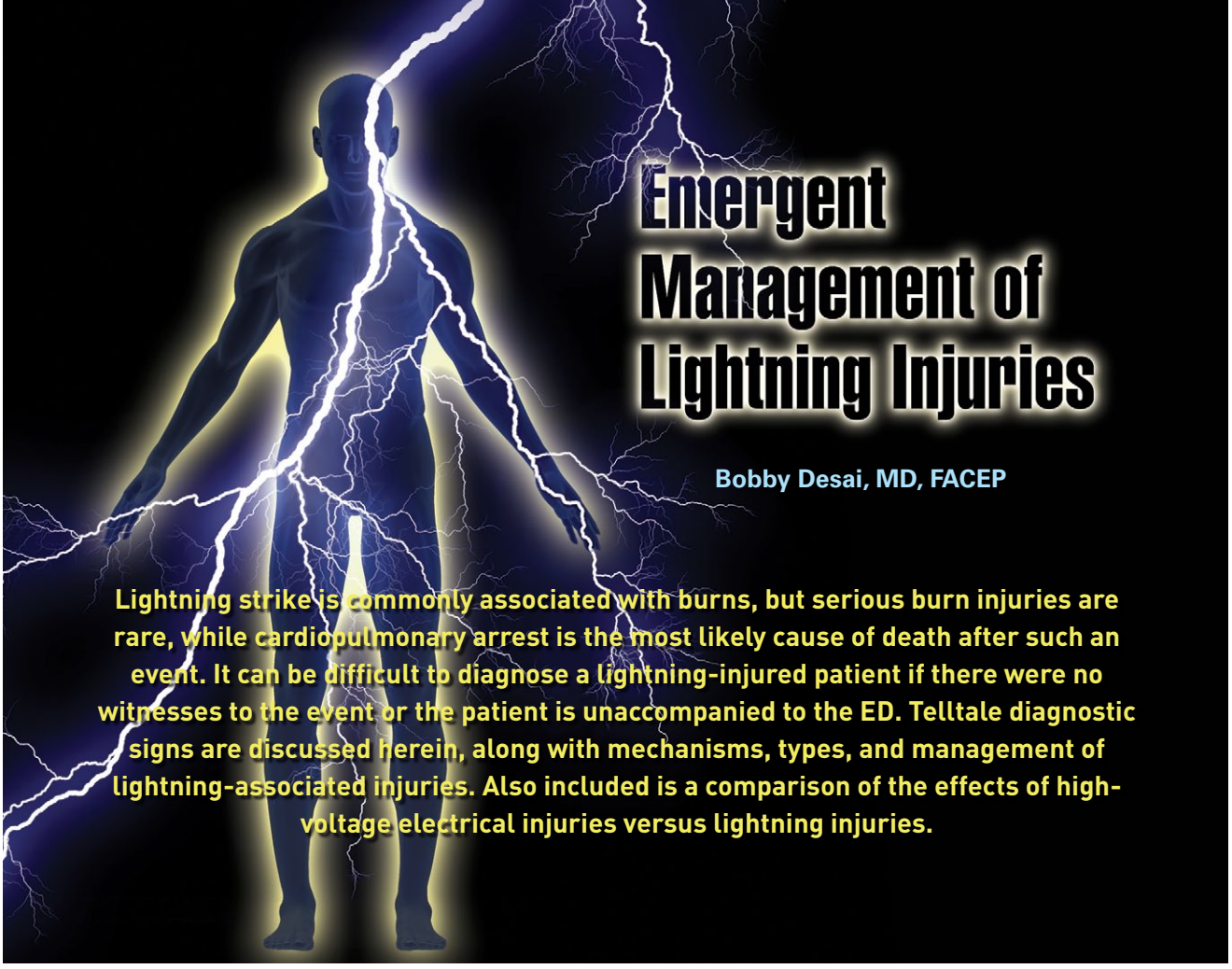

Emergent Management of Lightning Injuries

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Lightning strike is commonly associated with burns, but serious burn injuries are rare, while cardiopulmonary arrest is the most likely cause of death after such an event. It can be difficult to diagnose a lightning-injured patient if there were no witnesses to the event or the patient is unaccompanied to the ED. Telltale diagnostic signs are discussed herein, along with mechanisms, types, and management of lightning-associated injuries. Also included is a comparison of the effects of high-voltage electrical injuries versus lightning injuries.

