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# MECHANISMS OF LIGHTNING INJURY SHOULD AFFECT LIGHTNING SAFETY MESSAGES

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## ABSTRACT

The vast majority of newspaper reports of lightning injury portray direct strike as the predominant mechanism. However, direct strike actually causes only a small number of the injuries.[1] This paper will review the mechanisms of injury as well as a likely distribution between the mechanisms of injury in an attempt to dispel the myth that the majority of injuries and deaths are caused by 'direct' strikes.[2] Educational efforts should include not only warnings that apply to direct strike but to all of the other mechanisms as well.[3-4] At the same time, the most simple message is usually the best, regardless of the educational level or age of the audience.[3-5]

## 1 INTRODUCTION

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.[1,2] There are many reasons for misreporting including lack of knowledge of other 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. None of these may be intentional but do lead to errors in data collection and interpretation, prescription of lightning avoidance tactics, and perception of lightning risk by both the public and many professionals.

## 2 FACTORS LEADING TO ERRORS IN REPORTED INJURY MECHANISMS

There are multiple factors which lead to misreporting of lightning injury mechanisms.[6] Of necessity, the reports are retrospective and gathered largely from witnesses and survivors of lightning strike.[2] Few incidents are investigated by qualified experts and few criteria exist which define the evidence that should be sought for lightning strikes involving personal injury.

### 2.1 Witness and Survivor Accounts

Lightning injury is almost always a dramatic and unexpected event. Lightning is so sudden and its course so rapid and variable that the human eye cannot record it accurately. Even well trained lightning researchers are well aware of the differences between their visual observations and the wonders of modern high speed lightning photography.[7]

Witnesses often catch only a glimpse of the event, often at the edge of their visual field. They are not trained in what to observe nor how to interpret their observations. The incident often causes a highly charged emotional shock in the observer, particularly if anyone was injured, further affecting the observation. In addition, the human brain will often naturally and *totally involuntarily* complete or 'embroider' incomplete observations with details that have nothing to do with the actual occurrence.[1,2]

These factors also apply to the survivors themselves, complicated further by the fact that lightning more often than not causes confusion, sometimes loss of consciousness and amnesia for at least part of the event and in many cases for minutes to days after the event.

The longer the period between the event and the time the witness or survivor relates their story, the more likely the story is to be enhanced by their reflection, personal reading and research, as well as whatever interpretations and questions they

experience from friends, relatives, medical personnel, neighbors, reporters, and anyone else who comments to them on their story.

In more remote sites, the account of a lightning incident may be delayed by several days and go through several people before reaching authorities or newspaper reporters.[8] Each iteration of the story adds another layer where misinterpretations, misinformation and embellishments may creep in.

Nearly any reader of more than a few lightning injury accounts will find that the majority of injuries are believed and reported by witnesses and survivors to be 'direct' injuries. While this is understandable because few lay persons have any knowledge of other possible mechanisms, it nevertheless overemphasizes direct strike as a mechanism.

An additional factor that may color stories is the general trend for overuse of superlatives that has occurred in the last decade or two, not only by the media but in everyday life. Overdramatization of so many events in our lives, much less a dramatic event such as a lightning injury, seems to have become a norm for many, particularly those seeking to impress or gain attention.

### 2.2 Media Reports

For convenience or in order to meet their deadlines, reporters must often obtain their story from emergency personnel or police who were not even at the scene, compounding the chance for errors in observation and story recounting. Reporters who succeed in obtaining first person interviews from the witnesses or survivors are plagued by the problems mentioned above for witness and survivors accounts.

The majority of reporters are unlikely to have in depth knowledge of lightning science or lightning injury mechanisms. Misinformation and myths such as metal attracting lightning or rubber tires or rubber soled shoes 'saving' the person often included. Even the most well intentioned report can have serious inaccuracies, which, while not dangerous to anyone, nevertheless cloud data collection efforts.

