LIGHTNING SAFETY

"If you can see it - flee it; if you can hear it - clear it."

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PERSONAL LIGHTNING SAFETY TIPS

Teach this safety slogan: "If you can see it - flee it; if you can hear it - clear it."

1.***PLAN*** *in advance your evacuation and safety measures.* When you first see lightning or hear thunder, activate your emergency plan. Now is the time to go to a building or a vehicle. Lightning often precedes rain, so don't wait for the rain to begin before suspending activities.

2.***IF OUTDOORS...****Avoid water. Avoid the high ground. Avoid open spaces.* Avoid all metal objects including electric wires, fences, machinery, motors, power tools, etc. Unsafe places include underneath canopies, small picnic or rain shelters, or near trees. Where possible, find shelter in a substantial building or in a fully enclosed metal vehicle such as a car, truck or a van with the windows completely shut. If lightning is striking nearby when you are outside, you should:

> *A.* ***Crouch down****.* Put feet together. Place hands over ears to minimize hearing damage from thunder.
>
> *B.* ***Avoid proximity*** (minimum of 15 ft.) to other people.

3.***IF INDOORS...*** *Avoid water. Stay away from doors and windows. Do not use the telephone. Take off head sets.* Turn off, unplug, and stay away from appliances, computers, power tools, & TV sets. Lightning may strike exterior electric and phone lines, inducing shocks to inside equipment.

4.***SUSPEND ACTIVITIES*** *for 30 minutes after the last observed lightning or thunder.*

5.***INJURED PERSONS*** *do not carry an electrical charge and can be handled safely.* Apply First Aid procedures to a lightning victim if you are qualified to do so. Call 911 or send for help immediately.

Know Your Emergency Telephone Numbers

LIGHTNING SAFETY FOR CAMPERS AND HIKERS

published in "The Outdoor Network", vol ix, no.2, 1998

by Richard Kithil, President
National Lightning Safety Institute

…treat lightning like a snake: if you see it or hear it take evasive measures…

1.0 Summary. Some unexpected situations present extreme danger - an angry fer-de-lance, a Class VI rapid, crumbling cornices and rotten rock - these can be perilous events. There is no defense for lightning's "bolt-out-of-the-blue" occasional strike. But for the most part, lightning safety is a risk management procedure. Early recognition of the lightning hazard, with an awareness of defensive options, will provide high levels of safety.

COMMON MISCONCEPTIONS AND MYTHS.

1. Lightning never strikes twice… *it strikes the Empire State Building in NYC some 22-25 times per year !*

2. Rubber tires or a foam pad will insulate me from lightning… *it takes about 10,000 volts to create a one inch spark. Lightning has millions of volts and easily can jump 10-20 feet !*

3. Lightning rods will protect my ropes course…*lightning rods are "preferential attachment points" for lightning. You do not want to "draw" lightning to any area with people nearby.*

4. We should get off the water when boating, canoeing or sailing…*tall trees and rocky outcrops along shore and on nearby land may be a more dangerous place.*

5. A cave is a safe place in a thunderstorm…*if it is shallow cave, or an old mine with metallics nearby, it can be a deadly location during lightning.*

2.0 Atmospheric Physics 101. At any one time around the planet, there are 2000 thunderstorms and 100 lightning strikes to earth per second. The frequency of lightning increases in the lower latitudes (closer to the equator), and in the higher altitudes (mountainous terrain). In the USA, central Florida experiences some 10-15 lightning strikes per sq. km./yr. The Rocky Mountain west has about two thirds this activity. Central Africa, parts of Southeast Asia, and the Latin American mountain regions can experience two to three times as much lightning as central Florida.

Lightning leaders from thunderclouds proceed in steps of tens of meters, electrifying ground-based objects as they approach the earth. Ground-based objects may launch lightning streamers to meet these leaders. Streamers may be heard (some say they "sound like bacon frying") and seen (we may notice our hair standing on end). A connecting leader-streamer results in a closed circuit cloud-to-ground lightning flash. Thunder accompanying it is the acoustic shock wave from the electrical discharge. Thus, thunder and lightning are associated with one another.

3.0 Flash/Bang. We all possess a first-class lightning detection device, built into our heads as standard equipment. By referencing the time in seconds from seeing the lightning (the FLASH, or "F") to hearing the accompanying thunder (the BANG, or "B"), we can range lightning's distance. A "F" to "B" of five seconds equals lightning distance being one mile away. A "F" to "B" of ten = two miles; a "F" to "B" of twenty = four miles; a "F" to "B" of thirty = six miles; etc.

New information shows successive, sequential lightning strikes (distances from Strike 1 to Strike 2 to Strike 3) can be some 6-8 miles apart. Taking immediate defensive actions is recommended when lightning is indicated within 6-8 miles. The next strike could be close enough to be an immediate and severe threat.

Lightning is a capricious and random event. It cannot be predicted with any accuracy. It cannot be prevented. Advanced planning in the form of a risk management program is the best defense for maximum safety.

4.0 Standard lightning defenses. The eco-tourism environment is different from situations where substantial buildings or fully enclosed metal vehicles are the recommended shelters. Lightning in remote terrain creates dangerous conditions. Follow these guidelines:

LIGHTNING SAFETY TIPS.
AVOID: Avoid water. Avoid all metallic objects. Avoid the high ground. Avoid solitary tall trees. Avoid close contact with others - spread out 15-20 ft. apart. Avoid contact with dissimilar objects (water & land; boat & land; rock & ground; tree & ground). Avoid open spaces. **SEEK:** Seek clumps of shrubs or trees of uniform height. Seek ditches, trenches or the low ground. Seek a low, crouching position with feet together with hands on ears to minimize acoujstic shock from thunder. **KEEP:** Keep a high level of safety awareness for thirty minutes after the last observed lightning or thunder.

5.0 Medical treatment and symptoms. Treat the apparently dead first. Immediately administer CPR to restore breathing. Eighty percent of lightning strike victims survive the shock. Lightning strike victims do not retain an electric charge and are safe to handle. Common lightning aftereffects include impaired eyesight and loss of hearing. Electrical burns should be treated as other burns.

LIGHTNING SAFETY FOR OUTDOOR SPORTS EVENTS

Practice and training increase recreation performance. Similarly, preparedness can reduce the risk of the lightning hazard. Lightning is the most frequent weather hazard impacting athletics events. Baseball, football, lacrosse, skiing, swimming, soccer, tennis, track and field events...all these and other outdoor sports have been visited by lightning.

Education is the single most important means to achieve lightning safety. A lightning safety program should be implemented at every facility. The following steps are suggested:

1. A responsible person should be designated to monitor weather conditions. Local weather forecasts - from The Weather Channel, NOAA Weather Radio, or local TV stations - should be observed 24 hours prior to athletic events. An inexpensive portable weather radio is recommended for obtaining timely storm data.

2. Suspension and resumption of athletic activities should be planned in advance. Understanding of SAFE shelters is essential. SAFE evacuation sites include:
a. Fully enclosed metal vehicles with windows up.
b. Substantial buildings.
c. The low ground. Seek cover in clumps of bushes.

3. UNSAFE SHELTER AREAS include all outdoor metal objects like flag poles, fences and gates, high mast light poles, metal bleachers, golf cars, machinery, etc. AVOID trees. AVOID water. AVOID open fields. AVOID the high ground.

4. Lightning's distance from you is easy to calculate: if you hear thunder, it and the associated lightning are within auditory range…about 6-8 miles away. The distance from Strike A to Strike B also can be 6-8 miles. Ask yourself why you should NOT go to shelter immediately. Of course, different distances to shelter will determine different times to suspend activities. A good lightning safety motto is:

If you can see it (lightning) flee it; if you can hear it (thunder), clear it.

5. If you feel your hair standing on end, and/or hear "crackling noises" - you are in lightning's electric field. If caught outside during close-in lightning, immediately remove metal objects (including baseball cap), place your feet together, duck your head, and crouch down low in baseball catcher's stance with hands on knees.

6. Wait a minimum of 30 minutes from the last observed lightning or thunder before resuming activities.

7. People who have been struck by lightning do not carry an electrical charge and are safe to handle. Apply first aid immediately if you are qualified to do so. Get emergency help promptly.

LIGHTNING SAFETY AT SWIMMING POOLS

(Applies to Indoor and Outdoor Pools)

Lightning's behavior is random and unpredictable. We recommend a very conservative attitude towards it. Preparedness and quick responses are the best defenses towards the lightning hazard.

Swimming pools are connected to a much larger surface area via underground water pipes, gas lines, electric and telephone wiring, etc. Lightning strikes to the ground anywhere on this metallic network may induce shocks elsewhere.

The National Lightning Safety Institute recommends the following swimming pool safety procedures:

1. Designate a responsible person as the weather safety lookout. That person should keep an eye on the weather. Use a "weather radio" or the Weather Channel or other TV program to obtain good localized advanced weather information.
2. When thunder and/or lightning are first noticed, use the Flash-To-Bang (F-B) method to determine its' rough distance and speed. This technique measures the time from seeing lightning to hearing associated thunder. For each five seconds from F-B, lightning is one mile away. Thus, a F-B of 10 = 2 miles; 15 = 3 miles; 20 = 4 miles; etc. At a F-B count of thirty, the pool should be evacuated. People should be directed to safe shelter nearby.
3. Pool activities should remain suspended until thirty minutes after the last thunder is heard. The distance from Strike A to Strike B to Strike C can be some 5-8 miles away. And it can strike much farther away. Why take a chance with lightning?

VEHICLES AND LIGHTNING

What happens when lightning strikes a vehicle? The answer, gleaned from anecdotal observations, is all the way from "nothing" to "Wow ! What a mess…my car is a disaster."

Electrically speaking, at lightning's higher frequencies, currents are carried mostly on the outside of conducting objects. A thick copper wire or a hollow-wall metal pipe will carry most of the lightning on outer surfaces. This phenomenon is called Skin Effect. The same holds true for lightning when it strikes metal vehicles: the outer surface carries most of the electricity. The persons inside this steel box can be likened to protected by a partial Faraday Cage.

But, consistent with lightning's capricious nature, situations alter results. Is the car dry: one effect? Is it wet: another effect? If the car made of fiberglass (a poor conductor) or is it a convertible, Skin Effect principles may not work. [Corvette and Saturn owners please note.]

Some general recommendations include:

1. Personal Safety Issues: Reported incidents and related injuries make it clear that a person inside a fully enclosed metal vehicle must not be touching metallic objects referenced to the outside of the car. Door and window handles, radio dials, CB microphones, gearshifts, steering wheels and other inside-to-outside metal objects should be left alone during close-in lightning events. We suggest pulling off to the side of the road in a safe manner, turning on the emergency blinkers, turning off the engine, putting one's hands in one's lap, and waiting out the storm.
2. Heavy Equipment: Backhoes, bulldozers, loaders, graders, scrapers, mowers, etc. which employ an enclosed rollover systems canopy (ROPS) are safe in nearby electrical storms. The operator should shut down the equipment, close the doors, and sit with hands in lap, waiting out the storm. In no circumstances, during close-in lightning, should the operator attempt to step off the equipment to ground in an attempt to find another shelter. Very dangerous Step Voltage and Touch Voltage situations are created when a "dual pathway to ground" is created. Lightning voltages will attempt to equalize themselves, and they may go through a person in order to do so.
   Smaller equipment without ROPS is not safe. Small riding mowers, golf cars, utility wagons are examples. Rubber tires provide zero safety from lightning. After all, lightning has traveled for miles through the sky: four of five inches of rubber is no insulation whatsoever. People should safely abandon this machinery and get into a safe shelter.
3. School buses. Metal buses are good Faraday Cages. Make sure all windows are closed and the "hands on laps" rule is observed. Pull over and wait out the storm.
4. Damage. Reported damage to vehicles includes pitting, arcing, burning on both ext3erior and interior places. See the below photographs, courtesy of Mr. Brown, of his Jeep Cherokee which was struck by lightning. Cases have been reported of total destruction of vehicle wiring, and associated electrical and electronic systems. Cases from police departments report bad burns to the hands and mouth where officers were using radio microphones when their vehicles were struck. Cases describe total blow-out of all four tires in passenger cars. A video in our NLSI library shows a station wagon being struck by lightning in a heavy rain storm, with no damage whatsoever occurring.

Strike near

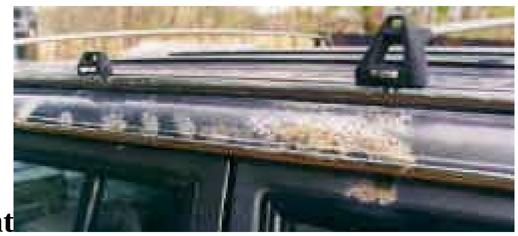
hatchback

close-up or strike

strike at

roof

roof strike closer to

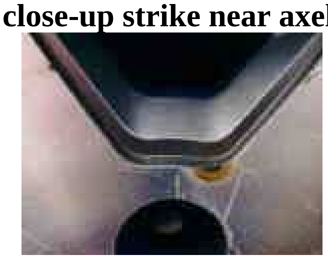


front

close-up

strike on wheel

close-up strike near axel



Are you interested in a CD-ROM collection of lightning photographs? NLSI is publishing a collection of high quality photographs for teachers, speakers and weather enthusiasts. Please let us know of your interest

Boating-Lightning Protection

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This document was extracted from the National Ag Safety Disc Safety Resource Directory.
This information is current as of Sept 1998.

"One minute the fisherman was sitting atop his elevated seat aboard his boat. The next minute he was dead--the victim of a lightning bolt."

This was the lead paragraph in a recent Florida newspaper article. These accidents can and do happen--and yet they need not.

Florida has more thunderstorms--and thus, more lightning strikes--than any other state (see Figure 1). Only three states have a higher death rate from lightning than Florida, and no state has more deaths or injuries.

Florida averages more than ten deaths and thirty injuries from lightning per year. Approximately fifty percent of the deaths and injuries occur to individuals involved in recreational activities, and nearly forty percent of those are water-related: boating, swimming, surfing, and others.

Those who enjoy Florida's waters certainly should understand the phenomena of thunderstorms--lightning and the precautions to take in order to keep these activities pleasurable--and how to prevent tragedy.

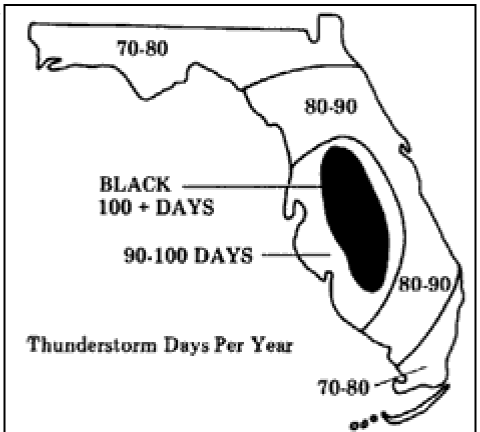

Figure 1

LIGHTNING PHENOMENA

Most lightning strikes occur in the afternoon--70 percent between noon and 6:00 p.m. As the air temperatures warm, evaporation increases. This warm, moisture-laden air rises and evaporates, forming fluffy cumulus clouds. As more moisture accumulates, the clouds darken and change into cumulus nimbus clouds--thunderstorm clouds--frequently, with a flattened top or anvil shape, reaching to 40,000 feet or more (see Figure 2).

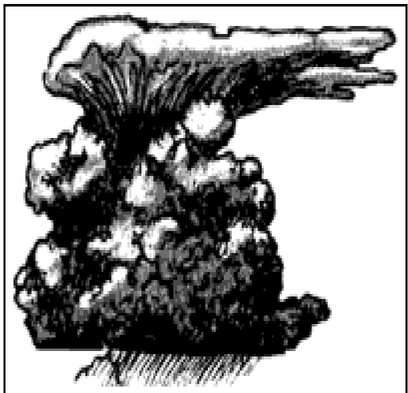
Figure 2

The upper portion of the cloud develops a positive electrical charge, the lower level a negative electrical charge. The air, because it is a poor conductor of electricity, restricts the regular flow of electricity between these, attracting electrical charges.

While this phenomenon is occurring in the clouds, a similar phenomenon is occurring on the surface.

Negative charges repel negative charges and attract positive charges. So, as a thunder cloud passes overhead, a concentration of positive charges accumulates in and on all objects below the cloud. Since these positive charges are attempting to reach the negative charge of the cloud, they tend to accumulate at the top of the highest object around. On a boat that may be the radio antenna, the mast, a fishing rod, or even you! The better the contact an object has with the water, the more easil these positive charges can enter the object and race upward toward the negative charge in the bottom of the cloud.

Lightning occurs when the difference between the positive and negative charges, the electrical potential, becomes great enough to overcome the resistance of the insulating air and to overcome the resistance of the insulating air and to force a conductive path between the positive and negative charges. This potential may be as much as 100 million volts. To help you understand the magnitude of this voltage, the voltage needed in an automobile to cause a spark plug to fire is only 15 to 200 vol s! And the spark plug gap is but a fraction of an inch!

Lightning strikes represent a flow of current from negative to positive, in most cases, and may move from the bottom to the top of a cloud, from cloud to cloud, or most-feared, from cloud to ground (see Figure 3). And when the lightning does strike, it will most often strike the highest object in the immediate area. On a body of water, that highest object is a boat. Once it strikes the boat, the electrical charge is going to take the most direct route to the water where the electrical charg will dissipate in all directions.

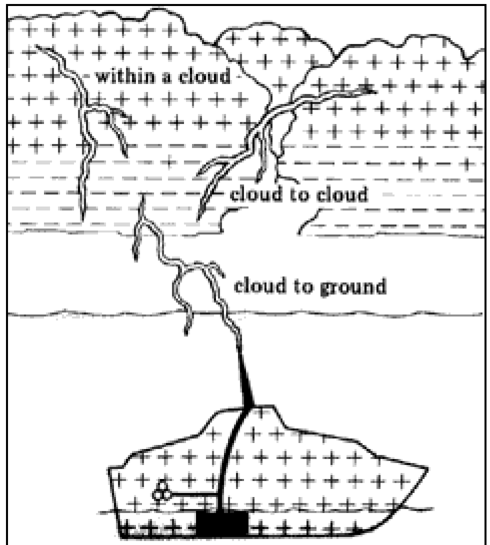

Figure 3

Let's consider a few possibilities. Lightning strikes the ungrounded radio antenna on your boat. The metal antenna carries the electrical charge to the radio, which does not have a good conductor to the water. Your hand is on the radio, or on metal connected to the radio. Your feet are on a wet surface, which is in contact with metal which extends through the hull of the boat to the water. Your body may then become the best conductor for the electrical charge.

A second example is a sailboat. Lightning strikes the mast. The electrical current follows the mast or wire rope to your hands, through your body to the wet surface, and then through the hull to the water.

Or, while operating a motor boat, the lightning strikes you, passes through your body to the motor, and then to the water.

Or, sitting in your aluminum or fiberglass rowboat, you are holding a graphite (a good electrical conductor) fishing rod. The rod is struck by lightning. The electrical charge passes through the rod, your body, then to the boat to the water.

In all four examples you could be seriously injured. You could be dead.

