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DISTRIBUTION OF LIGHTNING INJURY MECHANISMS

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1. INTRODUCTION

Lightning continues to be one of the leading causes of weather fatalities. Over time, many mechanisms have been proposed by lightning professionals and many 'common sense' assumptions have arisen, including many myths, particularly in the popular press. After examining hundreds of cases in some detail, we attempt to quantify the distribution of injuries associated with each of the commonly accepted mechanisms of lightning injury.

2. BACKGROUND

a. Data Collection

Nearly every state maintains a Trauma Registry. In addition, reports are mandated by various public health authorities for injuries such as dog and other animal bites and infections such as sexually transmitted diseases and adult chicken pox. However, there is no registry or mandatory reporting of lightning injury, and it is probably unrealistic to think a reliable and verifiable source of lightning injury data will ever exist.

Compilations of deaths and injuries (Table 1) are based on NOAA's monthly publication *Storm Data* that is compiled from reports from each local National Weather Forecast Office. They are also linked from the NOAA Lightning Safety Awareness Week website at www.lightningsafety.noaa.gov. In addition, a collection of media reports is in the database at www.struckbylightning.com.

For multiple reasons, all databases in Table 1 contain inaccuracies and underreporting (Mogil 1977; Lushine 1996; Cherington 1999; Lengyel 2004; Richey et al. 2007) and often misinterpretation. Deaths are generally better reported than injuries (López et al. 1993).

TABLE 1. Sources of lightning death and injury data.

NOAA's *Storm Data* (monthly)
Online www.StruckbyLightning.org database
National Safety Council
National Center for Health Care Statistics

Very few lightning incidents involving people have been investigated first-hand in a timely fashion by knowledgeable lightning experts. Reports of lightning injury come primarily from media reports and from personal anecdotes. While none of the following ways of misreporting incidents may be intentional (Table 2), they do lead to errors in data collection.

- Lack of knowledge of lightning injury mechanisms by the witness, victim or reporter,
- Errors in observation and assumptions by eyewitnesses untrained in lightning observation,
- Amnesia of the victims, and
- Over-dramatization of the event.

More often than not, media reports are written by junior reporters who have a deadline to meet, and little opportunity to do research on the subject. If victims and witnesses are unavailable, they will often use statements and second hand information from police or emergency medical responder reports and interviews.

Various public sources such as the National Safety Council and the National Center for Health Care Statistics rely on public health and state agency reports. However, not all people seek immediate care at the emergency department after

Table 2. Reasons for unreliability of data collection concerning type of mechanism involved in lightning death and injury.

No mandated lightning injury registry
Data sources taken from
Media reports
Personal anecdotes
Coroner reports
Hospital admissions
Lightning injury databases
Underreported in number
Incomplete, non-verifiable reports
Untrained observers and/or media
Primary versus secondary death coding
Deaths versus injuries

their injury. There is no mandatory reporting of lightning injury for patients who are seen but released. Databases which rely on state reports of hospital admission will be incomplete since most survivors do not require hospital admission (Cherington et al. 1999).

b. Mechanisms of Injury

Lightning injury could be examined from a number of different levels, including cellular physiology, electrical field effects, flashover versus internal flow of energy, and probably several other categories. Illustrations of these mechanisms are shown in Cooper et al. (2007). This paper will examine only the distribution of injury among the five most commonly proposed mechanisms in the last decade, as listed in Table 3.

Direct strike: Occurs when the lightning stroke attaches directly to the victim. This is most likely to occur in the open when a person has not taken the proper precautions in planning their outing or has been unable to find a safer location when an unanticipated thunderstorm forms in the area. While it is intuitive that a direct strike might be the most likely to cause fatalities, this has not been shown in any studies.

Contact potential: Occurs when a person is touching an object that is either hit by lightning or connected to something that has been hit by lightning at a distance such as plumbing, corded electrical appliances, telephones, headsets, hard-wired electronics, and long metal fences. A voltage gradient is established on that object from the strike point to the ground, and the person in

TABLE 3. Mechanisms of lightning injury.

Direct strike
Contact potential
Side splash/flash
Earth potential rise/ground current
--Step voltage
--Ground arcing
Upward streamer/leader

contact with the object is subject to the voltage between their contact point and the earth. A current therefore flows through them and sufficient energy can be transmitted to cause an injury.

