

Electrical Injuries: A Review For The Emergency Clinician

As usual, the emergency department is hopping. Two minutes before change of shift, a trauma patient rolls in—an electrician in his mid-30s brought in by his coworkers. The patient, who was found unconscious near the generator he was repairing, is awake and alert but amnesic, with burns over his chest and both arms. His vital signs are within normal limits. A number of management questions enter your mind, including the need for a cardiac evaluation and hospital admission. As you begin formulating a plan, the nurse tells you that a young woman has arrived after “getting shocked” by her hair dryer, which she was using while standing on a wet bathroom floor. She has no obvious injuries or complaints other than very mild erythema of her right palm. The nurse asks if you want to order an ECG or send any blood tests.

It is unusual to have 2 electrical injuries in a single night. No sooner has this thought crossed your mind than the nurse announces that EMS has brought in 3 campers whose tent was struck by lightning. One camper is in cardiac arrest with ongoing resuscitation for more than 10 minutes, another has blood coming from his ears and complains of difficulty hearing, and the third has pale, mottled, and numb lower extremities. While cursing yourself for having taken a position with single physician coverage, you quickly begin triaging these patients.

Electrical injury is not a common presentation in the emergency department (ED). Nonetheless, every emergency clinician will encounter at least one case during his or her career. Electrical injuries cause 5000 patients to seek emergency treatment each year and are responsible for approximately 1000 deaths annually in the

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CME Objectives

Upon completion of this article, you should be able to:

1. Identify the most serious conditions associated with electrical injury.
2. Recognize which patients require transfer and/or admission.
3. Develop an approach to treating lightning strike victims.
4. Discuss the controversies and need for more research with regard to cardiac monitoring following electrical injuries.

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United States. They also represent 2% to 7% of all admissions to burn units.¹⁻⁴ Patients with electrical injuries represent a special challenge because they encompass a wide spectrum of presentations—from thermal burns to arrhythmias to spinal cord injuries—that the emergency clinician, by definition, must know how to assess and treat.

Half of electrical injuries occur in the workplace^{2,5} and many result in litigation for negligence, product liability, or workers' compensation.⁶⁻⁷ High-voltage injuries have the highest potential for legal consequences as they usually involve young men at the height of their earning capability.^{1,2,4}

Critical Appraisal Of The Literature

Few prospective randomized controlled trials have been conducted on electrical injuries, so clinical practice is based on retrospective reviews and the general burn literature. This issue of *Emergency Medicine Practice* focuses on the challenges of evaluating and managing electrical injuries using the best available evidence from the literature. PubMed® (limits: English human trial, clinical trial, meta-analysis, practice guidelines, randomized controlled trial, and review), MD Consult journals/MEDLINE®, and Ovid MEDLINE® were searched for all literature published from 1966 to 2008 using the terms *emergency AND electrical injury*. The searches provided 120 articles; 65 were reviewed and found to be relevant. Additional resources were identified using reference lists from the reviewed articles. No information was added from searches of the American College of Emergency Physicians® (ACEP) clinical practice guidelines, the National Guideline Clearinghouse™ (www.guideline.gov), or The Cochrane Database of Systematic Reviews.

Many controversies surround the care of electrical injuries, including the role of cardiac monitoring. Practice guidelines developed by Arnoldo et al⁸ and published in the *Journal of Burn Care and Research* in

2006 use Class II and Class III evidence and are most helpful for determining when cardiac monitoring is required. **Table 1** summarizes these guidelines.

Etiology And Pathophysiology

Electricity is the flow of electrons. It can be expressed as voltage (V) and as current (I), which is measured in amperes (A). The obstruction to flow is the resistance (R). According to Ohm's law, $I = V / R$, current is directly proportional to voltage and inversely proportional to resistance. A plumbing analogy is often used: amperage is the volume of water flowing through a pipe; resistance is the diameter of the pipe; and voltage is the difference between the entrance and exit pressures of the pipe. The damage incurred during an electrical injury depends upon the voltage, the resistance of tissues, the amperage (or current strength), the type of circuit (direct or alternating current), the current pathway, and the duration of contact.^{3,9}

The safe range of human exposure to electric currents is narrow because of the small difference between the threshold of perception of current (about 0.2 to 0.4 mA) and the "let-go current" (about 6 to 9 mA for an adult).^{3,10} Amperage that exceeds the let-go current causes tetanic muscle contractions that prevent the release of the electrical source. (See **Table 2**). The let-go current is much more likely to be reached with exposure to alternating current (AC) than direct current (DC). Because the hand is the most common site of contact with a current source and the flexors of the upper extremity are much stronger than the extensors, when the let-go current is exceeded, the arm flexes and pulls the body closer to the source. Thoracic muscle tetany occurs just above the let-go current and causes respiratory distress. This reaction can be provoked by any electrical source, including transcutaneous electrical nerve stimulators, which caused tetanic paralysis of the chest wall and respiratory arrest in one patient.¹¹ Ventricular fibrillation is also estimated to occur at surprisingly low amperages.¹²⁻¹⁵

Table 1. Practice Guidelines For Cardiac Monitoring After Electrical Injuries

Characteristic	Cardiac monitoring NOT required if ALL the following are true	Cardiac monitoring IS required if ANY of the following are true
Electrocardiogram	Normal	Documented arrhythmia or evidence of ischemia
History of loss of consciousness	No	Yes
Type of injury	Low-voltage (≤ 1000 volts)	High-voltage (> 1000 volts)

Table 2. Physiologic Effects Associated With Various Electric Current Strengths^{3,10}

Current Strength (mA)	Physiologic Effect
0.2 - 2	Tingling sensation perceived
3 - 5	Let-go current for a child
6 - 8	Let-go current for an adult woman
7 - 9	Let-go current for an adult man
10 - 20	Tetany (inability to release source)
20 - 50	Respiratory arrest secondary to thoracic muscle tetany
50 - 100	Ventricular fibrillation

Tissues vary in their resistance to electrical flow. Nerves, muscle, and blood vessels have a low resistance and are good conductors of electricity. Tissues that offer greater resistance are more likely to transform electrical energy into heat. For example, bone, tendon, and fat have the highest resistance and tend to heat up and coagulate.³ As a consequence, internal muscle damage from electric current may be much greater than damage to more superficial muscles and soft tissues. Skin offers the primary resistance to electric current and dissipates much of the energy across its surface. Dry skin has intermediate resistance, but this is markedly reduced by moisture. Although each body tissue has a unique level of resistance, together they form a composite resistance.⁷

Because the body's resistance to electric current changes as the tissues break down, the only sure measure of a patient's electrical exposure is the voltage. Electrical injuries are traditionally (and arbitrarily) divided into high-voltage and low-voltage exposures. (See Table 3). A high-voltage exposure is defined as exposure to more than 1000 volts. A further distinction is made between injuries caused by high-voltage current that has direct contact with the body and flash injuries, which are caused by exposure to a high-voltage arc that stretches between the source and the victim.¹⁶ The arc may generate temperatures up to 5000°C (9032°F) and ignite clothing, resulting in secondary thermal burns.¹⁷ Low-voltage exposures include common household circuits in the United States and Canada, which provide 120 volts for general use and 240 volts for high-power appliances.⁵

Table 3. Comparison Of High-Voltage And Low-Voltage Electrical Injuries¹⁷

Characteristic	Low-Voltage Injury	High-Voltage Injury
Voltage, V	≤ 1000 V	> 1000 V
Type of Current	Alternating current	Alternating current or direct current
Duration of Contact	Prolonged	Brief (if direct current)
Cause of Cardiac Arrest	Ventricular fibrillation	Asystole
Cause of Respiratory Arrest	Thoracic muscle tetany	Thoracic muscle tetany or indirect trauma
Muscle contraction	Tetanic	Tetanic (if alternating current); single (if direct current)
Burns	Superficial	Deep
Rhabdomyolysis	Less common	More common
Blunt injury	Does not usually occur	Caused by falls and violent muscle contractions

It is important to distinguish between AC and DC. Most homes and offices use AC, in which electrons flow back and forth through a conductor in a cyclic fashion, standardized at a frequency of 60 cycles per second (60 Hz). Direct current is used in items such as batteries, automobile electrical systems, and high-voltage power lines. Exposure to DC causes a single muscle contraction that throws the victim away from the electrical source, whereas exposure to AC causes tetany that prolongs contact with the source, making it potentially more dangerous.¹⁷

Electrical injuries have 3 clinical presentations: (1) direct trauma from the electric current coursing through the body, (2) trauma from conversion of electrical energy to thermal energy, and (3) mechanical effects of the electric current, including violent muscle contractions and falls.¹⁸ Emergent evaluation of electrical injuries should follow the traditional pathway of primary and secondary surveys, followed by a detailed and specific history and physical examination describing specific injuries by system. Table 4 summarizes multi-system injuries.