Lightning causes an estimated 50 to 300 deaths per year and approximately five times as many nonlethal injuries[1,2]; however, injuries and deaths due to lightning are believed to be underreported. This may be due to several factors, including a lack of witnesses to the event and attributing a patient's symptoms to another etiology.

Lightning can occur in different forms, with streak lightning being the most common.[3] Most frequently, lightning is negatively charged; positively charged lightning is more powerful because of its stronger electrical field, and it may be associated with a different injury profile.[4] This may be due in part to the fact that it lasts 10 times longer and can originate several miles away from a storm. Burns and blunt trauma secondary to a splash mechanism may be more likely in victims of positively charged lightning, since this form of lightning can originate "out of the blue." Lightning generates intense heat around it, rapidly heating the air to 20,000°C, which is three times the temperature of the surface of the sun. This rapid heating generates a supersonic shock wave that decays to an acoustic wave heard as thunder.[5]

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MECHANISMS OF INJURY

Lightning produces injury and death by multiple mechanisms.[6] These include its electrical effect, the effect of the heat produced by the lightning, and the physical force of the lightning striking the ground or the individual. A direct strike injury is damage caused when the lightning bolt directly hits a victim. A splash mechanism indirectly injures a victim when the lightning hits another object, such as a tree, and splashes onto the victim.[7] Contact injury occurs when a victim is directly in contact with an object that has been struck by lightning. The concussive force of the lightning strike can lead to significant blunt trauma and specific lightning-related injuries, including tympanic membrane rupture. The victim can be thrown a great distance as well, which itself can cause significant trauma.[8]

Table. Patterns in High-Voltage Electrical Injury vs Lightning Injury

	High-Voltage Electrical Injury	Lightning Injury
Mechanism of injury	Direct contact	Multiple mechanisms
Voltage	Hundreds to thousands	Millions
Contact time	Can be prolonged	Immediate, brief
Cardiopulmonary effects	Ventricular fibrillation, asystole	Respiratory, cardiac arrest
Nervous system injuries	Paresthesias	CNS, PNS injuries; autonomic dysfunction
Entrance, exit wounds	Common	Rare
Secondary trauma	Less common	Common
Eye injuries	Less common	Common
Tympanic membrane rupture	Unusual	Common
Myoglobinuria/hemoglobinuria	Very Common	Rare
Skin	Fasciotomy commonly required	Fasciotomy rarely required

CNS = central nervous system; PNS = peripheral nervous system.

The Table compares features of high-voltage electrical injury versus those of lightning injury. Lightning should be considered in terms of its current, not its voltage. By its very nature, lightning is unidirectional and flows for a short time only, which is in contrast to alternating and direct current.[9] Because of this, lightning typically causes asystole rather than ventricular fibrillation. However, due to the intrinsic automaticity of the heart, the victim of a lightning strike is unlikely to die since cardiac activity will resume spontaneously. Furthermore, when first examined, the patient may be in cardiac arrest with ventricular fibrillation. Survival depends entirely on the length of time from the initial injury, as successful resuscitation may not be achieved if the victim has had prolonged myocardial ischemia. Even if a cardiac rhythm is reestablished from intrinsic cardiac automaticity, the concurrent "short-circuiting" of the respiratory electrical center can cause respiratory arrest, exacerbating the situation.[10,11] Due to the short duration of exposure, lightning strikes (unlike high-voltage electricity) do not cause significant burns or muscle breakdown leading to rhabdomyolysis and subsequent renal failure. However, burns—especially those of lesser severity—are common and are discussed in further detail on page 11.

INJURY CLASSIFICATION

Injuries from lightning strikes can be arbitrarily classified as minor, moderate, or severe.[12] Minor injuries include headache, transient amnesia, transient neurologic dysfunction, and tympanic membrane rupture. Permanent injuries may also be sequelae of the strike.

Moderately injured patients can present to the ED in lethargic, stuporous, and comatose states. They frequently have neurologic manifestations, including extremity paralysis and seizures, and may also have cardiovascular manifestations of the strike, including sympathetic instability and asystole with spontaneous return of a perfusing rhythm. Almost all patients with moderate injuries have tympanic membrane rupture. They must also be evaluated for signs of blunt trauma due to possible concussive damage from the lightning strike. Most patients with moderate injuries recover within hours. However, some patients demonstrate long-term sequelae, including neuropathies and sympathetic nervous system disorders. In addition, most victims of lightning strikes have evidence of first- or second-degree burns.

