

Injuries and deaths from lightning

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ABSTRACT

This paper reviews recent academic research into the pathology of trauma of lightning. Lightning may injure or kill in a variety of different ways. Aimed at the trainee, or practicing pathologist, this paper provides a clinicopathological approach.

As Ponocrates grew familiar with Gargantua's vicious manner of studying, he began to plan a different course of education for the lad; but at first he let him go on as before knowing that nature does not endure abrupt changes without great violence.

Rabelais, "The Old Education and the New", Gargantua, Book 1.

Translated from the first French edition into English by Sir Thomas Urquhart of Cromarty and Peter Antony Motteux, 1653.

LIGHTNING INJURIES

Pathology, (from the Greek pathos, meaning 'suffering' and logos, meaning 'word') deals with the causes and mechanisms of human disease. For this reason, pathology is one of the basic medical sciences and is vital to the understanding of disease and seeing to its appropriate treatment. It is important to realise that, like medicine, pathology is *not a clearly delineated science*. It owes its development to successive intellectual and technical borrowings from nearby disciplines such as anatomy, physiology, physics, chemistry, microbiology, immunology, genetics, and cell and molecular biology. For this reason, pathology reflects closely the body of knowledge gradually acquired in each of these disciplines.¹

Forensic pathology is the study of the diseases and injuries of the community. It is the last stronghold of the autopsy.^{2–6} Forensic medicine is that body of medical and paramedical scientific knowledge, which may be used for purposes of administration of the law.⁷

Keraunopathology and electropathology are subspecialties of forensic pathology. Electropathology concerns itself with the pathology of trauma of electrical injury. Keraunopathology concerns itself with the study of the pathology of trauma of lightning on the human and/or animal body.

This paper will review injuries and deaths from lightning strikes. This paper will focus on recent intellectual and technical developments from other disciplines.

The path of the lightning investigator is usually beset with many difficulties. Lightning flashes cannot be produced on demand; the investigator must therefore be ready with what is deemed *adequate* equipment before the occurrence of a thunderstorm.⁸

A thundercloud has a vertical extent of about 10 km and horizontal dimensions several times as large. The temperature varies from a few degrees

above zero at the base of the cloud to about minus 50°C at its top. Violent up and down draughts and severe turbulence occur in specific regions of the cloud.⁸

According to Malan (1967), an electrically active thundercloud may be regarded as an electrostatic generator suspended in an atmosphere of low electrical conductivity. It is situated between two concentric conductors, namely, the surface of the earth and the electrosphere, the latter being the highly conducting layers of the atmosphere at altitudes above 50–60 km.⁹

There are different types of lightning discharges: flashes to ground, ribbon lightning, beaded lightning, air discharges, cloud flashes or intra-cloud discharges and ball lightning.⁸

Rakov and Uman⁹ differentiate four types of cloud-to-ground lightning discharges: (1) downward negative lightning, (2) upward negative lightning, (3) downward positive lightning, and (4) upward positive lightning (figure 1). It is believed that downward negative lightning flashes account for 90% or more of global cloud-to-ground lightning, and that 10% or less of cloud-to-ground discharges are downward positive lightning flashes (figure 2). Upward lightning discharges are thought to occur only from tall objects (higher than 100 m or so), or from objects of moderate height located on mountain tops.⁹

The medicolegal and forensic perspectives surrounding a lightning strike have been highlighted in the newer literature from as early as 1995.¹⁰

Lightning may be defined as a transient, high-current electric discharge whose path length is generally measured in kilometres. The electric current involved in lightning strikes is direct current (DC) in the order of 30 000–50 000 Amps.¹¹ A lightning flash consists of several successive processes, some of which occur in times of the order of microseconds, while the discharge as a whole occupies an appreciable part of a second.⁹

Lightning is a natural hazard, lethal and destructive on short time scales and with important climatic effects on longer time scales (through the Nitrogen cycle and forest fire ignition). Lightning forms part of the global electric circuit.^{9 12} Lightning poses threats to aviation safety and to renewable energy production by wind turbines, and is known to adversely affect electric power utilities and transmission lines. Although it is hard to precisely predict what future lightning distributions will look like, the combination of large metropolitan areas, increased population and a warmer climate almost guarantee an intensification of the human exposure to lightning hazard.¹³



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Figure 1 Lightning (photo courtesy of Neale du Plooy).