Cutaneous Injuries

Burns are the most common injury associated with electrical accidents. Low-voltage injuries tend to create small, well-demarcated contact burns at the sites of skin entry and exit.¹⁶ In high-voltage injuries, the burns are serious and appear as painless, depressed, yellow-gray, charred craters with central necrosis.³ Although electrical burns often appear to be less impressive than flame burns on the surface, appearance cannot be used to predict the severity of injury. High-voltage injuries may largely spare the skin surface but cause massive damage to underlying soft tissue and bone, necessitating escharotomies, fasciotomies, or amputations.¹⁴ Fortunately, this level of damage is rare after low-voltage electrical injuries. In a prospective study by Blackwell et al of 212 low-voltage electrical injuries, only 19 (9%) of the cases involved significant cutaneous injury.¹⁹

The "kissing burn" is sometimes associated with electrical injury. (See Figure 1.) This burn occurs at flexor creases such as the antecubital fossa when a current arcs across both flexor surfaces. It is important to recognize this type of injury because it is often associated with extensive underlying tissue damage.¹⁰

Cardiac

The most serious presentation of electrical injury is cardiac arrest. It has been suggested that ventricular fibrillation is more common with low-voltage AC injuries, whereas asystole is seen more often with DC high-voltage injuries.²⁰ However, little clinical data support this claim. Other initial electrocardiogram (ECG) abnormalities reported in prospective studies include sinus tachycardia, right bundle branch block, first-degree AV block, nonspecific

ST-segment anomalies, QT-segment prolongation, and premature ventricular contractions.^{19,21} Atrial fibrillation has also been documented in several case reports.^{22,23}

The incidence of arrhythmias after electrical injury ranges from 4% to 17%, as evidenced in numerous prospective and retrospective studies.^{1,19,21,24-28} Overall, exposure to low-voltage AC is most likely to cause cardiac consequences as it increases the likelihood of current flow through the heart during the vulnerable relative refractory period. The mechanism behind electrically induced cardiac arrhythmias is not entirely clear but may involve patchy areas of myocardial necrosis that serve as arrhythmogenic foci, as well as increased cardiac sodium-potassium pump activity.¹³ Delayed arrhythmias are rare and tend to occur only in patients with an arrhythmia on presentation, as has been shown in multiple prospective and retrospective trials encompassing both low-voltage and high-voltage injuries.^{19,21,24-27,29,30} Thus it is important to obtain an initial ECG in the ED on all patients with an electrical injury, regardless of the voltage.

Electrical exposure may cause direct myocardial tissue damage via transcardiac passage of the electric current or indirect damage via ischemic injury precipitated by arrhythmia-induced hypotension or coronary artery spasm. Direct myocardial damage is thought to be caused by electric current flowing vertically (head to foot), whereas arrhythmias are more likely to be caused by electric current flowing horizontally (hand to hand).⁹ Myocardial functional abnormalities are demonstrated by echocardiography; this cardiac dysfunction may be either reversible or persistent.³¹ Myocardial infarction due to acute coronary artery occlusion after electrical injury appears to be rare.^{32,33}

Figure 1. Kissing Burn³



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Autonomic dysfunction following electrical injuries can cause serious cardiovascular complications related to the release of catecholamines. This may lead to cardiac arrest, transient hypertension, tachycardia, vasovagal syncope, thermoregulation, and vasoconstriction.³⁴ Patients with a history of vasovagal reactions may be at increased risk of sudden death from cardiac arrhythmia after an electrical injury.³⁵ Autonomic dysfunction has been implicated in keraunoparalysis, a phenomenon seen with lightning injury in which the extremities are temporarily paralyzed.³⁴

Respiratory

Respiratory arrest may immediately follow electric shock as a result of tetanic contraction of the thoracic musculature, injury to the respiratory control center of the central nervous system (CNS), or combined cardiopulmonary arrest secondary to asystole or ventricular fibrillation.⁹ Cardiac function may spontaneously recover because of automaticity; however, if respiratory arrest persists, secondary hypoxia develops. Blunt chest trauma due to falls or being thrown from a high-voltage source may cause pulmonary contusion.¹⁷

Vascular

Electrical injuries cause the greatest damage to the media layer of blood vessels and can lead to delayed aneurysm formation or rupture.^{10,17} Damage to the intima may result in thrombosis and occlusion immediately or over several days.³⁶ Vascular injury following electrical trauma is usually most severe in the small muscle branches where the blood flow is slower; this can create tissue necrosis.³⁷ Any vascular injury can also lead to edema and compartment syndrome.

Neurologic

High-voltage and low-voltage electrical injuries affect both the CNS and peripheral nervous system (PNS). Central nervous system lesions are more common with lightning injury, while PNS lesions are seen more often with electrical injuries. A retrospective review of 90 patients that focused on the neurologic consequences of electrical burns found that 50% of patients with low-voltage injuries and 67% of patients with high-voltage injuries had immediate neurologic symptoms.³⁸ The most common CNS symptom was loss of consciousness. Other neurologic symptoms were acute peripheral neuropathy and transient paralysis or paresthesia. However, a 20-year review by Arnoldo et al¹ involving 700 patients with electrical injuries showed that only 5% had acute neurologic complications, although 25% of patients went on to develop delayed neuropathies. More recently, a study of animal models has cemented a direct link between electrical injury and peripheral nerve damage.³⁹

Spinal cord damage is the most common delayed consequence of electrical injury and may resemble lower motor neuron disease, amyotrophic lateral sclerosis, or transverse myelitis.⁴⁰ The incidence of spinal cord injury following high-voltage electrical trauma ranges from 2% to 27%.⁴¹ This type of injury may occur when an electric current travels from arm to arm or from arm to leg, with the site of onset associated with current entry or exit.^{40,42} In a case series that reviewed high-voltage entry sites in the head and neck, an exit site in the lower extremities led to paraplegia, whereas an exit site in the upper extremities led to quadriplegia.⁴² Electrical injury has been proposed as a risk factor for amyotrophic lateral sclerosis; however, a recent systematic review of the literature that identified 31 articles found no support for a causal relationship.⁴³ Nevertheless, these reviews clearly support a syndrome of nonprogressive spinal cord damage after severe electrical injury. Partial or even complete recovery may occur, but delayed neurologic symptoms have an overall poor prognosis.

Musculoskeletal

Direct electrothermal energy leading to coagulation necrosis is the main cause of muscle injury and usually occurs only after high-voltage exposures. The damaged muscle may become edematous and necrotic, resulting in rhabdomyolysis or compartment syndrome. As bone has the highest degree of resistance, severe electrothermal bone damage such as periosteal burns and osteonecrosis is seen. Falls secondary to electrical injury and forceful tetanic muscle contractions create fractures and joint dislocations. In a well-designed retrospective study spanning 20 years and 700 patients, Arnoldo et al¹ reported 22 cases of fractures and 68 cases of muscle necrosis following high-voltage electrical exposure.