On arrival to the ED, patients with severe injuries are usually in extremis due to cardiorespiratory arrest, which can lead to anoxic brain injury. Prognosis is poor.[12]

EFFECTS ON ORGANS AND SYSTEMS

Nervous System

Injury to the central nervous system is caused by electrical current passing through the brain. This can cause significant damage to neuronal structures, leading to necrosis of brain tissue and formation of hematomas. Trauma resulting from the lightning strike's concussive force can cause multiple other injuries, including skull fractures, scalp hematomas, and tears within the dura. Respiratory arrest and subsequent cardiac arrest can result from neuronal injury within the brain stem. Seizures are also seen in lightning strike victims, as are signs of "short-circuiting" of neurons, eg, paresis, hemiplegia, ataxia, and cranial nerve palsies.[13,14]

FAST TRACK

Anterograde amnesia and confusion occur in nearly all victims of lightning strikes, with variable symptom duration.

Anterograde amnesia and confusion occur in nearly all victims of lightning strikes, with variable symptom duration (sometimes lasting for days).[15] Furthermore, victims often report severe, unremitting headaches that can last for months after the event. These patients may present with findings similar to those of a postconcussive syndrome, including nausea, dizziness or frank vertigo, and tinnitus along with the headache. These symptoms can be mistaken for a migraine-type headache, with the exception that the headache induced by lightning strike typically is generalized in nature.

The peripheral nervous system can also be severely affected in victims of a lightning strike, with pain and paresthesias as the most pronounced features. These symptoms typically are most noticeable in the extremities through which the current passed and do not necessarily manifest immediately after the injury. Among patients who have been severely injured by lightning, approximately two-thirds demonstrate lower extremity paralysis and one-third have upper extremity paralysis.[10] Due to sympathetic instability and vascular spasm, the skin of the affected extremities appears mottled, and these extremities also lack sensation and evidence of a pulse. These signs and symptoms usually resolve within several hours.[3,9] However, some patients have long-term autonomic dystrophy and even develop reflex sympathetic dystrophy subsequent to a lightning strike.[12,16-19]

Eyes

Eye injuries occur in more than 50% of individuals struck by lightning. There are many mechanisms for eye injury, including direct electrical damage, light damage, and blunt trauma.[15] If cataracts develop, this usually occurs within days following the strike. Autonomic disturbances (eg, Horner syndrome) affecting the eye are also possible and can be temporary or permanent. Fixed and dilated pupils cannot be used in this context as indicators of serious brain injury.[20]

Ears

Due to the significant noise and the shock wave inherent in lightning strikes, transient hearing loss is prevalent. As mentioned, a common finding is tympanic membrane rupture, which is seen in 50% of patients.[21] Any evidence of fluid or blood drainage from the ear canal warrants CT of the head to look for injury to the skull or brain.

Cardiopulmonary

Cardiopulmonary arrest is the most common cause of death following a lightning strike; however, the victim is not likely to die unless the arrest is a direct result of the strike.[10] Secondary cardiac arrest has been reported and is caused by paralysis of the brain stem respiratory center, resulting in hypoxia which itself leads to cardiac arrest. This can occur even if the heart has regained sinus function and a perfusing rhythm.[10] Other arrhythmias are also common, and these run the gamut from atrial to ventricular dysrhythmias. ECG is not useful as a screening tool, as changes indicative of ischemia may be delayed for as long as 1 week. Most of these changes resolve relatively quickly, but some, especially prolongation of the QT interval, may require several days to subside.[22] Direct injury to the lungs with pulmonary contusion and hemorrhage can occur as well.[23]

Skin

Due to the nature of lightning, visible entry and exit wounds are not common in lightning injury. Burns, however, are very common. Burns to the skin can be loosely categorized into five groups. The first category is linear burns (including flash burns); these are first- and second-degree burns caused by steam on the victim's skin. Linear burns are typically 1 to 4 cm wide and follow areas of moisture accumulation such as the axillae and the area beneath the breast.[3,6,9] Punctate burns, the second category, are discrete circular burns that are typically closely spaced and vary in size from a few millimeters to a centimeter in diameter.[15] The sine qua non of lightning injury is Lichtenberg figures (also known as *lightning flowers*), a ferning pattern of burns to the skin. These are not true burns, as evidenced by the fact that microscopic evaluation of biopsy samples reveals no damage to the skin.[24-27] The fourth type of burn is thermal, which is caused by the intense heat of the lightning, which can burn clothing and jewelry, causing second- and third-degree burns. Included in this category are contact burns, a subgroup of burns that occur when metal such as jewelry is heated by the lightning, causing burns to adjacent skin.[6,9] There is also a fifth group that encompasses a combination of these injury patterns.

