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Pathological Features of Death From Lightning Strike

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Summary

Lightning strikes cause more deaths in the United States than other natural disasters, such as hurricanes, tornadoes, volcanoes, and floods. Lightning is a transfer of an electrical charge and results from the sudden environmental discharge of static electricity. The power of lightning is estimated to be between 10,000 and 200,000 A of current, with estimated voltage ranging from 20 million to 1 billion V. The effects of lightning on the human body depend on a number of features, such as the intensity of the current, the time it spends passing through the body, the pathway involved, the activity and position of the person at the time of the event in relation to the ground, and the kind of strike (direct strike, contact voltage, side splash, ground strike, or wire-mediated lightning). Lightning strikes result in multisystem dysfunction, and survivors may experience prolonged disability following recovery from the initial insult.

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Electrical energy causes muscular spasm and necrosis, thrombosis, blood vessel tears, unconsciousness, and motor and sensory function abnormalities. Most deaths after lightning strikes occur either because of primary cardiac arrest or hypoxia-induced secondary cardiac arrest. If multiple persons are struck, attention at the scene should be directed first to those who appear dead, because they may be in respiratory arrest and in urgent need of immediate cardiopulmonary resuscitation that can be successful in lightning strike victims for far longer than would seem reasonable in other types of injury.

Key Words: Lightning strike; lightning injuries; direct strike; ground strike; contact voltage; side splash; side flash; wire-mediated lightning; flashover; Lichtenberg figures; burns.

1. Introduction

Lightning is a transfer of electrical charge resulting from the sudden environmental discharge of static electricity sandwiched between an upper negative-charged region, such as thunderheads, and a lower positive area *(1)*. When voltage between two oppositely charged fields exceeds atmospheric resistance, discharge occurs *(2)*. The most common types of lightning strikes are intracloud (the majority of discharges) and cloud-to-ground (some 20%), with ground-to-cloud and cloud-to-cloud lightning occurring only rarely *(2–4)*. However, a lightning strike may occur under fair weather conditions from a clear sky, far from any thunderstorm clouds *(5-8)*. Cherington and colleagues *(9)* discussed a case where the discharge originated in a cumulonimbus cloud that was approx 10 miles away and that was obscured by mountains. They called this phenomenon a "bolt from the blue."

The power of lightning is estimated to be between 10,000 and 200,000 A of current, with estimated voltage ranging from 20 million to 1 billion V *(10-12)*. A strike produces an intense burst of thermal radiation of up to 30,000 K within milliseconds and is accompanied by a shock wave of up to 20 atm that can contuse or perforate human organs *(10,11,13,14)*. Electrical energy follows the path of least resistance. Because tissues that have a low water and electrolyte content have a higher resistance, tissue resistance decreases in the following order: bone, fat, tendon, skin, muscle, blood vessel, and nerve *(4,11,15,6)*. The most important resistor to the flow of current is skin. Skin resistance varies from 1000 ohms on a sweaty palm to 1 million ohms on a dry, calloused hand *(11)*. The phenomenon of current traveling on the surface of wet skin without much penetration to deeper tissues is called "flashover" *(1-3,14)*. If it is raining or the person is perspiring, the water can vaporize with such force that the clothes are shredded and the shoes are blown off *(2,14)*.

Estimates reveal that there are approx 50,000 thunderstorms and 8 million lightning flashes per year worldwide *(17)*. Surprisingly, despite the vast amounts of energy involved, the overall mortality rate following lightning injury is only 30% *(8,18)*. The morbidity rate in survivors, however, is close to 70% *(2,19)*. Lightning strikes, although uncommon, still reportedly cause more deaths in the United States than other natural disasters, such as hurricanes, tornadoes, volcanoes, and floods *(16,18,20,21)*. In the United States, several thousand people are struck by lightning but survive, and approx 100 to 600 people die from lightning injuries *(2,4,8,10,14,17–19,22)* each year. These deaths occur primarily from May to September, between 3 and 6 PM, and mostly affect a young, active group less than 40 years of age *(8,18,19)*. The effects of lightning on the human body depend on a number of features, including the intensity of the current, the time it spends passing through the body, the pathway actually involved, and the activity and position of the person at the time of the event in relation to the ground *(1,10,13)*. In addition to these, a factor of major importance is the kind of strike, as a person may be hit by lightning in several ways *(4)*.

2. The Different Forms of Lightning Strikes

2.1. Direct Strike

Lightning may strike a person directly, usually entering through the head or an outstretched arm *(1,12,18,23,24)*. The current is then transferred to the body, and, in most of these cases, the exit pathway is through the soles of the feet because the lightning victim is normally standing, earthing him or herself through the ground *(12,14)* (Fig. 1). A direct lightning strike is the most damaging because the current discharges directly through the body and causes extensive thermal injuries and barotrauma *(2,12,19,23,25)*.