Renal

The kidneys are susceptible to ischemia after severe electrical injury. Muscle injury resulting in myoglobin release may also cause renal tubular damage and subsequent renal failure.

Other

Cataracts develop in up to 6% of patients with high-voltage injuries and in many patients after lightning injury.⁴⁴ Cataracts may occur immediately but more often develop months after the injury.⁴⁵

Hearing loss is a well-known sequela of lightning injury and may also occur after electrical injury.⁴⁶ Mechanisms include rupture of the eardrum by acoustic trauma, flow of electric current through the cochlea, and hemorrhage. Patients with injury to the eighth cranial nerve may also suffer from chronic tinnitus and imbalance problems. Damage to the middle or inner ear may result in infectious com-

plications including mastoiditis, sinus thrombosis, meningitis, and brain abscess.⁴⁷

Victims of electrical injury often experience a wide range of neuropsychological issues including depression, cognitive dysfunction, attention problems, anxiety, and chronic pain disorders such as complex regional pain syndrome (CRPS) that may be challenging to diagnose.^{48,49}

Differential Diagnosis

A history of electrical exposure makes the diagnosis. However, for a person found unconscious with unwitnessed cardiac arrest, it is appropriate to keep electrical and lightning injuries in the differential if the environmental setting or weather conditions warrant.

Prehospital Care

The primary goal during prehospital management of patients with electrical injuries is to secure the scene. The underlying theory presumes that if the victim is still in contact with the electrical source, he or she (or even the ground if it is wet) can become a conductor and electrocute the rescuer, although no published reports describe this. Before approaching the victim, medical personnel should ensure that the power source has been turned off. In high-voltage incidents, it is best to involve the local electric company. Once the scene is safe, prehospital rescuers should focus on aggressive and persistent cardiopulmonary resuscitation (CPR), even if the victim appears to be dead.⁵¹ Electrical injury victims are typically young and healthy, so CPR has a higher chance of success.⁵² When effective high-quality CPR begins immediately, patients experience a quicker resumption of spontaneous circulation and have better outcomes.^{52,53} If

Table 4. Summary Of Multi-system Presentations Of Electrical Injuries⁵⁰

System	Presentation
Skin	Cutaneous burns
Cardiac	Arrhythmias, cardiac arrest
Respiratory	Respiratory arrest due to muscle tetany or central nervous system causes
Vascular	Aneurysm formation, tissue ischemia
Neurologic	Loss of consciousness, transient paralysis or paresthesia, peripheral neuropathy, spinal cord injury
Musculoskeletal	Fractures or dislocations secondary to muscle spasm or falls, muscle necrosis, compartment syndrome
Renal	Myoglobinuria leading to renal failure
Other	Cataracts, neuropsychological effects

defibrillation or cardioversion is necessary, energy levels recommended by standard Advanced Cardiac Life Support (ACLS) protocols should be used (ie, no adjustment should be made because of the history of electrocution).⁵⁴

Prehospital management of electrical injuries includes routine care—the patient's cervical spine is immobilized with a cervical collar and backboard, any fractures are splinted, and burns are covered with clean, dry dressings. At least one large-bore intravenous line should be established, and a fluid bolus of 10 to 20 cc/kg of normal saline or Lactated Ringer's Solution should be given to any patients with cutaneous burns or hypotension. The fluid requirements of patients with electrical injuries are generally much greater than those of patients with thermal burns. (See the Treatment section.)

Transport to the closest appropriate facility should begin after basic treatments are complete. Patients who have experienced a significant burn injury should ideally be transported or transferred to a burn center, and patients who have encountered a high-voltage injury should be taken to a trauma center.

Emergency Department Evaluation

All electrical injuries should be evaluated and managed as multisystem injuries. Initial stabilization of patients with electrical injury should follow basic ACLS and Advanced Trauma Life Support® (ATLS) algorithms. A difficult airway evaluation is particularly important, as airway injury can progress rapidly in at-risk patients such as those with burns involving the face, mouth, or neck. Aggressive fluid resuscitation to maintain perfusion as measured by adequate urine output (1.0-1.5 cc/kg per hour) should be initiated. If heme pigment from rhabdomyolysis is present in the urine, urine output must be constantly monitored. Electrical injuries are similar to crush injuries, so formulas for fluid resuscitation based on percentage of body surface area burned are not applicable. It is critical to immediately remove any constricting objects such as rings because edema may develop quickly.

Nevertheless, some patients with low-voltage electrical injuries will be well-appearing with minimal signs of injury. These patients do not need to be rushed to the nearest ED or approached as a trauma patient. Common sense and the general appearance of the patient will go a long way in recognizing this subset of electrical injury victims.

All patients, whether exposed to low voltage or high voltage, should have an ECG done on presentation to evaluate for arrhythmias.⁸

History

Patients may not be able to provide a good history because of the severity of their injuries, loss of

consciousness, or confusion. Bystanders and pre-hospital providers are a good resource regarding the electrical source, the voltage, the duration of contact, environmental factors at the scene, and resuscitative measures already provided.³ Special attention should be paid to the electrical source; an injury that initially appears to have resulted from a low-voltage source (eg, a household appliance) may be due to a high-voltage source (eg, a capacitor that is contacted during repair of a television or microwave oven).¹⁰ Medical history (especially cardiac problems), medications, allergies, and tetanus immunization status should also be obtained.

Physical Examination

After a basic survey, a thorough but focused physical examination should be performed, with the size and location of any burns and the condition of the patient's extremities noted. Small, well-demarcated entry and exit wounds are often seen with low-voltage electrical injuries whereas depressed, necrotic-appearing burns are more commonly observed in high-voltage injuries. An assessment of vision and hearing should include fundoscopic and otoscopic examination. During the otoscopic examination, clinicians should look for tympanic membrane rupture, as this may be the only clue of lightning injury in a patient brought from the field.⁵⁵ The full range of motion of all joints should be tested to assess for fractures and dislocations. Serial neurovascular checks on all extremities are also necessary because vascular damage and delayed compartment syndrome may become apparent at any time.^{3,7}

Diagnostic Studies

Electrocardiogram

In guidelines that are based on an extensive review of the literature, Arnoldo et al⁸ recommend that all patients receive an initial ECG to assess for cardiac injury and arrhythmias. (See Table 1, page 2.) The issue of additional cardiac monitoring is discussed in the Controversies/Cutting Edge section.

Laboratory Tests

Table 5 lists the laboratory tests that should be performed in patients at risk for a conductive electrical injury (ie, patients with entry and exit wounds or cardiac arrhythmia) or in patients presenting with injuries beyond minor cutaneous burns.

Serial creatine kinase (CK) levels should also be drawn in patients with high-voltage injuries, as peak CK levels predict muscle injury, risk of amputation, mortality, and length of hospital stay.^{56,57} However, great caution should be used when interpreting cardiac markers in the setting of electrical injury. Creatine kinase myocardial isoenzyme (CK-MB) lev-

els correlate poorly with myocardial damage.^{56,58-60} McBride et al found that among 36 victims of high-voltage electrical injury, 50% had abnormal CK-MB levels, but only 2 patients sustained myocardial infarctions according to history, ECG findings, and clinical course.⁶⁰ Troponin levels in electrical injuries have not been studied.

Radiology

Victims of electrical injury should be approached as trauma patients. A head computed tomography (CT) scan to evaluate for intracranial abnormalities may be indicated in patients with electrical injury associated with a fall, persistent altered level of consciousness, or abnormal findings on neurologic examination. Plain films and/or CT scans of the spine should be ordered if a spinal injury is clinically suspected. Plain radiographs should be obtained in any area where the patient has pain, an obvious deformity, or decreased range of motion. There is a low threshold for obtaining plain films of the shoulders and pelvis, especially if these areas were in the path of the electric current, as there have been reports of delayed diagnoses of shoulder dislocations and femoral neck fractures.^{47,61}

Late evaluation of tissue perfusion and occult muscle damage prior to surgical exploration can be done with technetium-99 pyrophosphate scintigraphy.^{62,63} Magnetic resonance imaging with gadolinium can be a helpful adjunct to technetium-99 pyrophosphate scanning to better localize areas of muscle necrosis.^{62,64} Although there is not enough data to recommend routine use of these imaging modalities, they can be discussed with the trauma surgeon on a case-by-case basis.

