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Electrical Injuries in the Emergency Department: An Evidence-Based Review

Abstract

Electrical injuries can be caused by exposure to current from low-voltage and high-voltage sources as well as lightning strikes, and the circumstances of the exposure will dictate management strategies. Human tissues have varying resistance characteristics and susceptibility to damage, so injuries may be thermal, electrical, and/or mechanical, potentially causing burns, thrombosis, tetany, falls, and blast injury. This issue reviews the types of trauma seen with electrical injury and how body systems can be affected by occult or delayed effects, and the optimal evidence-based resuscitation and management strategies associated with each.

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This issue is eligible for 4 Trauma CME credits.

Case Presentations

You arrive to work at the regional burn center's ED, and a nurse pulls you into resuscitation bay 1. Paramedics have presented with a thirtysomething man in cardiac arrest. He had been helping his daughter build a curious device called a Jacob's ladder—a homemade machine that creates an electrical arc. His presenting rhythm was asystole but by the time of his arrival in the ED, he is in ventricular fibrillation. You wonder if his cardiac arrest is related to the device, and what your next best step is...

As you start work, you wonder where your end-of-shift colleague is. The question is answered when the curtain for bay 2 is pulled back and you see her intubating a young man. She tells you he arrived by ambulance for "burn care." He fell 12 feet to the ground after his mop pole touched a power line above the semi-trailer he was cleaning. There are minor burns to his hands and chest wall, but more worrisome is the pink fluid draining from his ears and nose. As you assess the patient, you wonder how best to prioritize the patient's workup...

Just as you sit down, a nurse tells you that he has put another electrical injury patient in bay 3; the patient is a 24-year-old man who accidently touched an electrical socket and was thrown backwards to the floor. He didn't hit his head, but he complains of feeling "tingly" all over and slightly nauseated. His vital signs are: blood pressure, 130/ 86 mm Hg; respiratory rate, 16 breaths/min; heart rate, 68 beats/min; and oxygen saturation, 100% on room air. He has no past medical history and a normal physical exam. The nurse asks if he should get an ECG and send a troponin; you wonder...what is best practice?

Introduction

Patients with electrical injury pose unique diagnostic and therapeutic challenges that emergency clinicians must not miss. Each year, approximately 10,000 patients present to United States emergency departments (EDs) with electrical burns or electric shock,[1] with fatalities declining from around 1000 per year in the early 2000s to 565 in 2015,[2] likely because of improved occupational protections.[3] An estimated 4% of burn center admissions are due to electrical burns.[4] Most electrical injuries are due to household or occupational exposures.[1,2] There is a trimodal distribution of patients with electrical injuries; young children are affected most often by household current, adolescent males by high-risk behavior (eg, playing near high-voltage current sources), and adult males by occupational exposure.[5-8] Lightning strikes are a subset of electrical injuries with unique features. In the United States, between 25 and 50 people die each year from lightning strikes.[2]

Electrical injuries can affect every organ system and can cause thermal, electrophysiological, traumatic, and metabolic derangement. Patients may resemble ordinary cardiac, trauma, or burn victims, making recognition challenging, and history is sometimes difficult to obtain. Management of these cases has evolved over time, especially in recommendations for cardiac monitoring and ear, nose, and throat (ENT) care for pediatric oral electrical burns. This issue of *Emergency Medicine Practice* reviews the current evidence for diagnosis and management of electrical injuries, focusing on recognition of life-threatening and occult injury.

Critical Appraisal of the Literature

A literature search was performed using Ovid and MEDLINE® for the period between 1966 to 2018, with the terms *emergency, electrical injury, electrocution*, and *lightning*. This provided a list of 477 articles that was narrowed to 88 after initial review. Some resources were identified from article reference lists, and some articles with redundant or outdated information were excluded. The experimental evidence pertaining to electrical injuries is limited, and most clinical practice is based on expert opinion and observational studies. The most recent statistical information was obtained directly from United States governmental survey and statistical data or from occupational and advocacy organizations. Practice guidelines are limited and based on expert opinion, case studies, and observational studies.

Etiology and Pathophysiology

Electricity is the movement of electrons down a gradient, from high to low potential. The *current* (I), measured in *amperes* (A), can be thought of as the total amount of electrons moving down the gradient per unit of time. *Voltage* (V) is the potential difference between the top and the bottom of the gradient, such as between 2 ends of a wire or the entrance and exit wounds on a patient with an electrical injury. *Resistance* (R) is the obstruction of electrical flow by a material, and is important in electrical injury because current will tend to follow the path of least resistance, providing important clues about underlying injury in particular types of electrical current exposure. Current is directly proportional to voltage and inversely proportional to resistance. Current can be alternating current (AC, switching between positive and negative flow) or direct current (DC, current flowing continuously in 1 direction).

Because most electrical injuries result from grasping an electrical source with the hands, tetany causes the inability to release the contact source,[3,8] and respiratory paralysis may occur if there is sufficient current.[9] Tetany can cause muscular contractions powerful enough to cause orthopedic trauma, rhabdomyolysis, and muscle necrosis,[10] and longer contact due to tetany means more tissue damage. The current required to prevent release of an electrical source because of muscle contraction is termed the *"let-go" threshold*. **(See Table 1.)** Humans are typically able to perceive AC that is between 0.2 mA and 2 mA.[11]

Varied Tissue Resistance to Electricity

Damage to tissues from electricity is largely—though not completely—due to thermal injury and is dependent on tissue resistance, voltage and amperage, the type of circuit (direct or alternating current), and contact duration.[12] Nonthermal injury can be due to electrical injury to nerve tissue, muscle or bone damage from tetanic contractions, and electrolyte derangement.[10]

Human tissues differ in their resistance to electrical energy.[12] The skin offers varying resistance levels, depending on its condition: dry skin offers the most resistance and can protect underlying structures, but as skin absorbs more energy, its resistance breaks down. Wet or lacerated skin offers much less resistance to electricity and allows current to flow to deeper structures.[9,12] Nerve tissue typically has the least resistance to electrical energy, and may be damaged even when current is of low voltage and no cutaneous or musculoskeletal manifestations are present.[11,13] Blood and vascular tissue have low resistance to current, and muscle and viscera have slightly higher resistance. Bone and fat have the highest resistance to current. The consequence of higher resistance is that more energy is lost to higher-resistance tissue in the form of heat, causing coagulation necrosis and burns both in the high-resistance tissues and in surrounding tissues. This poses a challenge for the emergency clinician, as the extent of surface burns may not reveal the extent of burns to visceral and deep muscular tissues, especially when the skin of the patient is wet or there is skin breakdown, lacerations, and/or abrasions.

Relating Voltage and Current to Tissue Injury

Both the type of current (AC or DC) and the voltage of the electrical source have important effects on the amount of energy transmitted to the body and subsequent tissue damage. Electrically sensitive tissues, such as nerve and muscle, are more sensitive to AC.[16] AC is found in lower-voltage applications such as standard home and office wiring, but is also found in high-voltage applications, including high-voltage transmission lines. DC does not cause as much sensation, has a higher let-go threshold, and requires more amperage to cause ventricular fibrillation.[17] DC is found in batteries, car and computer electrical systems, some high-voltage transmission lines, and capacitors.

