
ligh

Fred Weber, MD, JD

Making it momentary as a sound,
Swift as a shadow, short as any dream;
Brief as the lightning in the collied night,
That in a spleen unfolds both heaven and earth,
And ere a man hath power to say, "Behold!"
The jaws of darkness do devour it up:
So quick bright things come to confusion.

A Midsummer Night's Dream, William Shakespeare

The *British Medical Journal* expressing editorial opinion stated: "although lightning may strike twice in one place, it is unlikely to strike in one doctor's experience more than once." A case of lightning strike and death in the Atlantic City area in 1981 prompted investigation by the author. Two additional local cases are reviewed, the anatomy of a lightning stroke is examined, the mechanisms of lightning injury to the body are explained, and the treatment of the injured victim is outlined. Lightning has struck more than once in this doctor's experience.[1]

Case 1

MV was a 17-year-old white male. In mid-July, he and two other friends were water skiing in a small rented aluminum boat. Around midmorning, they noticed a gathering storm and made for the dock. While underway, rain began to fall and shortly thereafter, lightning struck near the stern of the boat. The individual in the bow felt electrical shocks but suffered no ill effects. The boy amidships was thrown to the deck but sustained no injury. In the stern, MV was rendered immediately unconscious by the strike. Soon thereafter, he exhibited twitching convulsive motions and subsequently turned blue. CPR was begun in the boat and was continued by the rescue squad in transit from the dock to the emergency room.

On admission, he was cyanotic with no obtainable blood pressure. A cardiac monitor showed ventricular tachycardia. He was immediately intubated and resuscitated with IV fluids, inotropic agents, calcium, atropine, and electric shock. No further heart rhythm was seen, no blood pressure was ever obtained, and he was pronounced dead 30 minutes after arrival in the emergency room.

Case 2

JD was a healthy, 55-year-old, white male smoker. As part of National Guard maneuvers, he was operating a communications station in upstate Pennsylvania. Lightning struck nearby, causing the radio panel where he was seated to explode. He was unconscious for a short time, awoke, and was admitted to a local hospital for observation. His admission chest X-ray showed a right upper lobe mass. He was transferred to this area where the surgeon performed a right thoracotomy and right upper lobectomy for Stage I squamous carcinoma of the lung.

He is alive and well, at six years after the lightning strike and surgery. Lightning saved the life of JD.

Case 3

MT is a healthy, 45-year-old white male who was vacationing with his family in Ocean City, New Jersey. Near dusk, a thunderstorm approached their rented second-story condominium. Peering at the storm through an open window, sparks were seen to fly from his wedding band. Lightning struck the house and MT was immediately hurled to the floor and rendered unconscious. Within minutes, he awoke and was transported to the hospital.

On admission he was awake and lucid. His vital signs were normal. He only complained of tightness in his chest. One set of cardiac enzymes was positive for myocardial damage. An electrocardiogram did not show any changes from a previous study, which was obtained from his private physician. He was discharged in two days and recovered without sequelae.

The history of lightning

The understanding that lightning would strike the highest object was unknown in medieval Europe. This knowledge deficit persisted until the mid 1700s. During the Middle Ages, it was common practice to attempt to ward off thunderstorms by the ringing of church bells. This practice was particularly hazardous to the bell ringers. One historian of the time recorded that, in a 30-year period, almost 400 churches were struck with the resultant death of 100 bell ringers.[2]

During the mid- to late-18th century, a great interest in lightning developed. Although not as dangerous as ringing a church bell, many experimenters began research into the nature of lightening. In 1753, Professor Reichman of St Petersburg, Russia, was killed when he attempted to direct a lightning bolt into his laboratory for study.[3]

