The Physical Effects of Lightning Injury

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Several thousand lightning-related injuries occur each year in the United States, resulting in nearly 600 deaths. Most incidents involve individual victims; group lightning strikes are rare. Ten soldiers were simultaneously injured in a group lightning strike while on training maneuvers at Fort Benning, Georgia. No deaths or loss of consciousness occurred, although two of the soldiers had amnesia for the event. All of the soldiers were hospitalized and observed for potential lightning-related complications. Ninety percent of the soldiers had first-degree skin burns, and all had focal muscular tenderness. Seventy percent had transient ST segment elevation that resolved. Fifty percent developed creatinine kinase (muscular component) elevation, but none developed myoglobinuria or acute renal failure. No patient had creatinine kinase (myocardial component) elevation. Transient hypertension and tinnitus were noted in 40% and 20%, respectively. No compartment syndromes or ocular manifestations developed. All 10 soldiers recovered uneventfully and returned to full active duty.

Lightning is a naturally occurring weather-related phenomenon. Estimates reveal that there are approximately 50,000 thunderstorms and 8 million lightning flashes per day that occur worldwide.[1] These estimates suggest that 300 to 600 persons die of lightning injuries each year in the United States and that several thousand more people are injured but survive.[2] Seventy percent of the deaths and injuries occur during the months of June, July, and August.[3] The incidence of deaths and injuries caused by lightning, however, frequently goes unreported and may be four to five times greater than stated.[1] Despite these reporting errors, lightning causes more deaths than any other weather phenomenon, including tornadoes, snowstorms, heat waves, and hurricanes.

Victims of lightning injury are struck in one of three distinct ways. The first mechanism is direct strike, the most serious strike, since all of the energy is transmitted through the individual. Chances of being struck are enhanced by wearing or carrying metal objects such as a metal helmet, a rifle, an umbrella, a golf club, or even a hairpin. This strike is not uniformly fatal, but it carries a high rate of serious morbidity because it frequently involves the head.

The second type of strike, termed a side flash, also called a flash discharge, splash, or spray, occurs when the lightning jumps from the primary strike area (such as a tree) through the air to a nearby object. This strike occurs because the resistance to the direct current flow between a tree and a person is less than that down the tree itself. This strike is probably the most common type of lightning injury.

The third mechanism of injury is called a ground strike, or stride potential, which occurs when lightning strikes the ground near a person. A person may have less resistance from one leg to the other than the resistance of the ground. Thus the lightning may enter through one leg and exit through the other. This mechanism may spare vital abdominal and chest organs from injury. Cooper,[4] however, notes a mortality of 30% in people with leg burns, while burns to the arm and trunk were not found to be important predictors of mortality.

An associated phenomenon of lightning injuries is the flashover phenomenon. Electricity is known to travel over the outside surface of a metal conductor. In the flashover phenomenon the majority of the lightning's energy is theorized to flow around the outside of the body of the victim,

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Submitted, revised, June 16, 1989.

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TABLE 1. SUBJECTIVE COMPLAINTS OF SOLDIERS AS A RESULT OF LIGHTNING STRIKE (N = 10)

Complaints	Number (%)
Dermal burns and abrasions	9 (90)
Dysesthesias in extremities	8 (80)
Minor orthopedic complaints (ankle sprain, painful shoulder, etc.)	4 (40)
Headaches	2 (20)
Chest pain	2 (20)
Amnesia for event	2 (20)

thus protecting the person in part from the damaging effects of the lightning. Wet clothing enhances the flashover phenomenon.[3]

Most incidents involve individual victims, while group lightning strikes are rare. This paper reports the effects of a lightning strike on a group of ten soldiers and reviews the current literature regarding common injuries, management of lightning-strike victims, and prevention guidelines of this commonly occurring natural phenomenon.

CASE REPORT

On June 3, 1987, ten soldiers in basic training were involved in a lightning strike at Fort Benning, Georgia. The soldiers had been gathering under oak trees for protection from the falling rain. As the rain and wind intensified, drill instructors began dispersing the soldiers away from the trees to low, open areas. Their efforts were suddenly terminated by a blinding flash and deafening thunderclap.

