adolescents who engage in risky behavior. The third group comprises adults who work with electricity. Electrical burns account for between 3% and 7% of admissions to burn centers in the United States each year, many of which are occupational injuries. The annual occupational death rate from electrocution is 1 per 100,000; this type of death occurs more frequently in utility workers, miners, and construction workers.

### PATHOPHYSIOLOGY

Definitions that should be familiar to those caring for patients with electrical injuries are listed in Box 132.1. Electrical current is the movement of electrical charge from one location to another. Current strength is expressed in amperes. Materials that allow electrical current to flow easily (low resistance) are referred to as conductors. Materials that do not allow flow of electrical current are called insulators.

All body tissues conduct electricity to some extent. Tissues with high fluid content conduct better than those with lower fluid content. Nerves tend to offer the least resistance, whereas bones offer the most. Table 132.1 lists body tissues according to level of resistance. Skin resistance can vary substantially, with wet skin having the lowest resistance. Factors determining the severity of the injury caused by the electrical current are listed in Box 132.2.

Any electrical charge greater than 1000 V is generally considered high voltage, although some authorities have argued that the risk for significant injury increases with charges exceeding 600 V. Typical household circuits in the United States are 110 V, with bigger appliances operating on 220-V circuits. Power lines in residential areas can have more than 7000 V.

Electricity causes injury in several ways, as listed in Box 132.3. As current passes through the body, the tissues through which it passes are heated, and significant damage can occur. The emergency physician (EP) must be aware of the potential for internal damage when caring for a victim of electrical injury; not all patients with significant internal injuries display significant external damage. Arc burns result from an electrical source through the air and can cause thermal injuries. Temperatures can reach 2500°C, which can ignite clothes or nearby material and cause thermal injuries. Flash burns occur when current strikes the body but does not penetrate the skin.

### EPIDEMIOLOGY

A strike of lightning is one of the most common environmental causes of sudden cardiac death and is responsible for between 50 and 300 deaths annually in the United States.\(^1\)\(^2\) Cloud-to-ground lightning strikes, the most destructive form of lightning, occur approximately 30 million times each year,\(^3\) most often in Florida and along the southeastern coast of the Gulf of Mexico.\(^4\) Lightning has struck more than 10 miles away from the rain of a thunderstorm, so the danger may not always be obvious or apparent.\(^5\) Electrical injuries can be equally devastating. The spectrum of injuries from both can range dramatically from minor, localized injuries to death.

Although lightning injury may be one of the most common injuries caused by natural phenomena, its incidence has not been tracked accurately. The incidence is higher in males and in people between 20 and 44 years of age, three of every four occurred in the South or Midwest, and one in four was work related.\(^6\) Sport-, wilderness-, and travel-related activities also place people at higher risk for lightning injuries.

Electrical injuries tend to occur in patients in three distinct age groups. The first group is toddlers who encounter household electrical sockets, cords, and appliances. The second is
Lightning delivers high-voltage direct current that tends to flow over the body rather than enter it. This event, often referred to as flashover, is one explanation for how people are able to sometimes survive exposure to such high voltage. Lightning current can also enter the victim and cause significant damage, particularly to the cardiac, respiratory, and neurologic systems. Blunt injury has been reported in up to one third of lightning victims as a result of both the direct force of the strike and rapid expansion of the surrounding air, which often causes the victim to fall or be struck by flying debris. Lightning can also cause thermal injury (burns) by hot steam produced from surrounding moisture or by metal objects heated by the electricity. Box 132.4 lists the mechanisms of injury from lightning strikes.

ANATOMY

Cardiac arrest is the primary cause of immediate death after both electrical and lightning injuries. Electrical injuries can result in virtually any type of dysrhythmia, although rhythm disturbances are unlikely if the exposure is to less than 120 V and water is not involved. Lighting also causes a variety of cardiac rhythm disturbances. Acute myocardial infarction is uncommon with both electrical and lightning injuries. Other cardiac sequelae of lightning injuries have been described and include cardiogenic shock and Takotsubo cardiomyopathy.

The head is a common point of contact for high-voltage injuries, and skull and cervical spine injuries occur as a result of blunt trauma from lightning and electrical injuries. Eye and ear injuries can both occur with electrical or lightning injuries, although they are more commonly associated with lightning.

Kidney damage or even acute renal failure can develop as a result of myoglobinemia, although this condition often responds well to fluid resuscitation. Gastrointestinal tract dysfunction, including bleeding and ulcer formation, has been described as well.
VICTIMS OF HIGH-VOLTAGE ELECTRICAL INJURY TYPICALLY HAVE SIGNIFICANT BURNS WITH A VERY DRAMATIC APPEARANCE. VICTIMS OF LOW-VOLTAGE ELECTRICAL INJURY OR LIGHTNING INJURY MAY APPEAR QUITE WELL. THE MOST SEVERE INJURIES ARE GENERALLY THOSE AFFECTING THE CARDIOVASCULAR AND NEUROLOGIC SYSTEMS, AND CARDIAC ARREST IS THE MOST COMMON CAUSE OF IMMEDIATE DEATH AND IS GENERALLY MANIFESTED AS ASYSTOLE (DIRECT CURRENT) OR VENTRICULAR FIBRILLATION (ALTERNATING CURRENT).