TABLE 1 Lightning statistics by state

STATE	DEATHS 1959-2003	CLOUD-TO-GROUND FLASHES/ YEAR 1997-2001	CLOUD-TO-GROUND FLASHES/ SQ MILE 1997-2001
Alabama	101	748,304	14.5
Alaska	0	not tracked	not tracked
Arizona	66	647,809	5.7
Arkansas	117	536,659	10.1
California	25	83,798	0.5
Colorado	123	499,888	4.8
Connecticut	15	16,420	3.3
Delaware	15	13,045	6.6
DC	5	550	8.1
Florida	425	1,322,177	23.1
Georgia	95	779,298	13.2
Hawaii	0	not tracked	not tracked
Idaho	26	83,441	1.0
Illinois	97	647,574	11.5
Indiana	85	429,690	11.9
Iowa	70	452,011	8.0
Kansas	61	656,492	8.0
Kentucky	87	447,771	11.2
Louisiana	132	790,043	17.1
Maine	23	38,252	1.2
Maryland	123	69,330	7.0
Massachusetts	26	21,629	2.7
Michigan	101	268,043	2.9
Minnesota	59	326,870	3.9
Mississippi	97	737,102	15.5
Missouri	86	703,582	10.1
Montana	26	337,301	2.3
Nebraska	44	331,293	4.3
Nevada	6	163,555	1.5
New Hampshire	8	16,277	1.8
New Jersey	61	34,408	4.5
New Mexico	88	847,661	7.0
New York	134	202,145	4.2
North Carolina	181	470,865	9.5
North Dakota	12	251,766	3.6
Ohio	136	379,917	9.2
Oklahoma	98	743,835	10.6
Oregon	8	49,858	0.5
Pennsylvania	121	243,283	5.4
Rhode Island	4	2,925	2.7
South Carolina	89	300,371	13.9
South Dakota	23	295,653	3.8
Tennessee	133	552,975	12.6
Texas	195	1,684,234	6.4
Utah	47	267,534	3.2
Vermont	14	22,413	2.8
Virginia	62	284,610	7.1
Washington	5	20,599	0.3
West Virginia	25	192,173	7.9
Wisconsin	56	289,078	5.2
Wyoming	27	300,464	3.1

Table adapted from: Number of Lightning Deaths by State from 1959 to 2003. National Weather Service,[21] and Rank of Cloud-to-Ground Flash Densities by State from 1997 to 2001.[22]

Benjamin Franklin made many significant contributions to science and, specifically, to the study of lightning. It is a credit to his luck and ingenuity that he was not killed while conducting his experiments.

It was in the summer of 1752 that Franklin flew his famous kite under a thunderstorm. During this experiment, when the kite string became wet with rain, sparks jumped from Franklin's hand to a key on the string. The kite was not hit by lightning. If it were, he would have been seriously injured or killed. In the "Kite Experiment," he proved that a strong electrical field exists beneath a thunderstorm. The wet string became a conductor and, when suspended in a strong field, a current was induced in the wet string, causing sparks to jump.[4]

Benjamin Franklin is credited with the invention of the lightning rod, a simple, yet elegant, device for protecting property and life. From his experiments, he concluded that lightning would preferentially strike the highest object in a given area. Using this conclusion, he constructed a lightening rod—a metal rod, commonly called the air terminal, placed on the highest point of the building. The air terminal was then connected to a wire, which descended outside the structure. This wire was buried deep into the ground, many feet from the protected area. The lightning rod functions in two ways. First, the lightning strike is promoted to a safe place, namely the air terminal. Second, the huge current flow is conducted harmlessly away into the earth. It is a credit to Franklin's genius that this device has survived, essentially unchanged, for 250 years.

