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A Fifth Mechanism of Lightning Injury

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Case Report

Abstract

There are four classic electrical mechanisms of lightning injury: direct strike, contact, sideflash, and step voltage, also called ground potential or ground current effect.[1-4] However, these do not always explain every injury. For years, a fifth mechanism has been postulated in the engineering literature by lightning researchers but has never been substantiated with any eyewitness cases.[4-6] This paper presents the first case report of a witnessed death initiated by injury from a weak upward streamer. In this case, we have a single, clean, well documented and witnessed case of injury where generated electricity was ruled out as a source and where no lightning was detected in the immediate area and time of the incident. None of the previously accepted mechanisms of lightning injury can explain this incident.

Keywords: Lightning Injury; Obstruction, Airway; Environmental Hazards; Environmental Medicine; Cardiac Arrest; Lightning; Electricity; Electrocution; Accidental Death; Case Report

Introduction

The purpose of this paper is to present the first witnessed and documented case of lightning injury caused by a weak upward streamer of lightning.

Classically, four electrical mechanisms of injury by lightning have been described: direct strike where the victim is directly hit by the lightning discharge; contact where the victim is indirectly injured by touching an object that is charged by a lightning strike; sideflash where the victim is injured when charge from a nearby object or other person flashes or splashes through the air to the victim; and step voltage (also known as ground current, step potential or nearly any combination of these words) where lightning hits the ground or a nearby object and travels through the ground to injure the victim.[1-4] Injuries may be caused both by electrical mechanisms of injury as well as mechanical trauma when the person is thrown by muscle contraction or suffers a fall.[7]

Many lightning researchers have postulated injury by a fifth mechanism, that of being part of a weak upward streamer, but engineers have never offered discrete cases to support their contention and only recently has a mathematical model for this mechanism been published in the engineering literature.[8]

Cloud Physics 101 – Lightning generation: what is an upward streamer?[9]

Lightning discharges are initiated in thunderclouds and begin as horizontal intercloud lightning that jumps in spurts 30-50 meters long. It branches, then retreats to the source only to refill the main established streamer channel and branch again at the endpoint of each of the 30-50 meter lengths, repeating this cycle over and over again in a matter of microseconds. This branching and

retreating mechanism in part explains why lightning does not 'always hit the tallest object'. The downward streamer only 'sees' a 30-50 meter radius from the tip of its last division.

As one or more streamers approach the ground, opposite charges are induced in the objects below the cloud, some of which produce 'upward streamers'. One or more of these may connect with the downward streamer to complete the cloud to ground channel. However, there are often multiple upward streamers that do not form a connection. Evidence of these appears in several photographs well known to the lightning research community and has been postulated to be an additional mechanism of injury.[10-11]

Methods

Data for this case was obtained from interviews with the victim's co-workers from the scene, the paramedic rescuer, the emergency physician, pathologist, a forensic engineer, and the utility company safety officer who investigated the incident and observed the autopsy. The family of the deceased was also interviewed. Materials from the transformer box as well as the victims' clothes and personal belongings were examined. Pictures of the deceased were examined as well as the autopsy report and microscopic slides of the wound. Lightning strike data for the area and time of the incident was obtained from Global Atmospherics, Inc.(GAI).

Co-workers involved with the incident participated in a recreation of the scene with the utility safety officer taking the position of the victim (see Photos). Permission from all those listed above was obtained for this publication.

Results

On September 29, 1998, a five-man crew of experienced utility workers was extending temporary power service in a new subdivision in North Carolina. The job was located between the forks of a road in the subdivision where there

was a surrounding tree canopy 40-50 feet high (Photo 1). Thunder had been heard and a light mist had started, but the crew chief who became the victim (man A in the re-enactment Photo 2) elected to finish the job of repositioning the transformer despite his crew's concerns.

In lifting and re-setting the concrete transformer pad, two of the crew (Men B and C in photo 2) were slightly downhill and backfilling the area under it as the crew chief (A) was working on establishing the electrical connections. A was kneeling between the transformer pad and the telephone installation boxes, both equipped with 8 foot ground rods. Man C reported a tingling rush up the left side of his body from his feet to his arm and head, and felt the hairs on his left side stand up immediately prior to the 'ZZZT' sound. Unlike Photo 2 shows, the hinged transformer lid was up and partially blocking the view of downhill man B. B, C, and D all reported hearing a 'loud ZZZT - like a BIG bug zapper' that they noted was 'quite unlike the sound of 7200 going to ground'. Man B had just turned towards the victim with a shovel of dirt when he heard the sound, looked up and reports a white flash around the victim's head and right shoulder. He asked the victim if he was all right. The victim replied, "No, no, I'm not," and sunk backwards onto the slight rise.