Some places in the world have a lot of lightning-related injuries and fatalities, whereas other places in the world have fewer lightning-related injuries and fatalities.¹⁴

Lightning deaths cannot be other than accidental and provide no real problems for the forensic pathologist. Occasionally the nature of the death may be uncertain if a dead body is discovered in the open with no marks upon it. It is well known that injury from lightning is capricious and unpredictable. Two people can stand side by side during a flash and one may be mutilated and killed while the other is unharmed. The physical damage in fatal lightning strike cases can vary from virtually nil to gross burning, fractures and even tissue destruction.²

Five mechanisms have traditionally been described in the mainstream medical literature regarding lightning injury.¹⁵ Briefly, these mechanisms are:

1. A direct lightning strike.
2. An indirect lightning strike caused by contact with an object such as a pole that was directly struck, or perhaps via a conductive wire, such as a corded telephone.¹⁶
3. A side flash that could occur from a struck object, such as a tree, to a nearby victim.
4. A person or animal standing near a struck object, or close to a flash of lightning to ground, could be injured by step voltages produced by a lightning current flowing through the



Figure 2 Smooth channel lightning (photo courtesy of Tessa Stuart).

resistance of the soil beneath. This earth current can then also flow in another pathway, namely, up one limb and down another of the victim, which could result in injury or even death.

5. Bodies could become sufficiently charged during the lightning leader development process to cause upward streamers to be initiated from them, leading to injuries.
6. Recently, a sixth mechanism of lightning injury was proposed, namely lightning explosive barotrauma.¹⁷

An understanding of these six mechanisms, together with the keraunopathology associated with these mechanisms, provides the background to this paper.

Most of the fatalities from lightning strikes occur among young people who are engaged in outdoor activities. Most lightning injuries occur in rural areas, people walking home during the late afternoon which is when thunderstorms occur. A safe shelter may be considered any fully enclosed metallic structure.

Death may occur due to a 'bolt out of the blue'. One case study from Conghua, Guangzhou, China, demonstrated this phenomenon. Based on a comprehensive analysis, the lightning was concluded to be a negative 'bolt from the blue' ground flash with seven return strokes. There was no cloud cover above the head of the victim. The most probable mechanism for the lightning injuries was the side flash.¹⁸

Lightning victims may present with minor lightning injuries, moderate lightning injuries or severe lightning injuries. This is almost tantamount to the 'dose' of lightning to which the victims were exposed. The dose would depend on aforementioned six mechanisms.¹⁹ In other words, the dose would depend on the way lightning interacts with the body.

Lightning strike is an environmental electrical injury with high rates of morbidity and mortality.²⁰

Due to the fact that lightning is a multiphysics phenomenon, the different physical components may injure the victim in a multitude of different ways. Lightning processes emit electromagnetic signals, for example.⁹ Lightning injuries may also be due to the light component, the heat component, the electrical component or the blast-wave component.

CHIEF MACROSCOPIC PATHOLOGY

Macroscopic findings are chiefly located on the external aspects of the body. Most of the signs of lightning are located externally on the clothing, shoes, jewellery and belt of the victim. This becomes important in cases where no clinical history is available.

Almost any organ system may be involved in lightning strikes, and prognosis depends on multiple factors. The physical injuries may resolve completely or may be associated with long-term effects, including psychological sequelae for the survivors.

The four main, non-kinetic, energy components of lightning (namely light, heat, electricity and barotrauma) account for most of the macroscopic pathology.

Light component

The light component of lightning may injure the eye and there is a relatively large body of literature describing such injuries.^{21–24}

In ophthalmology, injuries due to lightning strikes have been documented as various entities ranging from keratitis, cataracts, uveitis in the anterior segment to retinal detachments, papillitis and macular hole formation in the posterior segment.²⁵ Severe optic injuries have been reported in both fatal and non-fatal lightning injuries.

