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), calvarial (8), malarial (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.


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. 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. In South Africa, Eriksson and Smith reported a mean rate of 1.5 deaths per million inhabitants among the mainly urban population and 8.9 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
CHILDREN STRUCK BY LIGHTNING
Carter, Anderson & Cooper

Lightning strike data for this period was obtained from the national electrical power authority, Eskom ( Pretoria, South Africa), which operates a nationwide lightning location system. Other information is taken from South African views 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 Nyizimbo in the Northern Province of South Africa. Nearly all had been sleeping outside, until a light rain started and they moved inside.

<table>
<thead>
<tr>
<th>Author</th>
<th>No. Injured</th>
<th>Activity</th>
<th>Mortality Rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eppeley and Stewart</td>
<td>20 soldiers</td>
<td>On maneuvers</td>
<td>0 (0)</td>
</tr>
<tr>
<td>Buchner and Rothbaum</td>
<td>16 soldiers</td>
<td>On maneuvers</td>
<td>0 (0)</td>
</tr>
<tr>
<td>O'Brien‡</td>
<td>20 children</td>
<td>Playing soccer</td>
<td>1 (2.6)</td>
</tr>
<tr>
<td>Arden et al†‡</td>
<td>40 adults</td>
<td>By concussion stand</td>
<td>2 (4.3)</td>
</tr>
<tr>
<td>Current study</td>
<td>29 children</td>
<td>By concussion stand</td>
<td>4 (14)</td>
</tr>
<tr>
<td>Grills§</td>
<td>41 adults</td>
<td>Mountain hikers</td>
<td>11 (24)</td>
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</tbody>
</table>

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 × 3-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 rose eyes, 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 smell of burnt feathers and plastic.

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 30 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 "striping." 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 sticken 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 in knife-like burn cuts of a few millimeters in width, each about 10 cm long, on both hips. A surface scratch 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 L 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 keratoparalysis.

Figure. Schematic layout within the 10 x 5-m tent. Circle, Placement of children's heads; shaded area, deceased; C, cataract; M, muscular 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 8th (Y), whose cataract developed later and who was otherwise minimally injured, was next to the southeastern corner and next to Z, who developed persistent iritis 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 L) had ocic damage. F required tarsorrhaphy, and L had persistent deafness in the right ear. Although it is reasonable to expect that J had ear damage with the documented otorrhea, damage to his tympanum 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 sizes, 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 nearby 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. Four reported ongoing pain at 3-year follow-up (F, H, S, and U).

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.1-3,11,17 There are few reports of multiple casualty incidents, and only one involving children (Table 1). Only one6 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.13

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 Atmospheric Sciences, 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 reminiscences; and educated suspensions 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 sup-
port pole, which is assumed to be the one that showed
the 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 F were hardly hit, all affected, whereas E and F suffered extensive injuries, including head and eye effects, and the dog near to D 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 striking object, side flashes from a striking object, and high volt-
age gradients in the ground near to the point of strike.
Mechanical injury can occur as acoustic or blunt trauma from
explosive expansion and contraction of air around a
lightning strike 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,
within the clothes, the bedding, as well as the
ground covers. A combination of factors is usually seen
with lightning strike injuries, particularly where more
than one victim is involved.
If the pole were struck, side flashes between the victims
and the pole and other structures electrified by light-
nig 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 pho-
tograph of a scored and scorched pattern around the strike
point of lightning on a seemingly uniform golfing
green,23 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 light-
nig strike, has long been postulated and has been calcu-
lated to range from 10 to 400 A, enough to cause consid-
erable damage to human beings.19-23 As the lightning
leader of a flash approaches the ground from the thunder-
cloud, 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 elec-
trical literature includes more complete analysis of some
of the cases in this report and a detailed theoretic electric-
cal engineering model examining the upward streamers
as a possible mechanism to account for injuries not read-
ily explained by other mechanisms.23 An independent
forensic investigation that involved the upward streamer
mechanism has recently appeared in the emergency medi-
cine 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 inci-
dent.
The mortality figure of 14% (4/28) in our series is lower
than the reported mortality rates in studies by Cooper11
(20/66, 30%) and Andrews et al12 (43/221, 20%). The mortality rates in these two studies were probably falsely
elevated because of publication bias toward severe or dra-
matic cases. A more likely mortality rate of 10% injuries
was reported by Cherington et al.13 However, all of these
studies involved collections of individual cases and very
small groups, so that it is inappropriate to compare mor-
tality figures to this incident involving closely spaced
multiple and reclaiming victims.
Reports of fatalities in large groups hit by a single strike
range from 0% to 24% (Table 1).14-16 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 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 cur-
rent flow internally, thus increasing their chance of sur-
vival.21,22,26,27
Two of the children (I and J) suffered skull fractures.
Although fractures may occur with lightning, no compar-
is can be made because they have been reported rarely,
sporadically, and certainly not in any multiple casualty
groups.15,15
No reports or series of cases involving this number of
eye injuries (cataracts 29%; macular holes 14%) have
been reported previously28-32. The relationship of recur-
bent remission to this high rate is under study.
Only 2 (7%) children were reported to have suffered ocic injury. This is far less than the tympanic membrane damage reported by Cooper, 13 (50%) and Andrews et al. 21 (21%); this difference may be the result of a lack of mixing
of the ears and so upward bias in these studies. Animal work has shown evidence of ejection of the lightning through external orifices, but it is unknown whether this is the mechanism of ocic 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 light-
ing 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 fewer "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.

REFERENCES