Two of the crew, one an EMT, the other a combat medic, noted sonorous breathing but a strong pulse in the now unresponsive victim, cleared the victim's airway of chewing tobacco and began mouth-to-mouth ventilation. They were unaware that the victim wore dentures. The victim had lost his pulse by the time EMS arrived eleven minutes after dispatch. On attempting to intubate the victim, the paramedic found that the victim's upper dentures were fixed far back in his throat with a large wad of chew in back of it, both of which he attempted to remove prior to intubating the victim. The paramedic was unable to remove these objects with his fingers. He further noted that the dentures seemed to be fused to the victim's palate and, when forcefully removed with McGill forceps, had tissue attached to them. The safety officer from the utility company who

reported to the scene and also witnessed the later autopsy confirmed that there was a hole or tissue defect in the victim's palate. The dentures were lost at the time of the intubation and not available for examination.

The rhythm found by the paramedics was ventricular fibrillation. Despite oxygenation, multiple defibrillations, external pacing and medications, they were unsuccessful in establishing a useful or perfusing rhythm. Additionally, by this time, the light mist had turned into a downpour and a violent thunderstorm was occurring so that the rescuers were at risk of injury.

Resuscitation in the emergency department was also unsuccessful. The physician there noted several pinpoint brownish discolorations on the left upper chest, left upper thigh, knees and shins. The safety officer's remarks on the punctate marks was that 'all of which added together would not have covered more than a nickel in size.'

The autopsy showed a 53 yo white male 5'10'' tall and weighing 220 lb but with no evidence of coronary artery disease or occlusion. At autopsy, serosanguinous material was observed in the mouth and right ear canal. The pathologist also listed the pinpoint singes noted by the physician in the emergency department. Microscopic examination of sections through one of the deeper spots on the right knee showed 'coagulation of the tissues and rupture and streaming of the nuclei' consistent with a very superficial electrical burn and inconsistent with either an abrasion or coagulative injury seen with high voltage injuries. The heart showed minimal atherosclerosis and no blockage or thrombus in any vessel. The rest of the autopsy was noncontributory. The family noted that although the victim was overweight, he had no medical history of hypertension, diabetes, or coronary artery disease.

The electrical equipment, inspected by an experienced forensic engineer, by the author as well as by the utility's safety officer showed no evidence of damage. In addition, there was no disruption of any of the electrical systems in the subdivision nor shorting out of fuses in the electrical lines as would have been

expected from either an electrical malfunction or a lightning strike. There was no evidence of lightning damage to vehicle parked close by nor to any of the surrounding trees, all of which were alive two and a half months later when this investigation took place.

Even at the time of this author's investigation in December 1998, the clothing retained the odor of perspiration but no burn odor could be appreciated. Microscopic inspection of discolored areas of the victim's clothing corresponding to the marks on the body showed drop-like melting of the ends of the threads from exposure to very brief, very high heat as seen in lightning cases. No arc marks, as often occur with full lightning strikes or high voltage, were seen on the zipper, metal grommets of the shoes or personal belongings of the victim that had been in his pockets at the time of the injury.

Although the National Lightning Detection Network (GAI) detected lightning within a twenty-mile radius of the incident and later during the time the paramedics were present, none was documented within the immediate area and time of the incident.

Discussion

The literature contains many reports of the upward streamers. Krider published a remarkable photograph of a lightning strike to the side of a mountain in which multiple short streamers rose from the ground adjacent to a longer one that finally met the downward progressing lightning stroke.[10] A photograph in an article by Newcott and reprinted on National Severe Storms Laboratory lightning safety posters shows two non-connecting upward streamers, one from a TV antenna several hundred meters away, one from the top of a sycamore tree struck by lightning that is parallel but not communicating with the main lightning channel that hit the tree.[11]

Laboratory studies of the mechanism of long electric sparks, have shown that in the case of negative sparks, upward streamers may develop to meet the

downward progressing leader to complete the discharge process.[12] Carte et al report on a case where 28 young girls were camping with two adult counselors and seven dogs in South Africa.[13] Four of the girls and four of the dogs were killed and twenty-three of the girls sustained injuries of one sort or another. One of the authors proposes in a separate article that these injuries resulted from a mixture of sidesplash, ground current and postulated upward streamers for which he offers mathematical calculations.[8]

Injury by upward streamers has been suggested in several incidents where lightning has struck near people out of doors, in some cases killing one or more, and affecting others nearby usually throwing them to the ground and temporarily rendering them unconscious. Uman states that "*An individual can be involved in an upward leader which does not connect with the downward leader*" and that "*such an event is certainly less hazardous, due to its short duration and relatively low current, than a direct strike and is a likely cause, along with step voltage, for the simultaneous shocking of large groups of people*." [4] Mackerras writes "*In a situation where there is a lightning strike near a person in an open field, an unsuccessful upward streamer may arise from the person's head during the last stage of the downward progression of the first leader stroke. An unsuccessful streamer of this type would cause a current flow of the order of 10 to 100 A, lasting a few tens or hundreds of microseconds, through the trunk or head of the person.*"[5] He recounts a cricket match where lightning struck and killed one of the players and all the other players in the vicinity collapsed slowly and lay stunned on the ground for a period, then gradually got back on their feet.

