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HOW LIGHTNING KILLS AND INJURES (AND WHY WE DON'T KNOW MORE ABOUT IT)

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1. INTRODUCTION

Although lightning fatalities continue to decrease in the United States (Fig 1), lightning continues to be one of the leading causes of weather fatalities (Fig 2). The only acute cause of death from lightning is cardiac arrest at the time of the injury even if the actual pronouncement of death is delayed for a few hours or days by resuscitation efforts (Cooper 1980).

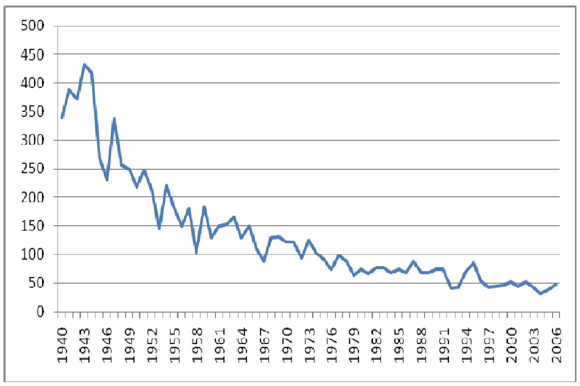

Figure 1. Lightning fatalities for the United States from 1940 through 2006 (NOAA 2007).

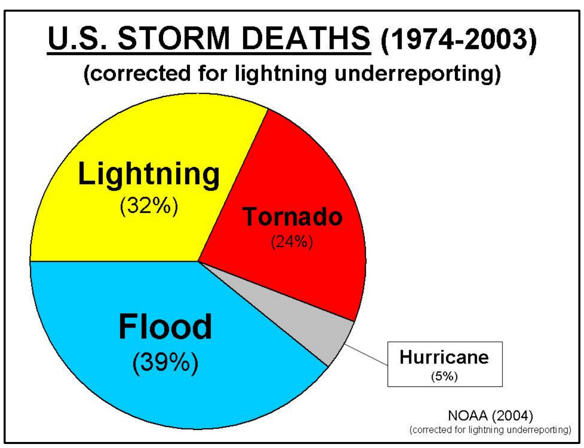

Figure 2. Weather related deaths in the US (1974-2003) by weather phenomena. (NOAA 2004). Lightning is the 2nd leading cause of storm deaths over this 30 year period (From Roeder, 2008).

2. RISK OF LIGHTNING INJURY

Due to underreporting of injuries as well as deaths (Cherington 1999; Duclos 1990,1990a; Holle 2003), it is difficult to pinpoint an exact percentage of deaths vs. injuries in the United States (U.S.). However, 10% has long been used as the common 'rule of thumb' U.S. mortality rate. Of the 90% who survive, many may suffer significant disabilities. Overall odds of injury in the United States have been estimated as shown in Table 1 (NOAA 2007a).

TABLE 1. Risk of becoming a U.S. lightning victim

2000 US Census - 280,000,000	
Reported deaths and injuries	1/700,000
Estimated deaths and injuries	1/480,000
Odds in a lifetime (est. 80 yrs)	1/5000
Odds of being affected	1/500

Rates and risk for the rest of the world's populations are hard to obtain (Holle 2008) and may be affected by many different factors (Table 2). Most of the geographic areas in the world where lightning is more common tend to have more agrarian and labor intense economies where workers may be more exposed to lightning and have fewer substantially constructed buildings in which to find safe shelter than in the U.S. Holle (2003) estimated the number of deaths in the tropical and subtropical areas to be about 24,000 per year and the injuries, using the 10% rule of thumb, to be 240,000.

TABLE 2. Factors which determine overall risk

Lightning density
Population density
Outdoor activity
Availability of safe shelter
Knowledge and compliance with lightning safety / injury prevention guidelines

3. PERSPECTIVES ON LIGHTNING AND LIGHTNING INJURY

Lightning injury may be viewed from a number of perspectives, usually dependent on the observer's training and experience (Table 3). Electrical perspectives may include investigation of the physical factors which produce lightning, prediction of lightning events, warnings, and reports of injuries in *Storm Data*, Most lightning injury prevention and safety recommendations are based on research from this perspective (Roeder 2008, 2008a, 2008b, Zimmermann 2002, Jensenius 2008).

Another level of 'electrical' observation is from the effect lightning has on the human body both from a macro view of visible injuries, a micro view including cellular effects, or a behavioral view of the effects of lightning injury on the individual or society (Cooper, 2008).

TABLE 3. Lightning injury perspectives

Electrical
- Atmospheric, meteorological – (safety)
- Medical
  - Macro – burns
  - Micro – cellular, functional disruption
  - Behavioral effects

Concussive / mechanical
- Thunder, acoustic, explosive force
- Muscle spasm, fall
- Blunt injury - musculoskeletal
  - Back injury, eardrum rupture, fractures
  - Secondary – debris missiles

There is also a non-electrical, mechanical perspective which includes acoustic effects as well as barotrauma from the explosive shock wave experienced when a person is very close to a lightning channel or when a person is thrown by muscle spasms and suffers a secondary impact. These can cause blunt injury including eardrum rupture, fractures, back injuries and contusion to the lung and other structures of the body. Secondary injury may occur when a tree or other object hit by lightning explodes dispersing debris missiles, although this is rare.

