, because of their high electrolyte and water content, have a low resistance and are good conductors.
- Bone, tendon, and fat, which all contain a large amount of inert matrix, have a very high resistance and tend to heat up and coagulate rather than transmit current.
- The other tissues of the body are intermediate in resistance (eg dry skin)

Current (Amperage)

Current, expressed in amperes, is a measure of the amount of energy that flows through an object.

- Amperage is dependent on the source voltage and the resistance of the conductor. (Remember $I=V/R$)
- The voltage of the source is known but the resistance varies
- The physical effect vary with different amperage.

Current Intensity	Probable Effect
1 mA	Tingling sensation; almost not perceptible
16 mA	Maximum current a person can grasp and "let go"
7-9 mA	"Let-go" current for an average man
6-8 mA	"Let-go" current for an average woman
3-5 mA	"Let-go" current for an average child
16-20 mA	Tetany of skeletal muscles
20-50 mA	Paralysis of respiratory muscles; respiratory arrest
50-100 mA	Threshold for ventricular fibrillation
>2 A	Asystole
15-30 A	Common household circuit breakers
240 A	Maximal intensity of household current (U.S.)

"let go" current

- the maximum current at which a person can grasp the current and then release it before muscle tetany makes letting go impossible.

Duration of contact

- The longer the duration of contact with high-voltage current, the greater the electro thermal heating and degree of tissue destruction.

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With lightening injury

- The extremely short duration and extraordinarily high voltage and amperage of lightning both result in a very short flow of current internally, with little, if any, skin breakdown and almost immediate flashover of current around the body.

Voltage

Voltage is a measure of the difference in electrical potential between two points and is determined by the electrical source. Electrical injuries are conventionally divided into high or low voltage using 500 or 1000 V as the most common cutpoint.

The higher the voltage the more is tissue distraction

No fatalities with low voltage

Pathway

The pathway that a current takes determines the tissues at risk, the type of injury seen, and the degree of conversion of electrical energy to heat. This is true whether high, low, or lightning voltages are being considered.

Current passing through the heart or thorax can cause cardiac dysrhythmias and direct myocardial damage. Current passing through the brain can result in respiratory arrest, seizures, and paralysis. Current in proximity to the eyes can cause cataracts

Mechanism of injury

1. Electrical Injury

2. Lightning Injury

Electrical Injury

- **The primary electrical injury is burns. Secondary blunt trauma results from falls or being thrown from the electrical source by an intense contraction of muscles. Electrical burns can be classified into four different types.**

Types of Electrical Burns

- **Direct contact**

1. **Electrothermal heating**

- **Low voltage** : limited to the affected area
- **High voltage** : burn any where along the current path

- **Indirect contact**

1. **Arc**: An electrical arc is a current spark formed between two objects of differing potential that are not in contact with each other, usually a highly charged source and a ground. Because the temperature of an electrical arc is approximately 2500° C, it is the most destructive indirect injury. It causes very deep thermal burns at the point where it contacts the skin. In arcing circumstances, burns may be caused by the heat of the arc itself, electrothermal heating due to current flow, or by flames that result from the ignition of clothing.
2. **Flame**: Ignition of clothing causes direct burns from flames.
3. **Flash**: When heat from a nearby electrical arc causes thermal burns but current does not actually enter the body

Lightning Injury

- Lightning injury may occur by five mechanisms.
- Direct strike
- **Orifice entry:** It has been substantiated experimentally that lightning strikes near the head may enter orifices such as the eyes, ears, and mouth to flow internally. This may help explain the eye and ear symptoms and signs that are reported with lightning injury.
- Contact
 1. **Side flash, “splash”:** Side flash or splash occurs as lightning jumps from its primary strike object to a nearby person on its way to ground
 2. **Ground current or step voltage:** Step voltage, a difference in electrical potential between a person's feet, may occur as lightning current spreads radially through the ground. A person is a far better conductor of electricity than the earth.
- **Blunt trauma:** Blunt injury from lightning can occur from two mechanisms. First, the person may be thrown a considerable distance by the sudden, massive contraction caused by current passing through the body. Second, an explosive or implosive force of lightning.

Associated Injuries

Respiratory System

Suffocation secondary to tetanic muscle contractions

Respiratory arrest secondary to direct injury .