Cataracts have been known to develop weeks to months post-lightning strike. Multiple theories exist as to why cataracts



Figure 3 Singeing of scalp hair. An adult woman who sustained direct lightning strike. Note the singeing of the scalp hair. (Photograph courtesy of Ryan Blumenthal.)

develop post-lightning strike.²⁶ One such theory suggests that the intensity of the light component of lightning may affect the crystalline structural proteins of the lens.

Heat component

The heat component of lightning may affect the clothing or the skin. Oftentimes, there are linear, first-degree burns, which may follow the skin creases. These marks may be centimetres long and generally follow the long axis of the body towards the ground. There may be superficial charring of the skin, chiefly over the trunk.²⁷

There is often a smell of singeing or burning about the body and its clothing. The hair may be scorched or singed (figure 3). The clothing may be scorched or singed (figure 4). Sometimes, synthetic clothing may even melt due to heat (figure 5).

Electrical component

The electrical component may cause Lichtenberg figures. Lichtenberg figures (arborescent or fern-like injuries) were named



Figure 4 Singeing of material. Note the scorching of the white material drawstring. This victim sustained direct lightning strike. (Photograph courtesy of Ryan Blumenthal.)



Figure 5 Melting of synthetic material. A photograph of an adult man found dead next to the side of the road with no medical history. Thorough examination was in keeping with lightning strike. The first clue was melting of synthetic fibres of clothing. (Photograph courtesy of Ryan Blumenthal.)

after Georg Christoph Lichtenberg (1742–1799).²⁸ Lichtenberg figures represent a vital reaction and are most commonly seen on light-skinned lightning strike survivors²⁹ (figure 6).

A possible explanation for Lichtenberg figures has been localised fractal pattern flow of lightning over body surfaces electrically interacting with capillaries and the iron component within the haemoglobin of the erythrocytes (Mary Ann Cooper—personal communication). Another possible explanation by Cooray *et al* is that the skin is bombarded by energetic electrons during the propagation of streamer discharges along the skin and that the keraunographic markings are as a result of superficial radiation injury with subsequent inflammation in the epidermis and superficial layers of the dermis, caused by the energetic electrons.³⁰

The electrical component of lightning may cause other, somewhat unusual, spark-like lesions, on the skin of victims (figure 7).

Cardiac effects of lightning injury

The electrical component may cause cardiac arrhythmias.³¹ Lightning strike injuries are considered to be high-voltage injuries.²⁰ The effects of the electrical current on the cardiovascular system are one of the main modes leading to cardiorespiratory



Figure 6 A classic Lichtenberg figure. (Photograph copyright of Mary Ann Cooper.)



Figure 7 Spark lesion on the skin. An unusual spark lesion found on the skin of a lightning strike survivor (photograph courtesy of Corrie Pieters).

arrest in these patients. Cardiac effects of lightning strikes may be transient or persistent, and may include benign or life-threatening arrhythmias. Prolonged resuscitation may lead to favourable outcomes especially in young and previously healthy victims.

The huge rise in voltage accompanying lightning strikes may result in a massive direct current shock, which in turn is capable of depolarising the entire myocardium.^{32 33} Furthermore, increased autonomic stimulation as a result of the shock received, with an associated catecholaminergic surge, may have additive effects on the heart rate and rhythm.

Further research is required to identify prognostic markers, either with regards to the patient's biochemistry or cardiac imaging results, in the acute setting in the 'stable' patient, thus establishing which ones may likely develop more sinister complications later on, as well as those who will benefit from close rhythm monitoring on discharge. The association between electrocardiographic ischaemic changes and underlying coronary obstruction is not fully established; further studies are required in this area to identify which patients require to be rushed to the catheter laboratory at an early stage, thus avoiding unnecessary invasive procedures.³¹

Neurological effects of lightning injury

The electrical component may also cause neurological effects, such as cerebral salt-wasting syndrome. Hyponatraemia may result in brain oedema and secondary nausea, headache, altered consciousness and sometimes death. Close monitoring of the serum sodium levels and immediate correction of electrolyte abnormalities is therefore necessary after severe brain damage. If left untreated without correct diagnosis, severe hyponatraemia may result in seizures and worsening cerebral oedema.³⁴

Salt wasting syndrome is a rare complication of lightning strike. There is limited literature on lightning-related salt wasting syndrome.^{34 35} It is unknown whether it is simply a trauma response, or a specific electrical response.