### 2.3 Underreporting of Lightning Injury

Studies have shown that lightning injury is underreported in the United States.[9] There is no legal requirement for reporting these injuries in the United States. In addition, many people do not go to a hospital if their injury does not appear to be severe at the time. The majority of lightning victims do not need admission to the hospital, further minimizing possible data capture by health statistics collecting agencies.

Storm Data, a monthly NOAA publication that is the major source of data on lightning injury in the United States, is taken from compilation of newspaper reports, trained storm spotters, emergency managers, television and web reports, and others. If an injury occurred on a busy news day in a large urban area, there is a good chance it will not be reported, at least in the newspapers, as opposed to an incident that occurs in a smaller community on a slow news day.

All of these factors contribute to the variable quality and quantity of data that is available for analysis by lightning researchers.

## 3 MECHANISMS OF LIGHTNING INJURY

Lightning current may initially be inflicted on a person in one of several ways.[1,2] Table 1

Table I: Distribution of Lightning Injuries by Mechanism.

| Mechanism | Percent |
|---|---|
| Direct Strike | 3-5% |
| Contact Injury | 3-5% |
| Side Splash / Flash | 30-35% |
| Ground Current | 50-55% |
| Upward Streamer | 10-15% |
| Blunt Injury | Unknown |

### 3.1 Direct Strike

A direct strike occurs when the lightning stroke attaches directly to the victim. This is most likely in the open when a person has been unable to find a safer location, and probably occurs no more often than 3 to 5% of injuries. While it is intuitive that direct strike might be the most likely to cause fatalities, this has not been shown in any studies.

### 3.2 Contact Injury

Contact, or touch potential, injury occurs when the person is touching or holding onto an object to which lightning attaches such as wire fencing or indoor hard wired telephones or plumbing, transmitting the current to the person.[10-13] A voltage gradient is set up on that object from strike point to ground, and the person in contact with the

object is subject to the voltage between their contact point and the earth. A current therefore flows through them. Contact injury probably occurs in about 3 to 5% of injuries.

### 3.3 Side Flash or Splash

A more frequent cause of injury, perhaps as much as 30 to 35%, is a side flash, also termed "splash". Side flashes 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. 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 or more 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 flash may also occur from person to person.

### 3.4 Ground Current or Earth Potential Rise

Earth Potential Rise (EPR), also known as ground current, 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 like it would in any other conductor. Earth has a finite resistance so that 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 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 is usually longer than in humans and where the heart may be involved along the pathway.

This is caused, for example, when the person, along with the environment around them, is raised in potential via EPR but contacts something else that may be the path to ground. For instance, if the telephone line is remotely earthed (grounded) away from the local EPR environment, the person using the phone during a strike may suffer shock as current flows through and away from the person through the phone line to its distant earthed point. This highlights that local electrical apparatus, including telephones, should be well grounded locally.

Ground current effects are possibly more likely to be temporary, slight and less likely to produce fatalities. However, multiple victims and injuries are frequent. Large groups have been injured on baseball fields, at racetracks, while hiking, and during military maneuvers.[14,15] Shocks via telephones, either incoming by contact potential or outgoing through EPR effect, can produce significant long term problems.[10-13]

Kitigawa has identified further subdivisions of the EPR phenomenon.[16] He notes that not only can EPR occur as above, but it can also occur in a manner similar to the surface flashes over a body, with arcs developing over a ground surface. It must be remembered that despite modeling to the contrary, the grounding earth is not homogeneous and provides arc generation points.

Irregularities are highlighted on mountain sides. 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 at least theoretically 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, parenthetically injuring the person just as they feel some degree of safety has been achieved.

### 3.5 Upward Streamer or Leader

The danger of upward streamers has been documented.[17,18] 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 occur even 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, they may carry several hundreds of amperes of current which can be transmitted through or around 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.[18] Upward streamer injury is probably a much underestimated mechanism of injury, and may account for as much as 10 to 15% of injury cases.