The anatomy of lightning

Lightning is a transient, high-current discharge, which is most commonly produced by thunderstorms. Lightning, however, does occur in many other settings. Hurricanes are a massive conglomeration of thunderstorms with frequent lightning. Erupting volcanoes frequently generate massive lightning displays. Sandstorms produce lightning in the desert. Snowstorms in the Arctic and Antarctic produce lightning. Lightning can also occur as a "bolt from the blue," when the lightning strike is not directly below the thunderstorm that generated it.[4] Estimates are that 100 lightning bolts contact the earth every second.[5]

In a thunderstorm, convective activity (upper level winds) causes electrons to be deposited at the base of the cloud, creating a strongly negative charge at the lowest level of the cloud. This induces a strong positive charge on the ground below. The set up is analogous to a large-scale capacitor. Lightning is the breakdown of the capacitor insulation, with the electrons flowing from the base of the cloud to the ground.

The lightning stroke itself consists of two components: a step leader and the stroke proper. As many as 20 lightning strokes can occur in less than two seconds, but the eye cannot resolve these individually and sees only the composite flash. In a dark room illuminated by lightning, the multiple nature of the strokes can be observed stroboscopically in a fan.

In the common cloud-to-ground stroke, the exploring step leader with many branches moves from the cloud toward the ground in a discontinuous fashion. Some 30 to 50 feet above the ground, the step leader will contact either a conducting object or an upward streamer from an object on the ground. (This object could be a person!) The dielectric of the natural capacitor has broken down.

The circuit is now complete and the second phase, the destructive phase, the stroke proper begins. All of the electrons in the base of the cloud now travel down the conductive pathway. The current flow is enormous, with up to 10^5 amperes discharged into the receiving object.[4,6,7]

Thunder is produced by the rapid expansion of the heated gasses in the vicinity of the stroke. If the lightning stroke is perpendicular to the observer, the thunder will be as a sharp clap. However, if the stroke is pointing toward you or away from you, a deep rich "rolling thunder" will result.

Lightning injury

A basic understanding of the mechanics of the lightning strike is helpful when describing lightning injuries. Current enters the body in three ways:[3]

1. Direct Hit
2. Side flash
3. Step Voltage

Direct hit

A direct hit occurs when an individual is the highest conductor in the area and initiates the upward streamer. The streamer contacts the step leader and completes the circuit. All current now flows through the person. Just prior to direct hit, people report tingling skin and hair standing on end, indicating the presence of a strong electrical field.

Current entry occurs at the head and, if the clothing is wet from rain, flashover will occur. This flashover (current flow) over the surface of the person results in many of the interesting observed phenomena. The clothing may be ripped off, and the victim found naked. Moist areas on the body are subjected to rapid heating and steam formation, resulting in burns of the axillae and groin. Hair and eyebrows are singed. Sweaty boots have exploded. Frequently, a victim is found naked and shoeless.

A unique type of mark, called Lichtenberg figures, is observed after flashover injury. It consists of a delicate branching pattern observed on the skin of victims. These arborescent (tree-like) designs are thought to be produced by cascading electrons in the strong electrical field. These are not true burns; if the individual survives, the Lichtenberg figures will spontaneously disappear in hours.[3]

Side flash

Side flash is the most common form of lightning injury. Side flash occurs when the individual is standing next to an object which has received a direct lightning hit, and the victim receives a secondary strike from the energized object (eg, the person who seeks shelter from a thunderstorm under a tree). The sequence is as follows: The tree receives a direct hit, causing current flow and flashover to occur on the tree. An individual with wet clothes stands close to the trunk. Current jumps from the tree trunk to the victim by a side flash.

One does not need to be outside to experience a side flash. Indoor lightning incidents are the result of this mechanism and can be just as dangerous as standing under a tree. When lightning strikes a house, all conductors within the structure become electrified. Current rushes through these conductors in an attempt to ground. These conductors include the telephone, television, and plumbing. All indoor conductors present a hazard for side flash. A local indoor lightning incident occurred when the victim was washing dishes at the sink with a silver spoon in her hand, while a thunderstorm was in progress. The house was struck, the plumbing was electrified, and side flash occurred to the victim at the sink. Side flash can be prevented by avoiding indoor conductors during a thunderstorm.[3] Do not talk on the telephone; do not take a shower; do not wash dishes during a thunderstorm.