OTHER THAN CARDIAC ARREST, THE MOST SIGNIFICANT OBVIOUS INJURIES CAUSED BY EXPOSURE TO ELECTRICITY ARE USUALLY BURNS, WHICH ARE FREQUENTLY MOST SEVERE AT THE SOURCE OF THE ELECTRICITY, AS WELL AS AT THE EXIT POINT, WHICH IS COMMONLY A GROUND CONTACT POINT (USUALLY THE HEEL). THE EP SHOULD ASSUME SIGNIFICANT UNDERLYING DAMAGE IN ALL patients WITH ELECTRICAL OR LIGHTNING INJURIES. LIGHTNING CONTACT IS GENERALLY INSTANTANEOUS AND LEADS TO FLASHOVER BURNS THAT ARE MORE OFTEN SUPERFICIAL AND MINOR. EXTENSIVE BURNS AND DEEPER INJURY ARE MORE COMMON WITH HIGH-VOLTAGE ELECTRICAL INJURIES, FREQUENTLY BECAUSE OF MORE PROLONGED CONTACT.

THE NEUROLOGIC EFFECTS OF ELECTRICAL AND LIGHTNING INJURIES CAN BE IMMEDIATE (WHICH ARE OFTEN TRANSIENT) OR DELAYED (WHICH LAST FOR A LONGER PERIOD AND ARE MORE LIKELY TO BE PROGRESSIVE). THE PROGNOSIS IS USUALLY BETTER FOR PATIENTS WITH MORE IMMEDIATE SYMPTOMS THAN FOR THOSE WITH DELAYED MANIFESTATIONS. INITIAL FINDINGS INCLUDE ALTERED MENTAL STATUS, WHICH IS FREQUENTLY TRANSIENT BUT CAN RANGE FROM SLIGHTLY AGITATED TO COMATOSE. AS CURRENT PASSES THROUGH THE SKULL, HEAT-INDUCED COAGULATION CAN OCCUR AND RESULT IN SUBDURAL AND EPIDURAL HEMATOMAS, AS WELL AS INTRAVENTRICULAR HEMORRHAGE. WEAKNESS AND PARESTHESIAS OF THE EXTREMITIES ALSO OCCUR AND ARE MORE COMMON IN THE LOWER THAN THE UPPER EXTREMITIES. SEIZURES HAVE LIKELY BEEN DESCRIBED.

UP TO TWO THIRDS OF VICTIMS OF LIGHTNING STRIKES EXPERIENCE KERAOUPHARALYSIS, A TEMPORARY PARALYSIS SPECIFIC TO LIGHTNING INJURIES THAT IS CHARACTERIZED BY BLUE, MOTTLED, AND PULSELESS EXTREMITIES (LOWER MORE COMMON THAN UPPER). PERMANENT PARESTHESIAS CAN RESULT BUT ARE UNUSUAL.

BLOOD IS A GOOD CONDUCTOR OF ELECTRICITY, AND VASCULAR DAMAGE FROM ELECTRICAL AND LIGHTNING INJURIES HAS BEEN WELL DESCRIBED. THROMBOSIS, HEMORRHAGE, AND ISCHEMIA CAN OCCUR AS A RESULT OF DIRECT DAMAGE TO VESSEL WALLS, VASOSPASM, OR BURNS. SMALL ARTERIES TO MUSCLE ARE AT Particular Risk.

SKIN FINDINGS INCLUDE FEATHERING BURNS, FLASH BURNS, CONTACT BURNS, PUNCTATE BURNS, BLISTERING, AND LINEAR STREAKING. A SPECIFIC TYPE OF BURN ASSOCIATED WITH ELECTRICAL INJURY IS REFERRED TO AS A “KISSING BURN,” WHICH OCCURS AT THE FLEXOR CREASES OF THE KNEES, ELBOWS, AND AXILLA. KISSING BURNS INDICATE EXTENSIVE UNDERLYING DAMAGE, SO EPS MUST BE SURE TO LOOK AT THE FLEXOR SURFACES FOR LIGHTNING OR ELECTRICAL INJURY WHEN EVALUATING PATIENTS WHO ARE VICTIMS.

CONTACT WITH ELECTRICAL CURRENT TENDS TO PRODUCE BURNS THAT RESULT IN DISCOLORED (OFTEN GRAY OR YELLOW), PAINLESS, DEPRESSED, PUNCTATE AREAS OF THE SKIN. IT IS IMPORTANT TO RECOGNIZE THAT TISSUE DAMAGE UNDER THESE BURNS CAN BE MASSIVE.