Voltage affects tissue in 2 ways. The first is through electroporation, which is the direct damage of cell membranes by high voltage.[18] The second is by overcoming the resistance of body tissues and intervening objects (clothes, water, machinery, etc). Very high voltages can even arc through nominally high-resistance air, causing burns without direct contact with the electrical source.[19] The resistance of dry skin is significantly reduced when current voltage exceeds 500 V. The fact that higher voltages reduce resistance to current and can increase injury leads to the useful (if arbitrary) heuristic of low-voltage versus high-voltage exposure. **(See Table 2.)** The United States Department of Energy's recommended cutoff standard for low voltage is 600 V,[20] a standard with which the authors of this review concur.

Patients with electrical injuries often have a complicated presentation, with multisystem injuries. Injury occurs from energy deposition in tissues in the form of heat (thermal injury), electrical damage to electrically sensitive tissue, and mechanical trauma that is often due to falls or forceful muscle contractions.[20] Mechanical trauma can occur even in patients with low-voltage exposure that would ostensibly cause minimal injury, as patients may respond to an electric shock by jerking away and then suffer subsequent trauma due to loss of balance and falling.

Table 1. Physical Effects at Selected Currents[14,15]

Current (mA)	Response
0.2-2	"Electrical" sensation
1-2+	Painful shock
3-5	Let-go threshold for children
6-10	Minimum let-go threshold for adults
22	99% of adults cannot let go
10-20	Tetany (contact area)
20-50	Tetany (respiratory muscles)
50-100	Ventricular fibrillation

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Table 2. Effects of Low-Voltage Versus High-Voltage Electrical Shock

Low-Voltage Shock Effects (< 600 Volts)	High-Voltage Shock Effects (600+ Volts)
Superficial burns	Deep and occult burns
No late arrhythmia	Case reports of late arrhythmia
Usually alternating current	Either alternating current or direct current
Rhabdomyolysis uncommon	Rhabdomyolysis common
Secondary trauma less common	Secondary trauma from falls and tetanic muscle contractions
Contact is prolonged (unable to let go)	Contact can be brief (thrown from voltage source)
Cardiac arrest from ventricular fibrillation	Cardiac arrest from ventricular fibrillation; direct damage to myocardium, causing asystole; and coronary artery thrombosis

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Differential Diagnosis

Most patients with electrical injury can be diagnosed by careful history. In cases where the patient is unable to give history, physical clues such as characteristic burns can give clinical suspicion for electric shock. Unexplained cardiac arrest in a patient in an open area during a storm or near high-voltage lines should put electric shock or lightning strike high in the differential. In some patients, the electrical injury will be minimal, and morbidity will be caused by secondary effects such as trauma from a fall.

Cutaneous Injury

Most electrical injuries present as burns to the skin.[19,21,22] Injuries from low-voltage exposures are more likely to be superficial burns at the entry and exit sites,[11,23] not significant cutaneous injuries.[24] However, if exposure time is prolonged, tissue damage can become more extensive, causing deep burns that may require skin grafts or debridement. High-voltage exposures are more serious, causing larger, deeper burns that are more likely to require extensive skin grafting, debridement, or amputation.[19] In high-voltage exposures, skin can be burned deeply enough to compromise the underlying vascular supply, especially when the burns are circumferential, necessitating escharotomy.

High voltage can overcome the typically high resistance of dry skin tissue and travel through subcutaneous tissue and deeper structures and cause deep, extensive burns underneath areas of relatively uninjured skin. Emergency clinicians must be aware of this possibility and consider the electrical pathway through the body of patients who experience high-voltage exposure. Flash burns can be caused by the arcing of high-voltage electrical energy through the air across large areas of skin.[19] **(See Figure 1.)** The direct conversion of electrical energy to thermal energy can be so vigorous that tissue can be heated sufficiently to cause explosive loss of skin, subcutaneous tissue, or muscle. **(See Figure 2.)**

Musculoskeletal Injury

Patients commonly suffer injured muscles, tendons, and bones after electrical exposure.[19,22,23] Injury mechanism is by either thermal or mechanical means. Thermal injury leads to muscle breakdown, rhabdomyolysis, myonecrosis, and edema that can become severe, and compartment syndrome can occur. Myonecrosis can be a late finding, occurring days after the initial injury.[21] When voltage and current are sufficient to overcome the very high resistance of bone, large amounts of heat are deposited in the bone and periosteal tissues.[14] This leads to osteonecrosis and periosteal burns, with subsequently poor bone healing. Mechanical injury is caused by forceful muscular contraction as a result of the

Figure 1. Flash Burns in a High-Voltage Injury

Although the burns may appear to be superficial, these findings should prompt a search for deep tissue injuries.
Image courtesy of Oklahoma University School of Community Medicine.

Figure 2. High-Voltage Burn

Evidence of a flash burn, with charring and ragged, deep burns on the third and fourth fingers, characteristic of entrance or exit wounds.
Image courtesy of Oklahoma University School of Community Medicine.

current and by falls due to syncope or aversion from the electrical exposure. In 2 retrospective analyses, 11% of patients with high-voltage exposures had traumatic injuries.[19,22] Traumatic injuries included fractures, dislocations, and significant muscular injuries. High-voltage injuries have an especially high surgical injury rate, with debridement, fasciotomy, and amputations for limb ischemia or widespread tissue damage being common.[19,21-23] Fractures can also occur in low-voltage exposures, although this is less common.[25] Spinal trauma can occur from hyperextension caused by forceful muscular contraction.[16]

Cardiovascular Injury

Electrical injury to the cardiovascular system is a feared, though rare, complication of both high- and low-voltage electrical shock. The pathway of the electric shock is predictive of potential myocardial injury or arrhythmia, and large surface burns and a vertical pathway through the torso between the entrance and exit points indicate higher risk of injury to the heart.[26] Common electrocardiogram (ECG) abnormalities from electrical exposure include atrioventricular block, bundle branch blocks, atrial fibrillation, QT prolongation, and ventricular arrhythmias.[27,28] In the worst-case scenario, electrical energy that travels through the heart can induce ventricular tachycardia or ventricular fibrillation; this is usually seen immediately after exposure.