Side splash/flash: Occur when lightning that has hit an object such as a tree or building travels partly down that object before a portion "jumps" to a nearby victim (Golde and Lee 1976). Standing under or close to trees and other tall objects is a very common way in which people are splashed. Current divides itself between the two paths in inverse proportion to their resistances. The resistance of the "jump" path represents an additional path separate from the path to earth from the stricken object. Side flashes may also occur from person to person.

Earth Potential Rise: Arises because the earth, modeled ideally as a perfect conductor, is not so in reality. When lightning current is injected into the earth, it travels through the earth just as it would in any other conductor. Earth has a finite resistance, and so voltages are set up in the ground, decreasing in size with distance from the strike point. The voltage (or potential) of the earth is raised, hence the term Earth Potential Rise (EPR).

There are several consequences of EPR. If a person is standing in an area where EPR is active, i.e. near the base of a strike, a voltage will appear between their feet and current will flow via the legs into the lower part of the body. This is more significant between front and back legs of animals, where the path may involve the heart.

Kitigawa (2000) proposed that ground arcing can also occur as a type of EPR. It must be remembered that despite modeling to the contrary, the grounding earth is not homogeneous and provides arc generation points. Kitigawa also noted that more serious injuries are likely to be caused by ground arcing which usually involves higher energies than by ground current.

Irregularities can be highlighted on mountain sides (Cooper et al. 2007). If the terrain is markedly irregular, the spreading lightning current may reach the surface and a surface arc discharge develop together with the flow of the conduction current in the ground. Because arcs carry considerable energy, a person exposed to a surface arc discharge is more likely to have a more severe effect, including thermal injuries, temporary paralysis, or even death. This mechanism of injury makes it particularly dangerous for someone on a mountain side to shelter inside a shallow cave or under a small cliff or outcropping of terrain where surface arcing is much more likely to occur, injuring the person just as they feel some degree of safety has been achieved.

Upward streamer/leader: Such streamers/leaders that do not attach to the main lightning channel can still be of a magnitude to injure the person who is the source of the leader (Cooper 2002). The danger of upward streamers has recently been documented (Anderson 2001; Carte et al. 2002; Cooper 2002). Injury may occur when a victim serves as the conduit for one of the usually multiple upward leaders induced by a downward stepped leader and its field. Streamers also occur when there is no attachment between them and the stepped leader. While one might think that these are weak in energy compared to the full lightning strike, and although upward leaders are poorly characterized, they may carry several hundred amperes of current to be transmitted through the victim. This mechanism has been mentioned by many engineering and physicist lightning experts in their writings, and a case report has been published in the medical literature (Cooper 2002). It is likely that a combination of these mechanisms may occur, especially when multiple victims are involved (Anderson 2001).

While mechanically many of these mechanisms could also impart blunt concussive force to the victims, this aspect was not directly examined in this paper.

3. RESULTS

An estimate of the distribution of the five mechanisms is provided in Table 4. While there is subjectivity to these values, it can be considered to be a starting set of values for future refinement. Note that direct strike is one of the lowest. This method is the one that much of the public and popular press lightning to be the most common, perhaps because they have little or no knowledge of other mechanisms. Unfortunately, much or most lightning safety advice is based on this assumption. However, other methods are more common, although the percentages are not especially well known at present.

TABLE 4. Estimated frequency of mechanisms of lightning injury.

Mechanism	Frequency
Direct strike	3 - 5%
Contact potential	15 - 25%
Side splash/flash	20 - 30%
Earth Potential Rise	40 - 50%
Upward streamer/leader	10 - 15%

4. SUMMARY

Although newspaper reports and personal accounts most often recount 'direct strike' as the mechanism of lightning injury, examination of hundreds of injuries reveals that 'direct strike' makes up a very small proportion of the injuries. The direct strike, although dramatically ascribed as the cause of injury in most media reports, probably occurs in as few as 3 to 5% of cases.

Contact potential, where the person is touching an object that is hit such as plumbing, corded appliances, telephones, headsets, electronics, and metal fences, occurs in around 15 to 25% of the cases

Side flashes from other objects such as trees or towers are probably more common and are estimated to be the causative mechanism in approximately one fourth of the cases. Ground potential or Earth Potential Rise, whether ground arcing or ground current, is the most common mechanism, occurring in up to half of the cases. Upward streamers/leaders that do not attach to the main lightning channel account for the remainder of the injuries. It is likely that a combination of these mechanisms occur in some cases.

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