FEATHERING BURNS (ALSO KNOWN AS LICHTENBERG FIGURES) ARE SPECIFIC TO LIGHTNING INJURIES AND RESULT FROM ELECTRONS SHOWERING INDUCED BY THE LIGHTNING THAT MAKE A FERN PATTERN ON THE SKIN. NO PERMANENT DAMAGE TO THE SKIN OCCURS, AND NO SPECIFIC THERAPY IS REQUIRED. PUNCTATE BURNS ARE FULL-THICKNESS BURNS THAT LOOK LIKE MULTIPLE SMALL BURNS FROM A CIGARETTE. DEEP BURNS ARE RARE WITH LIGHTNING INJURIES.

ORAL BURNS IN CHILDREN OFTEN REPRESENT ELECTRICAL INJURY FROM CHEWING OR SUCKING ON ELECTRICAL WIRES. THESE INJURIES ARE PARTICULARLY WORRISOME BECAUSE OF THE POSSIBILITY OF DELAYED BLEEDING, WHICH CAN BE MASSIVE FROM THE LABIAL ARTERY WHEN THE ESCHAR SEPARATES, SOMETIMES 5 DAYS OR MORE AFTER THE INJURY.

HIGH-VOLTAGE ELECTRICAL INJURIES AND LIGHTNING INJURIES CAN BOTH RESULT IN DAMAGE TO THE EYES AND EARS. ELECTRICAL INJURY IS MORE LIKELY TO INJURE THE EYE IF THE EXPOSURE INVOLVES THE HEAD OR NECK, AND SUCH INJURIES INCLUDE CORNEAL BURNS, RETINAL DETACHMENT, AND INTRAOCULAR HEMORRHAGE. DELAYED CATARACT FORMATION HAS BEEN DESCRIBED IN UP TO 6% OF PATIENTS. LIGHTNING INJURIES CAN ALSO CAUSE UVEITIS, IRIDOCYCLITIS, MYOPIA, ANISOCORIA, OR HORNER SYNDROME. IT IS FOR THIS REASON THAT FIXED, DILATED PUPILS ARE NOT A RELIABLE INDICATOR OF BRAIN DEATH IN LIGHTNING STRIKE VICTIMS. DAMAGE TO THE EAR IS COMMON WITH LIGHTNING INJURIES; RUPTURE OF THE TYMpanic MEMBRANE IS THE MOST COMMON FINDING, AND THE SYMPTOMS ARE GENERALLY TRANSIENT HEARING LOSS AND VERTIGO.

BLUNT TRAUMA IS COMMON IN THE SETTING OF ELECTRICAL AND LIGHTNING INJURIES, EITHER FROM BEING THROWN BACK FROM THE SOURCE OR FROM INCIDENTS RESULTING FROM THE EXPOSURE, SUCH AS FALLS. LONG-BONE FRACTURES, DISLOCATIONS, AND SOLID INTERNAL ORGAN INJURY HAVE BEEN ASSOCIATED WITH BOTH ELECTRICAL AND LIGHTNING INJURIES.

DIFFERENTIAL DIAGNOSIS AND MEDICAL DECISION MAKING

ELECTRICAL INJURIES ARE GENERALLY MORE OBVIOUS THAN LIGHTNING INJURIES. WITH THE EXCEPTION OF BATHTUB ELECTRICAL INJURIES, WHERE BURNS MAY NOT BE APPARENT, A GOOD HISTORY AND THOROUGH PHYSICAL EXAMINATION USUALLY REVEAL THE CAUSE OF THE ELECTRICAL INJURIES, IDEALLY INCLUDING THE TYPE OF CURRENT, VOLTAGE, DURATION OF CONTACT, AND SYMPTOMS IMMEDIATELY AFTER THE ATTACK. LIGHTNING INJURIES ARE NOT ALWAYS AS EVIDENT (LIGHTNING CAN STRIKE WHEN NO RAIN OR SNOW IS PRESENT AND EVEN ON MOSTLY SUNNY DAYS) AND MAY BE MANIFESTED AS CARDIAC ARREST, ALTERED MENTAL STATUS, OR PARALYSIS. RECOGNITION OF CLASSIC PATTERNS OF LIGHTNING INJURY, SUCH AS FEATHERING, MAY BE THE ONLY WAY TO INITIALLY DISTINGUISH THESE INJURIES FROM OTHER CAUSES OF CARDIAC ARREST, ALTERED MENTATION, OR ACUTE NEUROLOGIC INJURY. DIFFERENTIAL DIAGNOSES IN WHICH A HISTORY OF LIGHTNING INJURY OR HIGH-VOLTAGE ELECTRICAL INJURY IS NOT OBVIOUS ARE LISTED IN BOX 132.5.

