A Large Group of Children Struck by Lightning

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We report on the largest case to date of children with significant injuries from a single lightning strike. A retrospective analysis was done of the camping scene and injuries to 28 people (26 preadolescent girls and 2 adult supervisors) and 7 dogs from a documented lightning strike. Of the 35 victims sleeping in the tent, 4 girls and 4 dogs were fatally injured. The 2 adults were unharmed, but 23 of the children suffered injuries including burns (23), cataracts (8), macular holes (4), tympanic membrane rupture (2), and skull fracture (2). Many of these injuries occurred more frequently than would be expected from prior large reviews and reports.

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INTRODUCTION

In the past 4 decades in the United States, lightning has killed more persons on average each year than any other storm risk with the exception of floods.[1] Fortunately, fatalities have decreased from 6 per million population per year at the turn of the century to 0.5 per million inhabitants in the past decade in the United States.[2] In South Africa, Eriksson and Smith[3] reported a mean rate of 1.5 deaths per million inhabitants among the mainly urban population and 8.8 for the rural population during a 4-year period. Although the lightning flash density profile for the United States is similar to that of South Africa, South Africa has a much more rural population distribution and generally less substantial housing than the United States.

We report on a lightning strike to a large group of children camping in an isolated area in South Africa. Although there have been reports of injuries in large groups of people, none have had such a high proportion of serious injuries to children, and none have involved persons

positioned so closely together, raising special concerns about injury prevention for camping situations (Table 1).[4-8]

Lightning strike data for this period was obtained from the national electrical power authority, Eskom (Pretoria, South Africa), which operates a countrywide lightning location system. Other information is taken from interviews with victims, eyewitnesses to the scene, direct observation of the scene, photographs taken after the incident, limited autopsy information, and examination of bedding, clothing, and the tent itself. Parents were asked individually in writing whether they were willing to provide or confirm details of injuries to their children for the purpose of investigation and subsequent publication.

Survivors were asked to make independent drawings of the positions of the victims. As might be expected from the number of persons involved, the move to the tent in the dark of night, and the trauma of the event, not all of the survivors were sure of the locations of all of the other girls. As a result, many of the sketches were incomplete. Two of the drawings were more complete, agreeing substantially with each other, and were used to corroborate the remembrances of the others. The position of the sleeping bags afterward was also used to locate the position of individual victims (Figure). A 3-year follow-up on the children is included.

CASE REPORT

Twenty-six 10- and 11-year-old girls, 2 adults, and 7 dogs were sleeping in a large tent when it was struck by lightning at about 2:30 AM on November 11, 1994, in a rural area near Nylstroom in the Northern Province of South Africa. Nearly all had been sleeping outside, until a light rain started and they moved inside.

Table 1.
Injuries to large groups.

Author	No. Injured	Activity	Mortality Rate (%)
Epperley and Stewart[4]	10 soldiers	On maneuvers	0 (0)
Buechner and Rothbaum[5]	16 soldiers	On maneuvers	0 (0)
Dollinger[7]	38 children	Playing soccer	1 (2.6)
Arden et al[6]	46 adults	By concession stand	2 (4.3)
Current study	28 children and adults	Camping	4 (14)
Golde[8]	41 adults	Mountain hikers	11 (24)

Four lightning flashes occurred in the vicinity between 2:00 AM and 2:30 AM. All were single-stroke negative discharges, ranging from −33 to −67 kA.

The 10 × 5-m tent was located on an open grassy area of sandy soil and had been on this site for several months (Figure). No rain had fallen in the vicinity during this period, so that its floor was very dry. The general area was gently sloped and surrounded by trees that were further from the tent on the northern than on the southern side. The southern end was approximately 20 m from a wooden observation platform with a vertical metal pipe approximately 6 m in height alongside, beyond which were trees below a rocky east-west ridge. There were no underground or overhead cables or wires in the vicinity.

The main supports of the tent were two 3.6-m isolated metal poles at either end, which were inserted into a base made of a short metal pipe embedded in a concrete block in the ground. The support poles were 5 m apart, and each was 2.5 m from its respective end and from the sides of the tent. Eighteen equally spaced metal poles, 1.8 m in height and with rope stays, supported the sides and corners of the tent.