Case reports of delayed-onset cardiac dysrhythmias have led some emergency clinicians to initiate prolonged cardiac monitoring in patients with an electrical injury.[29] There have been no randomized clinical trials addressing this issue, but several well-designed observational studies have demonstrated no evidence of late-onset arrhythmia necessitating any intervention.[23,30-32] Hansen et al studied a Dutch cohort from 1994 to 2011, with 11,462 patients with both high- and low-voltage electrical exposure, and noted no patients with late-onset arrhythmia related to exposure. Patients with ventricular tachycardia or fibrillation in this cohort had these arrhythmias on arrival, although this cohort was young and healthy and the study may not have perfect applicability to other populations.[31]

Patients can have thermal and electrical injury to the myocardium, causing myocardial infarction, pericardial injury, and heart failure.[29] ST-segment elevation myocardial infarction is well-described in the literature, is often associated with normal coronary angiography, and is likely due to coronary artery vasospasm.[26,33,34]

Respiratory Injury

Respiratory failure secondary to electric shock is usually due to underlying cardiac arrest. Thoracic tetany can cause paralysis of the respiratory muscles.[9] Trauma from falls secondary to electrical exposure can cause pneumothorax or pulmonary contusion. Late findings include pulmonary effusions, pneumonitis, or pneumonia.[12] These are usually seen within a week of exposure. Another potential late finding is pulmonary embolus from deep venous thrombosis (DVT) after injury. The electrical resistance of lung tissue is relatively higher than other thoracic structures,[14] which may account for the decreased incidence of direct pulmonary injury, as more current will flow through the surrounding lower-resistance structures.

Vascular Injury

Blood vessels are highly conductive and are commonly injured by electrical burns,[9,14] leading to localized vascular injury or thrombosis. Coagulation necrosis and thrombosis in vascular structures causes damage to both the vessel and surrounding tissues. Smaller vessels have lower flow rates and are at higher risk for developing thrombosis. This small-vessel injury can lead to decreased tissue perfusion in muscles and visceral organs, with the consequence of tissue necrosis, edema, and compartment syndrome. Arterial thrombosis can cause acute limb ischemia.[35]

Patients with severe electrical burns who are hospitalized have increased iatrogenic risk of DVT, especially if they are immobilized or undergo multiple surgeries.[36] The total incidence of DVT in burned patients is around 1%, but in hospitalized patients, this rises to as much as 23%.[36-38]

Neurological Injury

Nerve tissue is highly conductive, and neurological injury after electric shock is common. This can be due to direct thermal damage to nerve tissue or from electroporation, which is especially damaging to nerve cells that are dependent on establishing electrolyte gradients for proper functioning. The most common neurological complaint after electric shock is loss of consciousness.

In a survey study of a cohort of both high- and low-voltage exposures, over 80% of patients had delayed neurological complaints, including numbness, weakness, paresthesia, and difficulty concentrating.[39] A prospective cohort study established a 28% incidence of neurologic injury in a primarily low-voltage exposure group,[40] similar to the 25% found in a study by Arnoldo et al.[19] Injury pattern is important, as many patients complain of paresthesia or permanent numbness at the entrance and exit sites, and a pathway that traverses the spinal cord (ie, from one limb to another) puts a patient at risk for spinal cord lesions. The amount of current and the voltage are relatively less predictive of the types and severity of neurologic injury.[40,41] Immediate symptoms often resolve and have a better prognosis than late sequelae. Patients may also develop secondary neurological injury from hypoxia and subsequent ischemia after cardiac arrest or spinal cord injury due to spinal artery vasospasm.

There is a higher incidence of spinal cord injury in high-voltage trauma.[42-44] These are most often reported as transverse lesions with posterior cord syndrome. Depression, chronic pain, anxiety, mood swings, and cognitive difficulty are all commonly described.[40-43]

Other Injuries

Any organ system can be impacted by electric shock. Visceral injury is rare but must be considered, especially in high-voltage injuries with a pathway through the thorax.[45] This can include pancreatic and renal injury, although bowel perforation is most common. Renal injury is also possible from myonecrosis and rhabdomyolysis.[11] High-voltage exposure is associated with the development of cataracts, macular injury, and retinal detachment.[46] Hearing loss, tinnitus, and vertigo due to inner ear dysfunction are well described.[47] These symptoms can be due to tympanic membrane perforation, ossicle injury, or cranial nerve damage and can be transient or permanent. Symptoms (especially cataracts) can occur years after initial injury.

Injury to the oral commissure in pediatric patients is a concerning electrical injury, and its treatment is controversial. Children may chew on an electrical cord, causing burns to the tongue and the palate. The depth of the injury may not be immediately apparent, and vascular injury to the labial artery or surrounding structures can lead to immediate or delayed severe bleeding, with possible airway obstruction and massive hemorrhage. There is no consensus on early versus late ENT intervention, oral splinting, or disposition management.[48,49]

Prehospital Care

A prehospital call for electric shock requires a high-priority response and may be a challenging scenario.[50,51] The voltage source at the scene may still be live, placing prehospital personnel at risk. It is paramount that first responders be protected from electrical exposure. If the patient is still connected to the electrical source, they cannot be approached until it is certain that the power source has been removed. In high-voltage injuries (power lines, transformers, etc) the responders should verify with local electrical authorities that the power source has been shut off.

Patients in cardiac arrest are managed following standard Advanced Cardiovascular Life Support (ACLS) guidelines.[52] If facial or neck burns are present or if there is any evidence of airway compromise, there is a high risk for airway loss, and these patients should be intubated early, especially if transport time to a hospital is likely to be prolonged. The success rate of cardiopulmonary resuscitation (CPR) is much higher in this patient population,[53,54] as they are less likely than the typical cardiac arrest patient to have underlying comorbid conditions.

Trauma is common in high-voltage injuries. Cervical spine immobilization is necessary in any patient with a significant injury or a loss of consciousness. Intravenous (IV) access should be established, and isotonic IV fluids given as a 10 to 20 mL/kg bolus in hypotensive patients or patients with evidence of burns. Patients with syncope or a decreased level of consciousness should receive an ECG and continuous cardiac monitoring. Disposition can be challenging, especially if the local burn center and the local trauma center are in different hospitals. In general, trauma takes priority over burns, so patients with evidence of significant trauma should be transported to a trauma center.[51] Patients who are exposed to high voltage and are obtunded or unconscious should be sent to a trauma center, as traumatic injuries are more common in this group.

Emergency Department Evaluation

Electrical injuries, especially high-voltage injuries, are potentially multisystem trauma combined with burns. Patients should receive a primary and secondary survey following both ACLS and Advanced Trauma Life Support® (ATLS) guidelines. Airway management is a priority, especially if head or neck burns are present.[50] Remember that the severity of the burn may not be apparent from the initial skin examination.

Patients must be completely disrobed, and rings and other jewelry should be removed. IV fluid resuscitation should proceed with the goal of maintaining diuresis at 1 to 1.5 mL/kg/hr. The amount of IV fluid required in severe burns can be very large and cannot be determined by the Parkland formula or other body surface area estimations.[19,52] Patients who have experienced high-voltage exposure should have an ECG and cardiac monitoring, although in low-voltage injuries with no syncope and a normal initial ECG, monitoring is not required. **(See Table 3.)** Well-appearing, minimally injured patients exposed to low voltages are much less likely to have severe trauma or burns, but should still have a full evaluation, as occult injuries are possible.[25]

Table 3. Indications for Cardiac Monitoring After Electrical Injury[24,27-29]

- Any high-voltage exposure (600+ V)
- Syncope
- Any abnormal rhythm or electrocardiographic evidence of ischemia
- Chest pain

History

History must include evaluation of the type of current (AC/DC), voltage, physical environment (outdoors/indoors, weather, risk of falling), and underlying medical conditions, especially cardiac conditions predisposing to arrhythmia. Note that a voltage source thought to be low voltage (eg, household current) may, in fact, be high voltage.[20] An example of this would be an exposure from a discharging capacitor in a high-energy household appliance, such as a television. Patients may not be able to provide history, so discussion with emergency medical services (EMS) personnel or bystanders is important. EMS personnel should be asked about the prehospital care undertaken, including resuscitative measures. As with all trauma patients, emergency clinicians should take a medical history and document allergies and medications and tetanus immunization status.