Step voltage

The third mechanism of injury involves step voltage. When a stroke of lightning contacts the ground, current is injected into the mass of earth and flows away from the point of impact. One can imagine a "bulls eye" of concentric circles, representing decreasing voltages, radiating from the center of the stroke. Step voltage usually occurs within 30 feet of the strike and is the second most common form of injury. An individual standing nearby is subjected to a potential difference of volts between his legs. This potential difference causes current to flow from one foot across the groin to the other foot. This current flow causes sudden contraction of the leg muscles, followed by temporary paralysis from the waist down. Step voltage explains the frequent observation that victims are "hurled" to the ground.

Step voltage is seldom fatal for humans, because the current path does not traverse the brain, heart, or respiratory centers. However, quadrupeds, such as cows, sheep, horses, and dogs, are frequently killed by step voltage, because the current flows through the chest and heart. In strikes involving grazing animals, entire herds may be found dead in a field after a thunderstorm.

Step voltage is important in swimming incidents during lightning, but there are few cases of this in the literature, due either to its rarity or the good sense of people not to go into the water during threatening weather.[3]

Group strikes

In group casualties involving humans, a few individuals are killed, either by direct hit or side flash. The rest of the victims are temporarily paralyzed by step voltage and fall. In large groups, there will be deaths. Group strikes are relatively common. The following two reported incidents are remarkably similar, although they occurred in different decades and on different continents.

In a celebrated report from England, lightning struck a tea stall shortly after 4 pm at the famous Ascot race course.[8] One woman was killed outright, and another woman died a cerebral death several days later. Many people were dazed and thrown to the ground. Half of those involved had paraesthesias, but only in a few did the paresthesias last more than a week. One third of patients received burns, but none required skin grafting. One patient had burns of the soles of both feet without other injury. One woman had multiple small areas of full thickness skin burns immediately beneath a pearl necklace she was wearing at the time of the incident. Five cases of deafness were reported.

Twenty years later in New York State, 47 children and counselors were swimming when a thunderstorm approached.[9] They sought shelter together under a tree and lightning struck. Two patients suffered cerebral damage, one dying, and one living in a chronic vegetative state. Sixteen were hurled to the ground. Paraesthesias were not reported. One child's boots were ripped open. Burns were again reported, but did not require grafts. In both reports, patients who died underwent post-mortem examination. All exhibited changes in the diaphragmatic area of the heart similar to an infarct.

During thunderstorms, people should not congregate together in groups. Although it is somewhat contrary to human behavior, all should scatter.

Pregnancy and lightning

There have been many reports of the association of lightning injury with pregnancy. It is known that electrical stimulation causes contraction of muscle. This was first reported by Allesandro Volta, and is the principle involved in pacemaker therapy. In a lightning event, the uterus is subjected to electrical stimulation and violent sudden contraction. The first lightning case involving a gravid female was reported by Pliny the Elder in 23 AD. He reported that "Macea, a lady of high stature in Rome was struck by lightning while pregnant and although the child was killed, she herself survived without being otherwise injured."[3]

A recent report details the case of a woman carrying a seven-month fetus. Lightning struck the woman while she was removing clothes from the clothesline before an approaching storm. Following the strike, she reported only transient numbness of the right arm and delivered a normal child after an 11-month gestation. The authors cite 10 cases of lightning strikes to gravid females: five delivered normally, four resulted in immediate abortion or cessation of fetal life. The remaining case ended in a normal delivery, but with subsequent fetal death at 16 hours.

The uterus is a muscle which will contract upon electrical stimulation. It is assumed that violent contraction of the uterus during the lightning strike proved lethal for half the fetuses. The factors responsible for survival or injury (eg direct hit, side flash, step voltage or other gestational factors) are not clearly defined.[10]

Cardiac injuries

Three mechanisms of cardiac injury are postulated.