The most probable layout of the tent occupants is shown in the Figure. The children have been referred to by letters, with their heads indicated by circles. Photographs showed their likely positions and the positions of the 4 dogs that died. The actual layout was almost certainly less tidy than depicted because of the hasty move inside when it began raining, with only flashlights for light.

The adult supervisors were awakened by a tremendous explosion and a feeling of having had a shock. They recalled strong, choking fumes with the smells of burnt feathers and plastic.

The tent poles were removed soon after the event. Subsequent examination showed one of the tall supporting poles had a small globule of metal at the top and evidence of arcing at the bottom consistent with metal damage by lightning. It is likely that this was the northernmost pole because most of the severely injured girls and all of the fatally injured were sleeping in the northern half of the tent.

Four children (J, M, N, and Q) were fatally injured at the time of the strike. They were located close to the northernmost tent pole. Four of the 7 dogs were also killed. The 2 adults and a small dog sleeping near the tent entrance were unharmed. Only 3 of the children escaped visible evidence of injury.

No immediate medical care was available to the victims. The closest farmhouse was more than a mile away,

and the closest medical facility was at least 50 miles away, requiring evacuation by bus through rough terrain. The campers had no communications equipment with which to call for help. Although theoretically there may have been a potential for survival of the 4 children who were fatally injured if immediate resuscitation had been attempted, in reality, wilderness situations such as this and the confusion at the scene usually preclude successful resuscitation.

Burns ranged from superficial erythema and "scorching" to deep partial-thickness burns and laceration-like burns to a few full thickness burns (Table 2). Many of the penetrating burns were described as punctate, "hot poker or skewer" burns, with smaller ones as "stippling." Only 2 examples of the pathognomonic flower-like Lichtenberg pattern (M and N) were observed. Both of these children died.

Burns in nightclothes could usually be related to underlying body burns. In a few cases, damage to sleeping bags was confidently associated with body burns. In others, information was too incomplete to draw any conclusions.

On autopsy, 2 (J and Q) of the fatally injured children were noted to have deeper "electrical" burns, and all 4 fatally injured children had punctate burns and singed hair or eyebrows. Although burns on the head and chest were recorded for all 4 fatally injured girls, similar burns were also reported in 10 of the 19 survivors with burns and those of the fatally injured girls appeared to be no more severe than those of some of the survivors.

Two children (O and R) had superficial burns around their necks. O wore a silver chain, of which no trace was found. R, the sole girl with burns to the two ends of her body, was lying in a vulnerable position close to the stricken pole and suffered extensive eye injury. The dog at the foot of R's sleeping bag died.

A linear pattern of 4 holes occurred on H's lateral left foot as if it had been "skewered." Victim V had the most unusual wounds, which were on the inside of both arms, extending from the elbows downwards, and knife-like burn cuts of a few millimeters in width, each about 10 cm long, on both hips. A surface scorch on K extended along the shin from the knee to a burn hole in a big toe. Four others, E, F, H, and S, also had extended scorches along their legs. Few burns occurred on hands (7%), whereas toes, especially the great toes, were more frequently affected (29%).

Although most burns healed within 2 months with little or no scarring, 3 girls' (E, F, and G) burns healed poorly or required grafts.

Victims I and J had fractured skulls. Victim J, who was fatally injured, had bloody otorrhea and rhinorrhea. No other fractures were reported.

Although several girls complained of sore muscles, none experienced keraunoparalysis.