Physical Examination

Patients require a thorough and methodical physical examination after the initial evaluation. Burns should be carefully assessed, noting size and location. After disrobing, all skin surfaces must be examined for occult injuries. Assess visual fields for clues to retinal injury or potential neurologic injury, assess hearing, and perform a complete ENT examination, including otoscopic and funduscopic examination. Extremities should be examined for bony tenderness, joint tenderness, and restriction in range of motion.

The path taken through the body by the current must be considered. Important clues about the path of the current can be found by noting the entrance and exit wounds (burns or open injuries), **(see Figure 2, page 4)**, but remember that there may have been other electrical pathways causing injury as well.[16] A careful primary and secondary survey is essential.

Perform serial examinations on the extremities to evaluate for vascular compromise and compartment syndrome. In high-voltage injuries and lightning strikes, the risk for traumatic injury is high, and evaluation of the chest, abdomen, and pelvis for trauma should be performed. This will include a search for signs of a basilar skull fracture (post auricular ecchymosis, hemotympanum, and clear nasal drainage), cervical injury, and pneumothorax or pulmonary contusion.

Diagnostic Studies

Electrocardiogram

Perform an ECG on all patients presenting with a history of electric shock. There are reports of myocardial infarction, arrhythmia, and other ECG abnormalities after both low- and high-voltage exposure. Patients with a low-voltage exposure, no arrhythmia in the field, no syncope, and no chest pain do not require further cardiac monitoring. There is evidence suggesting that high-voltage exposures without initial ECG changes may not require monitoring, but it is limited, and current clinical consensus does not support omitting cardiac monitoring in these patients.[24,27,30] Duration of monitoring varied in studies, but ranged from 6 to 24 hours.[30,32] Our recommendation is for overnight monitoring, or at least 8 hours of monitoring.

Laboratory Testing

There is no evidence that routine laboratory testing in patients with low-voltage, minor cutaneous burns is helpful. For serious injuries (eg, those with entrance and exit wounds or history of ECG abnormalities or dysrhythmia), obtain a complete blood cell count, complete metabolic panel, and urinalysis. Creatine kinase (CK) and CK-MB (creatine kinase-muscle/brain) testing can be helpful. CK helps assess for rhabdomyolysis. A CK-MB > 80 ng/mL is predictive of limb amputation.[55] Cardiac troponin is not helpful in most cases, although this was not assessed in the case of cardiac arrest.[56] Coagulation studies should be obtained if there is concern for intra-abdominal pathology or if the patient may require surgery. Obtain a pregnancy test in all women of childbearing years.

Diagnostic Imaging

Decisions for imaging are driven by history and physical examination. Perform a FAST (focused assessment with sonography in trauma) examination to screen for intra-abdominal pathology. In general, maintain a high index of suspicion for traumatic injury in high-voltage exposures or lightning strikes, or if the electrical injury resulted in a fall. Patients who have altered mental status, an abnormal neurological examination, or are unconscious should have computed tomographic (CT) scan of the brain and cervical spine, abdomen, and possibly chest. Obtain radiographic evaluation of any painful or deformed bony areas. Maintain a high index of suspicion for pelvic injuries and shoulder dislocations. Patients who complain of severe pain or inability to move the shoulder should have a CT scan if x-rays are negative, as posterior dislocations are difficult to see on plain x-ray.[57] Complaints of chest pain or abdominal pain should prompt further radiographic evaluation, with CT scanning preferred, to evaluate for injury. Extremity ultrasound with arterial and venous Doppler is useful to identify the possibility of thrombosis.

Treatment

Minor Injuries

Electrical injuries can be divided into minor and major injuries. Minor injuries are small cutaneous burns caused by low-voltage exposure. These patients should have a normal ECG and no history of syncope, chest pain, or orthopedic injury, with no airway involvement. These patients may require no intervention other than analgesia, return precautions, and follow-up with their primary care provider or the burn center.

Major Electrical Injuries

Initial treatment of severe electrical injury should be directed toward establishing airway patency and supporting breathing and circulation. Patients with any type of burn to the face or neck are at high risk for airway edema.[58] A prospective study found a higher risk of a difficult airway in patients with delayed intubation, especially if intubation was delayed until the patient arrived at the burn center.[59] This finding should prompt the emergency clinician to establish a definitive airway prior to transfer if there are burns to the face and neck, as high-voltage burns tend to involve structures deeper than observed on initial examination. Several backup airway options should be at the ready for these patients. Options include video-assisted laryngoscopy, bougie assistance, and fiberoptic equipment. A surgical airway setup (cricothyrotomy) should be available at the bedside. Maintain cervical spine immobilization in obtunded or unconscious patients requiring intubation. Establish IV access and give isotonic fluids to maintain urine output at 1 to 1.5 mL/kg/hr. Obtain an ECG and place the patient on cardiac monitoring.

Pain control is difficult in all severely burned patients, and it can be especially problematic in patients with electrical injuries. Opioid analgesia is preferred, and large doses may be required. A short-acting opioid such as fentanyl (1 mcg/kg IV), given as a continuous infusion, may allow for better pain control and is more easily titratable. Hypotension and respiratory depression are concerns, and it may be necessary to intubate a patient with high-voltage injury to more easily control pain.

Burned areas should be cleaned and dressed with an antibiotic dressing. Update tetanus immunization as indicated. For more information on managing thermal burns, see the February 2018 issue of *Emergency Medicine Practice*, "Emergency Department Management of Patients With Thermal Burns" at www.ebmedicine.net/Burns.