Cardiovascular System

Asystole (more likely if DC or high V)

Arrhythmias (more likely AC) (~15% pts)

Ventricular fibrillation most common fatal arrhythmia

Myocardial necrosis (thermal effect)

Anoxic injury secondary to respiratory arrest

Neurological System

Direct effects include LOC, autonomic dysfunction, amnesia, temp paralysis (keraunoparalysis (clear within hours))

Spinal Cord injury secondary to spine fracture secondary to muscle contractions

Peripheral motor/sensory losses (long-term sequel)

Associated Injuries

Skin

(~57% low V fatalities; ~96% high V fatalities)*

Superficial, partial or full thickness thermal burns

Degree of external injury can underestimate internal injury & vice-versa. One should not attempt to predict the amount of underlying tissue damage from the amount of cutaneous involvement

Muscle

Necrosis secondary to severe contraction or thermal injury

Compartment syndrome secondary to edema from deep injury & 3rd spacing

Skeletal

Osteonecrosis secondary to thermal injury

Fracture secondary to muscle contraction or blunt trauma

Associated Injuries

Renal

Pigment-induced renal failure

Hypovolemia secondary to 3rd spacing can lead to prerenal

GI

Injury rare, most commonly "Curler's ulcers" (ulcer from burn)

Head, Eye and ENT

Cataracts can develop up to 2 years after

Hearing loss from 8th nerve injury

Damage to any organ system secondary to blunt trauma

Damage to any organ system secondary to vascular damage

Associated Injuries

	Lightning	High Voltage	Low Voltage
Voltage, V	$>30 \times 10^6$	$>1,000$	<600 (<240)
Current, A	$>200,000$	$<1,000$	<240
Duration	Instantaneous	Brief	Prolonged
Type of current	DC	DC or AC	Mostly AC
Cardiac arrest (cause)	Asystole	Ventricular fibrillation	Ventricular fibrillation
Respiratory arrest (cause)	Direct CNS injury	Indirect trauma or tetanic contractions of respiratory muscles	Tetanic contractions of respiratory muscles
Muscle contraction	Single	DC: single; AC: tetanic	Tetanic
Burns	Rare, superficial	Common, deep	Usually superficial
Rhabdomyolysis	Uncommon	Very common	Common
Blunt injury (cause)	Blast effect, shock wave	Muscle contraction, fall	Fall (uncommon)
Mortality (acute)	Very high	Moderate	Low

DC, direct current; AC, alternating current; CNS, central nervous system.

Management

Securing the scene

- **Power source should be turned off**
- **Use of electrical gloves by medical personnel is dangerous**
- **Denergizing the lines**
- **Triage should be concentrated on the presence of cardiac or respiratory arrest**
- **Patients require cardiac & trauma care**

Management

Standard ABCDEs of any major trauma

Pulmonary

Low threshold for intubation, as respiratory failure common

Cardiac

Serial monitoring if high V, abnormal ECG, LOC, respiratory arrest, or PMH of CV dysfunction

Neuro

C-spine and log-roll precautions; CT head & spine often warranted
Thorough serial neurological exams, as vessel coagulation can result in late sequel

Management

Musculoskeletal

- Thorough evaluation for fractures
- Serial evaluations of limbs for compartment syndrome requiring emergent decompression
- Even in absence of compartment syndrome, persistent aciduria or myoglobinuria may require limb amputation

Skin

- Early debridement and later reconstruction
- Antibiotic prophylaxis (controversial)

Management

Renal

- Fluid resuscitation key, as 3rd spacing common & myoglobinuria secondary to rhabdomyolysis can cause ARF

Specific therapy

Rhabdomyolysis (damaging of skeletal muscle tissue)

- Urinary alkalization
- Mannitol & frusamide
- Urine output maintained at 1-1.5 ml/kg/hr
- Ph of blood maintained at 7.4 by sodium carbonate
- GI
 - Ulcer prophylaxis, as gastric ulcers (Curling's ulcers) can develop
 - Ileus uncommon, but should prompt evaluation for other injury
- Serial evaluation of liver, pancreatic, & renal function for traumatic/anoxic/ischemic injury
- Careful management of fluid and electrolytes to avoid acidosis and compartment syndromes

All patients require :

ECG

Cardiac enzymes

CT scan for victims with altered mental status or deterioration of neurological status

Laboratory :

CBC , Ur ,Cr, Na, K, urinalysis

Liver & pancreatic enzymes , coagulation if there is abdominal trauma

CK level (predict muscle injury)

Radiological study according to the injured area

Prognosis

Highly variable, depending on severity of both initial injury and subsequent complications

High morbidity/mortality in patients with multisystem organ failure

Advances in surgical interventions (early excision, fasciotomy, skin grafts, etc...) have improved prognosis.



Arcing electrical burns through the shoe around the rubber sole



High voltage injury to chest



High-voltage injury on the chest of a 16-year-old boy who climbed up an electric pole.



- **Rare pathognomonic “flower-like” branching** skin lesions in persons struck by lightning
- Caused by “flashover” effect of non-penetrating current
- Rapidly fade, not typically
- s e r i o u s