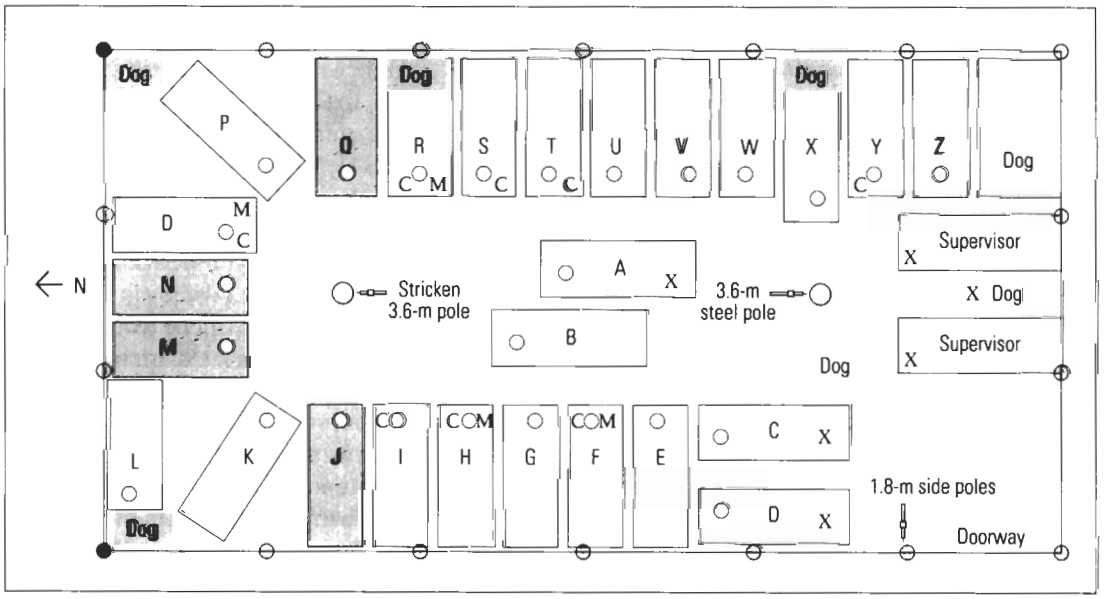

Figure.
Schematic layout withing the 10 × 5-m tent. ***Circle,*** *Placement of children's heads;* ***shaded area,*** *deceased;* ***C,*** *cataract;* ***M,*** *macular hole;* ***X,*** *not injured.*

Eight of the 24 survivors developed cataracts, and 4 of these developed macular holes (Figure). Seven of the 8 were in or close to the northern half of the tent, whereas the eighth (Y), whose cataract developed later and who was otherwise minimally injured, was next to the southeastern corner and next to Z, who developed persistent irritated and red eyes. Also close to this corner was a dog that survived but suffered eye damage in which the cornea later became opaque.

Two children (F and I) had otic damage. F required tympanoplasty, and I had persistent deafness in the right ear. Although it is reasonable to expect that J had ear damage with the documented otorrhea, damage to her tympanums was not documented.

For unknown reasons, the dogs in the tent appear to have been more susceptible to the effects of the lightning than the human beings. The 4 dogs that were killed were all adjacent to the sides of the tent (Figure). Three were German Shepherd–size, one in the northeastern corner, another on top of the foot end of R's sleeping bag, and a third almost opposite the southern main pole and close to lightly-injured W and X. The fourth was a medium-sized dog in the northwestern corner next to L, who also had relatively light injuries. All 4 fatally injured dogs were further from the stricken northern tent pole than nearer girls who survived.

Only the smallest dog, a Maltese poodle sleeping close to the unharmed adults, escaped visible injury. Two other large dogs were near the southern end of the tent. One dog in the southeastern corner had burns, and the other, which was sleeping close to the adults, suffered a damaged eye that later became opaque.

The school that the girls attended organized counseling for the survivors for approximately 6 months after the event. Emotional problems included anxiety, depression, and fear of storms. Subsequent school performance was not documented, and survivors were not formally assessed for other neurocognitive injuries often reported with electrical and lightning injuries.[9,10] Four reported ongoing pain at 3-year follow-up (F, H, S, and U).

Table 2.
Location and types of burns.

Location and Types of Burns	N (%)
Location	
Head/hair	14 (50)
Neck	6 (21)
Trunk	16 (57)
Upper extremity	10 (36)
Hands	2 (7)
Lower extremity	17 (61)
Toes	8 (29)
Type	
Mainly unilateral	13 (46)
"Deep" burns	7 (25)
Graft required	1 (3)
Scars without graft	4 (14)
Lichtenberg figures	2 (7)

DISCUSSION

This report documents the largest lightning multiple casualty event to children with such severe injuries. The majority of published data on lightning injuries involve single cases, small case series, or reviews of these collected cases.[11-13] There are few reports of multiple casualty incidents, and only one involving children (Table 1). Only one[4] documents people as closely spaced as these children, and none involve people lying down and away from high objects, raising special issues about camping, mechanism of injury, and injury prevention that to date have not been discussed in the medical literature. Although lightning safety guidelines have been published subsequently and have been modified for organized athletics, specific recommendations for wilderness situations may need further study.[14-17]

At the time of the event, lightning in South Africa was detected by Eskom, the national electrical power authority. This real-time network detects 70% of all cloud-to-ground flashes, with an accuracy dependent on the distance from the sensors.