The ten soldiers were found scattered around the smoking remains of a large oak tree, and the Fort Benning Mass Casualty system was activated. The lightning-strike victims were evacuated to Martin Army Community Hospital, where they were evaluated by triage teams from the departments of family practice and surgery.

The ten previously healthy soldiers, who ranged in age from 17 to 35 years (mean age 22.2 years), were admitted to the surgical intensive care unit for observation. None of the soldiers had lost consciousness, and all were fully alert at admission. Seven soldiers stated that they were thrown some distance from the tree when the lightning struck; two had no recall of the event; and one claimed he "saw God." Other complaints are included in Table 1.

Admission physical examination revealed four soldiers (40%) with blood pressure greater than 140/90 mmHg, which quickly resolved without treatment. Other vital signs were stable. All patients had localized tenderness to palpation on musculoskeletal evaluation. Serial examinations of involved extremities were performed. No asymmetry or changes in circumference developed to suggest impending compartment syndrome. Neurological evaluation revealed that seven (70%) of the patients had a derangement in two-point discrimination and light touch, but none had motor findings or changes in deep tendon reflexes. Nine (90 percent) of the patients had first-degree burns, some appearing in a serpiginous pattern along extremities (Figure 1); one soldier had a burn that outlined the metal pack frame he was wearing at the time of injury (Figure 1). None of the soldiers had second- or third-degree burns. Metallic objects carried in pockets were also damaged by the lightning. Each soldier was evaluated by the ophthalmology service for traumatic cataracts and lens dislocation. No ophthalmologic trauma was found. The only other pertinent physical findings were scattered abrasions and

Figure 1. Pack frame burn and serpiginous skin burn of leg

contusions. The physical examination and laboratory findings are summarized in Table 2.

Daily urinalysis during the 3-day hospitalization did not reveal the presence of proteinuria or myoglobinuria. At admission, elevations in creatinine kinase-musculoskeletal (CK-MM) were noted in 50% of the patients. Levels ranged from 3.08 to 10.87 μkat/L (185 U/L to 652 U/L) (mean of 5.95 μkat/L [357 U/L], normal <3.33 μkat/L [200 U/L]). All elevations of creatinine kinase returned to levels of less than 2.5 μkat/L by 72 hours. No creatinine kinase-cardiac (CK-MB) was detected. Results of liver studies, electrolytes, and hemogram were unremarkable for all patients.

Four of the patients had a 1- to 2-mm ST segment elevation in leads V_4 through V_6 on electrocardiogram. Two others had similar changes in leads II, III, and aVF. These findings were new, and resolved spontaneously within 12 hours. Radiographic studies were unremarkable.

The soldiers remained in Martin Army Community Hospital for 72 hours. No late complications developed. All were given an opportunity to counsel with a chaplain and psychiatry staff members. The soldiers were discharged to light duty with follow-up arranged with the ophthalmology service and their troop medical clinic. All soldiers returned to full duty within 1 week.

TABLE 2. PHYSICAL AND LABORATORY FINDINGS OF THE LIGHTNING STRIKE VICTIMS (N = 10)

Findings	Number (%)
Focal musculoskeletal tenderness	10 (100)
Skin burns (first degree)	9 (90)
Neurosensory deficits	7 (70)
Electrocardiographic ST segment elevation	6 (60)
Creatinine kinase elevation	5 (50)
Hypertension	4 (40)
Tinnitus and hearing deficits	2 (20)

DISCUSSION

This case report serves well to remind physicians of the potential harmful nature of lightning. A lightning strike can provide a wide array of injuries to an individual or group of victims that may vary widely in severity of injury.