It is unclear whether prophylactic antibiotics are beneficial. Their use is not currently recommended, based on a review of the burn literature, and it is controversial in intubated patients.[60,61] Nosocomial infection is a risk, and severely burned patients (ie, any patient with more than minor superficial burns) should be cared for using contact precautions, including sterile gowns, gloves, and face masks.[62] Patients are at high risk for limb ischemia and compartment syndrome. The emergency clinician must recognize these complications and involve general, vascular, and orthopedic surgery early in the patient's management for possible surgical intervention. There is no consensus on early surgical exploration of affected limbs in severe electrical injury, with most authors recommending a conservative approach.[63]

Special Populations

Pediatric Patients

Although children are more likely to sustain low-voltage injuries, they have higher relative morbidity because of their thinner skin, smaller body area, and lower resistance to electrical energy. Young children (aged < 5 years) are most likely to present with orofacial burns. There is up to 24% risk of labial artery bleeding[64] and primary tooth damage, and although there is no consensus on timing of surgical intervention or necessity of oral splinting, the emergency clinician should obtain early ENT intervention and strongly consider admission or transfer for observation. Labial artery bleeding is often delayed, and can be seen up to 2 weeks after initial presentation.[48,49]

Older children are more likely to be adolescent boys engaging in risk-taking behaviors. They have a higher incidence of high-voltage injuries and upper extremity injuries, often requiring fasciotomy or skin grafting.[6,8]

Pregnant Patients

The literature on electrical injury in pregnant patients consists mostly of case reports and a few cohort studies. In a small prospective study, low-voltage exposure did not change fetal outcomes.[65] Case reports describe fetal arrhythmia, fetal ischemic brain injury, and fetal demise.[66,67] Patients whose pregnancies are past the age of fetal viability (usually 20 weeks, though local practice can vary) should have fetal monitoring after experiencing electric shock. An ultrasound should be obtained if it has not yet been done during the pregnancy, and a 2-week follow-up ultrasound is also recommended.[67]

Patients With Taser (Electrical Control Device) Injuries

The electrical control device weapon, known by the brand name of Taser, is a device that typically shoots 2 barbed projectiles into the body in order to subdue an individual. **(See Figure 3, page 9.)** Devices vary by model, but there may be an initial 50,000 V shock, with multiple subsequent shocks.[68] There are case reports of ventricular fibrillation and of traumatic injuries from the metal barbs.[69] There is controversy surrounding the Taser literature, with some researchers calling into question the possibility of Taser-induced arrhythmia, suggesting that it is more likely to be due to underlying structural disease or "excited delirium."[70-73] Some patients report cognitive abnormalities immediately after exposure; it is not known whether there is a risk for permanent cognitive difficulty.[74]

Most Taser injuries are direct traumatic effects from the Taser darts and indirect trauma from falls or physical interactions with police.[68,75] These injuries are usually minor, although fractures and traumatic brain injuries have been reported. Injuries to sensitive body parts such as eyes and testicles have been reported. Pneumothorax and injury to a gravid patient are also considerations. Patients should be approached as standard assault/trauma patients, with the addition of an ECG to assess for arrhythmia, bearing in mind that some patients who present to the ED in police custody are under the influence of drugs, alcohol, or have mental illness. Complaints of chest pain or shortness of breath should be taken seriously, as Taser injury (increased sympathetic tone from the stressful encounter) and drug effects could all contribute to these symptoms. Management of a cardiac arrest in the setting of a Taser injury is unchanged from standard ACLS protocols.

Lightning Strikes

Lightning strikes present differently from other electrical injuries. Voltage is in the millions, and amperage in the thousands, but exposure time is measured in milliseconds, so total energy transfer is limited.[74,76] Because most lightning strikes occur in open areas outside and it is often raining during the exposure, highly conductive wet skin may cause the electrical energy from the strike to stay on the external skin surface, called the *flashover effect*. In addition, the rapid expansion of air causes a concussive blast. These unique features lead to unusual injury patterns, and patients can be thrown to the ground or into objects. Lightning-strike injuries can also occur inside a building, with current traveling through electrical wiring or through plumbing to cause electric shock to persons inside a structure.[76,77] EMS personnel should be aware of the potential for further strikes when responding to a possible lightning strike and take measures to protect themselves, moving the patient to a safer environment as soon as it is possible and safe to do so.[51]

In lightning injury, burns are common, and can be arc burns, flash burns to the surface, or deeper burns, although the short exposure time tends to limit total burn energy. Lichtenberg figures (a fine branching rash that may resemble bare tree branches) are pathognomonic for lightning injury. **(See Figure 4.)** These skin changes are superficial, do not require treatment, and fade within weeks. Ocular injury (including retinal detachment and cataracts) and otologic injury are common,[76,78] and tympanic membrane rupture occurs in up to two-thirds of cases.[75] Ophthalmologic consultation should be

Figure 3. An Electrical Control Device Used by Law Enforcement

Police-issue X26 TASER. This device delivers very high voltages for very short periods of time. The total energy imparted is 0.07J/pulse, with a maximum of 85 pulses.

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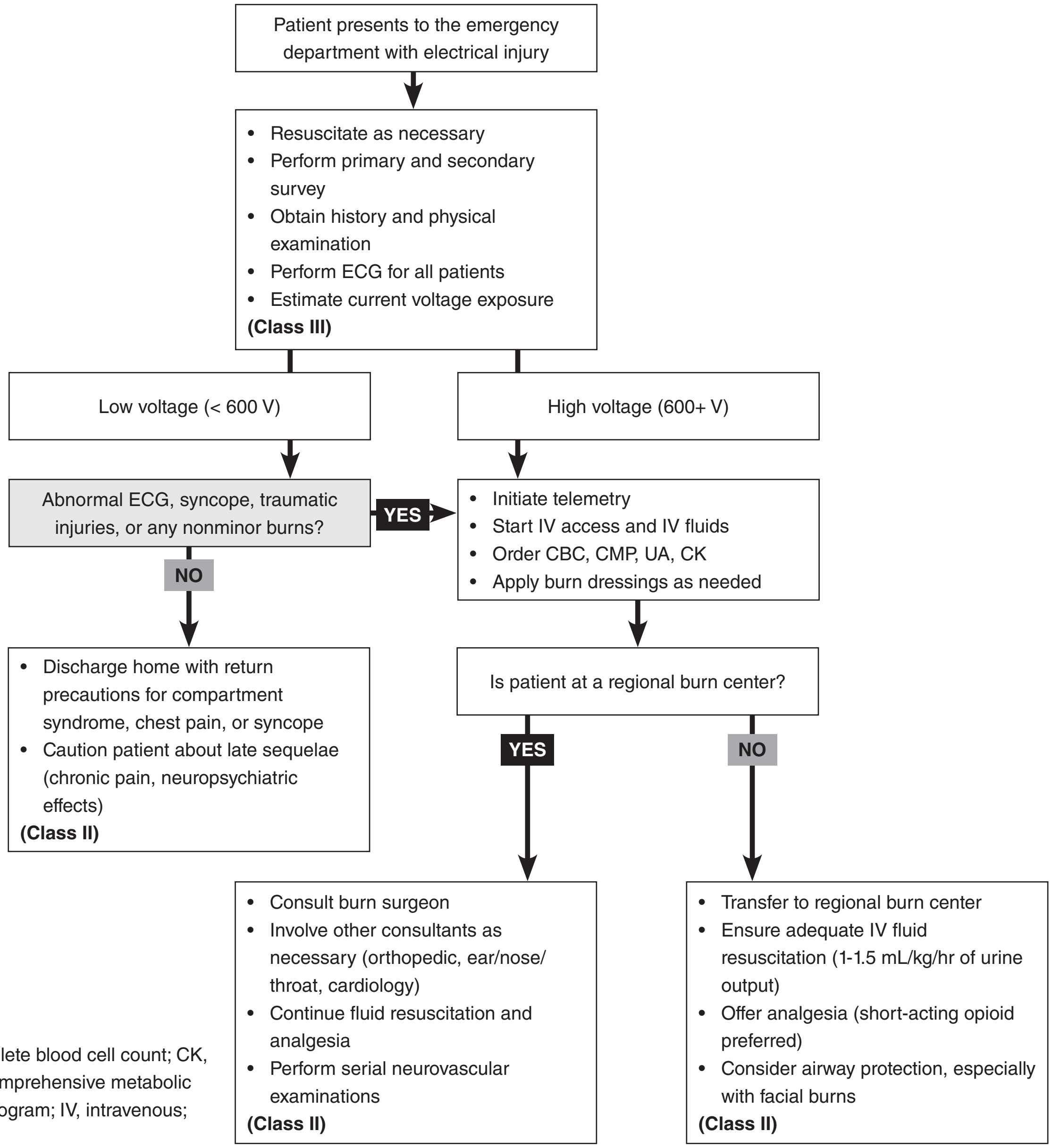
Figure 4. Lichtenberg Figures