Post electric shock or lightning shock syndrome has been proposed in lightning strike survivors.³⁶ The major neuropsychological consequences of which include depression and neurocognitive dysfunction with ongoing consequences. The proposed Diagnostic and Statistical Manual of Mental Disorders diagnostic criteria insist on a demonstrated context for the injury, both in the shock circumstance and also in the physical consequences.



Figure 8 Eardrum rupture. Photograph of a ruptured tympanic membrane in lightning strike (photograph courtesy of Ryan Blumenthal).

BAROTRAUMA COMPONENT

The barotrauma component may chiefly injure the ear.³⁷ In most of the surviving patients after a lightning strike, audiovestibular abnormalities have been reported. The most frequently reported type of abnormalities is a tympanic membrane perforation with hearing loss and external ear canal burn. However, a sensori-neural hearing loss and mixed-type hearing loss may also occur, but these occur rarely. A lightning strike may cause serious audiological damage. Therefore, it is necessary to perform a careful audiovestibular evaluation of the lightning-struck patient (figure 8).

Lightning strike may cause very different effects on the auditory system. These effects may show a simple change in hearing threshold up to total loss of hearing. Audiovestibular pathology, therefore, has to be considered, and patients admitted to the emergency department after being struck by lightning have to be examined more carefully because of this reason.^{38 39}

The barotrauma component may also injure hollow organs, the lung and the gastrointestinal tract. Lightning may cause pneumomediastinum due to the barotrauma component.^{40 41} There may be blunt force trauma, concussive trauma or other explosive (blast) injuries. It is therefore critical to seek out signs of barotrauma on the clothing (figure 9), shoes (figure 10), and skin, before clinically managing the patient.

CHIEF MICROSCOPIC PATHOLOGY

Internally, there is little to be seen in lightning strike victims. Histologically, most of the positive findings are located in the heart. Wave-like arrangement of the myocardial fibres and myocardial haemorrhage have been described in the literature.⁴² Disruptive injuries of internal organs, caused by the blast-like air displacement of lightning, may occasionally be seen under the microscope. Histological examination of the eye (optic atrophy), the ear (tympanic membrane, vestibular membrane and organ of Corti) and certain nerves (such as the facial nerve) may be justified in some cases, where degenerative changes are suspected.⁴³

CLINICAL MANAGEMENT

Prevention is better than cure. The best means to prevent being injured by lightning and resulting consequences is to take proper precautions during thunderstorms and to offer immediate medical assistance to those struck by lightning.⁴⁴

If the lightning incident occurs outdoors in a thunderstorm, best to carefully move the victim to a safe shelter, as medical



Figure 9 Tearing and tattering of clothing. The female victim of direct lightning strike. She was found dead in the field, 2 days after an electrical thunderstorm. Note the tearing and tattering of the yellow t-shirt. (Photograph courtesy of Ryan Blumenthal.)

personnel risk a further lightning strike outdoors and rain and bad weather may cause automated external defibrillators to short circuit. Management involves diagnosis, initial first aid and triaging of victims. All lightning victims should be assessed systematically according to the Advanced Trauma Life Support approach, which includes airway management with C-spine support, breathing and circulation management.

Once stabilised, laboratory tests and radiographic examination should be performed. Renal function tests are important, most notably sodium and potassium levels and muscle markers. ECG, chest X-rays, troponins and cardiac enzymes, rhabdomyolysis enzymes, full blood count, platelets, ureum, creatinine and electrolytes, should be considered as the baseline tests.

Treatment involves fluid therapy, cardiovascular therapy, burn treatment, assessing and managing central nervous system injuries, managing eye injuries and ear injuries, and assessing if pregnant in women (assessing fetal viability).