You need not even be in contact with the components of the boat struck by lightning. Unless the components of the boat which could conduct electricity are bonded together and are adequately grounded, there could be side flashes. A side flash occurs when the electrical charge jumps from one component to another seeking a better path to ground. You might be that "better path."

MINIMIZE LIGHTNING STRIKE DAMAGE

Do not become a lightning target. Preferably stay off, and definitely get off, the water whenever weather conditions are threatening. Check the weather. The National Weather Service (NWS) provides a continuously updated weather forecast for Florida and its coastline via the VHF/FM channels WX1 (162.550 MHz), WX2 (162.400 MHz), WX3 (162.475 MHz). Never go boating without listening to this service. Their short-term forecasts are quite accurate, but small localized storms might not be reported. Therefore, it is important that boaters learn to read the weather.

Watch for the development of large well-defined rising cumulus clouds. Once they reach 30,000 feet the thunderstorm is generally developing. Now is the time to head for shore. As the clouds become darker and more anvil-shaped, the thunderstorm is already in progress.

Watch for distant lighting. Listen for distant thunder. You may hear the thunder before you can see the lightning on a bright day. Seldom will you hear thunder more than five miles from its source. That thunder was caused by lightning 25 seconds earlier. The sound of thunder travels at one mile per five seconds (see Figure 4).

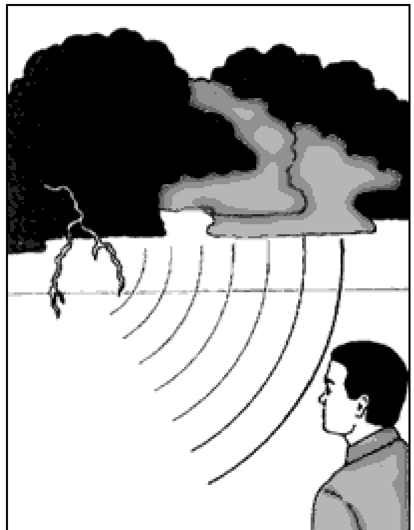

Figure 4

You are two miles from shore. The thunderstorm which is now five miles away is traveling in your direction at 20 miles per hour, which means it could be overhead within 15 minutes. Can you reach shore--two miles away--and seek shelter within that time? You better move!

LIGHTNING-PROTECTED BOATS

There is no such thing as lightning-proof boats, only lightning-protected boats. All-metal ships are rarely damaged, and injuries or deaths are uncommon. These ships are frequently struck, but the high conductivity of the large quantities of metal, with hundreds of square yards of hull in direct contact with the water, causes rapid dissipation of the electrical charge.

But small boats are seldom made of metal. Their wood and fiberglass construction do not provide the automatic grounding protection offered by metal-hulled craft. Therefore, when lightning strikes a small boat, the electrical current is searching any route to ground and the human body is an excellent conductor of electricity!

Today's fiberglass-constructed small boats, especially sailboats, are particularly vulnerable to lightning strikes since any projection above the flat surface of the water acts as a potential lightning rod. In many cases, the small boat operator or casual weekend sailor is not aware of this vulnerability to the hazards of lightning. These boats can be protected from lightning strikes by properly designed and connected systems of lightning protection. However, the majority of these boats are not so equipped.

Lightning protection systems do not prevent lightning strikes. They may, in fact, increase the possibilities of the boat being struck. The purpose of lightning protection is to reduce the damage to the boat and the possibility of injuries or death to the passengers from a lightning strike.

If you are considering the purchase of a new or used boat, determine if it is equipped with a properly designed and installed lightning protection system. Such a system is generally more effective and less costly than a system installed on a boat after it has been constructed.

LIGHTNING PROTECTION SYSTEM

The major components of a lightning protection system for a boat are an air terminal, main conductor, and a ground plate. Secondary components are secondary conductors, lightning arrestors, lightning protective gaps, and connectors (see Figure 5).

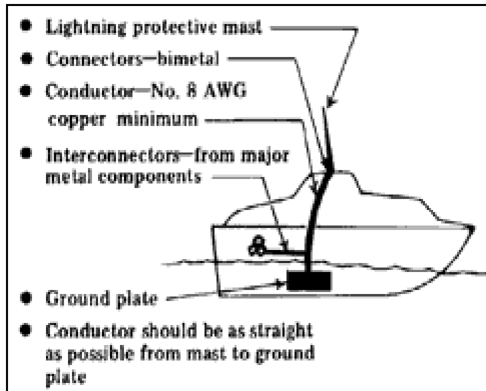

Figure 5

The mast, if constructed of conductive material, a conductor securely fastened to the mast and extending six inches above the mast and terminating in a receiving point, or a radio antenna can serve as the air terminal.

The main conductor carries the electrical current to the ground. Flexible, insulated compact-stranded, concentric-lay-stranded or solid copper ribbon (20- gauge minimum) should be used as the main conductor.

The ground plate, and that portion of the conductor in contact with the water, should be copper, monel or navel bronze. Other metals are too corrosive. The secondary conductors ground major metal components of the boat to the main conductor. However, the engine should be grounded directly to the ground plate.

Lightning arrestors and lightning protective gaps are used to protect radios and other electronic equipment which are subject to electrical surges.

The connectors must be able to carry as much electrical current as other components of the system. Further, the connections must be secure and noncorrosive.

On a large power boat or sailboat, a properly designed and grounded antenna could provide a cone of protection. Presently, however, the vast majority of the radio antenna is totally unsuitable for lightning protection. This is also true of the wires feeding the antenna. If the antenna is not properly grounded, it may result in injury or death and cause considerable property damage.

Sailboats with portable masts, or those with the mast mounted on the cabin roof, are particularly vulnerable as they are usually the least protected as far as grounding or bonding is concerned.

Ideally, an effective ground plate should be installed on the outside of all boats when the hulls are constructed. Unfortunately, this is not often done. Such a ground plate would help manufacturers design safer lightning protection systems for the boats.

LIGHTNING PROTECTION CODE

The National Fire Protection Association, Lightning Protection Code, suggests a number of ways in which the boater can protect his boat and minimize damage if the boat is struck or is in the vicinity of a lightning strike. These suggestions are summarized below:

- A lightning protective mast will generally divert a direct lightning strike within a cone-shaped radius two times the height of the mast. Therefore, the mast must be of sufficient height to place all parts of the boat within this cone-shaped zone of protection (see Figure 6).
- The path from the top of the mast to the "water" ground should be essentially straight. Any bends in the conductor should have a minimum radius of eight inches (see Figure 7).

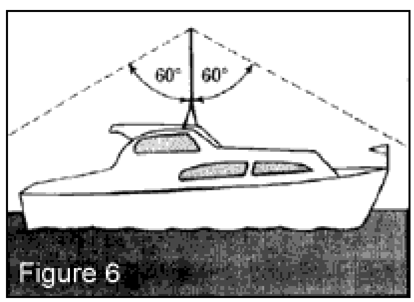

Figure 6

- To provide adequate protection, the entire circuit from the top of the mast to the "water" ground should have a minimum conductivity equivalent to a No. 8 AWG copper conductor. If a copper cable is used, the individual strands should be no less than No. 17 AWG. Copper metal or strips should be a minimum of No. 20 AWG.

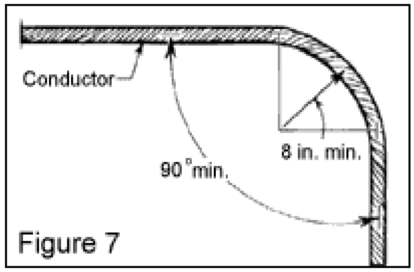

Figure 7

- Major metal components aboard the boat, within six feet of the lightning conductor, should be interconnected with the lightning protective system with a conductor at least equal to No. 8 AWG copper. It is preferable to ground the engine directly to the ground plate rather than to an intermediate point in the lightning protection system.
- If the boat's mast is not of a lightning protective design, the associated lightning or grounding connector should be essentially straight, securely fastened to the mast, extended at least 6 inches above the mast and terminate in a sharp receiving point.
- The radio antenna may serve as a lightning protective mast, provided it and all the grounding conductors have a conductivity equivalent to No. 8 AWG copper and is equipped with lightning arrestors, lightning protective gaps, or means for grounding during electrical storms. Most antennas do not meet these requirements. The height of the antenna must be sufficient to provide the cone-shaped zone of protection.
- Antennas with loading coils are considered to end at a point immediately below the loading coil unless this coil is provided with a protective device for by-passing the lightning current. Nonconducting antenna masts with spirally wrapped conductors are not suitable for lightning protection purposes. Never tie down a whip-type antenna during a storm if it is a part of the lightning protection system. However, antennas and other protruding devices, not part of the lightning protection sys em, should be tied down or removed during a storm.
- All materials used in a lightning protective system should be corrosion-resistant. Copper, either compact-stranded, concentric-lay-stranded or ribbon, is resistant to corrosion.
- The "water" ground connection may be any submerged metal surface with an area of at least one square foot. Metallic propellers, rudders or hull will be adequate.
- On sailboats, all masts, shrouds, stays, preventors, sail tracks and continuous metallic tracks on the mast or boom should be interconnected (bonded) and grounded.
- Small boats can be protected with a portable lightning protection system. This would consist of a mast of sufficient height to provide the cone of protection connected by a flexible copper cable to a submerged ground plate of at least one square foot. When lightning conditions are observed in the distance, the mast is mounted near the bow and the ground plate dropped overboard. The connecting copper cable should be fully extended and as straight as possible. The boaters should stay low in the middle or aft portion of the boat.

WHEN CAUGHT IN A STORM

Thunderstorms in Florida and over its coastal waters are frequently unpredictable. Even with the best weather reports, along with constant and accurate observations of climatic conditions, boaters can still be caught in open waters in a thunderstorm. Then, with or without a lightning protective system, it is critical to take additional safety precautions to protect the boat's personnel. These precautions during a thunderstorm are:

- Stay in the center of the cabin if the boat is so designed. If no enclosure (cabin) is available, stay low in the boat. Don't be a "stand-up human" lightning mast!
- Keep arms and legs in the boat. Do not dangle them in the water.
- Discontinue fishing, water skiing, scuba diving, swimming or other water activities when there is lightning or even when weather conditions look threatening. The first lightning strike can be a mile or more in front of an approaching thunderstorm cloud.
- Disconnect and do not use or touch the major electronic equipment, including the radio, throughout the duration of the storm.
- Lower, remove or tie down the radio antenna and other protruding devices if they are not part of the lightning protection system.
- To the degree possible, avoid making contact with any portion of the boat connected to the lightning protection system. Never be in contact with two components connected to the system at the same time. Example: The gear levers and spotlight handle are both connected to the system. Should you have a hand on both when lightning strikes, the possibility of electrical current passing through your body from hand to hand is great. The path of the electrical current would be directly through your heart--a very deadly path!
- It would be desirable to have individuals aboard who are competent in cardiopulmonary resuscitation (CPR) and first aid. Many individuals struck by lightning or exposed to excessive electrical current can be saved with prompt and proper artificial respiration and/or CPR. There is no danger in touching persons after they have been struck by lightning.
- If a boat has been, or is suspected of having been, struck by lightning, check out the electrical system and the compasses to insure that no damage has occurred.

SUMMARY

- Boating in Florida's waters is an enjoyable activity for many people. Keep it that way!
- Listen to the weather reports! Learn to read the weather conditions. Heed these reports and the conditions. Stay off or get off the water when weather conditions are threatening.
- Install and/or maintain an adequate lightning protection system. Have it inspected regularly. Follow all safety precautions should you ever be caught in a thunderstorm. By using good judgement, it is less likely that first aid or CPR will be needed while boating.

REFERENCES

- National Fire Codes. Lightning Protection Code--NFPA 78; Fire Protection Standard for Motor Craft--NFPA 302, 14. National Fire Protection Association, Batterymarch Park, Quincy, MA 02269.
- Standards and Recommended Practices for Small Craft. Standard E-4, Lightning Protection. American Boat and Yacht Council, P.O. Box 806, Amityville, NY 11701.
- Sitarz, Walter A. Boating Safety--Thunderstorms (MAP-5), Florida Sea Grant College Program, University of Florida, Gainesville, FL 32605.

ACKNOWLEDGEMENT

This publication, "Boating/Lightning Protection" (SGEB-7) replaces "Boating Safety/Thunderstorms" (MAP-5), a Florida Sea Grant bulletin published December 1978 and is acknowledged as a source of information for this bulletin

Lightning Safety Group Recommendations

ABSTRACT

On average, lightning causes more casualties annually in the US than any other storm related phenomena, except floods. Many people incur injuries or are killed due to misinformation and inappropriate behavior during thunderstorms. A few simple precautions can reduce many of the dangers posed by lightning. In order to standardize recommended actions during thunderstorms, a group of qualified experts from various backgrounds collectively have addressed personal safety in regard to lightning, based on recently improved understanding of thunderstorm behavior.

This "Lightning Safety Group" (LSG) first convened during the 1998 American Meteorological Society Conference in Phoenix, Arizona to outline appropriate actions under various circumstances when lightning threatens.

KEY CONCLUSIONS

The seemingly random nature of thunderstorms cannot guarantee the individual or group absolute protection from lightning strikes, however, being aware of, and following proven lightning safety guidelines can greatly reduce the risk of injury or death.

The individual is ultimately responsible for his/her personal safety and has the right to take appropriate action when threatened by lightning. Adults must take responsibility for the safety of children in their care during thunderstorm activity.

Safer Locations during Thunderstorms and Locations to Avoid

- No place is absolutely safe from the lightning threat, however, some places are safer than others.
- Large enclosed structures (substantially constructed buildings) tend to be much safer than smaller or open structures.
- The risk for lightning injury depends on whether the structure incorporates lightning protection, construction materials used, and the size of the structure (see NFPA 780, Appendix E & H).
- In general, fully enclosed metal vehicles such as cars, trucks, buses, vans, fully enclosed farm vehicles, etc. with the windows rolled up provide good shelter from lightning. Avoid contact with metal or conducting surfaces outside or inside the vehicle.

  AVOID being in or near:

  High places and open fields, isolated trees, unprotected gazebos, rain or picnic shelters, baseball dugouts, communications towers, flagpoles, light poles, bleachers (metal or wood), metal fences, convertibles, golf carts, water (ocean, lakes, swimming pools, rivers, etc.).

When inside a building AVOID:

Use of the telephone, taking a shower, washing your hands, doing dishes, or any contact with conductive surfaces with exposure to the outside such as metal door or window frames, electrical wiring, telephone wiring, cable TV wiring, plumbing, etc.

Safety Guidelines for Individuals

Generally speaking, if an individual can see lightning and/or hear thunder he/she is already at risk. Louder or more frequent thunder indicates that lightning activity is approaching, increasing the risk for lightning injury or death. If the time delay between seeing the flash (lightning) and hearing the bang (thunder) is less than 30 seconds, the individual should be in, or seek a safer location (see Safer Locations during Thunderstorms and Locations to Avoid). Be aware that this method of ranging has severe limitations in part due to the difficulty of associating the proper thunder to the corresponding flash.

High winds, rainfall, and cloud cover often act as precursors to actual cloud-to-ground strikes notifying individuals to take action. Many lightning casualties occur in the beginning, as the storm approaches, because people ignore these precursors. Also, many lightning casualties occur after the perceived threat has passed. Generally, the lightning threat diminishes with time after the last sound of thunder, but may persist for more than 30 minutes. When thunderstorms are in the area but not overhead, the lightning threat can exist even when it is sunny, not raining, or when clear sky is visible.

When available, pay attention to weather warning devices such as NOAA weather radio and/or credible lightning detection systems, however, do not let this information override good common sense.

Considerations for Small Groups and/or when the Evacuation Time is less than Ten minutes

An action plan must be known in advance by all persons involved (see Important Components to an Action Plan, P.5). School teachers, camp counselors, lifeguards, and other adults must take responsibility for the safety of children in their care.

Local weather forecasts, NOAA weather radio, or the Weather Channel should be monitored prior to the outdoor event to ascertain if thunderstorms are in the forecast. Designate a responsible person to monitor forecasted weather as well as to observe on-site developments to keep everyone informed when potential threats develop.

Recognize that personal observation of lightning may not be sufficient; additional information such as a lightning detection system or additional weather information may be required to ensure consistency, accuracy, and adequate advance warning.

Even though technology and instrumentation have proven to be effective, they cannot guarantee safety. Instrumentation can be used to enhance warning during the initial stages of the storm by detecting lightning in relation to the area of concern. Advance notification of the storm's arrival should be used to provide additional time to seek safety. Detectors are also a valuable tool to determine the "All Clear" (last occurrence of lightning within a specified range), providing a time reference for safe resumption of activities.

Safety Guidelines for Large Groups and/or when the Evacuation Time is more than Ten minutes

An action plan must be known in advance by all persons involved (see Important Components to an Action Plan). Adults must take responsibility for the safety of children in their care.

Local weather forecasts, NOAA weather radio, or the Weather Channel should be monitored prior to the outdoor event to ascertain if thunderstorms are in the forecast. During the event, a designated responsible person should monitor site relative weather condition changes.

Personal observation of the lightning threat is not adequate; additional information including detecting actual lightning strikes and monitoring the range at which they are occurring relative to the activity is required to ensure consistency, accuracy, and adequate advance warning.

Even though technology and instrumentation have proven to be effective, they cannot guarantee safety. Instrumentation can be used to enhance warning during the initial stages of the storm by detecting lightning in relation to the area of concern. Advance notification of the storm's arrival should be used to provide additional time to seek safety. Detectors are also a valuable tool to determine the "All Clear" (last occurrence of lightning within a specified range), providing a time reference for safe resumption of activities.

When larger groups are involved the time needed to properly evacuate an area increases. As time requirements change, the distance at which lightning is noted and considered a threat to move into the area must be increased. Extending the range used to determine threat potential also increases the chance that a localized cell or thunderstorm may not reach the area giving the impression of a "false alarm".

Remember, lightning is always generated and connected to a thundercloud but may strike many miles from the edge of the thunderstorm cell. Acceptable downtime (time of alert state) has to be balanced with the risk posed by lightning. Accepting responsibility for larger groups of people requires more sophistication and diligence to assure that all possibilities are considered.

Important Components of an Action Plan

Management, event coordinators, organizations, and groups should designate a responsible, person(s) to monitor the weather to initiate the evacuation process when appropriate. Monitoring should begin days and even hours ahead of an event.

A protocol needs to be in place to notify all persons at risk from the lightning threat. Depending on the number of individuals involved, a team of people may be needed to coordinate the evacuation plan. Adults must take responsibility for the safety of children in their care.

Safer sites must be identified beforehand, along with a means to route the people to those locations. School buses are an excellent lightning shelter that can be provided (strategically placed around various locations) by organizers of outdoor events, with larger groups of people and larger areas, such as golf tournaments, summer day camps, swim meets, military training, scout groups, etc.

The "All Clear" signal must be identified and should be considerably different than the "Warning" signal.

The Action Plan must be periodically reviewed by all personnel and drills conducted.

Consider placing lightning safety tips and/or the action plan in game programs, flyers, score cards, etc., and placing lightning safety placards around the area. Lightning warning signs are effective means of communicating the lightning threat to the general public and raise awareness.