1. Violent systole in response to electrical currents
2. Sympathetic discharge secondary to catecholamine release
3. Anoxic ischemia from respiratory arrest

All manner of electrocardiogram changes have been reported.[11,12] These consist of ST changes, T-wave inversions, and ischemic patterns. In most reports, enzyme elevations are not specific for myocardial damage and, therefore, could be caused by any muscle damage.

In post-mortem examination of the hearts of those who died by lightning, hemorrhagic areas of myocardial damage were found on the lower borders of the heart. This may be due to large current flow through the conducting pathways of saline solution in the bloodstream.[13]

Neurologic injuries

Neurologic complications following lightning injury are common. Loss of consciousness and retrograde amnesia are frequently seen. Step voltage causes temporary paralysis of the lower limbs. A lightning-specific injury known as keraunoparalysis can occur. This is character-

TABLE 2 **Lightning casualties in the US by location or activity**

RANK	LOCATION / ACTIVITY	RELATIVE FREQUENCY
1	Open areas (including sports fields)	45%
2	Going under trees to keep dry	23%
3	Water related activities (swimming, boating, and fishing)	14%
4	Golfing (while in the open)	6%
5	Farm and construction vehicles (with open exposed cockpits)	5%
6	Corded telephone (#1 indoor source of lightning casualties)	4%
7	Golfing (while mistakenly seeking shelter under trees)	2%
8	Using radios and radio equipment	1%

Adapted from: Updated AMS Recommendations for Lightning Safety-2002. [19]

ized by a bluish-white, cold and pulseless lower extremity. The condition is self limited and circulation and neurologic integrity will return spontaneously.[14]

Disturbances of the mental status of lightning victims can persist for months following injury. In a recent report, four children were injured while playing soccer on an open field.[15] One child received a direct hit, never regained consciousness, and died on the seventh day. The three remaining children were rendered unconscious but awoke spontaneously. When examined monthly after injury, they were found to have significant defects in abstract reasoning and difficulty with schoolwork. One child, although able to return to school, was unable to remember his sibling's names. All were bothered by recurrent memories of the event. Normal mental status returned in all children by six months.

Cataracts

Cataracts as a result of lightning strike were first reported in 1722. The development is variable and can appear at any time following the injury. Enucleation of the globe following severe eye injury has been performed as early as 10 days and as late as seven months.[3]

Deafness is reported and is due to rupture of the eardrum, probably secondary to concussive effects of the thunder.[16] Facial palsy has been reported in humans.[3]

Protection from lightning

Lightning protection involves common sense. To avoid injury, one must avoid lightning and its effects. Most commonly, lightning is associated with thunderstorms, therefore the detection and avoidance of thunderstorms is crucial. One must be observant for threatening weather at all times. NOAA weather radio, and the Weather Channel broadcast 24-hours-a-day for updates on severe or threatening weather. Table 1 shows a variety of lightning statistics by state.

A simple AM radio can be used as a very efficient thunderstorm locator, since each lightning discharge produces static. The intensity, frequency, and general trend of static can predict the movement of thunderstorms and, with a little practice, this technique can be very useful. An alert individual, using common sense, should not be surprised by severe weather.

The safest place to weather a thunderstorm is inside a substantial house that is protected by lightning rods. The inside of an automobile is a safe place in a thunderstorm, but very dangerous in a tornado. On a sailboat, there is a cone of safety under a well-grounded mast, which acts as a Franklin lightning rod. Do not stand under a tree. Do not approach plumbing. Do not talk on the telephone or radio. Do not stand at the window. Do not play golf. Do not walk on the beach.

The distance of the lightning strike can be simply estimated. The lightning flash travels almost instantaneously at the speed of light.

Thunder travels more slowly at the speed of sound. Each five-second delay between the lightning and the thunder represents one mile of distance to the stroke.