In our case, we have a single, clean, well documented and witnessed case of injury where generated electricity was ruled out as a source and where no lightning was detected in the immediate area and time of the incident. None of the previously accepted mechanisms of lightning injury can explain this incident. However, according to Uman, one of the premier lightning researchers in the

world, a developer of the National Lightning Detection Network, and also a consultant on this case, what was witnessed is consistent with a weak upward streamer. It is hypothesized that the co-workers were not injured because they were standing on equipotential lines around the telephone and transformer installations while the victim was situated in a much more vulnerable position on the radius between two eight foot grounding rods.

The sound described by the co-workers as well as the flash seen by one near the victim's head are all consistent with a weak upward streamer of lightning. The weather conditions of light rain preceding a fast moving violent thunderstorm were ripe for producing upward streamers of lightning. The burns seen on the victim's skin and examined microscopically were consistent with superficial electrical injury, not that seen with high voltage injury.

In this case, victim was stunned by the upward streamer but had an airway clear enough to make a remark to one of his co-workers as he was collapsing. It is well known that victims of electrical or lightning injury may speak or have some consciousness for up to ten or more seconds after the insult.[14] By the time the victim hit the ground, he was unresponsive and had sonorous respirations. The crew members report a bounding pulse, making a primary cardiac arrhythmia or arrest, noted by some authors to be the rule with lightning arrest, unlikely.[7] If the crew members were mistaken, however, he may have been in cardiac arrest. Regardless, it is clear that airway obstruction played a major role in this victim's death.

Among the causes of airway obstruction: he could have had flaccid muscles due to loss of a gag reflex, he could have aspirated the dentures during the fall or as a result of a forceful diaphragmatic contraction causing a strong inhalation, or the dentures could have been pushed into the airway during airway clearing attempts. The fact that his dentures were stuck to his palate may indicate heating of the metal of the dentures with fusing to the tissues and almost certainly removal of the dentures by digital methods would have been impossible prior to

the arrival of the paramedics with McGill forceps. Indeed, this is what the paramedics found on their attempts to clear the airway. Another common mechanism is for metal hooks on the dentures to catch in the tissue necessitating forceful extraction. It is unknown whether this man would have survived if his airway had been clear.

The Lightning Safety Guidelines promulgated by the Lightning Safety Group have been published in many venues over the last three years.[15-18] These guidelines address lightning safety for the individual, the small group with short evacuation times and the large groups with long evacuation times as well as first aid for the victim. It is apparent from this case report, as well as from considering the classic four mechanisms of lightning injury, that the individual who has not used prudent judgment may become victim of lightning. By the time a person begins to ask 'should I choose this or that way to decrease my risk', they have already made too many bad decisions. Except perhaps in a true wilderness situation, no one who has used prudent judgment, armed themselves with knowledge of the weather forecast, formed an escape plan, watched the weather and followed their plan should become the victim of lightning injury.

Conclusion

The conclusion at the end of the investigation was that this injury was due neither to a high voltage electrical insult nor a completed lightning strike, sidesplash or other previously accepted mechanism of lightning injury, but was certainly consistent with a low energy upward streamer. This is the first witnessed and well-documented case of injury by an upward streamer. As a result, even those persons do not become a direct part of the lightning stroke by the four accepted mechanisms may be a risk by becoming the origin of an upward streamer. This suggests strongly that the Lightning Safety Guidelines should be reviewed and incorporated into worker's safety programs. In this case,

a death could have been averted if the crew chief (and victim) had used good judgment and decided to delay the work as suggested by his crew.

While such a mechanism is postulated to have stunned the individual and initiated the injury, the ultimate cause of death was airway obstruction and cardiac arrest. It is unknown at what point the victim lost cardiac function or if the victim would have survived the lightning injury if the airway had been clear.

Recommendations for increasing the safety of those working in lightning prone areas include:

All crew members should be trained in CPR and airway management.

Crews should be aware of weather predictions and instructed in weather assessment, safer shelter assessment and when to cease activity and seek shelter.

In lightning prone situations, an enclosed metal vehicle large enough to accommodate all workers should be available at each job site and located closely enough for those working to seek shelter.

Work policies should not penalize workers for seeking shelter in lightning prone situations.

Work policies should incorporate the Lightning Safety Guidelines where applicable.

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