First Aid Recommendations for Lightning victims

Most lightning victims can actually survive their encounter with lightning, especially with timely medical treatment. Individuals struck by lightning do not carry a charge and it is safe to touch them to render medical treatment. Follow these steps to try to save the life of a lightning victim:

First: Call 911 to provide directions and information about the likely number of victims.

Response: The first tenet of emergency care is "make no more casualties". If the area where the victim is located is a high risk area (mountain top, isolated tree, open field, etc.) with a continuing thunderstorm, the rescuers may be placing themselves in significant danger.

Evacuation: It is relatively unusual for victims who survive a lightning strike to have major fractures that would cause paralysis or major bleeding complications unless they have suffered a fall or been thrown a distance. As a result, in an active thunderstorm, the rescuer needs to choose whether evacuation from very high risk areas to an area of lesser risk is warranted and should not be afraid to move the victim rapidly if necessary. Rescuers are cautioned to minimize their exposure to lightning as much as possible.

Resuscitation:

If the victim is not breathing, start mouth to mouth resuscitation. If it is decided to move the victim, give a few quick breaths prior to moving them. Determine if the victim has a pulse by checking the pulse at the carotid artery (side of the neck) or femoral artery (groin) for at least 20-30 seconds. If no pulse is detected, start cardiac compressions as well. In situations that are cold and wet, putting a protective layer between the victim and the ground may decrease the hypothermia that the victim suffers which can further complicate the resuscitation.

In wilderness areas and those far from medical care, prolonged basic CPR is of little use: the victim is unlikely to recover if they do not respond within the first few minutes. If the pulse returns, the rescuer should continue ventilation with rescue breathing if needed for as long as practical in a wilderness situation. However, if a pulse does not return after twenty t o thirty minutes of good effort, the rescuer should not feel guilty about stopping resuscitation.

CONCLUSION

Avoid unnecessary exposure to the lightning threat during thunderstorm activity. Follow these safety recommendations to reduce the overall number of lightning casualties. An individual ultimately must take responsibility for his or her own safety and should take appropriate action when threatened by lightning. School teachers, camp counselors, coaches, lifeguards, and other adults must take responsibility for the safety of children in their care. A weather radio and the use of lightning detection data in conjunction with an action plan are prudent components of a lightning warning policy, especially when larger groups and/or longer evacuation times are involved.

SMALL SHELTERS AND SAFETY FROM LIGHTNING

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1. Introduction
Small open shelters are common on golf courses, athletic fields, parks, roadside picnic areas, schoolyards, and elsewhere. Many of these shelters are built to protect against rain or sun, not lightning. What can be done to minimize risk for people inside them under direct and nearby lightning strike conditions? Although there is no such thing as a lightning-proof small outdoor shelter, a properly designed and installed lightning protection system may make a difference. Sometimes the difference is between life and death.
2. General Information on Lightning Protection of Structures
Basically, a lightning protection system for an ordinary structure includes (1) air terminals, (2) down conductors, and (3) ground terminals. These three elements of the system must form a continuous conductive path (actually at least two paths) for lightning current, with all connections between the elements typically being accomplished by bolting or welding. The function of such a system is to intercept lightning and safely direct its current to ground. If a structure has a metal roof and the thickness of this roof is 3/16 in. or greater, the roof can play the role of the air terminals. The structural metal framework (including metal support posts) can play the role of down conductors if it is electrically continuous. Sometimes the ground terminal is made of a buried bare conductor wire encircling the structure (also called a loop conductor). Such grounding is beneficial in that it additionally serves to intercept ground surface or underground electrical arcs that may develop toward the structure from a nearby object (such as a tree) struck by lightning. The closer the structure approaches a Faraday cage, the better its interior is protected from lightning effects.
3. Shelters Unprotected from Lightning
In the absence of the three-element lightning protection system described above, the structure should be considered unprotected from lightning. Small shelters without lightning protection should be avoided during thunderstorms, particularly if they are located in high areas (such as on a golf course hill) or near a tree or a small group of trees dominating the area. If there is no better choice only shelters in relatively low areas should be used, preferably surrounded by a large number of trees of approximately the same height. A disclaimer statement should be posted on each unprotected shelter by the organization running the outdoor facility. Such a disclaimer should include a clear statement that the structure does not offer protection from lightning. It would also be appropriate here to include a concise guide for personal safety from lightning.
4. Shelters Protected from Lightning
A small shelter equipped with a properly designed and installed lightning protection system provides reasonable protection from lightning. It is essential, however, that a person inside the shelter does not touch any element of the lightning protection system and tries to position himself or herself at approximately the same distance from all down conductors. . A small shelter, even one protected as described here, should be viewed as the last resort option. Better protected shelters such as large buildings and all metal vehicles should be sought instead when possible.
A properly protected small shelter should have at least one air terminal (or equivalent), at least two down conductors on two diagonally opposite sides of the structure (four down conductors provide better lightning protection than two conductors), and ground terminals connected to the down conductors. Two designs for ground terminals in common soils can be recommended. The first one (see Fig. 1A) includes vertical ground rods (not less than ½ in. in diameter and not less than 8 feet long), at least one for each down conductor, interconnected by a loop conductor buried a few inches under the earth's surface. The second design for ground terminals (see Fig. 1B) includes horizontal conductors, at least one for each down conductor, buried at a depth of not less than 2 ½ feet and extending away from the shelter for at least ten feet beyond the roof dripline. It also employs a loop conductor. In both designs, we suggest the addition of a buried metal mesh within the shelter perimeter (rebar of the steel-reinforced concrete floor can be used too), connected to the ground terminals. A floor made of asphalt, rock or wood may further reduce the lightning hazard for people inside the shelter.
An alternative lightning protection system consists of grounded overhead wires suspended above the shelter on separate poles. The loop conductor mentioned above can be employed here too.
Rod-type air terminals are usually solid (minimum diameter 3/8 in.) or tubular (minimum diameter 5/8 in., minimum wall thickness 0.033 in.) copper rods at least ten inches high. Air terminals should be placed on ridges of pitched roofs and around perimeter of flat roofs or gently sloping roofs at intervals not exceeding 20

ft. The distance from each end of the ridge to the nearest air terminal should not exceed 2 ft. Down conductors are usually in the form of stranded cables (minimum 17 AWG copper or 14 AWG aluminum). No bend of a conductor should form an included angle of less than 90 degrees, nor should the radius of a bend be less than 8 in. Down conductors should be covered with insulating material resistant to impact and climate conditions to a height of at least 8 feet above ground. Air terminals and down conductors can also be made of aluminum. Vertical ground rods are typically made of copper-clad steel or solid copper, and horizontal conductors are typically stranded copper cables. Aluminum conductors should not be closer than three feet to the earth for corrosion reasons. Bimetallic connectors should be employed to join aluminum conductors to copper conductors.

It is generally possible to find a local company that installs lightning protection on buildings and trees. Look in the Yellow Pages for "Lightning Protection" and "Electrical Contractors." These companies should follow the "Standard for the Installation of Lightning Protection Systems" (NFPA 780), which includes a one-paragraph section devoted specifically to shelters (Section E-1.1, P.32). The Underwriters Laboratories guideline is similar and is called "Installation Requirements for Lightning Protection Systems - UL96A."

References:

1. NFPA 780, Standard for the Installation of Lightning Protection Systems (1997), National Fire Protection Association, Quincy MA.

2. Installation Requirements for Lightning Protection Systems - UL96A (1998), Underwriters Laboratories, Northbrook IL.

3. NFPA 70 (1999), National Electrical Code, National Fire Protection Association, Quincy MA.

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Lightning Injury Facts

Myths, Miracles, and Mirages
Mary Ann Cooper, MD

An article about *both* lightning and electrical injuries

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Injuries from man-made, generated, or "technical" electricity have been reported for only about 150 years; but injuries from lightning must surely predate written records. Depictions of lightning affecting people or events appear in writings and drawings from almost every ancient religion. Although such an occurrence was sometimes interpreted as a positive sign of blessing, more often it was seen as a sign of the god's warning or vengeance.

Priests, the earliest astronomers and meteorologists, became proficient at weather prediction, interpreting changes in weather as omens of good or bad fortune, sometimes to the advantage of their political mentors. Observations of lightning and other natural phenomena were often used to decide matters of state, the scheduling of battles or other events. Lightning from the east was usually seen as a good omen. This is reasonable because it is probably the end of a storm. Lightning from the west was ominous, but also meant a storm was probably approaching.

Over the centuries, superstitions and myths have grown up about lightning that include avoidance, protection, the types of injuries, and their treatment. In this article, I cannot be all inclusive but will attempt to discuss some of the more common ideas, particularly those related to the medical field, as well as some myths about injuries from the newer form of injury by generated electricity. I will leave discussion of appropriate lightning and electrical protection to those who are more knowledgeable in these areas and have been kind enough to write articles for these issues of Seminars.

Disclaimer: This article is not meant to be a scientific treatise but to be entertaining and perhaps enlightening (no pun intended since it is a different spelling). I am giving my best reply to these myths based on a composite of 20 years of experience, reading, and discussions with patients, families, and professionals from many areas of expertise. I have had to reverse myself enough times since I began investigating lightning injuries in 1977 to ever claim that I know all there is to know about it and will be the first to encourage research into any of these questions. It seems that everyone has a lightning story. I hope you will have fun reading this and investigating these areas for yourself. Lightning and electrical injuries are fascinating and the myths that have grown up about them are myriad. I invite you to collect your own. If you will be kind enough to send them to me, I will forever be in your debt.

CLASSIFICATION OF MYTHS

Beliefs have grown up about these injuries that I will arbitrarily divide into the following groups:
1. Occurrence and demographics
2. Effects of the strike/types if injuries
   a. Positive effects
   b. Negative effects
3. Signifigance of the strike
4. Prevention/Avoidance

OCCURRENCE AND DEMOGRAPHICS

"I will probably never treat a victim of a lightning injury in my practice because they are so rare. "

False. It is true that injuries from electrical injuries are probably more common than lightning injuries, especially when low-voltage injuries are included. Best estimates place lightning injuries at somewhere between several hundred and a few thousand per yearn 4 It is common for the victims to avoid medical care initially, hoping that the symptoms will subside in a few hours or days. Most are not admitted to the hospital and thus do not become part of any state hospital admission databank. Lopez and Holle have done some of the best studies on the epidemiology of lightning injuries and I refer you to their articles in these issues and elsewhere. (5,6) It would be unusual to meet a neurologist who has not had at least one patient with complaints referable to an electrical event. Much research remains to be done into the best treatment, the differences between these groups, and long-term effects.

"I will probably never treat a victim of a lightning injury in my practice because no one lives to Tall about it."

False. In 1980, I published a study of collected literature and found only a 30% mortality.(7) Andrews (8) repeated the study a few years later and calculated it slightly differently at 20%. Both reviews would overestimate the mortality, as case reports will always be biased toward the more severe or interesting cases. Although Holle and Lopez report figures somewhat differently, my best guess on the mortality from lightning would be about 3 to 10% of all incidents. Projecting from numbers of between 75 and 150 reported deaths per year (and many do not get coded appropriately), there may be as many as 750 to 5000 injuries per year.

"Nowadays most lightning injuries occur on the golf course. "

False. Indeed, a large number are work-related. These include injuries to postal and construction workers and persons using telephones that have not been properly grounded. (5) The numbers of farmers injured has decreased farmers to work larger fields in better-protected vehicles. Injuries during recreation have increased. They occur to joggers, hikers, and campers, as well as golfers. In addition, a significant number of people are injured while participating in team sports.

"Some people can attract lightning."

Some have called themselves "human lightning rods," claiming that thunderstorms would change course to find them or that they had been struck multiple times. Given my experience with lightning victims, I must say that, although some may suffer little injury from a single strike, the majority have some type of sequela. When one claims to have been hit 20 or more times, the odds of being able to talk about it decrease logarithmically. Would any reasonable person not have enough sense to learn to avoid lightning after the first couple of hits?

"D'you know how many people are hit by lightning every year?"

EFFECTS OF LIGHTNING STRIKE/ELECTRIC SHOCK

These effects are what these two issues of Seminars in Neurology are all about: we have tried to address most of the questions that arise about electrical and lightning injuries, and the differences between lightning and electrical injuries and their treatment have been discussed in other articles.

Because so little has been studied in these injuries, it is often difficult to sort out the complaints that are real from those that are metaphysical, compensation-related, or due to normal aging. As discussed in the article by Engelstatter and Primeau, (9) a marginally compensated individual may see the injury as the precipitant for all subsequent problems in life. Although the physical and cognitive complaints are sometimes vague and often do not show on standardized testing, nevertheless, they present a consistent complex that is difficult to disbelieve after listening to them for 15 years from people who have nothing to gain from their disability. Even the complaints that we can objectify often have no good treatment, frustrating both the patient and the physician.

Among the claims of positive effects of lightning strike (and sometimes electrical injury) are the cures for persons who have been blind, deaf, or had serious illnesses. A few years ago there was a very well-publicized case of an elderly gentleman who was cured of his blindness and deafness by a lightning strike. Those of us who were consulted on this knew that these were hysterical complaints suffered as a result of a truck accident many years before but forbade the press to quote us out of respect for the gentleman.

I have had one call from another gentleman who asked if lightning could cause "hyper sexuality" because after his lightning injury he could not seem to get enough sex. While there is a neurological injury that can cause hypersexuality, more commonly lightning and electrical injury causes impotence, as a result of either direct nerve or spinal cord injury or depression. There is one published claim of improved intelligence on psychological testing after a prolonged cardiac arrest in a pediatric patient. A woman in southern Illinois became psychic after suffering a lightning strike while asleep in bed. Reportedly, her powers have been used by police agencies in locating missing persons and solving cases.

If remissions or cures of serious illness have occurred, as some have claimed, praise God, and I am happy for them and will not dispute their conclusions, but I cannot explain it by any medical literature, only supposition.

The medical literature and medical practice are resplendent with examples of myths that grow out of misread, misquoted, or misinterpreted information and that then continue to be propagated without further investigation, particularly when the author is an individual well-respected for other accomplishments. Not the least of these is the tenet that lightning victims who have resuscitation prolonged for several hours may still successfully recover. This belief seems to be grounded in the old idea of "suspended animation" the concept that lightning is capable of shutting off systemic and cerebral metabolism, allowing rescuers a longer period in which to resuscitate the patient. This concept, credited to the only article that Taussig ever wrote on lightning, actually first appeared in an article that was published quite some time before hers. The case recounted by Taussig that is the basis for this myth, when searched to its source, was a case reported by Morikawa and Steichen, F. While it does show a somewhat longer resuscitation period than usual, it is not as miraculous as reported in her paper or as propagated in subsequent references to it.

On the other hand, in a study of lightning survivors, Andrews has shown increasing prolongation of the QT interval, bringing up the theoretical possibility of toursades as a mechanism for the suspended animation reports.' Theoretically, if lightning hit at the right instant of the QRS interval, a toursades type of rhythm might occur, not only supplying minimal cerebral perfusion, but also perhaps resolving spontaneously. Toursade certainly has a better prognosis than fibrillation or asystole. There is new evidence from animal experiments to support the teaching that respiratory arrest may persist longer than cardiac arrest. (13,14) This study, in which Australian sheep were hit with simulated lightning strokes, showed histologic evidence of greater damage to the respiratory centers than the cardiac center in the medulla. Prolonged assisted ventilation may then, in some cases, be successful after cardiac activity has returned.

Among the myths about negative effects is the **"crispy critter"** myth.(3) This is the belief that the victim struck by lightning bursts into flames or is reduced to a pile of ashes. In reality, lightning often flashes over the outside of a victim, sometimes blowing off the clothes but leaving few external signs of injury and few, if any, burns.

Two other myths held by the lay public as well as many physicians that are particularly harmful to the lightning survivors are, "If you're not killed fly lightning you A be OK" and, "If there are no outward signs of lightning injury, the injury can't be serious.(8) The medical literature, by lack of follow-up case reports, implies that there are also few permanent sequelae of lightning injury. However, in the last few years, it has become apparent that permanent sequelae may and often do occur. In addition, both lightning and electrical victims with significant sequelae may have no evidence of burns. While the effects of amperage and voltage have been studied in animals, the effect of frequency, radio waves, and body impedance, as well as other effects, have not been elucidated well enough for us to be able to explain many injuries.

A myth that is still prevalent today is that the victim of lightning retains the charge and is dangerous to touch, since he is still "electrified " This idea has led to unnecessary deaths because of delaying resuscitation efforts.

Many patients, particularly those without external signs of injury, have been told, most often by medical professionals, that they have "internal burns" that are the cause of their problems. This is both a misnomer and an oversimplification for the cellular, vascular, biochemical, or other types of damage they may have incurred. So many questions need to be investigated in lightning and electrical injuries.

SIGNIFICANCE

"Lightning is a sign from God. "

I can claim no inside track on this one. Ancient Romans saw Jove's thunderbolts as a sign of condemnation and denied burial rites to those killed by lightning. Andeans hold similar beliefs and may ostracize the victim. In some cultures, medicines are made from stones that are believed to be a result of lightning strike. Roman, Hindu, and Mayan cultures all have myths that mushrooms arise from spots where lightning has hit the ground.(5)

In the poly-ethnic United States, belief in "fate" or "God's will" may affect how family, friends, or coworkers relate to the victim or how the victim feels about himself and his recovery. Some patients may have already consulted a healer before finally seeking the advice of a physician and in rare instances it may be difficult to treat a patient unless the help of a shaman or priest is employed to address the religious issues while the physician addresses the physical ones.

PREVENTION /AVOIDANCE

Several Roman emperors wore laurel wreathes and sealskin, which were believed to be protective. Pliny taught that a sleeping person was safe from lightning. Some of the references at the end of this article detail even more curiosities and myths.

"Wearing a rubber raincoat (substitute sneakers or other forms of clothing here) will decrease my chances of being hit." ***Conversely: "Wearing cleated shoes increases my chances of being struck."***

False, and probably false. The first is easy to dispel: if lightning has burned its way through a mile or more of air (which is a superb insulator), it is hardly logical to believe that a few millimeters of any insulating material will be protective. The second is a subject of contention but I tend to believe that there would be little effect from whatever is on the bottom of your feet. Certainly metal on the bottom of the feet can heat up and cause secondary burns, but it is unlikely to "draw" lightning to the person.

"I am safe in a car because the rubber tires protect me."

True and False. True because there have been no documented lightning deaths that have occurred in a hard topped metal vehicle with the windows rolled up. However, the composite tires have little, if any, part in this, for the same reasons as those just discussed with regard to insulation. The safety has to do with the fact that electrical current travels along the outside of a conductor (the metal body of the car) and dissipates to the ground through paths that include the tires and the rainwater.

"Wearing metal in my hair increases my chances of being hit. "

Questionable, although opinions exist both ways. Hairpins (who uses those anymore?) may be safe; metal helmets may not. The issue needs more study (and more publication). Kitigawa has shown fairly conclusively with dummies that metal about the head does not increase the likelihood of being hit (unless it projects far above the head, increasing the person's height).