Lichtenberg figures: cutaneous manifestations of phone electrocution from lightning. *The Journal of Plastic, Reconstructive & Aesthetic Surgery.* Volume 61, Issue 1. Aljay L. Mahajan, Ruchika Rajan, Padraic J. Regan. © 2008, with permission from Elsevier.

Clinical Pathway for Emergency Department Management of Electrical Injuries



Abbreviations: CBC, complete blood cell count; CK, creatine kinase; CMP, comprehensive metabolic panel; ECG, electrocardiogram; IV, intravenous; UA, urinalysis.

Class of Evidence Definitions

Each action in the clinical pathways section of *Emergency Medicine Practice* receives a score based on the following definitions.

Class I
- Always acceptable, safe
- Definitely useful
- Proven in both efficacy and effectiveness

Level of Evidence:
- One or more large prospective studies are present (with rare exceptions)
- High-quality meta-analyses
- Study results consistently positive and compelling

Class II
- Safe, acceptable
- Probably useful

Level of Evidence:
- Generally higher levels of evidence
- Nonrandomized or retrospective studies: historic, cohort, or case control studies
- Less robust randomized controlled trials
- Results consistently positive

Class III
- May be acceptable
- Possibly useful
- Considered optional or alternative treatments

Level of Evidence:
- Generally lower or intermediate levels of evidence
- Case series, animal studies, consensus panels
- Occasionally positive results

Indeterminate
- Continuing area of research
- No recommendations until further research

Level of Evidence:
- Evidence not available
- Higher studies in progress
- Results inconsistent, contradictory
- Results not compelling

This clinical pathway is intended to supplement, rather than substitute for, professional judgment and may be changed depending upon a patient's individual needs. Failure to comply with this pathway does not represent a breach of the standard of care.

obtained as soon as practical. Cardiac complications include sudden death, cardiac contusion, or coronary vasospasm.[77,79] Resuscitation is more likely to be successful in these patients than in typical cardiac arrest patients.[50,52]

Lightning strikes are especially problematic from a neurologic standpoint. Central nervous system dysfunction can be immediate or delayed, and can include ischemic stroke, spinal cord injury, or keraunoparalysis, a temporary condition that mimics spinal cord injury.[41-44,80-85] These patients can develop cerebral salt wasting syndrome, transient or permanent stroke symptoms, and peripheral nerve lesions. They are also at risk for trauma-related neurologic morbidity, eg, spinal cord fractures and skull fractures.[80,82-84] Pinpoint cerebral hemorrhage, ischemia, and infarction have been described, and injury may be detected only by magnetic resonance imaging (MRI).[84] Any organ system can be involved. Myoglobinuria and rhabdomyolysis are uncommon.[77,86] Vasospasm can mimic stroke, myocardial infarction, and bowel ischemia, or cause signs of compartment syndrome, though these findings are usually self-limited. The American College of Surgeons recommends that these patients be transferred to a burn center for further evaluation and treatment, as they have very complicated presentations and multiple system involvement.[52,87]

Controversies

Antibiotic prophylaxis is controversial in the burn literature.[60,61,88] Randomized controlled trials are rare and suffer from methodological problems.[61] Some trials showed benefit of antibiotic prophylaxis in the perioperative period and in mechanically ventilated patients. The most recent meta-analysis of trials did not support routine antibiotic prophylaxis in inpatient burn victims. Emergency clinicians should consult with the burn surgeon about antibiotic prophylaxis.

There is suggestive, but not definitive, evidence that cardiac monitoring is not necessary for any patients without ECG changes, regardless of voltage level,[32] but no well-designed prospective trials were found. The most recent literature continues to recommend cardiac monitoring for patients with a high-voltage injury or initial ECG abnormalities.[30,32]

Disposition

Low-voltage injuries in patients with normal ECG, no syncope or arrhythmia, and minimal injuries can be discharged home without prolonged cardiac rhythm monitoring. They should be given return precautions for chest pain, palpitations, syncope, and compartment syndrome. Follow-up should be explicitly arranged with either the patient's primary care provider or with the regional burn center.

High-voltage injuries require admission to a burn center. Regional burn centers will have a burn surgeon on call at all times, and the burn surgeon must be involved in care of all admitted burn patients. Orthopedic surgery, ENT, and cardiology should be consulted according to the patient's injuries. For emergency clinicians not at a burn center, transfer should be arranged to the burn center after initial stabilization. The transferring physician must be aware of the transport time and possible complications that may develop during transport, including airway loss and development of limb ischemia. Pretransfer stabilization may therefore involve intubation, fasciotomy, or escharotomy. Transport should be performed by ACLS-certified paramedics, and preferably by critical care-trained personnel such as air medical transport crews.[50,51] Ensure that crews are aware of treatment guidelines for fluid resuscitation, evaluation of neurovascular status, and analgesia. Trauma takes precedence over burn – patients with severe traumatic injuries will require transfer to a trauma center first.

Summary

- All patients with an electrical injury should receive an ECG. Low-voltage exposures with a normal ECG and no evidence of syncope do not need further hematological testing or cardiac monitoring.
- Injuries may be more than skin deep; evaluate for trauma to muscle, bone, viscera, and brain.
- The skin may be relatively spared, but patients can have subcutaneous burns, tissue edema, and compartment syndrome under undamaged skin.
- Cardiac resuscitation should proceed according to ACLS guidelines, and is likely to be successful.
- In partial- or full-thickness electrical burns, isotonic IV fluids should be administered to maintain urine output at 1 to 1.5 mL/kg/hr.
- Patients with low-voltage exposures with minimal apparent injury and a normal ECG can go home with good return precautions. All high-voltage exposures and lightning strikes should be transferred to a burn or trauma center for further evaluation.
- Burns from lightning strikes are likely to be superficial; however, the extremely high voltage in lightning strikes can cause neurologic complications, and secondary trauma from concussive force is a concern. Self-limited vasospasm can mimic neurologic, cardiac, and gastrointestinal ischemia, as well as compartment syndrome.
- Patients who are discharged must be given return precautions for neurological symptoms,

compartment syndrome, and syncope. They must be warned about potential late sequelae, such as cataracts, neurological and autonomic dysfunction, visceral injury, and vascular injury.