Table 5. Laboratory Tests Recommended For Patients With Electrical Injuries

Test	Rationale/Indication
CBC	All patients with injuries beyond minor cutaneous burns
Electrolytes	All patients with injuries beyond minor cutaneous burns
BUN and creatinine	All patients with injuries beyond minor cutaneous burns
Urinalysis	To evaluate for myoglobinuria (positive for blood but no red blood cells)
Serum myoglobin	If urinalysis is positive for myoglobinuria
Liver function tests/ amylase/lipase	If intra-abdominal injury is suspected
Coagulation profile	If intra-abdominal injury is suspected or if surgical course is projected
Blood type and screen/crossmatch	If surgical course is projected

Treatment

Cutaneous Injuries

Depending on transfer agreements with the local burn center, burns should be cleaned and then covered with sterile dressings. If the burns are treated locally, antibiotic dressings, such as mafenide acetate or sulfadiazine silver should be used to cover the wounds. Although scant evidence supports specific uses, mafenide acetate is preferred for localized full-thickness burns because it has better penetration, whereas sulfadiazine silver is preferred for extensive burns because it is less likely to cause electrolyte abnormalities.¹⁰ Tetanus immunization status should be determined and patients vaccinated as needed. Tetanus can occur in elderly patients who have not had regular boosters and immigrants who have never received a primary immunization series. Clostridial myositis is a reported complication of electrical injuries,⁶⁵ but no evidence supports the use of prophylactic antibiotics.

Management Of Injury To The Extremities

The upper extremities are frequently injured in electrical trauma and can be a source of morbidity and functional loss. A conundrum exists with such injuries: If fasciotomy and surgical exploration are not performed, deep muscle necrosis may be missed; but if they are performed unnecessarily, the patient may require multiple surgeries and have a protracted hospital and rehabilitation course. No prospective randomized controlled trials have assessed the role of immediate surgical exploration, but recent practice guidelines recommend a conservative approach, with the authors concluding that surgical decompression (ie, fasciotomy and assessment of muscle compartments) should only be performed if the patient develops progressive neurologic dysfunction, vascular compromise, increased compartment pressure, or systemic clinical deterioration due to suspected ongoing myonecrosis.^{8,65-74} No literature has been published on the management of the lower extremities, but it seems reasonable to follow the same guidelines.

When electrothermal burns affect an upper extremity, the limb should be splinted with the wrist at 35° to 45° of extension, the metacarpophalangeal joint at 80° to 90° of flexion, and nearly full extension of the proximal and distal interphalangeal joints (Z position) to minimize the space available for edema formation.¹⁰ The extremity should be kept elevated above the level of the heart to reduce edema. Frequent neurovascular checks of all extremities are crucial because compartment syndrome may become evident at any time.

Early orthopedic intervention in patients with an electrical injury and major fractures is also important. Fracture stabilization can be safely done

using internal fixation in the first 24 to 48 hours after a thermal burn.⁷⁵ Early fracture reduction allows for ideal stabilization, better wound care, and earlier patient mobility.

Myoglobinuria

Myoglobinuria is a common and concerning finding in patients with electrical injuries because it places them at risk for renal failure. Fluid resuscitation should be directed at maintaining a urine output of 1.0 to 1.5 cc/kg per hour until the urine is clear of myoglobin. Acute myoglobinuric renal failure with life-threatening consequences can occur if fluid resuscitation is delayed.⁷⁶ Some authors advocate the use of sodium bicarbonate (1 ampule or 50 meq added to each liter of fluid) to alkalinize the urine and mannitol (25 g every 6 hours) or furosemide to supplement diuresis.^{1,47,77,78} No evidence supports these practices, and they are mentioned here for completeness only.

Viscera

Although it is uncommon, electrical injuries may cause injury to the abdominal organs. In a review of 226 patients with either high-voltage or low-voltage electrical injuries treated at a single burn center, 4 patients (0.4%) suffered from visceral injuries.⁷⁹ All 4 patients sustained high-voltage electrical injuries involving the abdomen. The colon is the most commonly injured visceral organ, though there are case reports of injury to the small intestine,⁸⁰ gallbladder,^{81,82} and pancreas.⁸³ It may take 2 to 3 days post burn for the true level of visceral involvement to become clear.⁸⁴

Special Circumstances

Lightning Injuries

Lightning strikes cause more deaths per year on average than any other storm condition except for flash floods and river floods combined.⁸⁵ The National Oceanic and Atmospheric Administration documented 9818 injuries and 3239 deaths due to lightning during a 36-year period in the United States, an overall mortality rate of 32%.⁸⁵ Certain weather conditions, namely graupel (a type of frozen precipitation that resembles snow pellets or soft hail),⁸⁶ indicate that lightning strikes are likely.

Lightning behaves as an instantaneous, massive, unidirectional current. It is initially transmitted internally and then flashes over the body. Its voltage may exceed 1 million volts, but it dissipates within milliseconds. Because of the brief duration, lightning strikes rarely cause significant burns or soft tissue destruction, but they are more likely to result in cardiac and respiratory arrest, neurologic sequelae, and autonomic instability. Lightning depolarizes the entire myocardium and produces asystole rather

than ventricular fibrillation. The heart's intrinsic automaticity may restore cardiac activity but concomitant respiratory arrest due to thoracic muscle spasm or central respiratory depression may produce hypoxia-induced ventricular fibrillation. Virtually everyone who is struck by lightning will survive if they do not experience cardiac or respiratory arrest. Thus, when multiple victims are present, triage should be reversed; the highest priority should be given to patients who are in cardiac or respiratory arrest or who appear to be dead.⁵¹ Unlike patients with electrical injuries who may still be in contact with the electrical source, people who have been struck by lightning do not remain "charged" in any way and can be approached immediately.⁸⁷ Dilated, unreactive pupils are not an accurate indicator of death because of possible ocular injuries and/or autonomic instability following a lightning injury.

If a lightning strike occurs near a patient's head, it may enter the eyes, ears, or mouth. Tympanic membrane rupture frequently occurs in these patients and usually resolves without serious consequences. Permanent deafness can occur secondary to disruption of the ossicles. Ocular injuries such as corneal lesions, macular holes, vitreous hemorrhage, retinal detachment, and cataracts may occur after lightning injury.⁸⁸⁻⁹⁰ Bilateral cataract formation is common, though it may not develop for months or even years after the initial injury.⁹⁰

Four main types of superficial burns are seen in lightning strikes: linear, punctate, feathering, and thermal. Linear burns occur where sweat or water have accumulated (eg, in the axilla or running down the chest). Punctate burns resemble multiple small cigarette burns and often appear in a rosette pattern. "Tip-toe signs"—characteristic small, circular, full-thickness punctuate burns involving the sides of the feet and the tips of the toes—were seen in half of a group of 17 patients during a single lightning strike.⁹¹ Feathering burns, also called Lichtenberg figures, are pathognomonic for lightning injury. (See Figure 2.) They usually appear within one hour of the lightning strike and fade within a few days. Feathering burns are not true burns and do not require any treatment. Thermal burns may occur if the patient's clothing catches fire or if the patient is wearing any metal objects that heat up and cause a direct burn.³

Cardiac arrest is the primary cause of mortality in lightning injury; neurologic complications are the principal cause of morbidity. Lightning-related neurologic sequelae fall into 4 categories: immediate and transient symptoms, immediate and persistent symptoms, delayed symptoms, and traumatic lesions secondary to falls.^{92,93}