Lightning is a natural electrical discharge that occurs in the atmosphere. It is usually associated with cumulonimbus clouds (thunderclouds) but can also occur in dust storms, snowstorms, nuclear explosions, and volcanic eruptions. Static electricity builds up from the collision of water droplets and ice particles carried by updrafts and downdrafts within the thunderclouds. As this static energy accumulates, the upper regions of the cloud carry a strong net positive charge and the lower layers have a negative charge. The earth below is negatively charged but carries a more positive net charge than the cloud. A potential difference thus develops between the cloud and the ground that is roughly 1×10^5 volts. When this potential difference exceeds the insulator effect of the surrounding atmosphere, a lightning discharge occurs. There are four types of lightning discharges: (1) intracloud lightning (the most common type), (2) cloud-to-cloud lightning (rare), (3) cloud-to-ground lightning (approximately 20% of discharges), (4) ground-to-cloud lightning (rare).

The events in a cloud-to-ground lightning discharge occur as follows. The discharge process starts by breakdown between small regions of positively and negatively charged atmosphere. This breakdown creates a luminous process that descends in distinct downward branching steps typically 50 m in length and 50 microseconds in duration. This downward branching phenomenon, called a leader stroke, travels at 1/2000 the speed of light. As the leader stroke nears the ground, a pilot stroke will often arise from the ground to meet it about 50 m above the surface, thus completing the electrical arc. A return stroke from the ground to the cloud then occurs at roughly 1/10 the speed of light and carries most of the current averaging from a few thousand to 200,000 A and a voltage of 20 million to 1 billion.[5] This discharge can produce temperatures of 50,000 °F. Lightning is perceived as moving from cloud to ground because the leader stroke is very luminous and slower than the return stroke. The main electrical discharge, however, is from ground to cloud, and this discharge appears as an instantaneous brightening of the ionized pathway.[4]

A second stroke, called the dart leader, can occur from the cloud down this ionized pathway allowing more electrical discharge from the cloud to the earth. This discharge can in turn cause another return stroke from ground to cloud, a sequence of events that can occur three to four times, up to a record of 26 strokes. This phenomenon is often responsible for the scintillating aspect of lightning. The average duration of a lightning flash is 0.2 seconds. The air that is superheated by the lightning discharge rapidly expands in a cylindrical column, decaying within a meter or two from a shock wave to a sound wave. This sound wave comes from the entire channel of the discharge and is heard as peals, claps, rolls, and rumbles. Since light travels at 186,000 miles per second and sound at 750 miles per hour at sea level, the time in seconds between the flash

TABLE 3. COMPARISON OF LIGHTNING AND COMMERCIAL HIGH-VOLTAGE ELECTRICAL INJURIES

Characteristics	Lightning* Injuries	High-Voltage† Electrical Injuries
Duration	Very brief	Prolonged
Cardiac disturbance	Asystole	Ventricular fibrillation
Flashover phenomenon	Yes	No
Shock wave nature to injury	Yes	No
Occurrence	Outdoor Recreational	Occupational Household
Voltage and current peaks	Extremely high	Lower

*Direct current
†Alternating current

TABLE 4. ORGAN INJURIES CAUSED BY LIGHTNING

Organ System	Findings
Cardiovascular	Atrial and ventricular dysrhythmias Asystole Ventricular fibrillation Myocardial injury Vasomotor spasm Transient tachycardia and hypertension
Neurologic	Loss of consciousness or altered consciousness Amnesia for event Cerebral edema CK-BB elevation Transient motor paralysis Paresthesias Seizures Respiratory arrest
Cutaneous	Superficial abrasions, linear fernlike burns Full-thickness burns (rare) Punctate burns (partial or full-thickness)
Musculoskeletal	Muscle swelling (compartment syndromes) Myoglobin release Elevated CK-MM Muscle rupture
Renal	Renal failure (myoglobinuria)
Gastrointestinal	Gastric atony with dilation Gastrointestinal bleeding
Ocular	Cataracts Retinal injuries Lid burns Conjunctival chemosis or conjunctivitis Corneal lesions Paresis of accommodation Lens dislocation
Auditory	Tympanic membrane rupture Tinnitus Hearing loss
Psychiatric	Personality changes Hysterical blindness, deafness, and loss of speech Lightning and thunder phobias

CK-BB—creatinine kinase-brain
CK-MM—creatinine kinase-musculoskeletal

of light and the sound heard divided by 5 will give the approximate distance in miles.