Respiratory injuries associated with lightning strikes include pulmonary oedema, pulmonary contusion, acute respiratory distress syndrome and pulmonary haemorrhage. Although pulmonary involvement is rare, it should always be kept in mind, as well as lightning-induced primary lung damage. Lung contusion should be followed with strict vital signs monitoring.

Fluid resuscitation is important. Various mechanisms of trauma to the thorax or secondary effects due to cardiac damage should be taken into consideration. Lightning strike injuries should be handled as high-energy trauma. Most of the time, a conservative approach and support are sufficient. Resuscitation should be performed in accordance with the recommendations of the latest Resuscitation Council (Advanced Trauma Life Support)



Figure 10 Rupture of shoes. The right shoe of a lightning strike victim. This victim sustained direct lightning strike. The shoe was found lying separate from the body. Note the tearing and tattering of the leather shoe. (Photograph courtesy of Ryan Blumenthal.)



Figure 11 Intramyocardial haemorrhage. The heart muscle of a 10-year-old girl who survived lightning strike for a period of 10 days in intensive care unit before dying. Note the intramyocardial haemorrhage. (Photograph courtesy of Ryan Blumenthal.)

guidelines. Resuscitation of lightning strike cases is considered to be more successful than usual; therefore, physicians should apply vigorous and prolonged resuscitation.²⁰

The lightning-struck patient may have sustained blunt force trauma, or barotrauma. It may therefore be rational to approach such patients as multiple trauma patients.²⁰

Document and photograph the clothing. Thoroughly examine the skin. Keep the eyes wet and closed. Look inside the ears for tympanic membrane rupture; look for signs of concussive injury; look for singeing of hair, exclude magnetisation of metal (which is suspected to be a myth), look for secondary burns from surface discharge of metal or energetic electron burns; look for the 'tip-toe' sign—lightning exit wounds on base of the feet. Entrance and exit wounds will depend on whether or not the victim was wet or dry at the time of the strike. Wet victims typically incur 'flashover', with lightning flashing over the surface of the body. These findings may have relevance in understanding the path of the current in these victims and may help understand deep tissue injuries.

The complications of lightning strike may occur either early or late, or they may be local or systemic. The kidneys of lightning strike survivors may develop acute tubular necrosis, chiefly of the ischaemic type due to inadequate blood flow to the kidneys. Acute tubular necrosis of the toxic type, due to myoglobinuria, may also occur. Seek out signs of compartment syndrome. The heart should also be examined: a 10-year-old girl survived 10 days in the intensive care unit before succumbing; her heart showed intramyocardial haemorrhage at autopsy (figure 11).

Most of the resources and management will go into long-term care. Lightning victims may experience a range of psychological problems. These include fear of thunderstorms, anxiety, depression, disturbances in the sleeping rhythm, panic attacks, disorders of memory, learning, concentration and higher mental facility. Some lightning victims repeatedly re-experience the ordeal in the form of flashback episodes, memories, nightmares or frightening thoughts, especially when they are exposed to events or objects reminiscent of the trauma, for example, thunderstorms or sudden bright lights. This may, in some, be part of a post-traumatic stress disorder.⁴⁴ Key is to refer lightning strike survivors to support groups and other information sources.

An interaction with lightning strikes may have severe immediate as well as long-term consequences, both to victims and their families.⁴⁴ The doctor–patient relationship is critical when it comes to lightning strike patients. These victims may end up consulting ophthalmologists, otorhinolaryngologists, cardiologists, neurologists, physiotherapists, occupational therapists and so on, with the consequence that these patients often do not

even know who their doctor is. Key is life-long continuity of management.

Take home messages

- ▶ There are four types of cloud-to-ground lightning discharges.
- ▶ Lightning victims may present with minor, moderate, or severe injuries.
- ▶ The 'lightning dose' would depend upon the six mechanisms of attachment, in other words the way lightning interacts with the body.
- ▶ The light, heat, electrical and barotrauma components of lightning account for most of the keraunopathology.
- ▶ Prevention is better than cure.
- ▶ Lightning strike survivors may end up consulting multiple different medical specialities.
- ▶ Key is life-long continuity of management.

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