In the United States, similar lightning strike data can be obtained from Vaisala–Global Atmospherics, Inc. (GAI; Tucson, AZ), which operates the National Lightning Detection Network (NLDN) and provides lightning data to the National Weather Service, National Forest Service, the Federal Aviation Authority, public utilities, and other users.

As with any scene reconstruction, conclusions are dependent on facts, in this case, photographs and location of the bedding; anecdotal remembrances; and educated suppositions of the investigators. Although we cannot be absolutely certain of the positions of the victims, there was good agreement among the girls' independent drawings of the victim locations and the other data used, including photographs after the incident.

The Figure shows that the fatalities and many of the worst injuries seem to have been suffered by those sleep-

ing in the northern half of the tent, close to the main support pole, which is assumed to be the one that showed typical lightning damage. Most of those with ocular and head injuries were also located in the northern half of the tent. Most of the least-affected victims and dogs were in the southern half of the tent near the entrance.

A number of exceptions are readily apparent. Victims A, B, and P were hardly, if at all, affected, whereas E and F suffered extensive injuries, including head and eye effects, and the dog near to W died. Although these apparent anomalies may have arisen from uncertainty in establishing sleeping positions, there is also a certain randomness that may be a result of the capricious nature of lightning strikes or to other factors of which we are unaware.

Classically, electrical injury by lightning is caused by at least 4 mechanisms: direct strike, contact with a stricken object, side flashes from a stricken object, and high voltage gradients in the ground near to the point of strike.[2] Mechanical injury can occur as acoustic or blunt trauma from explosive expansion and contraction of air around a lightning stroke or the person being thrown by muscular contractions induced by current flow.[2,11-13]

In the lightning strike accident reported in this article, a situation of great complexity arose from a single stroke flash of lightning, as indicated by the large number and wide variety of effects, both in magnitude and in nature, on the sleepers, the clothing, and bedding, as well as the ground covers. A combination of factors is usually seen with lightning strike injuries, particularly when more than one victim is involved.

If the pole were struck, side flashes between the victims and the pole and other tent structures electrified by lightning is a possible mechanism. Contact injury is unlikely because none of the survivors reported contact with the pole. However, ground currents could originate from the pole but spread unevenly (as illustrated in a graphic photograph of a scored and scorched pattern around the strike point of lightning on a seemingly uniform golfing green[18]), accounting for the injuries to victims who were sleeping almost radially from the damaged pole.

A fifth electrical mechanism, injury from an upward streamer that does not connect nor complete a full lightning strike, has long been postulated and has been calculated to range from 10 to 400 A, enough to cause considerable damage to human beings.[19-22] As the lightning leader of a flash approaches the ground from the thundercloud, it is well known that upward streamers of charge are induced from objects on the ground, especially tall, pointed ones. A companion paper published in the electrical literature includes more complete analysis of some of the cases in this report and a detailed theoretic electrical engineering model examining the upward streamers as a possible mechanism to account for injuries not readily explained by other mechanisms.[23] An independent forensic investigation that involved the upward streamer mechanism has recently appeared in the emergency medicine literature.[24]

In addition, blunt injury from violent contraction of muscles induced by the electrical energy may have occurred, given the skull fractures of I and J and the chronic neck pain of S. Further investigation of blunt injuries was not documented at the time of the incident.

The mortality figure of 14% (4/28) in our series is lower than the reported mortality rates in studies by Cooper[11] (20/66, 30%) and Andrews et al[12] (43/221, 20%). The mortality rates in these two studies were probably falsely elevated because of publication bias toward severe or dramatic cases. A more likely mortality rate of 10% injuries was reported by Cherington et al.[25] However, all of these studies involved collections of individual cases and very small groups, so that it is inappropriate to compare mortality figures to this incident involving closely spaced multiple and reclining victims.

Reports of fatalities in large groups hit by a single strike range from 0% to 24% (Table 1).[4-8] The mortality rate of groups may well be linked to how close together they are and to many other factors, including the terrain and the number of strikes.