"Carrying an umbrella increases my risk of being hit. "

True. Increasing your height by any amount increases your chances of being hit by a calculable amount, although a prospective, population-based, double-blind, randomized study has not been done to prove this, nor has the composition (metal versus composite or plastic) of the umbrella or one-iron been studied. Other dangerous things to avoid: avoid being the highest object anywhere, be it a beach, small open boat, pier, meadow, or ridge. Avoid being under a lightning rod (except when inside a substantial habitable building that is protected) or standing near a metal fence, underground pipes, or other metallic paths that can transmit lightning energy from a nearby strike. Avoid swimming, because lightning energy can be transmitted through the water to you. Sailboats should be equipped with adequate lightning protection systems.

"When outdoors, I should stay away from trees."

Mostly true. Certainly you should stay away from the tallest trees, which are more likely to be hit and side-flash or splash to you. However, one would not want to become the tallest object in an area by standing in a meadow, either. Making the shortest, smallest target is probably the best answer if caught in the open. If you are in a forested area, it may be wise to pick an area of dense growth of saplings or smaller trees, rather than either a large meadow or tall trees. If on a ridge, get to a lower area.

Seeking shelter in a substantial building when possible is advisable. The sheds on golf courses, unless adequately protected by a lightning mitigation system, are potentially more dangerous because they offer height but little protection and lightning may splash from a hit to the shelter onto the inhabitants.

"When lightning hits the ground nearby, it is 'grounded ' and I am safe. "

Totally and absolutely FALSE. Despite the fact that we call the earth a "ground," it is very difficult to pump electricity into the ground. Most "earth" is a very good insulator. When lightning hits the ground, it spreads out along the surface and first few inches of the ground in increasing circles of energy called "ground current." If it contacts a fence or a water pipe or wire entering a house it can be transmitted for quite a distance and cause injury to persons near these paths. People, being bags of electrolytes, are better transmitters of electrical current than most ground is, and many are injured by ground current effect each year as the lightning energy surges up one leg that is closer to the strike and down the one further away.

"My mother always told me to stay off the telephone (out of the bath tub, away from windows, unplug the appliances, etc.) during a thunderstorm. "

Good advice, if not always practical. Again, the ground current effect of energy transmitted into the structure along wires or pipes may find the person a better conduit to ground.(3,4) Many injuries occur every year to telephone users *inside the home*. One of the biggest new areas of consumer fraud has to do with claims of loss of "valuable" databases on computers damaged by lightning.(5)

"Lightning only occurs with thunderstorms."

Most people know to seek shelter once the storm clouds roll overhead. Few realize that one of the most dangerous times for a fatal strike is before the storm. Lightning may travel as far as 10 km nearly horizontally from the thunderhead and seem to occur "out of the clear blue sky" or at least when the day is still mostly sunny. The faster the storm is traveling and the more violent it is, the more likely this is to occur. Another time underestimated for its potential danger is the end of a thunderstorm.(2-6)

"If we could just harness lightning we could use that to power the world for months. "

Uman eloquently explains the reason this cannot be done and is false in his book, All About Lightning.(2) He makes two points: it is impractical to intercept a sufficient number of the lightning strikes occurring in the world, and most of the energy in a lightning strike is converted to thunder, heat, light, and radio waves. He notes, "If its total energy were available, a single lightning flash would run an ordinary household light bulb for only a few months."(2)

"Lightning could be used for a military weapon. "

Again, Uman (2), a professor of electrical engineering who writes with wonderful clarity, is my source. "In view of the awesome destructive power of modern weaponry, the military use of lightning . . . would probably be more as a psychological than as a destructive weapon."(2)

And last but not least, **"Lightning never strikes the same place twice."**

In reality, the Empire State Building and the Sears Tower get hit thousands of times a year, as do mountain tops and radio-television antennas. If the circumstances facilitating the original lightning strike are still in effect in an area, then the laws of nature will encourage lightning strikes to continue to be more prevalent there. After all, that is the reason that lightning protection systems are required on many public buildings (including hospitals) by building codes.

CONCLUSION

Lightning and electrical injuries are fascinating and the myths that have grown up about them are myriad. I invite you to collect your own. If you will be kind enough to send them to me, I will forever be in your debt.

REFERENCES

1. Prinz: Lightning in history. In Golde RH, ed. Lightning, Vol 1. San Francisco: Academic Press, pp1-20, 1977.
2. Uman MA. All about lightning. New York: Dover, pp 1-160, 1986.
3. Cooper MA, Andrews CJ: Lightning injuries. Auerbach P ed. Wilderness Medicine, Management of Wilderness and Environmental Emergencies, 3rd ed. St. Louis: CV Mosby, pp 261-89, 1995.
4. Andrews CJ, Cooper, MA, ten Duis HJ, Sappideen C. The pathology of electrical and lightning injuries. In Wecht CJ, ed. Forensic Sciences, release 19 update. New York: Matthew Bender & Co., 1995:23A-3-23A-165
5. Lopez RE, Holle RL, Heitkamp TA. Deaths, injuries, and property damage due to lightning in Colorado from 1950 to 1991 based on Storm Data. In National Oceanic and Atmospheric Administration Technical Memorandum ERL NSSL-103
6. Holle RL, Lopez RE, Ortiz R. et al. Cloud-to-ground lightning related to deaths, injuries and property damage in central Florida. In Proceedings, International Conference on Lightning and Static Electricity, October 6~, Atlantic City, NJ, FAA Report No. DOT/FAA/CT-92/20,66-1-66-12, 1992.
7. Cooper MA. Lightning injuries: prognostic signs for death. Ann Emerg Med 9:134-8, 1980.
8. Andrews CJ, Darveniza M, Mackerras D. Lightning injury a review of clinical aspects, pathophysiology and treatment. Adv Trauma 4:241-52, 1989.
9. Primeau M, Engelstatter GH, Bares KK Behavioral consequences of lightning and electrical injury. Semin Neurol 15:279-85, 1995.
10. Taussig H. "Death" from lightning and the possibiliq of living again. Ann Intern Med 68:1345-50, 1968.
11. Morikawa S. Steichen F. Successful resuscitation after "death" from lightning. Anesthesia 21:222-3, 1960.
12. Andrews CJ, Colquhoun DM, Darveniza M. The QT interval in lightning injury with implications for the 'cessation of metabolism' hypothesis.J Wilderness Med 4:155-66, 1993.
13. Andrews CJ, Darvenia M: Effects of lightning on mammalian tissue. Proceedings, 1989 International Conference on Lightning and Stahc Electricity, Sept 26 28, Bath, England, 4A.4.1-4A.4.4, 1989.
14. Andrews CJ, Darveniza M. New models of the electrical insult in lightning strike. Proceedings, 9th International Conference on Atmospheric Physics, St. Petersburg, Russia, 1992.
15. Lowy B. Amanita muscaria and the thunderbolt legend in Guatemala and Mexico. Mycologia 66:188-90, 1974.
16. Ackerman L. Personal communication, Price-Hollingsworth Company

Emergent Care of Lightning and Electrical Injuries

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HISTORICAL PERSPECTIVE AND EPIDEMIOLOGY

While injuries from man-made, generated, or "technical" ' electricity have been reported for less than 300 years, in juries from lightning must surely predate written r records Electrical burns account for 4 to 6.5% of all admissions to burn units in the United States (1,2) and accounted for approximately 800 fatalities per year in the United States from 1984 through 1987. It is estimated that lightning causes 75 to 150 deaths per year, with 5 to 10 times more injuries. (3,4)

Most admissions of adults to burn centers from electrical injury are occupationally related. Almost two thirds of the fatalities occur in people between the ages of 15 and 40 years. Young children have a predisposition to injuries from low-voltage sources such as electric cords because of their limited mobility within a relatively confined environment (5) whereas older children and adolescents encounter electrical injury through various misadventures.

There is little literature on low voltage injuries or how their morbidity may differ from high voltage injuries.') Because no agency requires reporting of lightning injuries and because many persons do not seek treatment at the time of their injury, the incidence and frequency of injury and death from lightning are difficult to determine. In years that do not include Hurricane Andrew (1992), lightning killed more people in the United States annually than any other natural disaster except flash floods, including hurricanes, volcanoes, blizzards, and earthquakes.(7)) Although farmers used to be the primary victims of lightning, recreation-related injuries are now the more frequent and studies have noted work-related injuries juries in as many as 30 to 63% of victims annually. (7,8) Lightning incidents may involve more than one victim when the current "splashes" to other individuals or, as ground current, spreads the electrical power throughout the area where a group may be sheltered in a storm for a variety of factors that can affect the severity of the injury.'

PHYSICS OF INJURY

With high-voltage injuries, most of the injury appears to be thermal and most histologic studies reveal coagulation necrosis consistent with thermal injury. (9,10) Lee and others have proposed the theory of electroporation in which electrical charges too small to produce thermal damage cause protein configuration changes threatening cell wall integrity and cellular function." Some believe that there may also be magnetic effects on the tissue The factors that determine the nature and severity of what is primarily burn injury when high-voltage current flows through the human body are listed in Table 1. (4)

TYPE OF CIRCUIT

High-voltage direct current (DC) tends to cause a single muscle spasm, often throwing the victim from the source, resulting in a shorter duration of exposure but increasing the likelihood of traumatic blunt injury.

Alternating current (AC) is said to be about three times more dangerous than direct current of the same voltage, because continuous muscle contraction, or tetany, occurs when the muscle fibers are stimulated at between 40 and 110 times per second. The frequency of electrical transmission used in the United States is 60 Hz. Tetany occurs even at very low amperages.

It has been customary to use the terms "entry' and "exit" to describe electrical injuries. Particularly with AC, this is clearly a misnomer and the terms should correctly he "source" and "ground." The hand is the most common site of contact as it grasps a tool coming into contact with an electric source. Although all the muscles of the arm may be tetanically innervated by a shock, the flexors of the hand and forearm are much stronger than the extensors so that the hand grips the source of the current. At currents above the let-go threshold (6 to 9 mA), this can result in the person's being unable to release the current source voluntarily, prolonging the duration of exposure.

RESISTANCE

Resistance is the tendency of a material to resist the flow of current. Although the exact pathophysiology of electrical in- flow of current and is specific for a given tissue, depending on the injury is not well understood, there is at least an appreciation on its moisture content, temperature, and other physical

Table 1. Factors Determining Electrical Injury

Type of circuit
Resistance of tissues
Amperage
Voltage
Current pathway
Duration
Environmental factors

Properties: The higher the resistance (R) of a tissue to the flow of current, the greater its potential to transform electrical energy (1) to thermal energy (P) at any given current, as described by Joule's law:

$$P = I^2 \times R$$

Nerves, designed to carry electrical signals, and muscle and blood vessels, because of their high electrolyte and water content, are good conductors. Bone, tendon, and fat have a very high resistance and tend to heat up and coagulate rather than transmit current. The other tissues of the body are intermediate in resistance (Table 2). (14,15) Skin is the primary resistor to the flow of current into the body (Table 3) (10) Much of the energy may be dissipated at the skin surface, causing significant surface burns in a heavily calloused area, sometimes resulting in less deep internal damage than would be expected if the current were delivered undiminished to the deep tissues. Sweating can decrease the skin's resistance to 2500 to 3000 Q. Immersion in water can reduce this further to 1200 to 1500 Ohms and thus allow more energy to flow through the body, resulting in electrocution with cardiac arrest but no surface burns, such as in a bathtub injury

DURATION

In general, the longer the duration of contact with high voltage current, the greater the degree of tissue destruction. Although there is an extraordinarily high voltage and amperage with lightning, the extremely short duration and the peculiar physics of lightning result in a very short flow of current internally, with little, if any, skin breakdown and almost immediate flashover of current around the body, usually resulting in little, if any, burning of tissues.(8,16))

Table 2. Resistance of Body Tissues

Least
Nerves
Blood
Mucous membranes
Muscle
Intermediate
Dry skin
Most
Tendon
Fat
Bone

Current, expressed in amperes, is a measure of the amount of energy that flows through an object (Table 4). There is a very narrow range of safety with electric current between the threshold of perception of current (0.2 to 0 4 mA) and let-go current (6 to 9 mA), the level at which a person becomes unable to let go of the current source because of muscular tetany and becomes fixed to the electrical source, lengthening the duration of contact. Thoracic tetany can occur at levels just above the let-go current and result in respiratory arrest from the person's inability to move the muscles of respiration. Ventricular fibrillation is estimated to occur at an amperage of 50 to 120 mA). (17) As the tissue breaks down under the energy of the current flow, its resistance may change markedly, making it impossible to predict the amperage for any given electrical injury

VOLTAGE

Voltage is a measure of potential difference between two points. It is determined by the electrical source. Electrical injuries are conventionally divided into high or low voltage using 500 or 1000 V as the most common dividing lines. Although both high and low voltage can cause significant morbidity and mortality, high voltage has a greater potential for tissue destruction and can be responsible for severe injuries leading to major amputations and tissue loss.

PATHWAY

The pathway that a current takes determines the tissues at risk, the type of injury seen, and the degree of conversion of electrical energy to heat regardless of whether high, low, or lightning voltages are being considered. Current passing through the heart or thorax can cause cardiac arrhythmias and direct myocardial damage. Current passing through the brain can result in respiratory arrest seizures, direct brain injury, and paralysis. Current passing close to the eyes can cause cataracts.

Table 4. Amperage

	Milliampere
Tingling sensation from household current	1–2
Let-go current	
Man	7–9
Woman	6–8
Child	3–5
Tetany (freezing to circuit)	10–20
Respiratory arrest from thoracic muscle tetany	20–50
Ventricular fibrillation	50–100

Table 5. Mechanisms of Electrical Injury

Direct contact
Arc
Flash
Thermal
Blunt trauma

As current density increases, its tendency to flow through the less-resistant tissues is overcome, so that it eventually flows through the tissues indiscriminately, treating the body as a volume conductor, with potential destruction of all tissues in the current's path. Damage to the internal structures of the body may be irregular, with areas of normal-appearing tissue next to burned tissue and with damage to structures at sites distant from the apparent contact and ground points.

Probably the most important difference between light- and high-voltage electrical injuries is the duration of exposure to the current. The mathematics of the rapid rise and decay of lightning energy makes predicting lightning injury even more complicated than predicting man-made electrical injury. The study of such massive discharges of such short duration is not well advanced, particularly with regard to effects on the human body.

Lightning current may flow internally for an incredibly short time and cause short-circuiting of the body's electrical systems, but it seldom causes any significant burns or tissue destruction (3,15,18) Thus burns and myoglobinuric renal failure play a small part in the injury pattern from lightning, whereas cardiac and respiratory arrest, vascular spasm, neurologic damage and autonomic instability play a much greater role. (3,15 Lightning will tend to cause ventricular asystole rather than fibrillation. Although automaticity causes the heart to begin beating again, the respiratory arrest that often accompanies cardiac arrest may last long enough to cause secondary deterioration of the rhythm to ventricular fibrillation and asystole, which is more resistant to therapy than was the first arrest. (15,18) '9 The secondary arrest, just a theory in the past, has recently been elegantly shown to occur experimentally in sheep. (16,18) Other injuries caused by blunt trauma or ischemia from vascular spasm, such as myocardial infarction (20-27) spinal artery syndromes, may occasionally occur. (28-30)

MECHANISMS OF INJURY

The mechanisms of electrical injury are listed in Table 5. It is often difficult to determine which mechanism of injury has caused burns at the time of a patient's presentation to the emergency department. This may make it difficult to assess the injury and offer a prognosis based on history and physical examination alone. The most destructive indirect injury occurs when a person becomes part of an electrical arc, since the temperature of an electrical arc is approximately 2500 degrees Celsius. (14) The arc may cause clothing to ignite and cause secondary thermal burns. The electrical flash burn usually results in only superficial partial-thickness burns.

Blunt injury may occur in electrical injury as the person is thrown clear of the source by intense muscular con traction or it may result from a fall from a height. The violent muscle spasms associated with AC injuries can cause fractures and dislocations. (31.32)

Table 6. Mechanisms of Lightning Injury

Direct strike
Orifice entry
Contact
Side flash, “splash”
Ground current or step voltage
Blunt trauma

Muscle damage may be spotty, with areas of viable and nonviable muscle found in the same muscle group. Periosteal muscle damage may occur even though overlying muscle appears to be normal

Vascular damage is greatest in the media, possibly because of the diffusion of heat away from the intima by the How of blood, but can lead to delayed hemorrhage when the vessel eventually breaks down. (14,33,34) Intimal damage may result in either immediate or delayed thrombosis and vascular occlusion as edema and clots form on the damaged internal surface of the vessel over a period of days. (34) This injury is usually most severe in the small muscle branches, where blood flow is slower. (35) This damage to small arteries in muscle, combined with mixed muscle viability that is not visible to gross inspection, creates the illusion of "progressive" tissue necrosis. Damage to neural tissue may occur from many mechanisms. Nerve tissue may show an immediate drop in conductivity as it undergoes coagulation necrosis similar to that observed in muscle tissue.

In addition, it may suffer indirect damage as its vascular supply or myelin sheaths are injured. As with other vascular damage and edema formation, signs of neural damage may develop immediately or be delayed by hours to days.

The brain is frequently injured, because the skull is a common contact point. Histologic studies of the brain have revealed focal l petechiae in the brain stem, widespread chromatolysis and cerebral edema. (14)

Immediate death from generated electricity may be from asystole, ventricular fibrillation, or respiratory paralysis, depending on the voltage and pathway.

Lightning injury may occur by five mechanisms (Table 6). The mechanism of injury of a direct strike is self-evident . Recently, it has been postulated (20) and substantiated experimentally in sheep (16,18,36) (18) 36) that lightning strikes near the head may enter orifices such as the eyes, ears, and mouth to flow internally, as reported in the article by Andrews in this issue. This would help to explain the myriad eye and ear symptoms and signs that have been reported with lightning injury.

Injury from contact occurs when the person is touch- object that is part of the pathway of lightning current, such as a tree or tent pole. Side flash or splash occurs as lightning jumps from its pathway to a nearby person and adopts the person as its pathway. (3,28,33,37) 33 3'

Step voltage occurs as a result of lightning current spreading radically through the ground. A person who has one foot closer than the other to the strike point will have a potential difference between the feet so that a current may be induced through the legs and body. This is a frequent killer of large livestock such as cattle and horses because of the distance between their hind legs and forelegs. (3)

Table 7. Differential Diagnosis of Lightning Injuries

Cardiac arrhythmias
Myocardial infarction
Cerebrovascular accident
Subarachnoid hemorrhage
Seizures
Closed head injury
Spinal cord trauma

Blunt injury from lighting may occur as the person is thrown by the opisthotonic contraction caused by current passing through the body and from the explosive/implosive fore c caused as the lightning pathway is instantaneously superheated and then rapidly cooled after the passage of the lightning is over. The heating is seldom long enough to cause severe burns but does cause rapid expansion of air followed by rapid implosion of the cooled air as it rushes back into the void. (3)

DIFFERENTIAL DIAGNOSIS

Electrical injuries are usually self-evident from history and physical surroundings, except in the case of bathtub accidents, where no burns occur, or of foul play. It is necessary to attempt to differentiate between mechanisms of burn injury because flash burns have a much better prognosis than arc or conductive burns. Injuries from blunt trauma and falls may also be present.