**FACTS AND FORMULAS**

**Ohm’s Law:**

\[ V = I \times R \]

where \( V \) = potential (in volts); \( I \) = current (in amperes); \( R \) = resistance (in ohms)

\[ P = I^2 R t \]

where \( P \) = heat (in joules); \( I \) = current (in amperes); \( R \) = resistance (in ohms); \( t \) = time (in seconds)
Lightning and Electrical Injuries

Injury

DIAGNOSTIC TESTING

Cardiac monitoring and electrocardiography are indicated for all but the most benign electrical injuries and for virtually all lightning injuries. QT prolongation is a common finding. Complete blood counts are usually recommended, but their results should be normal. Abnormalities are more likely to be found when checking electrolyte, blood urea nitrogen, and creatinine values. Urinalysis should be performed to look for evidence of myoglobinuria, the presence of which indicates rhabdomyolysis. The serum creatine kinase value may also point to rhabdomyolysis. Acute myocardial infarction is rare with either lightning or electrical injuries. Computed tomography of the head should be performed in anyone with altered mental status or a significant headache given the risk for intracranial bleeding from either direct contact (particularly lightning) or the resulting head trauma. Cervical spine films should be obtained for patients with altered mental status or significant cranial injuries, including burns. A pregnancy test should be performed on all women of childbearing age.

TREATMENT

Prehospital providers must be particularly vigilant about scene safety. With electrical injuries involving a discrete electrical source other than intact electrical outlets, the power must be turned off before the victim is approached. Any provider at the scene of a lightning injury must remember that lightning can strike in the same place twice. In addition, both electrical injuries and lightning injuries should be considered to pose a high risk for concomitant blunt trauma, and spinal immobilization should be initiated unless clearly not indicated.

Lightning injuries are an exception to the general rule that in mass casualty and disaster situations, people in cardiac arrest should be categorized or tagged as “black” (expectant or dead) and receive the lowest priority for treatment on the scene. Unlike the situation in most other mass casualty situations, cardiac arrest in the setting of lighting or electrical injury may be quickly reversed with defibrillation. Triage for multiple victims of lightning injuries at one scene should concentrate on those in cardiorespiratory arrest, and immediate treatment of those who are breathing can be reasonably delayed when necessary. Regardless of whether there are multiple casualties, victims of lightning injuries who are in cardiac arrest should be aggressively resuscitated whenever possible because evidence suggests that success rates are higher than in patients in cardiac arrest from other causes, even when the interval before resuscitation is prolonged.

Rhabdomyolysis can be treated effectively by aggressive fluid administration, with the goal of urine output greater than 1 mL/kg/hr. Formulas used to determine fluid resuscitation in burn victims cannot be used for electrical injuries. Fluid resuscitation in patients with lightning-related injuries does
not have to be very aggressive unless they are hemodynamically compromised. Fluid overload is a common iatrogenic complication in patients with lightning injuries.

Fasciotomy must be considered in patients with extremity burns from high-voltage electrical injuries in which compartment syndrome is a concern. Circumferential burns are more likely to result in compartment syndrome.

Tetanus boosters should be administered to patients whose immunization status is not up to date and even to those whose immunization status is current if they have significant muscle damage or contamination of the wounds because electrical wounds are especially prone to tetanus.

**FOLLOW-UP, NEXT STEPS IN CARE, AND PATIENT EDUCATION**

Asymptomatic patients with normal physical findings who were victims of low-voltage electrical injury can be discharged safely without significant evaluation or observation. Patients with low-voltage injuries for whom risks are higher include those whose skin was wet during the injury, those with tetany, and those in whom the current traversed the thorax. Patients with mild symptoms, normal electrocardiographic findings, and no evidence of myoglobinuria can be discharged after a period of observation (generally 4 to 6 hours, although no research has confirmed this interval) and with recommendation for outpatient follow-up.

Any patient who experienced cardiac or respiratory arrest or clear loss of consciousness or has abnormal or changed electrocardiographic findings, hypoxia, chest pain, dysrhythmia observed by a medical care provider, or serious concomitant injury should be admitted.

**DOCUMENTATION**

A large percentage of electrical injuries involve legal claims of some sort (e.g., worker’s compensation, manufacturers), so the medical record should be complete with particular emphasis on the available history, physical findings, and treatment rendered. The record should include the following:

- Whether loss of consciousness was involved
- Voltage of the exposure if known
- Initial symptoms
- Skin findings
- Electrocardiographic findings
- Condition and symptoms at discharge

**SUGGESTED READINGS**


**REFERENCES**

References can be found on Expert Consult @ www.expertconsult.com.
CHAPTER 132
LIGHTNING AND ELECTRICAL INJURIES

REFERENCES