In this case report all but one soldier were involved with a side flash from the energized tree. The exception was sitting on the ground at the time and was probably involved with a ground strike, since his injury was on his buttocks. The flashover phenomenon occurred with at least one soldier as manifested by a metal container of cough drops being spot-welded by the strike.

Lightning causes death or serious injury in about one third of its victims, and permanent sequelae in about two thirds of its survivors.[4] Factors related to fatal outcome include leg burns, burns to the head, and immediate cardiopulmonary arrest.

Lightning injuries differ from high-voltage electrical injuries in several important ways, as shown in Table 3.

Fortunately in this group of soldiers there were no deaths or permanent neurologic sequelae. Death usually occurs as a result of cardiac or respiratory arrest.[5] Current takes its least resistant path to the ground. The tissue order from least resistant to greatest resistance is nerve, blood vessel, muscle, skin, tendon, fat, and bone.[6] Multiple sources have well summarized the clinical effects to organ systems caused by lightning strike.[2,3] These effects are briefly categorized in Table 4.

Persons struck by lightning show evidence of multisystem damage, and the most dramatic effects occur to the cardiovascular and central nervous systems. One can consider lightning to be the ultimate in "cosmic cardioversion,"[7] depolarizing the entire myocardium at once, followed by a period of asystole. If asystole occurs, the cardiac rhythm will usually start spontaneously and slowly and gradually speed up. In Cooper's study,[4] 72% of patients had loss of consciousness, 86% had confusion and amnesia, and 69% had paralysis, especially of the lower extremities. This paralysis resolved completely in most cases. Respiratory arrest from paralysis of the respiratory center in the brain stem can also occur. The duration of apnea, rather than the duration of asystole, is considered to be the critical factor in morbidity and mortality.[8]

This study of ten soldiers simultaneously struck by lightning is one of mild injuries. Ninety percent had some degree of superficial skin burn, 80% had short-lived paresthesias lasting for hours to days, and 20% had transient tinnitus and hearing deficits that resolved before discharge. In this group there were no soldiers with loss of consciousness, permanent neurologic sequelae, significant musculoskeletal injury, eye injury, or death. Fifty percent had elevated creatinine kinase levels, but none had myoglobinuria. Of note, 60% had transient ST elevation documented on admission electrocardiogram, with no clinical significance. The literature supports transient nonspecific ST-T wave changes commonly occurring after lightning strike that typically resolve spontaneously.[1–3] There have been several cases of reported myocardial injury and necrosis felt to be secondary to lightning burns to the heart manifested by electrocardiographic changes and elevated creatinine kinase levels.[9,10] These soldiers did not have myocardial infarctions, and all were well upon discharge 3 days later.

The burns noted in this series are commonly seen. There are many forms of cutaneous lesions ranging from pathognomonic feather-like skin markings (known as Lichtenburg figures) to partial and full-thickness burns that may be linear to punctate in nature.[11] Most burns will resolve spontaneously within 24 hours without scarring.

MANAGEMENT

The prehospital treatment of lightning victims is crucial. In other mass casualty situations, attention is focused typically on the survivors of the accident so that resources and manpower can save the living; prolonged resuscitation of apparently dead or dying victims generally is not attempted. In lightning strikes the strategy is just the opposite. Taussig[12] states that "if a group of persons are struck by lightning, attention should first be directed to the dead because those who show signs of life will in all probability recover although their injuries may need treatment." Therefore, patients who are unconscious and apparently dead should receive the highest priority for aggressive basic and advanced cardiac life-support resuscitative efforts. It has been reported[13] that a young boy was successfully resuscitated after having no vital signs for 13 minutes after being struck by lightning. The postulated reason for recovery is that all cellular metabolism simultaneously stops at the time of the initial strike, causing the deleterious affects of anoxia to be slowed. Appropriate cervical spine precautions should also be considered, as the victims of lightning strike may be violently thrown by the energy of the current.

Once the patient arrives in the emergency department, standard principles for care of the severely injured should be applied. The airway should be stabilized and adequate respiration and circulation maintained. A history from the patient or witnesses about the event should be obtained, and the potential for loss of consciousness resulting from seizures, hypoglycemia, or a drug overdose should not be forgotten. The physical examination should include serial evaluations of distal pulses and peripheral sensorimotor testing.