Kidneys

Due to the short duration of lightning strikes, myoglobinuric renal failure is not common since significant muscle breakdown does not typically occur. This is in direct contrast to high-voltage electrical injury, in which it commonly occurs.

OTHER INJURIES

Concussive Force Injuries

Since victims of lightning strike can be thrown several yards from the site of the strike, evaluation for blunt trauma is mandatory. Evaluation for bony injuries should be performed with appropriate radiologic studies, including CT if indicated.

DIAGNOSIS

It is important to recognize that the diagnosis of a lightning-injured patient may be difficult, especially if the patient is unaccompanied. Historical features, including witnesses to the event, a storm in the area, and physical findings, are immensely helpful in establishing

the clinical picture. The differential diagnosis is broad and includes cerebrovascular etiologies such as stroke, hemorrhage, and seizures, as well as cardiovascular causes such as arrhythmias and myocardial infarction.

Telltale signs of lightning injury include an arboreal-type burn (ie, Lichtenberg figures), tympanic membrane rupture, and disheveled appearance of the patient (including clothing that is blasted apart). The patient is also likely to be confused or amnestic to prior events.

Laboratory and Radiologic Testing

Recommended laboratory tests include electrolyte measurement, assessment of renal function, complete blood count, and cardiac enzyme studies, including creatine kinase and troponin assays. ECG is mandatory, as is cardiac monitoring.

The decision to order radiologic evaluation depends on the patient's presentation and the physician's assessment. CT of the head may be warranted in patients with altered mental status. Further CT scans may be indicated in patients with evidence of significant blunt trauma.

MANAGEMENT

The highest priority is to assess and stabilize the patient's airway, breathing, and circulation. Cardiopulmonary resuscitation should be instituted immediately if the victim is in cardiac arrest. Due to the risk for secondary cardiac arrest, this should be continued not only until spontaneous circulation occurs but until spontaneous respirations occur as well (or until the airway is secured). Following resuscitation and the primary survey, another careful survey should be performed with the patient completely undressed; if possible, history from witnesses and EMS personnel should be obtained. The patient's eyes should be examined for reactivity, acuity, and presence of cataracts; the ears should be evaluated for hearing, tympanic membrane rupture, and telltale signs of basilar skull fracture, including hemotympanum. Cardiovascular assessment should include documentation of pulses in all extremities, and the patient should be continually monitored for evidence of arrhythmia. The abdomen should be assessed for evidence of acute traumatic injury. Evaluation for focal neurologic abnormalities, including sympathetic dysfunction of an affected extremity, should also be performed. The extremities will be cold and clammy and have decreased sensation and pulses. Finally, with the patient completely undressed, the skin and extremities should be examined for any evidence of burn injury.

IV access should be obtained and crystalloid started. In addition to continuous cardiac monitoring, further invasive monitoring may be warranted depending on the patient's vital signs and overall clinical status. Unless the patient is truly hypotensive, fluid administration should not be aggressive, due to the risk for cerebral edema,[15] and once the patient has been stabilized, fluids should be restricted because of this risk. Since lightning strike alone rarely causes hypotension, significant hypotension mandates evaluation for other etiologies of shock, especially abdominal or chest hemorrhage and long bone fractures.

DISPOSITION

The disposition of lightning-injured patients depends on the clinical scenario. Patients with minor injuries can be observed for several hours in the ED, while those with severe symptoms should be admitted for further management. Follow-up should be arranged as required for those who are discharged.

CONCLUSION

Lightning strike is one of the most common environmental causes of death. It is important to understand that the mechanism of injury, the resulting injury pattern, and the potential complications associated with lightning strike are all quite different from those seen with high-voltage electrical injury. Classic injuries associated with lightning strikes include tympanic membrane rupture and arboreal burns. Lightning strikes can result in some delayed effects, including cognitive and behavioral issues, cataracts, and peripheral nervous system dysfunction. The patient should be informed of the potential for these effects and educated appropriately. **EM**

REFERENCES

1. Hornstein RA. Canadian lightning deaths and damage. CIR-3719, TEC-423. Meteorological Branch, Dept of Transport, Canada; 1962.
2. Cooper MA, Andrews CJ, Holle RL, Lopez RE. Lightning injuries. In: Auerbach PS, ed. *Wilderness Medicine: Management of Wilderness and Environmental Emergencies.* 5th ed. St. Louis, MO: Mosby; 2007:67-108.