The differential diagnosis for lightning injuries is more complex, often because the incident is unobserved (Table 7). It includes the differential for unconsciousness, paralysis, or disorientation from a number of causes. (3) Evidence- of a thunderstorm or a witness to the lightning strike may not be available. The presence of typical burn patterns, when present, may be helpful.

CLINICAL FINDINGS AND MANAGEMENT

RESUSCITATION AND TRIAGE AT THE SCENE

Once the accident scene is controlled, a quick initial assessment of the patient is indicated with attention to the airway, breathing, and circulation. High-flow oxygen and intubation should be provided if necessary. Cardiac monitoring is essential and, if the patient is in cardiac arrest, standard advanced life support protocols should be instituted.

Electrical injury patients often require a combination of cardiac and trauma care, since they often have blunt injuries and burns as well as cardiac damage. At least one large-bore intravenous line of normal saline or Ringer s lactate solution should be started, with fluid resuscitation dependent on the degree of apparent injury. Injury to the cervical spine should be presumed, and protective measures provided until it can be excluded on the basis of history, physical examination, or radiologic study. Use of a backboard, as with other trauma patients, is helpful for both stabilization and transport. Any fractures should be splinted and burns dressed with clean, dry dressings. An electrical injury should be treated like a crush injury rather than a thermal burn because of the large amount of tissue damage under normal skin. No formula for optimal intravenous fluids based upon percentage of burned body surface area can be counted on. A bolus of 10 to 20 ml/kg of isotonic fluid can reasonably be given to a hypotensive patient.

The major cause of death in lightning injuries is cardiac arrest. In the absence of cardiopulmonary arrest, patients are highly unlikely to die of any other cause."' Lightning acts like a cosmic DC countershock, sending the heart into asystole. (3,16) Although automaticity may lead to the heart s restarting, the respiratory arrest often lasts longer than the cardiac pause and may lead to a secondary cardiac arrest with ventricular fibrillation from hypoxia. (3,19.33) If the patient is properly ventilated during the time between the two arrests, the second arrest may theoretically be avoided. Hypothermia should also be ruled out when patients have been soaked with rainwater.

EMERGENCY DEPARTMENT ASSESSMENT AND RESUSCITATION

The patient after an electrical injury is often unable to give a good history, either because of the severity of injury and accompanying shock and hypoxia or because of unconsciousness or confusion that often accompanies less severe in juries. History from bystanders and emergency medical personnel regarding the type of electrical source, duration of contact, environmental factors at the scene, and resuscitative measures provided can be helpful. Information on prior medical problems, medication history, tetanus immunization status, and allergies should be sought. Likewise, the patient after a lightning strike, as in other environmental emergencies, may be unable to provide a history, and bystanders stories of the incident may be confused. Although it is interesting to try to unravel the history, this is often difficult to do and may take unnecessary time during the acute resuscitation phase. With both types of injuries, the patient may grossly appear to be alert, oriented and able to repeat his history and give complaints, but this does not preclude serious functional brain injury similar to that found with blunt head injury patients. All patients receiving a high-voltage injury should be transported to a hospital and receive an electrocardiogram (EGG), cardiac isoenzyme level study, urinalysis for myoglobin, complete blood count (CBC), and other tests and radiographic studies as appropriate for their injuries. Resuscitative efforts should be continued in the emergency department with adequate fluid administration and insertion of a Foley catheter for the more severely injured electrical patient. If rhabdomyolysis is present, appropriate treatment should be carried out, with a rate sufficient to maintain a urine output of at least 1.0 to 1.5 ml/kg/hr when heme pigment is present in the urine and 0.5 to 1.0 ml/kg/hr when it is not. Because burns from lightning and low-voltage sources seldom involve deep tissues, myoglobinuria and the need for fluid loading, mannitol or furosemide diuresis or fasciotomy for compartment syndromes are rare. (3,19,28.38) '9 If cardiac arrest or suspected intracranial injuries occur in lightning patients, fluid restriction may actually be desirable to avoid pulmonary edema and increased intracranial pressure. (3,19,39,40) Patients with lightning and low-voltage injuries may present with little objective evidence of injury or, alternately, cardiopulmonary arrest. After initial resuscitation of these patients, other conditions may be identified. These are rarely life-threatening Such patients too may have significant residual morbidity from pain syndromes or neurologic and cognitive damage that is similar to that experienced with blunt head injury. (41-49) (see Primeau and Engelstatter in this issue of Seminars) .

HEAD AND NECK

The head is a common point of contact for high volt-injuries and the patient may exhibit burns as well as neurologic damage. Cataracts develop in approximately 6 percent of cases of high-voltage injuries and should be suspected whenever electrical injury has occurred in the vicinity of the head. (50) Although cataracts may be present initially or develop shortly after the accident. they more typically begin to appear months after the injury. Visual acuity and fun- examination should be performed at presentation or as soon as practical for documentation. Referral to an ophthalmologist familiar with electrical cataract formation may be necessary after the patient s discharge from the hospital. (51,52)

Cataracts may also occur with lightning injuries but are probably less common. (3,19,54) Clinical findings in lightning pa tie patients may include skull fractures. (3,28,29,54) Typanic membrane rupture is frequently found h1 lightning patients and may be secondary to the shock waves direct burn or basilar skull fracture. (3,19,55) Although most recover without serious sequelae '9 disruption of the ossicles and mastoid (19,55) may occur as well as cerebrospinal fluid otorrhea hematympanic and permanent deafness. (56-60) Other injuries to the eyes may include corneal lesions, uveitis, iridocyclitis, vitreous hemorrhage, optic atrophy, retinal detach, and chorioretinitis. Cervical spine injury may be caused by a fall or being thrown in either type of injury.

CARDIAC INJURY

Cardiac arrest either from asystole or ventricular fibrillation is a common presenting condition in electrical accidents. Other observed presenting arrhythmias include sinus tachycardial transient ST elevation reversible QT prolongation premature ventricular contractions atrial fibrillation and bundle branch block. (33,65-68) Acute myocardial infarction has been reported but seems to be relatively rare. (67, 69-71 Recent research has shown that damage to skeletal muscles may produce an inordinate rise in the vtrsyinr creatine kinase (CK) MB fraction leading to a spurious diagnosis of myocardial infarction in some settings.(7)

In lightning injuries cardiac damage or arrest caused by either the electric shock or induced vascular spasm may occur. (2?) Lightning patients who do not have cardiopulmonary arrest at the time of the strike generally do well with supportive therapy. (3,19) Those who have cardiopulmonary arrest may have a poor prognosis particularly if there is hypoxic brain damage. (3,19,39)

Numerous arrhythmias have been reported with light-injuries in the absence of cardiac arrest. (3,14) Nonspecific ST-T wave-segment changes and prolonged QT interval may occur and serum levels of cardiac enzymes are some- elevated. (3,38,73-75) '; Hypertension is often present initially with lightning injury but usually resolves in an hour or two so that treatment is not usually necessary. (3)

Although ECG changes and arrhythmias are common with electrical injuries large series of patients have under gone anesthesia and surgical procedures in the first 48 hours of care without cardiac complications. If the patient has none of the indications listed in Table 8 cardiac monitoring probably is not necessary or can be safely discontinued after 12 hours of normal rhythms. (39) Invasive monitoring such as for central venous pressure or intracranial pressure and use of Swan-Ganz catheters should be guided by the patient s status. (40,76)

Table 8. Indications for Electrocardiographic Monitoring

Cardiac arrest
Documented loss of consciousness
Arrhythmia observed in prehospital or emergency department setting
History of cardiac disease
Presence of significant risk factors for cardiac disease
Concomitant injury severe enough to warrant admission
Suspicion of conductive injury
Hypoxia
Chest pain

CUTANEOUS INJURY

Other than cardiac arrest the most devastating immediate injuries that can accompany an electrical injury are burns. The most common sites of contact for the current include the hands and the skull. The most common areas of ground are the heels. There may be multiple contact and ground points.

Because high-voltage current often flows internally and can create massive muscle damage one should not attempt to predict the amount of underlying tissue damage from the amount of cutaneous involvement or use the rule of nines for calculating fluid resuscitation. (15, 33) Cutaneous burns should be covered with antibiotic dressings such as mafenide acetate (Sulfamylon) or sulfadiazine silver (Silvadene). (77) (78) Mafenide is preferable for localized full-thickness burns because of its better penetration. Sulfadiazine silver may be preferable for patients with extensive burns: when Mafenide is used on more than 15 to 20% of the body electrolyte abnormalities may occur because it inhibits carbonic anhydrase. Electrical burns are especially prone to tetanus infection and patients should receive tetanus toxoid and tetanus immune globulin on the basis of their immunization history. Clostridial myositis is common but prophylactic administration of high-dose penicillin to prevent clostridial myonecrosis is controversial and should be discussed with the managing surgeon or burn unit. In general systemic antibiotics are usually not used unless there is infection proved by culture or biopsy.

A peculiar type of burn associated with electrical injury is the kissing burn which occurs at the flexor creases as the electric current arcs causing arc burns on both flexor surfaces. (16) Extensive underlying tissue damage is often present here where the current became concentrated in its passage. Severe burns to the skull and occasionally to the aura have been reported. (79-82)

A special type of burn from low-voltage injuries is the mouth burns that occur secondary to sucking on household electrical extension cords and are the most common electrical injury seen in children under 4 years of age. (5) These burns usually represent local arc burns may involve the oricularis oris muscle and are especially worrisome when the commissure is involved because of the need for splint and the likelihood of cosmetic deformity. (83-85) A significant risk of delayed bleeding from the labial artery exists when the eschar separates. (84, 85) s 8's Damage to developing dentition has been reported and referral to an oral surgeon familiar with electrical injuries is recommended. (83, 86)

With lightning injuries the skin may show no signs of injury initially. Deep burns occur in less than 5% of the reported injuries.' As mentioned previously burns are usually superficial if present at all. They may consist of four typeset l, l ~

1. Linear bums tend to occur in areas where sweat or water accumulates (for example, under the arms or down the chest) (19)
2. Punctate burns appear like multiple small cigarette burns often with a heavier central concentration in a rosette like pattern They seldom require grafting. (88)
3. Feathering burns are not true burns and actually show no damage to the skin itself. (87) They seem to be a complex caused by electron showers induced by the lightning and make a fern pattern on the skin.(87,89,90) They require no therapy. Regular thermal burns occur if the clothing is ignited (88) or may be caused by metal that the person is wearing or carrying (87) that heats up with the flashover
4. Combinations of all of these may occur. (3)

EXTREMITY INJURY

In high-voltage injuries muscle necrosis can extend to sites distant from the observed skin injury and compartment syndromes can occur secondary to vascular ischemia and muscle edema. With electrical injuries the thought in regard to damaged extremities is to favor early and aggressive surgical management including early decompressive escharotomy fasciotomy carpal tunnel release or even amputation of an obviously nonviable extremity. (2,5,91,94) Although it is preferable to stabilize the patient prior to transfer to the operating room this is not always possible.

Extremities that have teen burned should be splinted in functional position to minimize edema and contracture formation. The hand should be splinted in 35° to 45° extension at the wrist 80° to 90° flexion at the metacarpophalaneals and almost full extension of the proximal interphalaneal and distal interphalangeal joints to minimize the space available for edema formation. (93) During the first several days of hospitalization frequent monitoring of the neurovascular status of all extremities is essential.

Fractures of most of the long bones and spine (95) because of trauma associated with electrical injury have been reported. Both posterior and anterior shoulder dislocations caused by tetanic spasm of the rotator cuff muscles have been reported but do not seem to be as common as most texts stress."-" Numerous types of fractures and dislocations have been reported with lightning injury.'

VASCULAR INJURY

Vascular damage from the electrical energy may be evident early or late (34,35) Because the arteries are a high-flow system heat may be dissipated fairly well and result in little apparent initial damage but thrombosis with subsequent thrombosis or rupture The veins on the other hand, arc a low-flow system allowing the heat energy to cause more rapid Pulses and capillary refill should be assessed and documented in all extremities, and neurovascular checks should be repeated x frequently

This progressive vascular compromise can cause a burn that initially was assessed as a partial-thickness burn develop into a full-thickness burn as the vascular supply to the area becomes compromised. Progressive loss of muscle because of vascular ischemia downstream from damaged vessels may lead to the need for repeated deep debridements.

NERVOUS SYSTEM

Acutely, computed tomography (CT) or magnetic resonance imaging (MRI) is indicated to rule out intracranial hemorrhage or other injury in any patient with neurologic deterioration or clouded mental status. (19,76,96,96a,b,c) With high-voltage injuries, loss of consciousness may occur but is usually transient unless there has been a significant head injury as well, although prolonged coma with recovery has been reported. Patients may exhibit confusion, Pat affect, and difficulty with short-term memory and concentration (see Primeau and Engelstatter in this issue of Seminars). A seizure may occur after electrical injury as either an isolated event or part of a new-onset seizure disorder. (4) Hypoxia and injury should be ruled out as causes of the seizure. Neurologic symptoms may improve, but long-term disability is common.

Spinal cord injury may result from fractures of the cervical, thoracic, or lumbar spine (95, 97-99) Neurologic damage in patients without evidence of spine injury seems to follow two patterns, immediate and delayed. (97,98,100) Patients with immediate damage develop symptoms of weakness and paresthesias within hours of the insult, although extremity weakness frequently goes undiagnosed until ambulation is attempted. (41,97) Lower extremity findings are more common than upper extremity findings. These patients have a good prognosis for partial or complete recovery. Delayed neurologic damage may present from days to years after the insult. (The question of causal connection is addressed elsewhere in this issue of Seminars.) The findings usually fall into three clinical pictures: ascending paralysis, amyotrophic lateral sclerosis, or transverse myelitis. (99) Although recovery has been reported, the prognosis is usually poor. (97)

With lightning, up to two thirds of the seriously injured patients have keraunoparalysis on initial presentation, with lower and sometimes upper extremities that are blue, mottled, cold, and pulseless because of vascular spasm and sympathetic nervous system instability. (19,101) Generally, this clears within a few hours, although some patients may be left with permanent paresis or paresthesias. (3,19,25,33) Paraplegia (2) intracranial hemorrhages (57,77,97) creatinine kinase (CK) MB isoenzyme elevations, 3. 38, 73-75) 75 seizures, 89 and electroencephalographic (EEG) changes have been reported.' The vast majority of lightning patients will behave as though they have had electroconvulsive therapy, being confused and having anterograde amnesia for several days after the incident. Loss of consciousness for varying periods is common. (19,103)

Peripheral nerve damage is common, and recovery is usually poor for all types of electrical injuries. (45,104)

Table 9. Primary Complications and Causes of Death in Electrical Injuries in Temporal Order of Occurrence

Cardiopulmonary arrest
Overwhelming injuries
Cardiac arrhythmias
Hypoxia and electrolytes
Intracranial injuries
Myoglobinuric renal failure
Abdominal injuries
Sepsis
Tetanus
Iatrogenic
Suicide

A syndrome of delayed muscle atrophy caused by electrical injury of the nerves has been described even in the absence of cutaneous burns. (32)

VISCERAL INJURY

Injury to the lungs may occur because of associated blunt trauma but is rare from electrical current perhaps because air is a poor conductor. injury to solid visceral organs is rare but damage to the pancreas and liver has been reported. (105) Injuries to hollow viscera including the small intestine , (106,107) large intestine , (14,105) bladder (81,106) and gallbladder. (105) have also been reported. With lightning pulmonary contusion and hemorrhage have been reported . (29,108,109) Blunt abdominal injuries have been reported but are rare/ (3) None of the other intraabdominal catastrophes associated with electrical injury has been reported with lightning injury.

LOW VOLTAGE INJURIES

Evaluation of low-voltage injuries should include a good history because injury that initially appears to be from a low-voltage source may turn out to have been caused by a discharge from a capacitor (as in the repair of televisions and convection or microwave ovens) or other high-energy source. Although burns from low-voltage sources are usually less severe than those from high-voltage sources , (5,6,110,111) patients may still complain of paresthesias for an extended period experience cardiac arrhythmias or develop cataracts if the shock occurs close to the face or head. Low voltage mouth injuries in children were discussed in the section of this article on cutaneous injuries.

COMPLICATIONS

The complications of high-voltage electrical burns are listed in Table 9. Cardiac arrest generally occurs only with the initial presentation or as a final event after a long and complicated hospital course.

Many of the complications are like those of thermal burns and crush injuries; they include infection clostridial myositis and myoglobinuria The incidence of acute myoglobinuric renal failure seems to have decreased since the institution of adequate fluid therapy. Fasciotomies or carpal tunnel release may be necessary for treatment of compartment syndromes. (91-94) Tissue loss and major amputations are common with severe high-voltage injuries and result in the need for extensive rehabilitation.

A nasogastric tube should be placed in the seriously injured patient because of the risk of adynamic ileus and stress ulceration. Ulcer prophylaxis with H(2) blockers or sucralfate (Carafate) may be beneficial. Peritoneal ravage or abdominal CT scan may be indicated to rule out intrabdominal injuries if the ileus seems to be prolonged or if the history and physical examination indicate it.

A head CT or MRI scan is also indicated to rule out intracranial injuries and hemorrhage if the patient s level of consciousness does not markedly improve during the emergent course.

Ophthalmologic documentation is important in those patients having injury upward from the shoulders since they can develop cataracts.

Neurologic complications such as loss of consciousness difficulty with memory and concentration (47-49) peripheral nerve damage (46,104) and delayed spinal cord syndromes may occur. (41,95, 97-100) Damage to the brain may result in a permanent seizure disorder. (54) Stress ulcers are the most common gastrointestinal complication after burn ileus Abdominal injuries from ischemia vascular damage burns or associated blunt trauma may be missed initially, 14,81,105-111) The most common causes of hospital mortality are pneumonia sepsis, and multiple organ failure because of the complexity of the injury.

Long-term psychiatric sequelae include body image changes marital problems inability to continue working in the same profession and suicide. Treatment for lightning patients can usually be based primarily on routine common-sense treatment of their presenting injuries with attention and follow-up for the long term problems of pain and cognitive dysfunction. In the past patients with lightning injuries have often been treated like those with high-voltage injuries. However these injuries are distinctly different. High-voltage injuries tend to cause deep internal injuries myoglobinurea renal failure shock and massive loss of tissue and function. Lightning injuries tend to cause few external or internal burns and rarely cause myoglobinuria. There is usually little tissue loss although there may certainly be permanent functional impairment. As a result treatment of lightning patients rarely requires massive fluid resuscitation fasciotomies for compartment syndromes mannitol and furosemide diuretics alkalinization of the urine amputations or large repeated debridements. In fact most lightning patients particularly those with head injuries should probably have their fluids restricted to decrease the likelihood of cerebral edema.

LABORATORY, ELECTROCARDIOGRAPHIC, AND RADIOLOGIC EVALUATION

The laboratory evaluation of the patient sustaining an electrical injury depends on the extent of injury. All patients with evidence of conductive injury or significant surface burns should have the following laboratory tests: CBC electrolyte level serum myoglobin blood urea nitrogen creatinine level and urinalysis with special attention to myoglobinuria. Patients with severe electrical injury or suspected intra-abdominal injury should also have obtained amylase aspartate and alanine transaminases alkaline phosphatase and clotting indexes. (68) Sending blood for type and cross-match should be considered, particularly if major debridement embridements may be necessary. Arterial blood gas determinations arc indicated if the patient needs ventilatory interior or alkali therapy.