Case Conclusions

The Jacob's ladder patient clearly experienced a high-voltage electric shock. His vital signs were stable on arrival, and the cardiac monitor showed occasional premature ventricular contractions. Though these patients generally do well without deterioration, best practice continues to advocate for 12 to 24 hours of cardiac monitoring. You admitted him to the telemetry unit; there was no indication for antiarrhythmic treatment. He remained asymptomatic for 24 hours, at which time he was discharged.

The pink fluid draining from the nose and ears of your patient who fell off the semi-trailer was caused by the patient having sustained a basilar skull fracture from the fall.

Risk Management Pitfalls for Electrical Injuries in the Emergency Department (Continued on page 13)

1. **"I sent the patient with a low-voltage minor electrical burn home and told her she was fine (she was!). She came back to the ED 2 weeks later and is angry because she developed dizziness and paresthesia in her fingers."**
   Electrical injuries have a high incidence of delayed neurological sequelae,[41] with studies noting between 25% and 80% of patients reporting neurological complaints after electric shock.[39,40] It is important to give specific, detailed discharge instructions, including return precautions for numbness, dizziness, weakness, and mental status changes.

2. **"I admitted an electrician with upper extremity and facial burns and airway management who was injured working on a high-voltage line. The orthopedic surgeon called and is angry because he has an open foot fracture. The ED was busy; I can't take every single patient's boots off."**
   High-voltage injuries have a high incidence of orthopedic injuries, and electrical current at entrance and exit sites can be sufficient to cause open injuries. Remember to completely undress patients so you do not miss injuries on your primary and secondary survey.

3. **"The man was found lying in the grass, unconscious. His CT scan and labs were normal. He seemed confused on re-evaluation, so I admitted him for altered mental status, which I thought was probably drug-related. The next day I got a call from the hospitalist; apparently the ENT said he has extensive inner and middle ear damage and is now deaf."**
   Patients found unconscious for no apparent reason in an open area should have lightning strike in the differential. (Lightning can strike even when it is not raining, during an event called a "dry" thunderstorm.) The concussive force of the strike can be sufficient to rupture tympanic membranes and cause inner ear damage.[47] A thorough ENT examination is necessary.

4. **"A patient was brought in by the police last night. He was 'minding his own business' and somehow ended up Tasered. He said it hurt to lift his arm. I x-rayed his humerus and elbow, both negative, with normal pulses and sensation, so I discharged him into police custody. Unfortunately, they brought him back 2 days later… he ended up being diagnosed with a scapular fracture."**
   Taser (or other electroshock weapon) injuries are on the rise in the United States, and 1 out of 9 police-related injuries presenting to United States EDs are caused by these devices.[76,77] The majority of injuries are minor abrasions, lacerations, and contusions. Forceful muscle contraction can cause fractures, including spinous process fractures and scapular injuries. Cardiac electrical capture with subsequent ventricular fibrillation and asystole is a rare complication.[78]

5. **"I work at the regional burn center. EMS brought in a 45-year-old lineman who touched a high-voltage line. The shock entered his left arm and exited his right leg. I admitted him to burn ICU, gave IV fluids for his open injuries, but I didn't have time to recheck him. He needed multiple doses of pain medicine. While he was holding in the ED his arm became tight, shiny, and pale…he had a delay in his emergent fasciotomy."**
   Burn patients with significant orthopedic injuries are at high risk for compartment syndrome, and electrical burns are at even higher risk because of the full-thickness nature of many of these injuries. Frequent neurovascular checks are a must, especially in the first 12 hours. Your ED should have a protocol for neurovascular checks for these patients, and progressive or uncontrolled pain should prompt further investigation.

The burns on his hand and chest most likely represented the entrance and exit of the electrical discharge and the fall possibly due to a transient dysrhythmia. Fortunately, his vital signs were stable and there was no evidence of myocardial damage. Instead, the leaking cerebrospinal fluid was the biggest concern, and you were reminded of the importance of a careful secondary survey in patients with electrical injuries. The patient was admitted to the neurosurgical ICU, remained stable, and had an uneventful recovery.

Your third patient who sustained a shock from an electrical socket has a low-voltage injury. His exam was normal, as was his ECG. There was no indication for doing a troponin nor any indication for cardiac monitoring. You discussed with the patient the possible side effects from a low-voltage injury, including persisting numbness and tingling, which generally resolves. The patient was discharged with instructions to return for any cardiac symptoms; you called him 24 hours later and all symptoms had resolved.

Risk Management Pitfalls for Electrical Injuries in the Emergency Department (Continued from page 12)

6. **"The 2-year-old had a small burn on his face after playing with an electrical cord. There was no airway involvement, and I sent him home to follow up with a burn specialist. Then 24 hours later, he came back bleeding profusely from the mouth…that airway was touch-and-go."**
Oral burns in children who chewed on an electrical cord have up to 24% incidence of bleeding from the labial artery. Proper initial management is controversial, but ENT consultation should be obtained, and if the patient goes home, you must give strict discharge instructions and set patient/family expectations for the possibility of bleeding.[48,49]

7. **"This patient was transferred to our burn center for evaluation of his high-voltage burns after he was cleared by the trauma center. We admitted him to the burn floor, where he had a seizure and then became obtunded. It turned out he had a basilar skull fracture. The surgeon asked me if I had looked behind his ears.'"**
Initial traumatic injuries may not be apparent in high-voltage exposures, and you should do a thorough traumatic evaluation in these patients. In this case, early recognition of a skull fracture (which may reveal the Battle sign, with bruising behind the ears) could have prompted seizure prophylaxis, neurosurgical consultation, intracranial pressure monitoring, etc.

8. **"My patient had a high-voltage burn that had entry at his head and exit from the right arm. He had some minor facial burns and an arm fracture. We admitted him to the floor, but he boarded in the ED for a while. I'm glad he did, because he became progressively more dyspneic and needed emergent intubation. He had a lot of edema; I barely got the tube passed."**
Remember that the extent of burn seen on the skin in high-voltage burns may not give an accurate picture of underlying burn injury. You cannot use traditional burn metrics of soot in the mouth or nares, facial hair singeing, or burns to the lips as risk factors for intubation. Maintain a high index of suspicion for airway involvement and consider fiberoptic laryngoscopy or early intubation in electrical burns involving the face or neck.

9. **"We saw a patient who grabbed a low-voltage line with both hands. She said that her left arm hurt, but there was no sign of trauma, x-ray was negative, and her ECG was completely normal. That night she returned, and her arm was cold and pale."**
There is a risk of acute arterial and venous thrombosis in patients injured by electric current. This is hypothesized to be due to both thermal damage and electrical damage to the intima of the vessel. In a patient with unexplained pain in a limb after electrical injury, you must document neurovascular status and serial examinations. If pain persists, further workup is necessary, which may include ultrasound, CT angiography, or formal angiography.