3. Andrews CJ, Cooper MA, Darveniza M, Mackerras D. *Lightning Injuries: Electrical, Medical and Legal Aspects.* Boca Raton, FL: CRC Press; 1992:12.
4. Cannel H. Struck by lightning—the effects upon the men and ships of H M Navy. *J R Nav Med Serv.* 1979;65(3):165-170.
5. Christian HJ, McCook MA. Lightning and atmospheric electricity research: a lightning primer. Characteristics of a storm. NASA Global Hydrology Resource Center Web site. http://thunder.nsstc.nasa.gov/primer/primer2.html. Accessed September 15, 2011.
6. National Oceanic and Atmospheric Administration. Damage and impacts. National Severe Storms Laboratory Web site. http://www.nssl.noaa.gov/primer/lightning/ltg_damage.html. Accessed September 14, 2011.
7. Golde RH, Lee WR. Death by lightning. *Proc Inst Electrical Engineers.* 1976;123:1163-1180.
8. Cooper MA. A fifth mechanism of lightning injury. *Acad Emerg Med.* 2002;9(2):172-174.
9. Cooper MA. Emergent care of lightning and electrical injuries. *Semin Neurol.* 1995;15(3):268-278.
10. Cooper MA. Lightning injuries: prognostic signs for death. *Ann Emerg Med.* 1980;9(3):134-138.
11. Kobernick M. Electrical injuries: pathophysiology and emergency management. *Ann Emerg Med.* 1982;11(11):633-638.
12. Cooper MA, Andrews CJ, Holle RJ, Lopez RE. Lightning injuries. In: Auerbach PS, ed. *Wilderness Medicine: Management of Wilderness and Environmental Emergencies.* 4th ed. St. Louis, MO: Mosby; 2001:72-110.
13. Cherington M, Vervalin C. Lightning injuries: who is at greatest risk? *Phys Sportsmed.* 1990;18:58-61.
14. Cherington M, Yarnell P, Hallmark D. MRI in lightning encephalopathy. *Neurology.* 1993;43(7):1437-1438.
15. O'Keefe Gatewood M, Zane RD. Lightning injuries. *Emerg Med Clin North Am.* 2004;22(2):369-403.
16. Cohen JA. Autonomic nervous system disorders and reflex sympathetic dystrophy in lightning and electrical injuries. *Semin Neurol.* 1995; 15(4):387-390.
17. Hooshmand H. *Chronic Pain: Reflex Sympathetic Dystrophy Prevention and Management.* Boca Raton, FL: CRC Press; 1993.
18. Raja SN, Hendler N. Sympathetically maintained pain. In: Rogers M, ed. *Current Practice Anesthesiology.* 2nd ed. New York, NY: C.V. Mosby Year Book;1990:421-425.
19. Schwartzman RJ, Kerrigan J. The movement disorder of reflex sympathetic dystrophy. *Neurology.* 1990;40(1):57-61.
20. Grover S, Goodwin J. Lightning and electrical injuries: neuro-ophthalmologic aspects. *Semin Neurol.* 1995;15(4):335-341.
21. Qureshi N. Indirect lightning strike via telephone wire. *Injury*. 1995;26(9):629-630.
22. Andrews CJ, Colquhoun DM, Darveniza M. The QT interval in lightning injury with implications for the "cessation of metabolism" hypothesis. *J Wilderness Med.* 1993;4(2):155-166.
23. Soltermann B, Frutiger A, Kuhn M. Lightning injury with lung bleeding in a tracheotomized patient. *Chest.* 1991;99(1):240-242.
24. Dulcos PJ, Sanderson LM. An epidemiological description of lightning-related deaths in the United States. *Int J Epidemiol.* 1990;19(3):673-679.
25. Hocking B, Andrews C. Fractals and lightning injury. *Med J Aust.* 1989;150(7):409-410.
26. Bartholme CW, Jacoby WD, Ramchand SC. Cutaneous manifestations of lightning injury. *Arch Dermatol.* 1975;111(11):1466-1468.
27. Cherington M, Olson S, Yarnell PR. Lightning and Lichtenberg figures. *Injury.* 2003;34(5):367-371.