Immediate and transient neurologic symptoms include loss of consciousness, confusion, anterograde amnesia, weakness, and paresthesia. Although these symptoms are purportedly very common, sup-

porting data from retrospective reviews are sparse. In a retrospective review of 22 lightning strike victims in Turkey, only 5 complained of confusion and amnesia, though loss of consciousness was not measured.⁹⁴ Keraunoparalysis is a transient neurologic paralysis that is pathognomonic for lightning injury. Keraunoparalysis is characterized by lower and occasionally upper extremities that are numb, blue, mottled, cold, and pulseless. Thought to be caused by transient vasospasm and autonomic nervous system dysfunction, keraunoparalysis usually resolves on its own within a few hours.⁹⁵

Immediate and persistent neurologic syndromes associated with lightning injury include hypoxic encephalopathy and intracranial hemorrhage. The usual locations of intracranial hemorrhage in lightning injury are the basal ganglia and brainstem.⁹⁶⁻⁹⁹ Cerebral infarction is a rare but possible complication.¹⁰⁰⁻¹⁰¹ Delayed neurologic sequelae include motor neuron disease and movement disorders, although it is difficult to establish a clear association with lightning strikes. Traumatic falls associated with a lightning strike may result in spinal cord injury and epidural and subdural hematomas. Additionally, lightning injury survivors may experience persistent behavioral and neuropsychological effects such as memory and attention deficits, posttraumatic stress disorder (PTSD), depression, and chronic fatigue. In one case series involving patients with lightning injuries seen in a neurology clinic, neuropsychological testing revealed mild impairments in memory, attention, and visual reaction times in all 6 patients studied.¹⁰² Two of the patients were also diagnosed with depression, and one showed convincing evidence of PTSD. This study was obviously limited by its small size and selection bias, but it does point out some interesting findings.

Figure 2. Feathering Burn



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Once cardiopulmonary arrest, spinal cord injury, intracranial injury, or other blunt injury have been excluded, the management of lightning victims should be supportive and symptomatic. Lightning injury is distinct from high-voltage electrical injury, and it should be treated as such to avoid iatrogenic morbidity and mortality.⁸⁷ Because lightning strike patients rarely sustain burns or soft tissue injuries, they generally do not require fluid resuscitation or surgical decompression of their extremities.

Electrical Injuries In Children

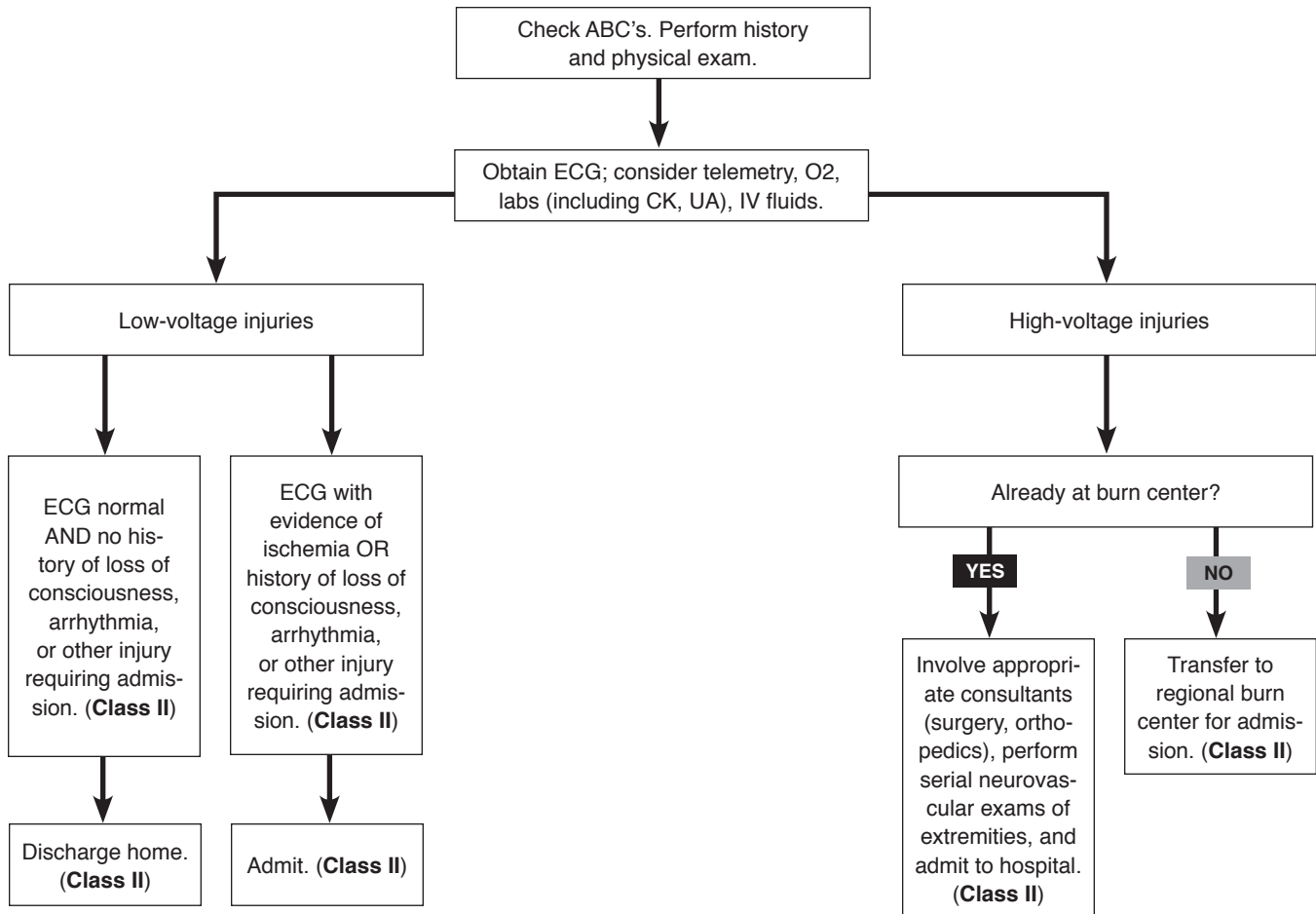
Most electrical injuries in young children occur in the home and are usually associated with electrical cords (60-70% of cases) and wall outlets (10-15% of cases).¹⁰³ The most common injury seen in young children is an oral arc burn, caused when the end of a live extension cord is put in the mouth or when the cord is bitten. These oral burns can be devastating and can result in injury to the commissure of the lip, the tongue, or the floor of the mouth. Electrical burns to the tongue and mouth can bleed significantly and put these patients at risk for aspiration. Swelling of the tongue and floor of the mouth may be extensive and can lead to airway obstruction. Hospital admission for airway observation or intervention and parenteral support is often required in cases of severe electrical burns to the orofacial region.¹⁰⁴

Because of the risk to developing dentition and the possibility of a poor cosmetic outcome, patients with orofacial electrical injuries require surgical and dental consultation for oral splinting (ie, at the lip commissure), postburn debridement, and possible reconstructive surgery.^{3,26} Severe bleeding from the labial artery occurs in about 5% to 10% of patients with oral burns when the eschar separates up to 2 weeks after the initial electrical injury.^{28,104} Educating parents on how to control bleeding from the labial artery is crucial for outpatient management of these injuries.

In general, children experience many of the same injuries as adults following electrical trauma. The anatomical and physiologic characteristics of children, such as thinner skin, make them more susceptible to severe injuries, especially in the extremities.⁵⁰ Surgical consultation should be obtained early with regard to the need for debridement and fasciotomy.