All patients should be evaluated for myoglobinuria a common complication of electrical injury. A patient with an ortho-toluidine dipstick examinationa of the urine that is positive for blood, but with no red blood cells seen on microscopic analysis, should be presumed to have myoglobinuria and be treated accordingly. creatine kinase CK levels should be determined and isoenzyme analysis performed Peak CK levels have been shown to predict the amount of muscle injury, risk of amputation, and ultimate hospital stay; however, the clinical value of a single level in the acute setting has not been established." Cardiac enzyme levels should be interpreted with care in diagnosing myocardial infarction in the setting of electrical injury. The peak CK level is not indicative of myocardial damage in electrical injury because of the large amount of muscle injury. Although CK-MB fractions, ECG changes, thallium studies, angiography, and echocardiography have correlated poorly in most reports of acute myocardial infarction, (66,67,69) cases of infarction with all of these present have been reported. it' Recent human studies have indicated that skeletal muscle cells damaged by electrical current can contain as much as 20% to 25% CK-MB fraction, as opposed to the usual 2% to 3%, suggesting injured skeletal muscle as the source of the elevated CK-MB fraction and not true myocardial injury." All patients sustaining an electrical injury should receive cardiac monitoring in the emergency department and an ECG regardless of whether the source was high or low voltage. Indications for admission for ECG monitoring are listed in Table 8.'969

Radiographs of the cervical spine should be performed if spinal injury is likely. Radiographs of any other areas in which the patient complains of pain or has an apparent deformity should be performed. CT scan and MRI may be useful in evaluation of trauma and are essential for evaluation of possible intracranial injuries, particularly if the patient does not show progressive improvement in level of consciousness (56, 76, 96, 96c)

In lightning patients, studies should include CBC, urine for myoglobin (using the Quick visual check and dipstick methods), and an ECG. Cardiac isoenzymes are indicated in patients with chest pains, abnormal ECGs, or altered mental states. Other laboratory examinations may be indicated by the severity of the patient's injuries (for example, arterial blood gas measurement if he or she is on a ventilator). Radiographic studies, particularly cerebral scanning, may be indicated, again depending on the individual patient's presentation and progress during evaluation and treatment.(96)

DISPOSITION

All patients with significant electrical burns should be stabilized and transferred to a regional burn center with expertise in electrical injuries, if possible. (94) In addition to burn care and extensive occupational and physical rehabilitation, severely injured patients may need counseling for themselves and their family because of the extensive life changes consequent to the injury.

Purely thermal burns should be treated as such and disposition made accordingly with appropriate close follow-up.

Asymptomatic patients with low-voltage injuries in the absence of significant cutaneous involvement changes or urinary heme pigment can probably be discharged safely will, reflect in follow-up.

Indications for admission for 12 to 24 hour ECG monitoring are listed in Table 8. Any case in which corporal conduction is suspected should probably be admitted for monitoring. Patients should be informed of the potential for development of delayed cataracts, weakness, and paresthesias, and appropriate referrals made if these develop.

Electrical injury during pregnancy from low voltage sources hits been reported to result in stillbirth. (113) Obstetric consultation should probably obtained in all pregnant patients reporting electrical injury, regardless of any symptomatology a the time of presentation. Patients in the second and third trimesters should receive fetal monitoring and be followed as high-risk patients for the remainder of their pregnancy. (114) First trimester patients should be informed of the risk of spontaneous abortion and if no other inclinations for admission exist, may be discharged with instructions for threatened miscarriage and close obstetric follow up. Prognosis for fetal survival after lightning stroke varies. (3, 19) Consultation with other specialists may be indicated for otic and ophthalmic damage, although these are usually' not emergent considerations.

Treatment of pediatric patients with oral burns is more controversial. There is good evidence for cardiac injury, need for ECG monitoring, or occurrence of myoglobinuria in isolated oral burns. In general, these patients need surgical and dental consultation for planning of debridement, oral splinting, and, occasionally, reconstructive surgery. Since there is a 10% risk of delayed hemorrhage from the labial artery, some centers recommend admission until separation of the eschar occurs. Admission for observation and planning of definitive therapy is also recommended by some centers. Treatment of patients with lightning injuries usually calls for simple common sense and patience. Many of the signs, such as lower extremity paralysis and mottling and the neurologic signs of confusion and amnesia, resolve with time and need only observation, provided spinal cord and intracranial injuries have been ruled out. More severely injured lightning patients may need both trauma and cardiology consultations although lightning injuries tend to be more of a medical problem than a trauma problem in most cases.

SUMMARY

High-voltage electrical injuries may be devastating, with extensive burns, cardiac arrest, amputations, and long, complicated hospitalizations. Low-voltage injuries, after other pathologic and high-voltage sources are ruled out, tend to be rather benign acutely although they may have significant long-term morbidity, including chronic pain syndromes.

Lightning injuries affect 800 to 1000 persons per year.(9) In lightning injury, cardiac arrest is the main cause of death, burns tend to be superficial, and injuries often are what one would expect of short-circuiting or overloading the body's electrical systems (tinnitus, blindness, confusion, amnesia, cardiac arrhythmias, and vascular instability).

Although high-voltage injuries may require the services of trauma Puma surgeons, in general, therapy for low-voltage and lightning Jury is supportive and involves cardiac r resuscitation for the more seriously injured and supportive care for the less severely injured. long-term problems from sleep disturbances, anxiety attacks, pain syndromes, peripheral nerve damage, fear of storms (for lightning patients), and diffuse neurologic and neuropsychological damage may occur in electrical and lightning patients.(42) Other sequclae such as seizures or severe brain damage from hi hypoxia during cardiac arrest and spinal artery syndrome vascular spasm are indirect results of electrical and lightning injury.

REFERENCES

1. Ahrenholz DH, Schubert W. Solem LD. Creatinine kinase as a prognostic indicator in electrical injury. Surgery 1988; 104:741
2. Hanumadass ML. Acute electrical burns: a 10 year clinical experience. Burns 1986;12:427-9
3. Cooper MA, Andrews CJ. Lightning Injuries. In Auerbach P. ed: Wilderness medicine, 3rd ed, St. Louis: Mosby-Year- book, 1995:261-89
4. Duclos PJ, Sanderson LM. An epidemiological description of lightning-related deaths in the United States. IntJ Epide-miol 1990;19:673-9
5. Baker MD, Chiaviello C. Household electrical injuries in children: epidemiology and identification of avoidable hazards AmJ Dis Child 1989;143:59-63
6. G. Fontanarosa PB, Abert SJ, Chaudhari M. Low voltage electrical injuries in adults: patterns of injury, clinical features and acute complications Presented at Society for Academic Emergency Medicine, 1993
7 Lopez RE, Holle RL, Heirkamp TA Lightning casualties and property damage in Colorado from 1959 to 1991 based on Storm Data Weather Forecasting 1995; 10:114-26
8. Coates L, Thong R. Siciliano F. I.ightning fatalities in Australia, 1824-1991. Nat Hazards 1993,8:21~33
9 Chilbert M, et al: Measure of tissue resistivity in experimental electric burns. J Trauma 1985;25:209-15
10 Puschel K Brinkman B. Lieske K Ultrastuctural alteration of skeletal muscles after electrical shock Am J Forensic Med Pathol 1985;6:246-51
11. Lee RC. Role of cell membrane rupture in the pathogenesis of electrical Trauma,J Surg Res 1988;44:709-13
12. Papatheofanis FJ, Papatheofanis BJ. Acid and alkaline phosphatase activity in bone following intense magnetic field irradiation of short duration Int J Radiat Biol 1989, 55:1033-5
13. Papatheofanis FJ. Use of calcium channel antagonists as magnetoprotective agents (unpublished)
14. Jaffe RH Elecuopathology: a review of the pathologic changes produced by electric currents. Arch Pathol 1928 5:839-69
15 Cooper MA Electrical and lightning injuries. Emerg Med Clin North Am 1984;2:489-501
16. Andrews CJ. Studies in aspects of lightning injury. Ph.D. Dissertation, University of Queensland, 1993
17. Biegelmeier C. New knowledge of the impedance of the human body In BridgesJ, Ford 1, Sherman 1, Vainberg M, eds: Electric shock safety criteria Elmsford, NY: Pergamon 45 Press, 1985
18. Andrews CJ, Darveniza M. Effects of lightning on mammalian tissue. Proceedings of the International Conference Lightning and Static Electricicity, Bath, UK September 1989:104
19. Cooper MA Lightning injuries: prognostic signs for death. Ann Emerg Med 1980;9:134-8
20. Darveniza M Electrical aspects of lightning injury and damage. In Andrews CJ, Cooper MA, Darveniza M, Mackerras D, eds: Lightning injuries: electrical, medical, anti legal aspects Boca Raton, FL: CRC Press, 1991:23-39
21. Ekoe JM, Cumlbigilam M, laques O, Baiag R. Disseminated intravascular coagulation and acute myocardial necrosis caused by lightning. Int Care Med IY85;11:160-2
22. I.ichtenberg R. Dries D, cl al. Cardiovascular affects of lightning spikes. Am Coll Cardiol, 1993, 21:531-6
23. Moran KT: Electric- and lightning-induced cardiac arrest reversed by prompt cardiopulmonary resuscitation. JAMA, 1986:255:2157-61
24. Pierce MR, Henderson RA, Mitchell JM. Cardiopulmonary arrest secondary to lightning injury in a pregnant woman. Ann Emerg Med 1986:15:597-9
25. Sinha AK Lightning-induced myocardial injury, a case report with management. Angiology 1985;36:327-31
26. Subramanian N. Somasundaram B. PeriasamyJK Cardiac injury due to lightning[and]report of a survivor. Indian HeartJ 1985;37:72-3
27. Zeana CD. Acute transient myocardial ischemia after lightning injury. IntJ Cardiol 1984;5:207-9
28. Woods J, Spinal atrophic paralysis following lightning stroke. S Afr Med J 1952;6:92-5
29 Buechner HA, Rothbaum JC. Lightning stroke injury—a rcport of multiple casualties from a single lightning bolt. Milit Med 1961;126:755-62
30. Leys K Spinal atrophic paralysis case following lightning stroke. Edinb MedJ 1942;49:657-9
31 Stueland DT. Bilateral humeral fractures from electrically induced muscle spasm J Emerg Med 1989;7:457-9
32. Francis DA, Heron JR. Progressive muscular atrophy and posterior dislocation of the humerus following electrical shock. Postgrad MedJ 1984;60:143-4
33. Cooper MA. Electrical and lightning Injuries. In Rosen 1', ed. Emergency medicine, 5th ed, New York: Mosby-Yearbook, (in press)

34 Bongard O. Fagrell B. Delayed arterial thrombosis following an apparently trivial low-voltage electrical injury. Vasa 1989;18:162-4
35 Hunt JL. Vascular lesions in acute electrical injuries I Trauma 1974;14:461-3
36. Andrews CJ, Darveniza M. New models of the electrical install in lightning strike. Proceedings of the 9th International Conference on Atmospheric Physics, St. Petersburg Russia, 1992.
37. Arden CP Lightning accident at Ascot Bt- Mcd J h35G;I: 1450-3
38. Yost JW, Holmes FF. Myoglobinuria following lightning smoke JAMA 1974;228:1147-8
39 Andrews CJ, Cooper MA, tenDuis HJ, Sappideen G. The pathology of electrical and lightning injuries. In Wecht CJ, ed. Forensic Sciences, Chapter 23A, Release 19 update NY: Matthew Bender & Co, 1995
40. Lehman LB. Successful management of an adult lightning victim using intracranial pressure monitoring. Neurosurgery 1991;28:907-10
41 Hooshmand H. Radfar F. Beckner E The neurophysiologic aspects of electrical injuries. Clin Electoencephalogr 1989;20: 111-6
42 Cooper MA, Andrews CJ, ten Duis HJ. Neuropsychological aspects of lightning injury. Proceedings of the 9th International Conference on Atmospheric Physics, St Petersburg Russia, 1992
43. Dolling S. Lightning-strike disaster among children. Br l Med Psycho 1985;58:375-83
44. Dolling Sit, O'Donnell JP, Staley AA Lightning-induced disaster: effects on children's fears and worries. I Counsel Clin Psycho 1984;52:1028-38
45. Kotagal S. Rawlings CA, Chen SC, et al. Neurologic, psychiatric, and cardiovascular complications in children struck by lightning Pedriatrics 1082;70:190-2
46 Shantha TR. Causalgia induced by telephone-mediated lightning electrical injury and treated by interpleural block Anesth Analg 1991;73:507-8
47 Kelley KM, Pliskin N. Meyer C, Lee RC. Neuropsychiatric aspects of electrical injury: the nature of psychiatric disturbance. Ann N Y Acad Sci 1994;720:213-8
53. Sheaf MB. Lightning cataracts. Wic Med 1 1984; 83:23-24
54 Critchley M. Neurological effects of Lightning and electricity. Lancet 1934;1:68-75
55. Bergstrom L. The lightning damaged ear. Arch Otolary 1974;100:117-21
56. Poulson P. Knudstrup P. Lightning causing inner ear damage oke.and intracranial haematoma. J Laryngol Otol 1986;100:1067-71
57. Shaw GP, Atkinson LS. Heanug loss secondary to lightning strike. Otolaryngology 1981;2:233-34
58. Uliss KS. Otologic lightning bolts. Am I Otolaryugol 19S0; 1 :33~7
59. Jones DT, Ogren FP, Roh LH, Moore CF. Lightning and its effects on the auditory system Laryngoscope 1991;30: 830-4
60. Kristensen S. Tveteras K Lightning-induced acoustic rupture of the tympanic membrane (a report of two cases) J Otolaryngol Otol 1985;99:711-3
61. Abt. The pupillary responses aher being snuck by lightning. JAMA 1985; 54:3312
62. Campo RV, Lewis RS. Lightning-induced macular hole. Am J Otolaryugol 1984;97:792-4
63. Casuen JA, Kytila J. Eye symptoms caused by lightning. Acta Ophthalmol 1983;41:139-42
64. Noel W. Clarke WN, Addison D. Ocular complication of lightning .J Pediatr Ophthalmol Strabismus 1975;17:245-6
65. Purdue GF, HuntJL. Electrocardiographic monitoring after electrical injury: necessity or luxury? J Trauma 1986; 26:16~7
66. Housinger TA, Green L, Shahangian S. et al A prospective study of myocardial damage in electrical injuries. J Trauma 1985;25:122-4
67. Hammond J. Ward GC. Myocardial damage and electrical injuries: significance of early elevation of CPK-MB isoenzymes. South MedJ 1986;79:414-6
68. Jensen PJ, Thomen PEB, Garrerv P. et al. Electrical injury causing ventricular arrhythmias. Br Heart J 1987;57: 279-83
69. Ku CS, Lin SL, Hsu TL, et al. Chang MS. Myocardial damage associated with electrical injury. Am Heart J 1989;118: 62-24
70. Kinney TJ Myocardial infarction following electncal injury. Ann Ernerg Med 1982;11:622-5
71. Walton AS, Harper RW, Coggins CC. Myocardial infarction after electrocution. MedJ Aust 1988;148:365-68
72. McBride,JW. Is serum creatine kinase-MB in electrically injured patients predictive of myocardial injury? JAMA 1986;255:764-7
73 Andrews CJ, Colquhoun DM, Darveniza M. The QT interval in lightning injury with implications for the 'cessation of metabolism' hypothesis. Wilderness Med 1993;4:155-66

74. Chia BL Electrocardiographic abnormalities and congestive cardiac failure due to lightning stroke. Cardiology 1981; 68:49-53
75. Palmer ABD' Lightning injury causing pro1Ongation of the OT imerval. Postgrad MedJ 1984;63:891-4
76. Cherington M, Yarnell P. Hallmark D. MRI in lightning encephalopathy. Neurology 1993;43:1437-9
77. Waymack JP, Rutan RL. Recent advances in burn care in electrical injury. Ann N Y Acad Sci 1994;720:230-8
78. Gottdieb LJ, Saunders J. Krizak TJ. Surgical technique for salvage of electrically damaged tissue. In Lee RC, Cravalho
89. Hocking B, Andrews CJ. Fractals and lightning injury. Med j Aust 1989;150:409-10
91. Holibilan C.J. Early surgical decompression in the management of electrical injuries. AmJ Surg 1982;144:733-9
92. Dixon CF. The evaluation and management of electrical injuries. Crit Care Med 1983;11:38-89
93. Hentz VR. Burns of the hand: thennal. chemical and electrical. Emerg Clin North Am 1985;3:391-402
94. American College of Surgeons: Commitee on Trauma. Injuries burns and cold, Advanced Trauma Life Support Program instuctor manual, 1988
95. Rajam KH, Reddy DR, Sathyanarayana E, Rao DM Fracture of vertebral bodies due to accidental electric shock.J In-dian Med Assoc 1976;635-6
96. Cherrington M, Yarnell P, Lammereste D. Lightning strikes: nature of neurological damage in patients evaluated in hospital emergency departments. Ann Emerg Med 1992: 21 :575-8
96a Mann 11, Kozic Z, Boulos MI. CT of lightning injury AJNR 1983;4:976-7
96b. Stanley LD, Suss RA. Intracerebral hematoma secondary to lightning strike: case report and review of the literature Neurosurgery 1985;16:686-8
96c Wakasugi C, Masui M Secondary brain hemorrhages associated with lightning stroke: report or a case. Jpn J Legal Mecl 1986;40:42-4
97. Varghese C, Mani MM, Redford JB. Spinal cord injuries following electrical accidents. Paraplegia 1986;24: 159-66
98. Vincent FM. Spinal cord injury from electric current: a case report. Arch Phys Med Rehabil 1981;62:498-9
99 Levine NS, Atkins A, McKell DiA,, et al Spinal cord injury following electrical accidents: case reports J Trauma 1975; 15:459-63
100. Christiensen JA, Balis GA, WaumettJD Delayed neurologic injury secondary to high-voltage current with recovery. J Trauma 1980;20:166-8
101 ten Duis HJ, Klasen HJ Keraunoparalysis, a 'specific' light-ning injury Burns 1985;12:54-7
102 Baker R. Paraplegia as a result of lightning injury Br Med J 1978;4: 1464-6
103. FrayneJH, Cilligan BS. Neurological sequelae of lightning stroke. Clin Exp Neurol 1987;24:195-200
104. Mankani MH, Abramov CS, Boddie A, Lee RC. Detection of peripheral nerve injury in elecuical shock patients. Ann N YAcad Sci 1994;720:206-12
105. unusual complication of an electrical burn. Arch Surg 1972,105:494-6
106. Williams DB, Karl, RC. Intestinal injury associated with low-voltage electrocution. J Trauma 1981;21:246-50
107. BrandayJM. Visceral complications of electrical burn injury: a report of two cases and a review of the literature. West Indian MedJ 1989;39:110-2
108. Moulson AM. Blast injury of the lungs due to lightning. Br MedJ 1984,289:1270-1
109. Solterman B. Frutiger A, Kuhn M. Lightning injury with lung bleeding in a tracheotomized patient. Chest 1991;99:240-3
110. Moran KT, Munster AM, Low Voltage electrical injuries: the hidden morbidity. JR Coll Surg, Edin, 1986; 1:227-30
111. Budnick LC. Bathtub-related electicutions in the United States1979-1982 JAMA
112. Lewin RF, Arditti A, Sclarovsky S. Noninvaslve evaluation of electrical cardiac inJury. Br HeartJ 1983,49:190-2
113. Lleberman JR, Mazor M, Macho J, et al. Electrical accidents during pregnancy. Obstet Gynecol 1986,67:861-3.
114. Sherer DM, Schenker JG., Accidental injury during pregnancy, Obstet Gynecol Surv; 44- 330-1

Behavioral Consequences of Lightning and Electrical Injury

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Immediate manifestations in survivors of lightning and electrical injuries include altered consciousness, confusion, disorientation, and amnesia.(1,2) Subsequently, patients show either normalization of mental status or sequelae ranging from headaches and distractibility to persistent psychiatric disorder and dementia. (3,4) The fact of this variety has been recognized for a long time. (5)

Behavioral effects have been described in numerous case reports (3); research, however, has been relatively scant and subject to a number of shortcomings. (6) These include sampling bias and heterogeneity, cross-sectional rather than longitudinal or prospective evaluation, and inadequate assessment and analysis of premorbid factors and concurrent psychopathology. We are as yet unable to predict from the "magnitude" of an electrical or lightning injury what the combination or duration of behavioral sequelae will be among survivors. As these shortcomings are remedied (6,8) knowledge of the prevalence and nature of morbidity will permit more effective clinical care. At present, however, our understanding is only partial; clinicians, attorneys, employers, and families continue to puzzle over the problems of lightning and electrical injury patients, who in turn wonder what is wrong and who can help. In this article, we discuss selected literature and present original findings with the aim to address four main questions:

1. What are the behavioral (cognitive and psychologic) sequelae among survivors of lightning injury (LI) and electrical injury (EI)?
2. Do LI and EI differ in outcome?
3. What models of brain-behavior disturbance best describe morbidity in LI and EI?
4. What recommendations for assessment and treatment can we make?