Burns to the head and chest were recorded for all 4 fatally injured girls, as well as in 10 of the 19 survivors with burns (14/28, 50%). Although death and cardiac arrest have been correlated with burns to the head by Cooper,[11] correlation to position of the victims has not been determined.

Four children (E, F, H, and S) had extended scorches along their legs, suggesting a potential gradient along their bodies exceeding about 200 kV/m, energy sufficient to produce external arcing or flashover and reduced current flow internally, thus increasing their chance of survival.[21,22,26,27]

Two of the children (I and J) suffered skull fractures. Although fractures may occur with lightning, no comparison can be made because they have been reported rarely, sporadically, and certainly not in any multiple casualty groups.[11,12]

No reports or series of cases involving this number of eye injuries (cataracts 29%; macular holes 14%) have been reported previously.[28-32] The relationship of recumbent position to this high rate is under study.

Only 2 (7%) children were reported to have suffered otic damage. This is far less than the tympanic membrane damage reported by Cooper[11] (50%) and Andrews et al[12] (21%); this difference may be the result of a lack of examination of the ears and to upward bias in these studies. Animal work has shown evidence of entry of the lightning through cranial orifices, but it is unknown whether this is the mechanism of otic damage for these children.[2,26]

The emotional upset reported here is consistent with other reports of injuries to a group of children.[7] However, long-term effects in children have not been well studied. It is unknown whether the range and permanence of behavioral and neurocognitive effects of lightning reported in adults are mirrored in children or to what extent they may affect an individual child's neurocognitive development and learning abilities.

In summary, we have presented a case report on lightning injuries to a group of campers consisting mainly of children. Wilderness camping includes a risk of lightning injury that varies with the location, time of day, and terrain. There may be few "safer" shelter areas, and medical care may be miles away. In this report, sleeping children were lying flat on the ground and were packed closely together in a tent in an open area; these factors probably influenced the injuries they suffered. Although prevention of these injuries may have been difficult at the time and camping situations need further study, lightning safety guidelines that address many situations have been formulated since this incident occurred and are making their way into the recreational and camping literature.[14-17] Emergency physicians, as injury prevention specialists, and pediatricians, as parent educators, should be familiar with these guidelines and should educate their patients and communities about the risks of lightning injury and the choices they can make to avoid it.

Many persons and organizations helped in the acquisition of information about this event and with advice. We are grateful to: the mothers and daughters who responded to our questioning, sometimes repeatedly; the environmental education center (where the incident occurred) for providing much help; the school concerned, which overcame great reluctance to be reminded of this tragic event; Eskom (in particular Michelle Redelinghuys) for making Lightning Positioning and Tracking Sensor (LPATS) records on lightning available to us; the South African police service at Nylstroom for providing photographs; the University of Pretoria, through Jan Meiring, PhD, for access to the medical library; Chris Andrews, MD, PHD, for comments and helpful advice; and Ronald Holle, MS, for suggestions and careful editing of several drafts.

REFERENCES

1. Curran EB, Holle RL, Lopez RE. Lightning fatalities, injuries and damage reports in the United States, 1959-1994. NOAA Tech Memo NWS SR-193, October 1997. Available at: http://www.nssl.noaa.gov/~holle/techmemo-sr193.html. Accessed March 13, 2002.

2. Cooper MA, Andrews CJ, Holle RL, et al. Lightning injuries. In: Auerbach PS, ed. *Wilderness Medicine. Management of Wilderness and Environmental Emergencies.* 4th ed. St. Louis, MO: Mosby; 2001:72-110.

3. Eriksson AJ, Smith MA. A study of lightning fatalities and related incidents in Southern Africa. *Trans SA Inst Elec Eng.* 1986;163-178.

4. Epperly TD, Stewart JR. The physical effects of lightning injury. *J Fam Pract.* 1989;29:267-272.

5. Buechner HA, Rothbaum JC. Lightning stroke injury: a report of multiple casualties resulting from a single lightning bolt. *Mil Med.* 1961;153:755-762.