Chen and Sareen¹⁰³ attempted to determine if cardiac monitoring is necessary in children by performing a systematic review encompassing 7 retrospective studies, each involving a minimum of 35 patients. They concluded that otherwise healthy children who are exposed to common household electric current (low-voltage, no water contact) and who are asymptomatic in the ED and have no evidence of arrhythmia or cardiac arrest in the field

Clinical Pathway For Managing Electrical Injuries



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
- Non-randomized or retrospective studies: historic, cohort, or case control studies
- Less robust RCTs
- 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

Significantly modified from: The Emergency Cardiovascular Care Committees of the American Heart Association and repres-

tatives from the resuscitation councils of ILCOR: How to Develop Evidence-Based Guidelines for Emergency Cardiac Care: Quality of Evidence and Classes of Recommendations; also: Anonymous. Guidelines for cardiopulmonary resuscitation and emergency cardiac care. Emergency Cardiac Care Committee and Subcommittees, American Heart Association. Part IX. Ensuring effectiveness of community-wide emergency cardiac care. *JAMA*. 1992;268(16):2289-2295.

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.

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may be safely discharged without an initial ECG or any inpatient cardiac monitoring. Although the literature on high-voltage pediatric electrical injuries is more limited, some authors recommend admitting patients with these injuries for cardiac monitoring.²⁸

Electrical Injuries In Pregnant Women

The management of the pregnant woman after an electrical injury should focus on protecting the well-being of both mother and fetus. The obstetrical team should be consulted as soon as possible, and fetal heart monitoring should be initiated for any patient beyond 20 weeks' gestation. Fetal monitoring and tocodynamometry are indicated in electrical injuries that involve any mechanical trauma because of the potential for placental abruption.¹⁰⁵ Ultrasonography to assess fetal viability may also be prudent, especially if the patient experiences decreased fetal movement, vaginal bleeding, fluid leakage, or abdominal pain. Close obstetrical follow-up is mandatory if the patient is discharged. Burns have adverse effects on a pregnancy because they increase spontaneous uterine activity and affect circulation to the uteroplacental unit secondary to volume shifts; thus, aggressive care is needed in these cases.¹⁰⁶

Scant literature is available on fetal outcome in pregnant women who have been exposed to electrical injury. There are numerous case reports of fetal demise following electrical trauma, with a cumulative fatality rate of around 73%.¹⁰⁷ Complications have included spontaneous abortion, intrauterine growth retardation, oligohydramnios, and sudden cessation of fetal movement. A recent prospective cohort study compared 31 pregnant women exposed to an electric shock (mostly low-voltage) between 4 and 36 weeks' gestation with a matched control group. Of the 31 exposed women, 28 gave birth to healthy infants, 1 had a child with a ventricular septal defect, and 2 had spontaneous abortions. In the control group, 30 healthy babies were born, and there was 1 spontaneous abortion. The authors concluded that most cases of electrical injury do not pose a major risk to the fetus, although it must be noted that patients in their study had a much lower rate of transuterine current than did patients in previous case studies.¹⁰⁸

Taser®

With increased use of conducted electrical weapons (ie, Tasers®) by law enforcement agents and by civilians seeking personal protection, emergency clinicians can expect to see more patients in the ED with Taser® injuries. Tasers® use compressed nitrogen to fire 2 metallic darts up to 35 feet and transmit an electrical impulse through up to 2 inches of clothing. The Taser® causes involuntary contractions of the regional skeletal muscles and makes it impossible for the target to move voluntarily. The peak volt-

age across the target's body is approximately 1200 V (delivered in rapid pulses over 5 seconds), and the average current is approximately 2.1 mA.¹⁰⁹ The electric shock delivered by the Taser® is neither pure AC nor pure DC and is probably similar to rapid, low-amplitude DC shocks.¹¹⁰

After reports of deaths in police custody following Taser® use, concern has been raised regarding its safety.¹¹¹ However, a recent small prospective study by Ho et al¹⁰⁹ found no evidence of Taser®-induced cardiac arrhythmias, ECG changes, or electrolyte abnormalities. Additionally, a prospective series involving 218 patients shot with the original Taser® in the early 1980s described 3 deaths secondary to cardiac arrest; however, all 3 of these patients had high levels of phencyclidine (PCP) in their blood, and this was cited as the cause of death.¹¹² The authors concluded that the death rate in their series was no higher than that reported for PCP toxicity alone. Although data regarding the effects of the Taser® are limited, it appears most healthy subjects may be safely discharged from the ED after dart removal and evaluation for any other injuries. Although some authors recommend an ECG in patients who have been shot with the Taser®, no current evidence supports this practice.¹¹⁰

Controversies/Cutting Edge

Cardiac Monitoring After Electrical Injury

Electrical injuries can cause cardiac arrest, cardiac arrhythmias, and even direct myocardial damage. However, it is not always clear which patients need to be admitted to the hospital for cardiac monitoring and for what duration. Traditionally, patients with low-voltage electrical exposure who have a normal ECG on presentation and no history of loss of consciousness or arrhythmia have been discharged home without cardiac monitoring.¹⁹ This practice is supported in the guidelines recommended by Arnoldo et al.⁸ (See Table 1, page 2.) Application of the guidelines to the pediatric population is also safe.^{24-26,103,113} In fact, Chen and Sareen concluded that some low-risk children do not even require an initial ECG.¹⁰³

The literature on cardiac monitoring in high-voltage electrical injury is especially sparse. Bailey et al²¹ recently published a multicenter prospective study involving 134 patients who had at least one of the following risk factors prompting the use of cardiac monitoring: transthoracic current, tetany, loss of consciousness, or a high-voltage injury (> 1000 volts). None of the patients in this study developed late potentially lethal arrhythmias. Most of the patients had transthoracic current and/or tetany as a risk factor, leading the authors to conclude that these patients could be safely discharged from the ED if their initial ECG results were normal. For the few patients with

high-voltage electrical injuries, the authors suggested that cardiac monitoring be continued until adequate evidence supports a recommendation. Most patients with high-voltage electrical trauma have sufficient injuries to require admission anyway.

No published studies have directly evaluated the optimal duration of cardiac monitoring after electrical injury. Currently, this decision is left to the clinician. In several studies, the reported monitoring time was 24 hours after admission if the initial ECG was normal or 24 hours after resolution of any arrhythmias.^{25,28,114}

Disposition

According to the American Burn Association's burn center referral criteria, patients with injuries due to electrical burns, including lightning injury, should

be referred to a burn center.⁷⁷ No qualifiers are included with this recommendation, so decisions about which patients truly require transfer are left to the emergency clinician's discretion. Patients with extensive electrical burns will likely require multiple surgeries and extensive occupational and physical rehabilitation and are best served at a burn center. Patients who have abnormal neurologic findings suggestive of spinal cord injury or CNS dysfunction or who have extensive visceral or vascular injury require admission to the intensive care unit or to an area with a similar level of care for frequent monitoring and rapid intervention. Additionally, all patients with a history of loss of consciousness, documented arrhythmias either before or after arrival to the ED (including cardiac arrest), ECG evidence of ischemia, or who have a sustained a high-voltage electrical injury should be admitted for additional monitoring.⁸

Risk Management Pitfalls For Electrical Injuries (Continued on page 13)

1. **"Results from the patient's eye examination were normal when he presented to the ED after a lightning injury last month. I don't know why he's back now weeks later complaining of decreased vision."**

Cataracts is a common sequela of lightning injury and can also be seen after electrical injury. Cataracts may affect one or both eyes. They may be present at the time of injury but often don't develop until weeks to months after the initial insult. All patients presenting after electrical or lightning injury should be warned of this possible complication, and ophthalmology follow-up should be arranged as needed.

2. **"I used the Parkland burn formula to estimate the patient's fluid resuscitation needs. I don't understand why he is still hypotensive and his urine output is poor."**

Electrical injuries are different from purely thermal burns. They are closer to crush injuries because there may be extensive soft tissue and muscular injury that is not obvious from the surface. Because cutaneous burns from electrical injuries do not represent the full extent of injury, formulas for fluid resuscitation based on percentage of body surface area burned are not applicable. Fluid resuscitation should maintain a urine output of 1.0 to 1.5 cc/kg per hour.