10. **"This high-voltage injury patient came to the ED with 10% total body surface area burns. I followed the Parkland formula for fluids, but she stayed hypotensive and, during her hospital course, developed acute renal failure. I thought that formula was solid for taking care of a burn patient."**
Electrical burns on the skin do not necessarily give a clear picture as to how much tissue was actually damaged by thermal and electrical energy. Isotonic IV fluids sufficient to maintain urine output at 1.0 to 1.5 cc/kg/hr must be given to these patients. Continue fluid resuscitation until you reach that urine output and urine myoglobin has cleared. Fluid requirements may be much higher than specified by the Parkland formula. CK levels and myoglobinuria should be monitored.

Time- and Cost-Effective Strategies

- Cardiac monitoring in patients with no arrhythmia, syncope, or ECG changes is unnecessary.
- Do not delay transfer to a burn center; once you have determined that transfer is necessary and the patient is stabilized, further diagnostic testing may delay definitive care.
- Many low-voltage exposures may be safely discharged home if there are no or only minor burns, no ECG changes, and no worrisome findings on examination.
- A urinalysis can screen for the presence of myoglobin, leading to a search for rhabdomyolysis.

References

Evidence-based medicine requires a critical appraisal of the literature based upon study methodology and number of subjects. Not all references are equally robust. The findings of a large, prospective, randomized, and blinded trial should carry more weight than a case report.

To help the reader judge the strength of each reference, pertinent information about the study, such as the type of study and the number of patients in the study is included in bold type following the references, where available. The most informative references cited in this paper, as determined by the author, are noted by an asterisk (*) next to the number of the reference.

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CME Questions

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1. **Injuries from high-voltage electrical shock can affect any organ system. Regarding high-voltage injuries, which of the following is TRUE?**
   a. These injuries are less likely than low-voltage injuries to cause rhabdomyolysis.
   b. The extent of skin burns is likely to reflect underlying deep tissue burns.
   c. Electrical energy will preferentially take the path of least resistance but may overcome skin resistance in high-voltage exposure.
   d. Fluid resuscitation should proceed according to the Parkland formula based on the percentage of total body surface area that is burned.

2. **Which of the following tissues offers the most resistance to electricity?**
   a. Nerve
   b. Muscle
   c. Vascular
   d. Bone

3. A 20-year-old man who experienced a low-voltage electrical exposure through his hands is ready for discharge from the ED. He is concerned about possible delayed complications from his injury. Which of the following concerns could be a delayed complication of a low-voltage injury?
   a. Cardiac rhythm changes, palpitations, and chest pain
   b. Mood swings and depression
   c. Vision loss from cataracts
   d. Fractures missed on the initial examination

4. A 2-year-old child presents to your ED after chewing on an electrical cord. A small burn is seen at the corner of the mouth. The child has no active bleeding and no evidence of airway involvement. What is the appropriate next step in treatment of this patient?
   a. Early intubation and admission or transfer to pediatric intensive care is the standard of care.
   b. Administer early IV antibiotics, as the primary risk is secondary infection.
   c. Obtain ENT consultation and give parental instruction for delayed bleeding.
   d. Apply oral splinting and order ENT follow-up.

5. A 27-year-old electrical lineman presented to your small community ED after a high-voltage line injury. He had a loss of consciousness and fell from height out of his bucket truck. He has burns to his left arm, chest wall, and both feet, and is found to have a pneumothorax, multiple rib fractures, and a grade II splenic laceration. After initial evaluation and stabilization, including intubation and chest tube insertion, you determined that he requires a higher level of care and will require transfer. Regarding his immediate care, which of the following is TRUE?
   a. His burn care takes precedence over the trauma care, and he should be transferred to the burn center.
   b. His trauma care takes precedence over the burn care, and he should be transferred to the trauma center.
   c. IV fluids should be given according to the Parkland formula for burn resuscitation.
   d. From an electrical standpoint, he should not require further cardiac monitoring.

6. A 36-year-old man presents to the ED with a complaint of electrical shock while changing an outlet. He states that his screwdriver touched across the contacts, causing a bright flash and a loud noise. He has no apparent burns or trauma, no syncope, and a normal ECG. What is the appropriate management for this patient?
   a. Admit for further cardiac monitoring.
   b. Discharge home with outpatient follow-up, including precautions for the development of paresthesia, pain where he was shocked, muscle spasm, or chest pain.
   c. Order CBC, CMP, creatine kinase, urinalysis, aggressive fluid resuscitation, and burn unit admission.
   d. Order x-rays of the hand holding the screwdriver, and discharge if they are normal.

7. A 32-weeks' pregnant patient presents to the ED after accidentally grasping a clothes dryer cord (240 V) that had exposed wiring. She felt an electric shock, but has no worrisome findings of burns, vascular or compartment syndrome, and has a normal ECG. She is concerned about her fetus. Based on your knowledge of electrical injuries in pregnancy, your next step in the care of this patient and her fetus is:
   a. Discharge home with instructions to follow up with her obstetrician.
   b. Listen for fetal heart tones; if they are normal, the patient can be discharged for follow-up with her obstetrician.
   c. Admit for maternal cardiac monitoring.
   d. Monitor both the patient and fetus.

8. The police arrive with a 24-year-old man who was subdued using an electrical control device (Taser). He is very anxious, complaining of chest pain, and has mydriatic pupils bilaterally. Vital signs are: heart rate, 132 beats/min; blood pressure, 154/90, mm Hg; temperature, 37.4°C; respiration, 26 breaths/min; PaO_2, 99% on room air. His ECG shows only sinus tachycardia. Proper treatment and disposition include:
   a. He can be discharged into police custody.
   b. He should receive a chest x-ray to go along with the ECG; if it is negative, he can be discharged.
   c. He should be evaluated for causes of his chest pain and treated for sympathomimetic toxicity.
   d. He needs a workup for the possibility of burns to deep muscle compartments.

9. **EMS brings in 3 young adults from a local outdoor concert. It is storming outside, and apparently the 3 patients were separated from the crowd, underneath a tree. One is in cardiac arrest, one is dazed and has a fine branching rash on the upper extremities, and one is unconscious but breathing. Regarding the initial care of these patients, which of the following is TRUE?**
    a. Care should be prioritized to the patient who is unconscious but breathing.
    b. The red markings are indicative of deep cutaneous injury.
    c. There is a low likelihood of significant trauma in these patients.
    d. CPR and ACLS are much more likely to be successful in this cardiac arrest patient than in the general population.

10. **You are evaluating a patient who has been struck by lightning. He complains of tinnitus that progresses quickly to deafness. Regarding hearing loss after a lightning strike, which of the following is TRUE?**
    a. Hearing loss is permanent after these injuries because the auditory nerves are permanently damaged.
    b. The tympanic membrane can be ruptured by the force of the lightning strike.
    c. Inner ear structures are not at risk of damage from lightning injuries.
    d. Hearing loss is always immediate.

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Objectives: Upon completion of this article, you should be able to: (1) describe the pathophysiology and epidemiology of electrical and lightning strike injuries, both obvious and occult, (2) determine the severity of injury based on the mechanism of the electric shock and the physical examination, and (3) disposition patients based on the severity of the injury and likelihood of delayed effects.

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