4. PRESENTATION OF LIGHTNING INJURY

Until 1980, the majority of papers on lightning injury in the medical literature were case reports with no overall organized view of prognosis, injury complications or likely outcomes. A retrospective review and analysis of these reports plus a small sample of the author's cases showed a correlation between death and burns to the head or both legs, but not arm to arm or hand to foot (Cooper 1980). It also showed that cardiac arrest was more likely to occur if there were burns on the head and that cardiac arrest was the only acute cause of death. These correlations continue to hold up nearly thirty years later.

Unlike gunshot wounds where a specific entry and exit wound may be found, or high voltage electrical burns, where massive internal injuries and external burns are often extensive and deep, lightning generally causes few significant external signs of injury in the majority of cases. This is due to several factors, including the physics of lightning, flashover, the decreased or modified energy levels that occur with the most common mechanisms of injury (Cooper, 2008a), inadequate exposure time for burns and other skin damage to occur, and perhaps other factors not yet described (Cooper 2007). While electrical field effects are important in technical electrical injuries and may produce electroporation of cells, it remains to be seen if the same effects are seen with the complex electrical fields generated by lightning.

In a study of survivors, less than one third suffered any external marks or burns (Cooper 2007). Although occasionally deep burns similar to high voltage injury can occur, they are rare in the population seen in the US and other economically developed countries.

Lightning is primarily a nervous system injury, involving injury to any or all of the three divisions of the nervous system. Since nerve tissue does not heal well, survivors may have permanent damage or disability including chronic pain due to peripheral injury or thought processing and attention problems due to brain injury. Autonomic injury has also been described with positive tilt tests, dizziness, changes in sweat and temperature patterns, hypertension and rarely cardiac arrhythmias. The discussion of nerve injury, healing, cell death, scarring and resulting change in function is far too complex to include in this paper.

A more extensive discussion of the medical presentation of lightning injury as well as a complete bibliography of lightning injury publications is available at www.uic.edu/labs/lightninginjury.

5. DIAGNOSIS AND CARE OF LIGHTNING INJURY

The physics of lightning is far better understood than the pathophysiology of lightning injury. There is no 'gold standard' or unequivocal test that can validate lightning injury in all who claim it nor are there easily available, inexpensive, simple or easily interpreted tests that can measure the extent of injury. While similar brain and cognitive injury has been well documented with technical electrical injury where more research and funding has been available, it is unclear how these deficits occur, particularly when the brain is not in any way in the pathway of electrical current.

Care and rehabilitation are also far from well-defined or exact. They vary with the clinical judgment and expertise of the professionals involved, family or patient self-advocacy and follow-through, patient resources, resource management and availability as well as the severity and range of injury suffered by the survivor.

6. STUDIES OF LIGHTNING INJURY

Research on the medical consequences of lightning injury has been sparse, in large part because of lack of funding as well as few injuries and deaths relative to areas such as cancer, heart disease and HIV. One of the current more active research groups is the Chicago Electrical Trauma Program which performs multidisciplinary evaluations of survivors of electrical and lightning. Unfortunately, the funding for the majority of these evaluations comes primarily from cases in litigation, obviously biasing the sample.

One of the areas of investigation involves use of a powerful research magnet to perform functional MRI (fMRI) of the brain (Cooper 2008). The commonly available clinical diagnostic MRI is merely an anatomic or static picture. An fMRI differentiates between actively functioning vs resting areas of the brain, 'lighting up' based on the concentration of oxygenated hemoglobin. By using activities or tests designed to target language perception, for instance, areas of language processing can be differentiated from those used simply to hear verbalized nonsense sounds.

In the case of lightning injury, a test was developed to study attention deficit, a large factor in the cognitive deficits that lightning and electrical survivors often suffer. Normal, matched controls performed the same tasks. Preliminary findings were initially surprising but, in fact, also supported another frequent problem of easy mental fatigability that many survivors find incapacitating. Since the majority of the study subjects were injured by electricity, more lightning survivors need to be studied before the findings can be generalized.

7. STAGES OF LOSS AND RECOVERY

Survivors of lightning injury suffer the same stages of loss initially described by Elizabeth Kubler-Ross in her landmark study, 'On Death and Dying'. In fact most people who have serious loss, whether a job, a disability, or the loss of a loved one suffer these same stages to a more or less extent.

These stages are:

1. **Denial** -- 'This can't be true; it didn't happen to me; I'll wake up tomorrow and it will be gone and I'll be like I was before.'
2. **Anger** – Since it is hard to be angry at lightning, anger is often displaced to the family, to physicians or comes out as an angry 'I'm going to lick this' attitude.
3. **Bargaining** – 'If I can just find the right pill / right exercise / right doctor, etc, this will all go away.' This stage can lead to desperate searching for magic answers that do not exist.
4. **Depression** – From experience, we expect that most problems such as a sprained ankle or laceration will resolve in a specific and finite time. When symptoms do not resolve or improve in a few weeks or a few months, the patient must face the reality that they may never resolve, resulting in despair and depressive symptoms.
5. **Acceptance** – With good support, and depending on the survivor's personality and other factors, many learn to accept their limitations, put them in their place and move on with the rest of their lives.

None of these stages are 'clean' but overlap and recur during the post-injury and recovery period. They are a normal physiologic response to loss and, like physical and mental recovery from other illness or injury, take their own time and cannot be rushed. The acceptance stage, for instance, rarely occurs before two to three years post-injury.

8. SUMMARY – PREVENTION OF INJURY IS ALWAYS BETTER THAN TREATMENT

Since there is no medical therapy or intervention that is known to stop the cascade of injury and disability once it is set in motion with the initial insult, it is far better to prevent the injury than to treat the survivors.

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