3. **"The patient's shoulder appeared normal on examination and an anteroposterior (AP) radiograph looked fine to me. I don't know how I missed a posterior dislocation."**

Shoulder dislocation can occur after electrical injury secondary to tetanic muscle contractions or from falls. Posterior dislocations are difficult to diagnose because the external appearance of the shoulder and an AP radiograph view may be deceptively normal. Key signs to look for on examination are an arm fixed in internal rotation, pain on abduction, and pain on external rotation. An axillary or transscapular view is often needed to make the diagnosis radiographically.

4. **"I saw this patient in the ED 3 months ago with a minor electrical injury to her hand. I don't know why she's back now complaining of diffuse pain, swelling, and coolness of her entire forearm."**

Complex regional pain syndrome (CRPS), formally called reflex sympathetic dystrophy, is a recognized delayed complication of electrical injuries. Patients with CRPS often present months after their initial injury. CRPS is a clinical diagnosis, and symptoms include diffuse pain (often involving a much larger area than the original injury), swelling, decreased range of motion, and temperature or skin color differences. This chronic condition requires long-term care involving multiple specialists.

5. **"This patient who was struck by lightning was slightly confused on arrival to the ED and couldn't remember what had happened to him. I thought this was true of almost all people struck by lightning and was nothing to be too concerned about."**

Patients with low-voltage electrical injury who are asymptomatic or have only mild cutaneous burns, normal ECG results, and no history of loss of consciousness may be safely discharged home. It is important to give these patients clear instructions for follow-up and information about which symptoms should lead them to seek medical treatment. For example, patients with electrical injuries should immediately return to the ED if they develop chest pain, palpitations, lightheadedness, loss of consciousness, signs or symptoms of wound infection (fever, worsening erythema, purulent discharge), or cold, mottled, or painful extremities. They should also be alert for the delayed development of cataracts, neurologic symptoms (weakness, paresthesia, CRPS), and neuropsychological effects (memory and attention problems, depression).

Summary

Although electrical injuries are uncommon, all emergency physicians will face them at some point. The management of electrical injuries is challenging because patients present with a broad spectrum of complaints and injuries. Patients with electrical injuries can have complex multitrauma and multiorgan issues, and early care is crucial for a good outcome. Emergency clinicians should remember these important points: (1) ECG for all patients and cardiac monitoring when indicated, (2) fluid resuscitation to prevent hypovolemia and renal failure, and (3) frequent neurovascular checks for signs of compartment syndrome in any involved extremities.

Risk Management Pitfalls For Electrical Injuries (Continued from page 12)

Patients with lightning injuries often sustain loss of consciousness, memory loss, or confusion associated with event. However, these patients are also at high risk for traumatic brain injury secondary to falls or blunt trauma associated with the lightning injury. Any patient whose mental status does not rapidly improve or who has external evidence of head injury should undergo a head CT scan in the ED.

6. **"I did a neurovascular exam on this patient's arm when he arrived in the ED 4 hours ago. I don't understand why he has compartment pressures of 50 mm Hg now."**
Compartment syndrome may develop at any time in patients with electrical injuries. It is essential to continue frequent neurovascular checks on these patients and to involve surgical consultants early on.
7. **"The patient was awake and alert when he came in, talking up a storm. The burns on his face didn't seem to bother him at all. I don't understand how he ended up with a crash airway."**
Similar to patients with thermal burns, patients with electrical injuries and burns involving the face, mouth, or neck should be evaluated for a difficult airway. These patients may have unseen swelling or injury as a result of their exposure and may rapidly lose their airway. Establishment of an early definitive airway is imperative when this concern exists.
8. **"When that lightning strike patient came in**

with pulseless, blue legs I thought he must have thrown a clot. I thought I was doing the right thing when I started him on a heparin infusion. Now he has a head bleed and needs neurosurgical intervention."

Keraunoparalysis is pathognomonic for lightning injury. It is a form of temporary paralysis where the extremities are numb, blue, cold, and pulseless. It usually resolves on its own within a few hours and does not require any specific treatment.

9. **"I have read a lot about electrical injuries, and I know how important fluid resuscitation is. I tried fluid resuscitation for my patient with a lightning strike injury, and he ended up with flash pulmonary edema."**
Lightning injuries are distinct from electrical injuries and should be managed as such. Myoglobinuria is rare after lightning injury, and patients with lightning injuries generally do not require aggressive fluid resuscitation. Management of lightning injuries is largely supportive.
10. **"I took care of this 3-year-old girl 2 weeks ago when she presented with an oral arc burn. She was healing well. I don't understand why she is back now with severe bleeding."**
Oral arc burns are very common in children who bite into electric cords. In 5% to 10% of cases, there may be severe bleeding from the labial artery when the eschar separates, which can occur up to 2 weeks after the initial burn. Parents should be preemptively instructed on how to control such bleeding.

Case Conclusion

The electrician who came in after being found unconscious near a generator remained confused throughout his ED stay. You made sure he had a C-collar in place and ordered head and C-spine CT scans. You also obtained an initial ECG and continued telemetry. After sending off labs, including a CK and myoglobin level, you began IV fluids for a goal urine output of 1.0 to 1.5 cc/kg per hour. A surgical consultant evaluated the patient's upper extremities, and you conducted frequent neurovascular checks. Once the patient was stabilized, you transferred him to the regional burn center. When you followed up on the patient's course, you learned that he underwent fasciotomy of his right upper extremity for compartment syndrome that developed 12 hours after his initial injury.

The young lady shocked by her hair dryer remained relatively asymptomatic, complaining only of mild pain from the superficial burns on her right palm. The results of her initial ECG were normal. You applied a clean, dry dressing to her palm, gave her a tetanus vaccination, and discharged her home with instructions to follow up with her primary doctor in the next few days. You also instructed her to return to the ED if she develops chest pain, palpitations, lightheadedness, or loss of consciousness.

The minute the 3 patients struck by lightning rolled in, you ran to assist the patient in cardiac arrest. You called for additional help and began CPR following ACLS protocols. A definitive airway was placed, but the patient remained pulseless and asystolic. You continued

CPR and held off on treating the other 2 patients until this critical patient was stabilized. You were certain these patients would survive even if they had to wait longer to be evaluated. After several cycles of CPR and epinephrine and atropine, the first patient regained normal sinus rhythm. You cheered silently and then moved on to the secondary survey.

Note

Full-color versions of the figures in this article are available at no charge to subscribers at www.ebmedicine.net/topics.

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, will be included in bold type following the reference, where available. In addition, the most informative references cited in this paper, as determined by the authors, will be noted by an asterisk (*) next to the number of the reference.

Cost-Effective Strategies

1. **Admit patients solely for cardiac monitoring only if they have sustained a high-voltage injury or have a history of loss of consciousness, cardiac arrhythmia either before or during their presentation to the ED, or ECG evidence of ischemia.**

Risk Management Caveat: Be sure that all patients sent home without cardiac monitoring follow up with their primary doctors and that they have received explicit instructions to seek medical attention if they develop any cardiac symptoms.

2. **Electrical burns, similar to thermal burns, may be complicated by infection. While the tetanus vaccine is often given to patients with electrical injuries, there is no evidence to support the use of prophylactic antibiotics for systemic effect.**

Risk Management Caveat: Electrical burn patients should be monitored closely for signs and symptoms of infection such as fever, worsening erythema around the burn site, or purulent

discharge from the wound, and treated with antibiotics as needed.

3. **According to the American Burn Association recommendations, all patients with electrical injuries should be transferred to a burn center.⁷⁷ This recommendation does not differentiate between low-voltage and high-voltage injuries or between severity of injuries. Obviously, there will be some electrical trauma victims whose injuries are so minor that they can be adequately treated at the local ED. It is left to the discretion of the emergency clinician to determine which electrical injury patients truly require transfer.**

Risk Management Caveat: Patients with high-voltage electrical injuries or evidence of severe or extensive electrothermal burns and patients requiring consultations with specialists should be transferred to a regional burn center as soon as possible.