LITERATURE

Empirical studies that focus on assessment and outcome in LI and EI are described in Table 1 (4,7,9-16). Since the methods and findings are diverse, prevalence rates for various problems remain to be clarified. A few studies assessed the frequency of self-reported problems in special cohorts. For instance, Shaw and York-Moore (9) surveyed 28 of the 50 people injured by lightning in the 1955 Ascot incident in England, and Andrews and Darveniza recently studied telephone-mediated lightning injury in Australia among 132 persons contacted retrospectively (13) and 10 identified at the time of their injury.(14) In these reports, 10 to 20% of patients exhibited psychologic problems. In contrast, from a consecutive series of electrical injury patients admitted to a burn unit, Grossman et al (7) selected a sample of 16 characterized by intermediate severity for a prospective study of psychiatric sequelae. They found "persistent neurobehavioral disorder" in 75% of those whose injury was by direct current. In the remaining studies in Table 1, the individuals came to attention because of their complications, and almost all of them showed abnormalities such as depression and memory impairment. (4,10-12,15,16)

NEUROPSYCHOLOGIC FINDINGS

The neuropsychologic deficits associated with LI and EI tend to be nonspecific and to resemble those of traumatic brain injury.(4,17) While disturbances of language, awareness, or visuospatial functions seem to be rare, impairments of attention, concentration, verbal memory, and new learning are very frequently identified.(7,10, 12,13,15,16) Survivors may thus experience a reduced capacity to function, both occupationally and socially, and may complain of forgetfulness, inefficiency, and inability to handle even mildly stressful situations. These new obstacles and sense of loss may contribute to psychologic disorders, which in turn affect cognition.

The prediction of impairment from initial injury factors is imprecise. First, the subacute course in LI and EI is quite variable, with some patients returning to premorbid status and others experiencing persistent impairments. Progressive impairment has also been reported, such as the cases with dementia listed in Table 1 from Daniel et al (4) and Troster and Ruff.(12) Second, such variables as voltage level or whether loss of consciousness occurred do not correlate with neuropsychologic profiles.(4,17) For example, case descriptions of LI indicate that neither cardiac arrest nor gross central nervous system (CNS) lesions necessarily predict poor outcome.(18) Also, although both of the EI patients described who deteriorated had sustained high-volt-age injuries (more than 8000 V), such poor outcome was not the rule within high-voltage groups. For instance, data from an archival study of 90 EI cases (19) suggested good outcome in 56% of patients receiving high-voltage injuries (compared to 91% of patients receiving low-voltage injuries), at least in terms of resolution of CNS symptoms observed during inpatient care.

In EI and LI cases with persistent cognitive deficits, poor memory is a common complaint, and emotional distress is also prominent. In an investigation of memory functioning after EI, Bares (20) compared 20 patients early in their course (between I and 57 days after injury) to 20 patients with late sequelae (9 months to 4 years post-injury) on a 280 measure of verbal memory that differentiates the components of acquisition, retention, and retrieval.(21) The groups were matched on age, sex ratio, years of formal education, and estimated premorbid intelligence. Within-group variability was high, and mean group differences on index scores were not significant. Relative to normative expectations, however, 56% of subjects in the acute group and 68% of subjects in the post-acute group had component scores in the impaired range (lower than 1 standard deviation below the mean). Thus, both early and late EI were associated with a deficit in verbal memory, with the late EI group tending to be worse. Acquisition and retrieval were more affected than retention, as is seen in the so-called subcortical syndromes as well as in affective disorders. When self-report of depression was analyzed, (22) the post-acute group showed a significantly higher frequency of symptoms of depression, but this variable did not account for memory performance. Furthermore, neither involvement in litigation nor history of loss of consciousness ac-counted for memory results in this study, suggesting independence of memory impairment from individual differences in initial injury, affective status, and money issues.

Taken together, these findings provide some support for the phenomenon of delayed or progressive decline of cognitive and emotional functioning after EI. Prospective serial assessment of memory function and affective status is needed to establish the frequency of decline. Since the subjective experience of poor memory may arise from other cognitive or emotional factors such as distractibility or fatigue, these should also be assessed.(23) The lack of obvious correspondence between neuropsychologic deficits and in-jury variables or other individual differences highlights the need for thorough evaluation.

PSYCHOLOGIC MORBIDITY

The studies cited in Table 1 describe a variety of emotional problems, ranging from anxiety to marital break-down to major depression, and illustrate several main features of late psychologic sequelae: they are variable in severity and duration, they are difficult to predict from injury parameters, and their etiology is not readily inferred. For example, such reported difficulties as sleep disturbance, memory deficit, depression, sexual dysfunction, and chronic pain, as well as weakness, dizziness, and confusion may arise from neurologic injury, psychologic reaction, or from the subtle interrelationship between the two.

Table 1. Investigations of Behavioral Sequelae of Lightning (LI) and Electrical (EI) Injury*

Study	*Sample (n)*	*Postinjury Interval*	*Cognitive Deficits†*	*Psychologic Morbidity†*	*CT/EEG Findings*	*Outcome*
Shaw and York-Moore[9] (1957)	LI (28)	>1 yr (self-report)	NA	18% with anxiety, depression, or hysteria	NA	NA
Hopewell[10] (1983)	EI (1)	Acute, 50 days	Verbal retrieval (disorientation cleared)	NA	Abnormal EEG (left temporal slowing)	Returned to work (6 mo)
Daniel et al[4] (1985)	EI (11)	1–36 mo	73% "cognitively impaired"	89% with abnormal MMPI (Hs,D,Hy)	NA	Severe deterioration in 1 pt
Mancusi-Ungaro et al[11] (1986)	EI (10) Flash (7) Non-EI (36)	2–26 mo	NA	Abnormal MMPI (7 of 10 scales), abnormal BDI (depression) in EI group	NA	2 of 10 returned to work (6 mo)
Troster and Ruff[12] (1987)	EI (1)	3 yr	Attention, memory, IQ	Severe depression	NA	Demented
	EI (1)	6 mo	Verbal memory	Abnormal MMPI (Hy,Hs)		NA
	LI (1)	1 mo–2 yr	Attention, verbal memory	Mild distress		Good (memory improved)
Andrews and Darveniza[13] (1989)	Telephone mediated LI (132)	>3 yr (self-report)	6% memory loss	4% anxiety, shock; 10% depression, other	NA	<10% with long-term distress
Andrews and Darveniza[14] (1992)	Telephone mediated LI (10)	Acute	NA	20% "marked disturbance"	NA	NA
Frayne and Gilligan[15] (1987)	LI (1)	Acute, 6 weeks	Concentration, problem-solving, coordination	NA	Abnormal CT (right posterior infarct)	Deficits resolved gradually
	Telephone mediated LI (1)	3 weeks	Verbal memory, new learning	Transient personality change	Normal CT, EEG	Returned to work
Hooshmand et al[16] (1989)	EI (16)	3–12 mo	Concentration, memory, judgment	MMPI depression (14); amotivation, anxiety, irritability also noted	Normal CT (15), atrophy (1), slow EEG (9)	Not working (11/13), divorced (9/11)
Grossman et al[7] (1993)	EI (16) Flash (18)	Serial tracking for 1 yr	Attention, memory, general decline in EI group	PNBD (12), PTSD (1) in EI group	NA	NA

*Among EI studies, single-case reports involved high-voltage exposure while the remaining samples were heterogeneous for volt-age level.
†BDI: Beck Depression Inventory; CT: computed tomography; EEG: electroencephalogram; MMPI, Minnesota Multiphasic Personality Inventory (Hs, D, and Hy are clinical scales); NA, not assessed; PNBD, persistent neurobehavioral disorder (organic brain syndrome); PTSD, post-traumatic stress disorder.

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The dilemma of etiologic specificity is illustrated by Engelstatter (24) who reviewed symptom checklists collected retrospectively from 100 lightning strike survivors and 65 electric shock survivors, all of whom presented with chronic sequelae 2 or more years postinjury (mean interval, 4.5 years). Tables 2 and 3 reveal a wide range of complaints in this group, suggesting diffuse dysfunction and varying degrees of potential debilitation. In both the EI and LI samples, nine of ten of the most frequently reported com-plaints are of a variety that may be primarily psychologic in nature or that often reflect a psychologic component. Five of the top 10 are classic symptoms of depression, for both EI and LI patients.

Frequencies in Tables 2 and 3 give the impression of diffuse, nonspecific neurobehavioral dysfunction in complicated LI and EI. Cluster analysis was utilized to deter-mine whether subtypes of late outcome could be identified. Since the original questionnaires consisted of more than 70 yes/no items about symptom occurrence, the data were first submitted to factor analysis to identify symptom dimensions. Six factors accounting for 47% of the total variance were extracted. (Explained variance ranged from 27% for the first factor to 3% for the sixth.)

Table 2. Frequencies of Common Aftereffects Reported by 65 Electrical Injury and 100 Lightning Injury Survivors*

Symptom	***Electrical Injury Sample (%)***	***Lightning Injury Sample (%)***
Neurobehavioral		
Sleep disturbance	74*	44*
Memory deficit	71*	52*
Attention deficit	68*	41*
Headaches	65*	30
Irritability	60*	34*
Inability to cope	60*	29
Reduced libido	55	26
Unable to work	54	29
Chronic fatigue	48	32
Dizziness	48	38*
Easily fatigued	48	38*
Communication problems	46	25
Incoordination	40	28
Confusion	38	25
Chronic pain	29	21
Weakness	25	29
Sensory		
Numbness	63*	36*
Paresthesias	60*	40*
Tinnitus	48	33
Photophobia	46	34*
Hearing loss	31	25
Visual acuity reduced	25	20
Emotional		
Depression	63*	32
Flashbacks	51	20
Agoraphobia	46	29
Emotional problems	38	24
Personality change	29	19
Storm phobia	7	29
Nightmares	26	12
Other		
Muscle spasms	63*	34
External burns	54	32
Decreased grip strength	51	34
Stiff joints	48	35*
Back problems	46	25
Inability to sit long	45	32
Arthritis	38	19
Hyperhidrosis	31	25
Internal burns	28	21
Bowel problems	25	23

*The 10 most common symptoms for each injury group are indicated by asterisks. Symptoms in italics are the ones most likely to have an organic basis; etiology for other symptoms may be organic, psychologic, or both.

The 10 most common symptoms for each injury group are indicated by asterisks. Symptoms in italics are the ones most likely to have an organic basis; etiology for other symptoms may be organic, psychologic, or both. Remaining symptoms loaded weakly on more than one factor.

Factor 1 encompassed a variety of neurobehavioral complaints, including depression, fatigue, dizziness, confusion, sleep disturbance, tinnitus, paresthesias, numbness, headaches, and neuropsychologic deficit (decreased attention, memory, and coordination). This constellation may be termed Global."

Factor 2 included anxiety, chronic pain, weakness, nightmares, personality change, and suicidal ideation, and may be termed "anxiety reaction."

Factor 3 grouped epilepsy and cardiac problems.

Factor 4 included paraplegia, aphasia, and physical dependent; this appears to be a "disability" factor.

Factor 5 included amputation and various systemic problems.

Factor 6 included auditory deficit. Remaining symptoms loaded weakly on more than one factor.

Cluster analysis of these factors as well as age for 149 subjects resulted in four subgroups, generally characterized by age and symptom specificity (Table 4). Cluster A (41 % of cases) showed predominance of the "global" and "anxiety reaction" factors. Cluster B (27% of cases) showed predominance of the "global" factor. Cluster C (9% of cases) was characterized by "disability." Cluster D (23% of cases) had amputation/systemic complaints (factor 5). These analyses were not able to isolate subgroups with discrete psychiatric syndromes; 68% of the cases (clusters A and B) are characterized by multiple complaints and distress, the etiology of which is not obvious. The database did not include systematic information about severity of initial injury, onset or duration of dysfunction, results of diagnostic workups, status of compensation claims if any, or premorbid adjust-meet, and the role of these factors in predicting outcome is not known.

DIFFERENCES BETWEEN SURVIVORS OF LIGHTNING AND ELECTRICAL INJURIES

As noted elsewhere in this issue, the mechanisms of injury by lightning strike and electrical shock differ. One might expect a bimodal pattern of outcome in lightning (severe versus mild), but a more continuous distribution of severity of problems in electrical injury, since intensity of current and duration of exposure are variable.

Table 3. Additional Symptoms Noted in the Literature and Their Frequency of Report in 65 Electrical Injury and 100 Lightning Injury Survivors

Symptom	*Electrical Injury Sample (%)*	*Lightning Injury Sample (%)*
Neurologic		
History of coma/loss of consciousness	9	15
History of convulsions	11	7
Seizure disorder	12	12
Aphasia	8	6
Paralysis	8	11
Inability to walk	11	11
Ataxia	3	5
Deafness	12	13
Dry eyes (Sjögren's syndrome)	23	9
Cardiovascular		
Heart problems	14	12
History of heart attack	6	10
Irregular electrocardiogram	3	3
Elevated heart rate	6	6
Drop in heart rate	3	4
Hypertension	5	6
Other		
Amputation	6	2
Pinched nerves	18	17
Bladder problems	18	17
Kidney problems	11	10
Skin problems	18	12
Random fears	17	11
Suicidal thoughts	11	6
Out of body experience	18	5
No known aftereffects	0	4

The studies with assessment of LI cited in Table l involve only a few cases, (12,15) but these would suggest that, compared to EI, LI has milder and shorter-term neuropsychologic effects. Within LI, milder aftereffects are reported for telephone-mediated injury than LI in the field. (25)

Within EI, physical trauma is a function of the mode and duration of exposure, the pathway of current, and the differential resistance of tissues in its path. As noted earlier, voltage level alone is not a reliable predictor. On the other hand, the studies that compared subjects with only flash burns to those experiencing passage of current''' showed clearly worse psychologic outcome for the latter, suggesting that the CNS and systemic effects and not external burns correlated with morbidity. Estimating CNS damage, how-ever, is difficult, since entrance and exit points may not define the actual pathway.(1) Thus, characterizing the difference in injury between cases with better versus worse out-come awaits further study.

Table 4. Characteristics of Subgroups Resulting from Cluster Analysis on the Symptom Factor Scores for 87 Lightning Injury and 62 Electrical Injury Survivors*

Clusters	No.	Ratio of LI : EI	Mean Age (yr)	Factors 1†	2	3	4†	5	6
A	61	33 : 28	38.1	++	+				
B	46	23 : 17	50.8	++					
C	14	11 : 3	21.0	−−		+	++	−	
D	34	20 : 14	67.2	−−	−			+	

*Distinguishing elevations (++,+) and low scores (−−,−) on factors are indicated. Factors are described in the text.
†Significant differences between clusters.

The question of differences between LI and EI in psychologic outcome was addressed with the data from Engelstatter (Tables 2 and 3). (24) This sample was self-selected and seems to represent the complicated end of the LI and EI spectrum. When scores on symptom factors already described were subjected to discriminant analysis, the EI survivors were differentiated by higher scores on the "global" factor, and the LI survivors were more likely than EI cases to have auditory sequelae (factor 6). Age and sex of subject did not distinguish the groups. Although 30% of the cases in each group were misclassified, suggesting overlap between LI and EI with poor outcome, the discriminant function was statistically significant ($p < 0.001$), and the finding of greater severity of neurobehavioral and emotional problems in EI than in LI is consistent with the literature.

THE QUESTION OF MODELS

A number of possibilities have been suggested for models to guide diagnosis and management of LI and EI. They derive from presumptions about the underlying organic injury as well as from similarities in presentation to other syndromes. Precise mechanisms need further study. Sources of injury include the passage of current through the vascular and nervous systems, anoxia associated with cardiac or respiratory arrest, blunt trauma (direct strike or secondary head injury), and peripheral injury (such as burns and tympanic membrane rupture). (2) The mechanisms of injury by lightning and man-made electricity could plausibly underlie the diverse symptoms patients re-port. (2,10,16,20,26) For instance, damage to small blood vessels and to myelin could be associated with delayed onset of pain or sensorimotor loss; traversal by current of hypothalamic and brainstem centers could lead to endocrine and autonomic dysfunction, and so on. Multiple, diffuse com-plaints are not the exception.

HEAD INJURY

Whether or not primary CNS injury or secondary head injury can be documented, the model of traumatic brain injury seems appropriate (4, 7, 17). Such common complaints in LI and EI as headaches, disturbances of attention and memory, and autonomic dysfunction are consistent with a head injury model. Postconcussion syndrome seems particularly instructive. It is characterized by subtle, nonfocal neuropsychologic deficits such as impairment of concentration and memory, as well as complaints of headaches, dizziness, fatigue, irritability, and depression, in association with a nor-mal neurologic examination.(27) Magnetic resonance imaging (MRI) studies of Mild Closed Head Injury have revealed punctate hyperintensities (believed to be axonal shearing) in some cases, and focal contusions, usually in frontal and temporal regions, in others. Functional imaging studies such as positron emission tomography (PET), evoked potential recordings, and autopsy results have also suggested postconcussion brain damage.(27)

Recognizing the ambiguities in EI, Grossman et al (7) described "persistent neurobehavioral disorder" (defined as three or more persistent deficits in cognitive, psychomotor, or interpersonal performance) in 12 EI patients followed for 1 year; since only two had positive MRI studies, whereas eight had auditory abnormalities, CNS involvement was considered to be covert compared to peripheral signs and behavioral disturbance. A study of cognitive dysfunction in EI suggests that it is analogous to that in head injury: profiles of neuropsychologic deficits were reported to be similar in eight EI patients and eight head injury patients matched demographically.(6) The head injury model also has the potential to accommodate psychiatric sequelae in EI and LI, since various CNS insults are known to result in concurrent emotional disturbance (such as personality change with cerebral tumor, or depression with left hemisphere cerebrovascular accident).