### 3.6 Blunt Injury

Finally, persons may suffer from (non-electrical)

blunt injury, either by being close to the concussive force of the shock wave produced by a nearby lightning strike or if ground current or some other mechanism induces intense muscle contractions, which can 'throw' the victim. Victims have been witnessed to have been thrown tens of yards by either mechanism. In addition, some have theorized that a person struck by lightning may suffer from explosive and implosive forces created by the thunderclap, with resulting contusions and pressure injuries, including tympanic membrane rupture. Another mechanism of blunt injury is blast injury resulting from vaporization of water on the body surface from a surface flashover spark. Lightning blast injury to the skull, brain, and viscera has been elegantly demonstrated in animals.[2,19]

### 3.7 Combination of Mechanisms

There have been many reports of multiple injuries. It is likely that these may involve groups who are exposed to a combination of mechanisms, with the majority of the people injured by EPR and upward streamers, sometimes complicated by side flashes if people are standing too close together.[14,17] Information on the exact mechanisms remains poorly documented and understood.

## 4 DISCUSSION

The distribution of injuries between the different mechanisms is based on the reviews of hundreds of cases over a period of more than three decades by researchers from primarily developed countries with diverse geographies. Over the last century, the highest incidence of injury in these countries has moved from the rural to the urban setting and from work related to recreation and leisure activity related.

It is unknown if the distribution of injuries would be significantly different in other countries or regions. Differences in the distribution between mechanisms could potentially occur for areas of minimal geographic diversity (e.g. a country that is entirely desert), population distribution and employment (urbanization vs highly agrarian labor intense regions where larger populations might be exposed to lightning during harvest or planting seasons), level of construction and housing standards which provide safer shelter[20] or other factors.

While a major objective of this paper was to dispel the myth that all lightning injuries and deaths are caused by direct strike, the most important conclusion that should be drawn from this information is that any public education effort should take into account all of the mechanisms.[3,5] At the same time, giving long lists of 'do's' and 'don'ts' can lead to confusion and difficulty remembering the 'rules' when a lightning threat presents itself.

In the United States, the National Lightning Safety Awareness Week campaign has moved from detailed instructions, extended explanations and long lists to the simple motto "When thunder roars, go indoors".[5] Thunder can be heard up to about 10 miles away in quiet conditions, but not nearly that far in the presence of wind, traffic, and when inside a structure. This rule removes any doubt about if it's time to take action, and is effective as a thunderstorm approaches.

For a more objective approach or for those areas where more warning may be necessary, the 30-30 rule was developed at the 1998 lightning safety meeting.[21] The first 30 refers to the time in seconds between seeing lightning and hearing thunder from that flash (the second 30 refers to the wait time; see next section). If the time interval from flash to bang is 30 seconds or less, people are in danger from lightning and should be actively seeking a designated safe place. This count of 30 seconds indicates that lightning is 10 km (6 miles) away, using the speed of the sound of thunder of five seconds per mile. Six miles includes about 80% of all subsequent cloud-to-ground lightning flashes in a storm.[22] Variations of the 30-second rule are widely used at military and civilian airports for radii between and five and ten miles, where validated and accurate cloud-to-ground lightning detection systems are used. In such situations, too many warnings from a large radius around a point results in a lack of trust in the method, while too small a radius misses too many storms and potential injuries.

Comparison of the two methods indicates that "When thunder roars, go indoors" is a useful approach for everyday use. It has been found that even preschool children can remember this. In fact, children employing this rule are sometimes much better at lightning safety than adults who may be distracted by their work, recreational activity or because they are using electronic devices.

## 5 CONCLUSION

The vast majority of lightning injuries and deaths are caused by mechanisms other than direct strike. Any public education efforts should take into account all of these mechanisms and should employ simple and easily remembered rules to prevent lightning injury.

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