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1. **Which tissue has the highest resistance?**
 - a. Skin
 - b. Nerve
 - c. Bone
 - d. Muscle
2. **Which statement regarding high-voltage injuries is NOT true?**
 - a. High-voltage injuries involve more than 1000 volts.
 - b. High-voltage injuries rarely cause deep burns.
 - c. High-voltage injuries require transfer to a regional burn center.
 - d. High-voltage injuries require admission for cardiac monitoring.
3. **Which is a rare consequence of electrical injury?**
 - a. Acute myocardial infarction
 - b. Cardiac arrest
 - c. Compartment syndrome
 - d. Spinal cord injury
4. **What is the main treatment for myoglobinuria?**
 - a. Sodium bicarbonate to alkalinize the urine
 - b. Furosemide to improve diuresis
 - c. Mannitol to increase urine output
 - d. IV fluid to maintain urine output of 1.0 to 1.5 cc/kg per hour
5. **Which is more commonly associated with electrical injury than with lightning injury?**
 - a. Cardiac arrest
 - b. Neurologic symptoms
 - c. Cataracts
 - d. Significant burns or soft tissue injury
6. **Which patient may be safely discharged home from the ED?**
 - a. A young man who sustained a high-voltage injury and has deep burns to his upper extremities.
 - b. A middle-aged female presenting after a low-voltage injury who is asymptomatic and has a normal ECG.
 - c. A young woman presenting after a low-voltage injury who had a transient arrhythmia on arrival to the ED.
 - d. A middle-aged man who sustained a low-voltage injury and who is asymptomatic but has new ST segment changes on ECG.
7. **Which is NOT an indication for surgical decompression of an upper extremity electrical injury?**
 - a. Progressive neurologic dysfunction
 - b. Increased compartment pressure
 - c. Joint dislocation
 - d. Vascular compromise
8. **Which statement regarding conducted electrical weapons (ie, Tasers®) is true?**
 - a. They are known to cause cardiac arrhythmias.
 - b. They cause involuntary contractions of regional skeletal muscles leading to immobilization of the victim.
 - c. They utilize only DC currents.
 - d. Patients with a Taser® injury should always be admitted for cardiac telemetry.
9. **Which statement describes why AC is considered more dangerous than DC?**
 - a. AC causes tetanic muscle contractions that prolong contact with the electrical source.
 - b. AC has a higher voltage.
 - c. AC causes more traumatic injuries secondary to falls.
 - d. AC is more likely to result in associated thermal burns.
10. **What is the top priority in providing prehospital care to patients with electrical injuries?**
 - a. Initiating CPR as quickly as possible in patients with cardiac arrest.
 - b. Transporting patients as rapidly as possible to a regional burn center.
 - c. Placing C-collars on patients to stabilize any possible cervical spine injuries.
 - d. Ensuring that the electrical source has been turned off and that it is safe for rescuers to approach the victim.
11. **Which diagnostic tool has NOT been shown to be helpful in managing adult patients with electrical injuries?**
 - a. ECG
 - b. Basic laboratory tests including complete blood cell count, electrolytes, serum urea nitrogen/creatinine, and urinalysis.
 - c. Troponin
 - d. Creatine kinase
12. **Which is NOT a standard treatment for cutaneous electrothermal injuries?**
 - a. Clean dry dressings placed in the field
 - b. Prophylactic systemic antibiotics to protect against clostridial myositis
 - c. Antibiotic dressings such as mafenide acetate or sulfadiazine silver
 - d. Tetanus vaccination

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Our Editorial Board developed *EM Practice Guidelines Update* with you in mind, so we welcome your feedback. Please email JagodaMD@ebmedicine.net with your comments and suggestions.

May 2009 Errata

In the May 2009 issue of *Emergency Medicine Practice*, "Complications in Pregnancy Part II: Hypertensive Disorders of Pregnancy and Vaginal Bleeding," there are two errors.

1. On page 9 (right column, first paragraph), the sentence incorrectly reads: "A contained acute hemorrhage will appear **hyperechoic**..." The corrected sentence reads: "A contained acute hemorrhage will appear **hypoechoic**..."
2. In Table 9, the side effects for nitroprusside and nitroglycerine are reversed. The side effect of nitroprusside is "cyanide production." The side effects for nitroglycerine are "headache, tachycardia, methemoglobinemia, increased intracranial pressure."

We regret the errors and apologize for any confusion.

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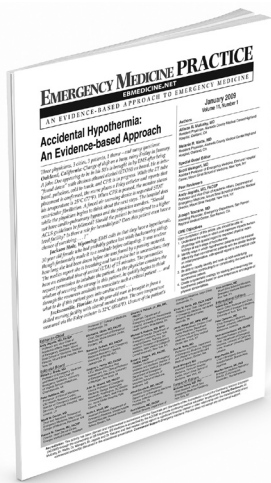
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EVIDENCE-BASED PRACTICE RECOMMENDATIONS

Electrical Injuries: A Review For The Emergency Clinician

Czuczman AD, Zane RD. October 2009; Volume 11, Number 10

This issue of Emergency Medicine Practice focuses on the challenges of evaluating and managing electrical injuries, using the best available evidence from the literature. For a more detailed discussion of this topic, including figures and tables, clinical pathways, and other considerations not noted here, please see the complete issue at www.ebmedicine.net/topics.

Key Points	Comments
Survey the scene carefully and make sure the electrical source has been shut off before approaching any victims of electrical injury.	Although no published reports describe this, the underlying theory presumes that if the victim is still in contact with the electrical source, he or she (or even the ground if it is wet) can become a conductor and electrocute the rescuer.
Always start with the ABCs, and follow basic Advanced Cardiac Life Support and Advanced Trauma Life Support algorithms.	Take note of any electrothermal burns involving the face, mouth, or neck, as they may make obtaining a secure airway more difficult. Also look for tympanic membrane rupture during the otoscopic examination, as this may be the only clue of lightning injury in a patient brought from the field. ⁵⁵
Obtain an initial ECG for all adult patients. ⁸	An ECG should be obtained for both low-voltage and high-voltage injuries.
Use cardiac monitoring for patients with arrhythmia or evidence of ischemia on electrocardiogram, loss of consciousness, and high-voltage (> 1000 volts) injuries. ^{8,19,21,103}	This recommendation is based on the practice guidelines developed by Arnoldo et al and published in the Journal of Burn Care and Research in 2006 using Class II and Class III evidence. ⁸
Watch out for rhabdomyolysis in electrical injury patients, especially those with a high-voltage injury.	If heme pigment from rhabdomyolysis is present in the urine, urine output must be constantly monitored.
Do not use any formula for IV fluid resuscitation that is based on percentage of body surface area burned. These formulas are not applicable in electrical injuries because there may be significant underlying musculoskeletal injury.	Fluid resuscitation should maintain a urine output of 1.0 to 1.5 cc/kg per hour. ⁷⁶
Involve consultants early on and consider transfer to a regional burn center for any patients with significant electrothermal burns. ⁷⁷	Patients with extensive electrical burns will likely require multiple surgeries and occupational and physical rehabilitation and are best served at a burn center. Patients who have abnormal neurologic findings suggestive of spinal cord injury, CNS dysfunction, or extensive visceral or vascular injury require admission to ICU or an area with a similar level of care for frequent monitoring and rapid intervention. All patients with a history of loss of consciousness, documented arrhythmias (including cardiac arrest) before or after arrival to the ED, ECG evidence of ischemia, or who have a sustained a high-voltage electrical injury should be admitted for additional monitoring. ⁸
Immediately remove any constricting objects such as rings because edema may develop quickly.	Vascular injuries can also lead to edema and/or compartment syndrome. Vascular injury following electrical trauma is usually most severe in the small muscle branches where the blood flow is slower; this can create tissue necrosis. ³⁷

See reverse side for reference citations.

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These references are excerpted from the original manuscript. For additional references and information on this topic, see the full text article at ebmedicine.net.

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