The skin should be closely examined and vision and hearing determined. The patient should have an electrocardiogram, and laboratory work should include creatinine kinase, renal function, and urine myoglobin determinations as appropriate.

Patients should be hospitalized if they are in a coma, have major head injury, or have been successfully resuscitated after cardiac arrest. Patients with electrocardiographic changes, chest pain, paralysis, sympathetic instability, or other neurologic abnormalities should also be admitted. Patients with a brief loss of consciousness, amnesia, or confusion can be discharged, with appropriate central nervous system precautions, under the care of a responsible adult, unless the caretaker is felt to be inadequate or apprehensive. Patients with skin burns can be treated as outpatients in the usual fashion. Vision and hearing should be screened, and patients should be informed that cataract formation may occur after the injury and that they should be checked by an ophthalmologist 6 months later. A follow-up visit with a physician should be done the next day.

PREVENTION

Prevention is the best treatment for lightning injuries. If an electrical storm is approaching, seek shelter inside a car, steel-framed building, or a house. Do not stand in a doorway or near a window or a fireplace. Do not take a bath during a thunderstorm or use the telephone. There were four deaths and 36 injuries reported between 1959 and 1965 from using the telephone during a lightning storm.[1] Contact with plumbing and electrical appliances should be avoided.

It is important to respect the power of lightning storms, and all outdoor activities should be stopped. Swimming should be avoided, and umbrellas, fishing rods, golf clubs, kites, and metal bats should be discarded. Similarly, rifles, metal helmets, hairpins, jewelry, and other conductive items should be removed. If one is wearing metal-cleated shoes, these should also be taken off. If one is caught in the open, one should seek low ground. Immediately drop to the ground in a squatting position or on one's side in a fetal position. If squatting, the legs should be kept together to reduce stride potential. If possible, lie on a rubber or plastic raincoat for insulation. Avoid railroad tracks, as they should not be walked on or touched during a lightning storm. Avoid standing under tall or isolated objects, such as a tree, as doing so increases your chance of sideflash. If no shelter is available, then a grove of trees shorter than adjacent groves is preferable to wide open areas. Lightning can strike twice in the same place, and immunity after an initial strike cannot be assumed. If in a group, the group should spread out to minimize the chances of all being injured and thus not being able to help each other.

References

1. Tribble CG, Persing JA, Morgan RF, et al: Lightning injuries. Compr Ther 1985; 11(2):32–40
2. Craig SR: When lightning strikes. Pathophysiology and treatment of lightning injuries. Postgrad Med 1986; 79(4):109–124
3. Cwinn AA, Cantrill SV: Lightning injuries. J Emerg Med 1984; 2:379-388
4. Cooper MA: Lightning injuries: Prognostic signs for death. Ann Emerg Med 1980; 9:134–138
5. Moran KT, Thupari JN, Munster AM: Lightning injury. Physics, pathophysiology and clinical features. Ir Med J 1986; 79:120–122
6. Kobernick M: Electrical injuries: Pathophysiology and emergency management. Ann Emerg Med 1982; 11:633
7. Auerbach PS: Lightning strike. Top Emerg Med 1980; 2:129–135
8. Strasser EJ, Davis RM, Mechey MJ: Lightning injuries. J Trauma 1977; 17:315–319
9. Kleiner JP, Wilkin JH: Cardiac effects of lightning stroke. JAMA 1978; 240:2757–2759
10. Jacksons HD, Parry DJ: Lightning and the heart. Br Heart J 1980; 43:454–457
11. Cooper MA: Lightning injuries. In Auerback PS, Geehr EC (eds): Management of Wilderness and Environmental Emergencies. New York, Macmillan, 1983, pp 500–520
12. Taussig HB: Death from lightning and the possibility of living again. Ann Intern Med 1968; 68:1345–1355
13. Rauitch MM, Lane R, Safar P, et al: Lightning injury. N Engl J Med 1961; 264:36–38