PSYCHOLOGIC DISORDERS

A variety of syndromes, including post-traumatic stress disorder (PTSD), conversion disorder, major depression, and adjustment disorder,(28) are suggested by the constellation of patients' complaints and have been considered in the literature.(29) The question of whether these are "organic" or "reactive" is a difficult one; for instance, it has been pointed out that the experience of electrical shock is the prototype of one-trial aversive conditioning and a potent inducer of PTSD symptoms. (11,29) Furthermore, when both affective disorder and cognitive impairment are present, it is not initially clear whether one or the other is primary.

PTSD shares with the possible presentation of late EI and LI the features of the acute frightening trauma, gradual emergence of psychologic symptoms, the experience of flashbacks, and a tendency to avoid associated stimuli. As noted in Table 1, this is occasionally the formal diagnosis.(7,29) It was actually more commonly diagnosed for persons with flash burns rather than direct exposure to current in the study by Grossman et al.(7) When lightning simultaneously injures several people, a comparison to sequelae of natural disaster may be apt; (30) symptoms of PTSD, if not the full syndrome, may occur along with other reactions such as survivor guilt.

Depression is a common finding, as noted in the Eng-elstatter (24) and Bares (20) data as well as in the other studies. Anxiety disorders have also been reported; they include specific forms of phobic disorders related to the initial incident (storm phobias in LI) or to subsequent activity (agoraphobia).(2) Anxiety and depression may be constituents of adjustment disorders as well. Adjustment to an acquired deficit is clearly affected by premorbid factors such as personality and coping style. (31) Obsessional types of persons are prone to brood over all the perceived changes, and brittle types tend to be dissatisfied with intervention efforts. Since risk for injury is a function of occupation and lifestyle, (2,19) the population of victims includes formerly vigorous, independent, and perhaps risk-seeking persons who may resist treatment efforts, or feel humiliated by their limitations. Some survivors attribute all subsequent difficulties in life to the injury and others experience an intolerable threat to their sense of control.(17,25) Emotional distress in turn tends to lower functional capacity, and a cycle of frustration is maintained. EI or LI may also increase risk for substance abuse, mainly through self-medication with alcohol or the overuse of prescription medications.

Somatoform disorders (characterized by physical com-plaints that have little or no basis in known medical illness) are also discussed in the literature.(29) Preoccupation with or exaggeration of multiple symptoms raises the question of somatization disorder, although this formal diagnosis is not defined by abrupt onset. Pain disorder has features consistent with complaints in EI and LI and may account for chronicity in some cases. Conversion disorder was de-scribed in the earliest studies (5,9) and remains important in the differential diagnosis. Criteria for conversion disorder (28) include a predisposing event and symptoms that cannot be fully explained by objective testing ("pseudo-neurologic"). As is apparent in Tables 2 and 3, numerous symptoms in EI and LI refer to the nervous system, and without hard signs on the neurologic examination or positive neuroimaging results, etiology is ambiguous. On the other hand, conversion symptoms usually resolve in a matter of weeks, whereas the late complaints in LI and EI may last for months or years. Since conversion and genuine neurologic symptoms often coexist,(28) ruling out neurogenic disorders is difficult and the presumption of a neurogenic component seems wiser.

The role of secondary gain is no more or less prominent in the sequelae of EI and LI than in other instances of injury, and in a percentage of cases is likely serving to maintain chronicity, although it falls short of an adequate explanation for the host of symptomatology presented in the literature. Sophisticated neuropsychologic assessment can help identify consciously or unconsciously feigned behavioral deficits. Further research on mechanisms of injury should improve etiologic inferences.

A prototype of psychologic disorder is not evident; symptom constellations in individuals may overlap with these formal categories, and presentation may be atypical, with delayed onset or protracted course. As noted in the data presented earlier, we found that 68% of the group with chronic complaints reported multiple neurobehavioral and emotional symptoms that cut across diagnostic categories. The frequency of psychiatric disability is difficult to estimate from the literature, but the cohort and prospective studies in Table 1 suggest that at least 10 to 20% of survivors will experience persistent psychologic sequelae and that a portion of those will have significantly diminished ability to function.

Survivors of EI and LI may or may not have demonstrable tissue damage. If they do, appraisal and treatment of disability seem straightforward. However, many patients with histories of electric shock or lightning strike present with atypical or diffuse complaints, especially in the late phase, when etiologic judgments are more difficult. It is this patient group that is most likely to be misdiagnosed, misunderstood, or dismissed by clinicians as malingerers or neurotics.

SYNDROME DEFINITION

Even though the severity of impairment in late EI and LI is quite variable, clinicians in widely separated treatment settings are familiar with the picture of multiple, diffuse neurobehavioral complaints.(4,24,25) A label for the phenomenon, such as postelectrocution or postelectric shock syn-drome, (24,25) seems warranted. The consistency of observations on postelectric shock syndrome among researchers and clinicians is one validation of the syndrome, whether organic factors, psychogenic factors, or both are its basis.

Andrews and Darveniza (13) identified three outcome groups in their retrospective study of telephone-mediated lightning injury. One group (40% of the sample) usually had relatively brief symptoms of 24 hours to 1 week in duration. A second group (50%) reported moderate sequelae up to 3 months postinjury, and a third group (10%) exhibited more severe and continuing disability beyond 3 months. Data reviewed here suggest that a fourth group exists, a group of LI and EI survivors who maintain significant symptomatology beyond 3 years postinjury and perhaps for a lifetime.(24) This group may also be characterized by a greater degree of psychologic overlay in their presentation and level of dysfunction. Our collective experience would suggest that the first 12 months following injury are crucial in the recovery process, with the most substantial gains being observed during that time and subsequent recovery possible up to 36 months postinjury. Then recovery plateaus, and remaining com- plaints reflect chronic dysfunction. Premorbid psychologic adjustment and physical health play an important role in the individual response to injury and the recovery process, as well as in the ultimate extent of disability experienced.

RECOMMENDATIONS FOR ASSESSMENT AND TREATMENT

Medical management is described elsewhere in these issues. Several authors recommend counseling from the outset to explain complications, reassure patients about their course, and head off reactions like PTSD. (1,2,17) Optimal management through the course of EI and LI would include serial, multidisciplinary assessment for systemic, neurologic, and neuropsychologic effects.(6-8) The reality of subtle dysfunction must be recognized; conventional diagnostics such as computed tomographic (CT) scan may be negative, whereas tests emphasizing functional integrity such as measures of regional cerebral blood flow may reveal abnormalities.(8,27) Likewise, in the neuropsychologic assess-meet, reliance should be placed on thorough evaluation of attention/concentration, problem-solving, sensorimotor functions, and component functions of memory rather than on less sensitive measures such as IQ. Feigning of deficits can also be addressed psychometrically. Psychologic assessment should include premorbid history as well as current psychopathology. Corroborative interview with a relative is desirable to characterize change from premorbid levels and identify problems in day-to-day functioning.(6)

Neuropsychologic deficits should be tracked, and cognitive retraining provided for persistent problems, as is prescribed in traumatic brain injury.(17) Psychologic difficulties and pain/dysesthesia symptoms may well warrant pharmacotherapy, such as clomipramine or other tricyclics for depression and carbamazopine for neuralgia. (2) Even for cases likely to have substantial or complete recovery, supportive psychotherapy may prevent reactive disorders and facilitate return to previous roles. Anxiety disorders and depression are amenable to behavioral and cognitive-behavioral psychotherapy, respectively. For cases with significant loss of function, the treatment goal would be to assist in adaptation and adjustment to disability. Our clinical impression is that most patients do improve and that the physician has the opportunity to influence outcome through his or her reassurance, patience, and attitude of acceptance.(25)

CONCLUSIONS

Postelectric shock syndrome is a disorder of persistent cognitive and psychologic disturbances following LI or EI. Cognitive complaints and deficits resemble those in mild to moderate traumatic brain injury. Psychologic disturbances range from specific phobias to major depression and are often associated with multiple somatic complaints referable to the nervous system. The mechanisms of CNS injury are still under study, and the etiology of persistent complaints may be multifactorial. Patients who have not recovered from initial effects after 3 months are at risk for long term sequelae and disability. Evaluation should be interdisciplinary Psychotherapy, pharmacotherapy, and neuropsychologic intervention are often indicated.

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REFERENCES

1.Cooper MA, Johnson K Electrical injuries. In Rosen P, Barkin RM, Braen CR et al, eds. Emergency medicine, 3rd ed. St. Louis: Mosby-Year Book 1992:969-78
2. Cooper MA, Andrews CJ. Lightning injuries. In Auerbach PS, Geehr ED, eds. The management of wilderness and environ-mental injuries, 3rd ed. St. Louis: Mosby-Year Book (in 17. press)
3. Cooper MA, Andrews CJ. Clinical presentation of the lightning victim. In Andrews CJ, Cooper MA, Darveniza M, Mackerras D, eds. Lightning injuries: electrical, medical, and legal aspects. Boca Raton, FL: CRC Press, 1992:47-70.
4. Daniel M, Haban OF, Hutcherson WL, Bolter J, Long C. Neuropsychological and emotional consequences of accidental, high voltage electrical shock. Int J Clin Neuropsychol 1985;7:102-6
5. Critchley M. Neurological effects of lightning and of electricity. Lancet 1934;1:68-72
6. Pliskin NH, Meyer GJ, Dolske MC, et al. Neuropsychiatric aspects of electrical injury. A review of Neuropsychological research. Ann NY Acad Sci 1994;720:219-23
7. Grossman AR, Tempereau CE, Brones ME, et al. Auditory and Neuropsychiatric behavior patterns after electrical injury. J Burn Care Rehabil 1993;14:169-75
8. Cooper MA. Postelectrocution syndrome—long term effects of lightning injury. Presented at International Conference on Lightning and the Mountains, Mont Blanc, Chamonix, France, June, 1994
9. Shaw D, York-Moore ME. Neuropsychiatric sequelae of lightning stroke. Br Med J 1957;2:1152-5
10. Hopewell C. Serial Neuropsychological assessment in a case of reversible electrocution encephalopathy. Clin Neuropsy-chol 1983;2:61-5
11. Mancusi-Ungaro HR, Tarbox AR, Wainwright DJ. Posttraumatic stress disorder in electrical burn patients. J Burn Care Rehabil 1986;7:521-5
12. Troster Al, Ruff RM. Accidental high-voltage electrocution: neurobehavioral sequelae in three cases. Presented at National Academy of Neuropsychology meeting, Chicago, November 1987
13. Andrews CJ, Darveniza M. Telephone-mediated lightning in-jury: an Australian survey. J Trauma 1989;29:665-71
14. Andrews CJ, Darveniza M. Special aspects of telephone-mediated lightning injury: an Australian perspective. In Andrews C, Cooper M, Darveniza M, Mackerras D, eds. Lightning injuries: electrical, medical, and legal aspects. Boca Raton, FL: CRC Press, 1992:163-89
15. Frayne JH, Gilligan BS. Neurological sequelae of lightning stroke. In Eadie M, Lander C, eds. Clinical and experimental 31. neurology. Baltimore: Williams & Wilkins, 1987:195-200
16. Hooshmand H. Radfar F. Beckner E. The Neuropsychological aspects of electrical injuries. Clin Electroencephalogr 1989;20:111-20
17. Heilbronner RL. Rehabilitation of the Neuropsychological sequelae associated with electrical trauma. Ann N Y Acad Sci 1994;720:224-9
18. Cherington M, Yarnell P. Lammereste D. Lightning strikes: nature of neurological damage in patients evaluated in hospital emergency departments. Ann Emerg Med 1992;21:
19. Grube BJ, Heimbach DM. Acute and delayed neurological sequelae of electric injury. In Lee RC, Cravalho KG, Burke JF, eds. Electrical trauma: the pathophysiological manifestations and clinical management. New York: Cambridge University Press, 1992:133-52
20. Bares K Nature of memory deficits in electrical injury patients. Unpublished manuscript
21. Delis DC, Kramer JH, Kaplan E, Ober BA. The California Verbal Learning Test manual. New York: The Psychological Corporation, 1987
22. Beck AT, Steer RA, Garbin MG. Psychometric properties of the Beck Depression Inventory: twenty-five years of evaluation. Clin Psychol Rev 1988;8:77-100
23. Ravdin L, Clements C, Primeau M, et al. Memory functioning in neuroborreliosis. J Int Neuropsychol Soc 1995;1:136

24. Engelstatter GH. Neuropsychological and psychological sequelae of lightning and electric shock injuries. Presented at Fourth Annual Meeting of Lightning Strike and Electric Shock Victims International, Maggie Valley, NC, May, 1994
25. Andrews CJ. Telephone-related lightning injury. Med J Aust 1992;157:823-6
26. Farrell D, Starr A. Delayed neurological sequelae of electrical injuries. Neurology 1968;18:601-6
27. Brown Sit, Fann JR, Grant I. Postconcussional disorder: time to acknowledge a common source of neurobehavioral morbidity. J Neuropsychiatry Clin Neurosci 1994;6:15-22
28. Diagnostic and statistical manual of mental disorders, 4th ed. Washington DC: American Psychiatric Association, 1994
29. Kelley KM, Pliskin N. Meyer G. Lee RC. Neuropsychiatric aspects of electrical injury. The nature of psychiatric disturbance. Ann NY Acad Sci 1994;720:213-8
30. Dollinger SJ. Psychological management of lightning victims. In Andrews CJ, Cooper MA, Darveniza M, Mackerras D, eds: Lightning injuries: electrical, medical, and legal aspects. Boca Raton, FL: CRC Press, 1992:137-9
31. Kay T. Neuropsychological diagnosis: disentangling the multiple determinants of functional disability after mild traumatic brain injury. In Horn L, Zasler N. eds. Rehabilitation of postconcussive disorders, vol 6. Philadelphia: Hanley & Belfus, 1992:109-27

KIDS' LIGHTNING INFORMATION AND SAFETY

by Sabrina

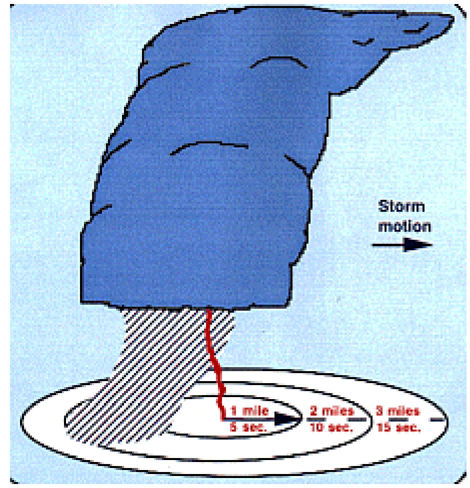
FLASH TO BANG PAGE

How close was that lightning?

By counting the seconds between the lightning "flash" and the "bang" of thunder, you can tell how far away the lightning was. Each five seconds equals one mile. If you count 15 seconds, the flash was 3 miles away and you know that you are in a high danger zone. Six miles (30 second count) is still in the high danger zone. Lightning can strike far from where the rain is falling, and sometimes even when no rain is falling at all. This is why people are sometimes hit where they can see blue sky and the sun is shining. ***Bolt from the Blue*** is an awesome PHOTO that shows lightning striking miles away from the storm cloud. This picture shows lightning reaching far from a storm. The photographer guesses that it hit the ground

about 3 to 5 miles away from the storm. If you were standing there and it was daytime, the lightning would have come out of a blue sky with no cloud above you and no rain falling on you. This is why flash to bang counting is so very important. Remember that lightning can strike 10 or possibly even 15 or more miles from a cloud

Ron Holle of the National Severe Storms Laboratory drew this picture to show what "flash-to-bang" distance means... The rings are 1, 2 and 3 miles from the lightning strike and the thunder sound will take 5, 10 and 15 seconds to reach the rings. Remember that lightning can strike up to 10 (maybe even 15 or more) miles away from a storm, so if you drew rings up to 10 miles, there would be danger anywhere inside the 10th ring. How long would it take the sound of thunder to reach the 10th ring?



When you feel that lightning may be about to strike....
When you feel that you are really in trouble with a thunderstorm....

LIGHTNING SAFETY POSITION

What can you do IF......

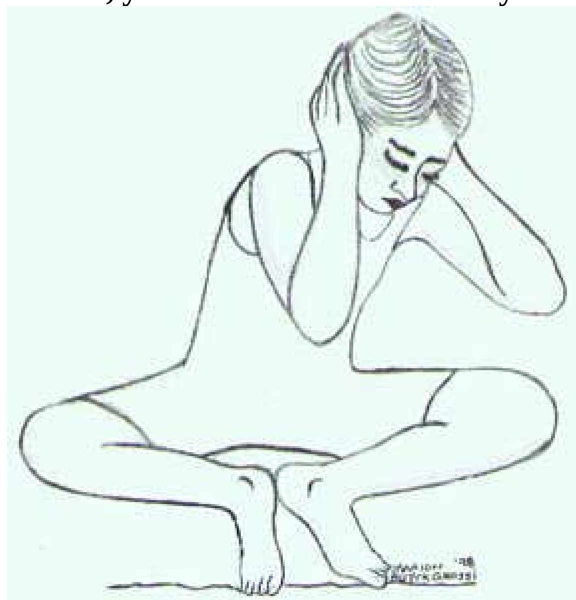
....you are caught in a thunderstorm, lightning seems to be striking all around you, and there is no shelter?

....you and a friend are outside someplace, and your skin and hair feel prickly or you see your friend's hair start to stand up and form a halo?

....your "flash to bang" count (see my flash to bang page) is very short, and there is no shelter anywhere near you?

Lightning Safety Position

You may have heard that if you can't find a shelter, you should lie down flat on your



stomach. Well, doing that is not safe at all. If lightning hits someplace near you and travels through the ground, it could pass through your whole body and electrocute you.

Lightning safety experts have invented a *"lightning safety position"* that is very important to know if you are caught in a thunder storm and you can't find a shelter. This position looks hard, but it could save your life. There are several reasons for doing it.

- It makes you a smaller target.
- With your heels together, if lightning hits the ground, it goes through the closest foot, up to your heel and then transfers to the other foot and goes back to the ground again. If you don't put your feet together, lightning could go through your heart and kill you.
- You put your hands over your ears to protect them from thunder.

[Image (c)1999 Anubis Productions and Marian Hyuk Grossi]

The lightning safety position is not as easy to do as it looks. I suggest that you practice it with your family and friends.

You may have some hard choices to make. There are no guarantees when it comes to lightning safety. If you are in a thunder storm, should you stay in the lightning safety position or should you run and try to find shelter? I suggest that you discuss this with your family and visit some of the professional lightning safety links on my main lightning safety page.