If there is no shelter, find a place outside, away from tall trees, water, and other conductors, preferably not in the middle of an open field (eg soccer field, beach or golf course)(Table 2). Squat down and crouch into a ball, keeping your feet together to avoid step voltage. Tuck your head to your chin and place your hands over your ears.[19,20]

Treatment of the lightning victim

Treatment of the lightning victim is not complicated. The victim carries no residual current and can be approached safely. Those who show any sign of life after a strike have a good prognosis and can be expected to recover spontaneously. Individuals who appear dead should be treated with standard cardiopulmonary resuscitation techniques. The airway must be secured, ventilation established, and circulation restored. Ravitch was the first to report a survivor of lightning injury after prolonged resuscitation.[17]

Helen Taussig, MD

Helen Taussig was a brilliant pediatrician from Johns Hopkins University. She described death by lightning as a two-way street.[18] Her interest was aroused by two lightning cases involving three people and one fatality. Taussig was the first to recognize that those who show any movement after the strike will probably recover and emphasized that those who appear dead should be resuscitated first. These principles of treatment are sound and enduring.

Summary

In summary, lightning is dangerous. Lightning can kill. The best prevention is being observant and avoiding threatening weather. If caught, do not become a conductor and initiate an upward streamer in preparation for a direct hit. Do not stand next to a conductor. If you are struck, are lucky enough to survive and are conscious, your responsibility is to those around you.

About the author

Fred Weber, MD, JD, graduated from New Jersey Medical School, Newark, New Jersey, in 1974, and has since specialized in general and cardiothoracic surgery. In 1999, he received his law degree at Rutgers University School of Law in Camden, New Jersey. Weber is currently an attending surgeon at the Atlantic City Medical Center, in Atlantic City, Shore Memorial Hospital in Somers Point, Burdette Tomlin Hospital, and Cape May Court House Community Hospital in Toms River, New Jersey. He presented a session on lightning at AST's 35th Annual National Conference in Washington, DC, in May.

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Editor's note: For additional information on Helen Taussig, see *The Surgical Technologist,* July 1999; for Allesandro Volta, see December 2002.

CE Exam

246 AUGUST 2004 1 CE CREDIT IN CATEGORY 1

Lightning

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1. How did medieval Europeans attempt to ward off thunderstorms?

a. fly kites
b. ring church bells
c. light candles
d. all of the above

2. Which is true about Benjamin Franklin's experiment with lightning?

a. The key was hit by lightning.
b. Lightning struck the kite.
c. Sparks jumped from Franklin's hand to the key.
d. The key lit up with electricity.

3. A lightning rod is based on the principle that:

a. lightning seeks metal
b. lightning will strike the highest point
c. metal repels lightning
d. metal acts like a magnet for lightning

4. Lightning may be produced during:

a. erupting volcanoes
b. sandstorms
c. snowstorms
d. all of the above

5. The current in a lightning bolt may discharge up to ___ amperes to the receiving object.

a. 10^0
b. 10^3
c. 10^5
d. 10^7

6. ____ is the most common form of lightning injury.

a. direct hit
b. electric flash
c. side flash
d. step voltage

7. Injury by ___ is seldom fatal for humans.

a. direct hit
b. electric flash
c. side flash
d. step voltage

8. If an injured person was the highest conductor in the area of a lightning strike, he/she received a:

a. direct hit
b. electric flash
c. side flash
d. step voltage

9. Keraunoparalysis is:

a. anoxic ischemia from respiratory arrest
b. violent contraction of the uterus
c. temporary, pulseless, lower-extremity paralysis
d. rupture of the eardrum

10. A lightning victim that appears dead should be treated first:

a. for burns
b. with CPR
c. for residual current
d. none of the above

246 AUGUST 2004 1 CE CREDIT IN CATEGORY 1

Lightning

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3	❑	❑	❑	❑	8	❑	❑	❑	❑
4	❑	❑	❑	❑	9	❑	❑	❑	❑
5	❑	❑	❑	❑	10	❑	❑	❑	❑

Mark one box next to each number. Only one correct or best answer can be selected for each question.