6. Arden, GP, Harrison SH, Lister J, et al. Lightning accident at Ascot. *Br Med J.* 1956;1:1450-1453.

7. Dollinger SJ. Lightning-strike disaster among children. *Br J Med Psychol.* 1985;58:375-383.

8. Golde RH. *Lightning Protection.* London, United Kingdom: Edward Arnold Publishers; 1973:186.

9. Primeau M, Engelstetter G, Bares K. Behavioral consequences of lightning and electrical injury. *Semin Neurol.* 1995;15:279-285.

10. Pliskin NH, Capelli-Schelpfeffer M, Law RT, et al. Neuropsychological symptom presentation after electrical injury. *J Trauma.* 1998;44:709-715.

11. Cooper MA. Lightning injuries: prognostic signs for death. *Ann Emerg Med.* 1980;9:134-138.

12. Andrews CJ, Darveniza M, Mackerras D. Lightning injury: a review of clinical aspects, pathophysiology and treatment. *Adv Trauma.* 1989;4:241-287.

13. Andrews CJ, Darveniza M. Telephone-mediated lightning injury: an Australian survey. *J Trauma.* 1989;29:665-671.

14. Lightning Safety. In: NCAA Committee on Competitive Safeguards and Medical Aspects of Sports. *Sports Medicine Guidelines.* 1997-1998 ed. Indianapolis, IN: National College Athletic Association; 1997:12-14.

15. Holle RL, RE López, Zimmermann C. Updated recommendations for lightning safety–1998. *Bull Am Meteorol Soc.* 1999;80:2035-2041.

16. Walsh KM, Bennett B, Cooper MA, et al. National Athletic Trainers' Association Position Statement: lightning safety for athletics and recreation. *J Athletic Training.* 2000;35:471-477.

17. Zimmermann C, Cooper MA, Holle RL. Lightning safety guidelines. *Ann Emerg Med.* 2002;39:660-664.

18. Newcott WR. Lightning, nature's high-voltage spectacle. *National Geographic.* 1993;184:88-89.

19. Anderson RB, Carte AE. Struck by lightning. *Archimedes R2.* 1989;31:25-29.

20. Darveniza M. Electrical aspects of lightning injury and damage. In: Andrews CJ, Cooper MA, Darveniza M, et al, eds. *Lightning Injuries: Electrical, Medical, and Legal Aspects.* Boca Raton, FL: CRC Press; 1992:23-37.

21. Mackeras D. Protection from lightning. In: Andrews CJ, Cooper MA, Darveniza M, et al, eds. *Lightning Injuries: Electrical, Medical, and Legal Aspects.* Boca Raton, FL: CRC Press; 1992:145-156.

22. Uman MA. Physics of lightning phenomena. In: Andrews CJ, Cooper MA, Darveniza M, et al, eds. *Lightning Injuries: Electrical, Medical, and Legal Aspects.* Boca Raton, FL: CRC Press; 1992:6-22.

23. Anderson RB. Does a fifth mechanism exist to explain lightning injuries? *IEEE Eng Med Biol Mag.* 2001;20:105-113.

24. Cooper MA. A fifth mechanism of lightning injury. *Acad Emerg Med.* 2002;9:172-174.

25. Cherington M, Walker J, Boyson M, et al. Closing the gap on the actual numbers of lightning casualties and deaths. In: *Proceedings of the 11th Conference on Applied Climatology.* January 10-15, 1999. Dallas, TX: American Meteorological Society; 1999:379-380.

26. Andrews CJ. *Studies in aspects of lightning injury* [doctoral dissertation]. Brisbane, Australia: University of Queensland; 1993.

27. Dhashi M, Kitigawa N, Ishikawa T. Lightning injury caused by discharges accompanying flashovers: a clinical and experimental study of death and survival. *Burns.* 1986:12:496-501.

28. Handa JT, Jaffe GJ. Lightning maculopathy. A case report. *Retina.* 1994;14:169-172.

29. Campo RV, Lewis RS. Lightning-induced macular hole. *Am J Ophthalmol.* 1984;97:792-794.

30. Noel LP, Clarke WN, Addison D. Ocular complications of lightning. *J Pediatr Ophthalmol Strabismus.* 1965;17:245-246.

31. Castren JA, Kytila J. Eye symptoms caused by lightning. *Acta Ophthalmol.* 1963;41:139-143.

32. Grover S, Goodwin J. Lightning and electrical injuries: neuro-ophthalmologic aspects. *Semin Neurol.* 1995;15:335-341.