2.2. Contact Voltage

The difference between a direct strike and a side splash is the contact voltage. It occurs if people are wearing or carrying something metal, such as an umbrella, golf club, or a weapon *(2,23,26)*. If lightning strikes this metal object, the current will flow to the body of the victim, if this pathway is the way of least resistance *(23)*.

2.3. Side Splash

A side splash or side flash strike occurs when lightning discharges—after a primary strike to an adjacent object such as a tree—to a victim who has no

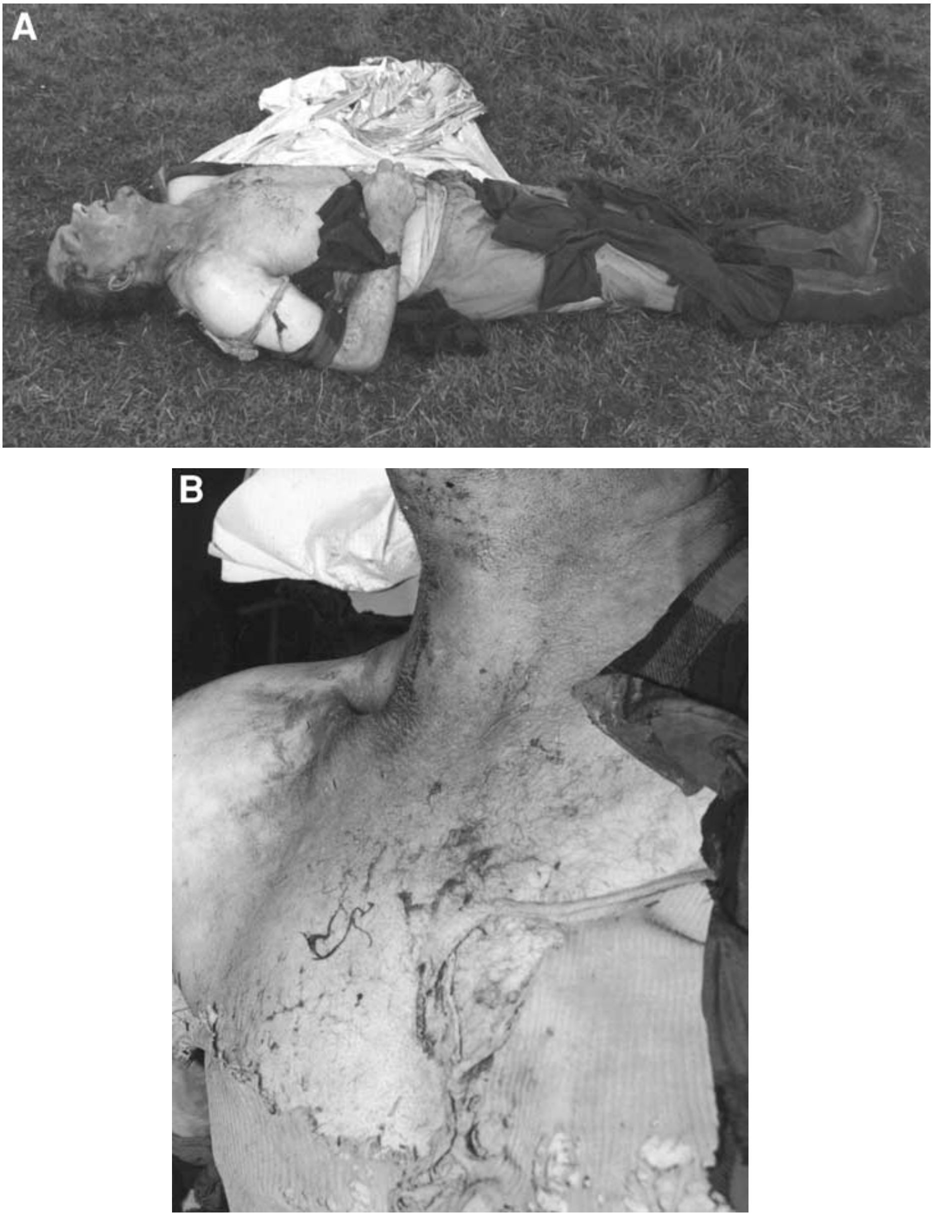

Fig. 1. Fatal direct lightning strike of a 63-year-old farmer. **(A)** Scene of death was an open field on a rainy day. The clothes are partially shredded, but the rubber boots are not blown off. **(B,C)** The skin of chest and right arm shows a fern-like pattern below the entrance point (neck) of the lightning strike. **(D)** The exit point was characterized by a melted sole of the right rubber boot, **(E)** a defect of the stocking, and **(F)** a plantar second- to third-degree burn with melted fabric from the sock. (Courtesy of Dr. Michael Tsokos, Hamburg, Germany.) *(Figure continues on two following pages.)*

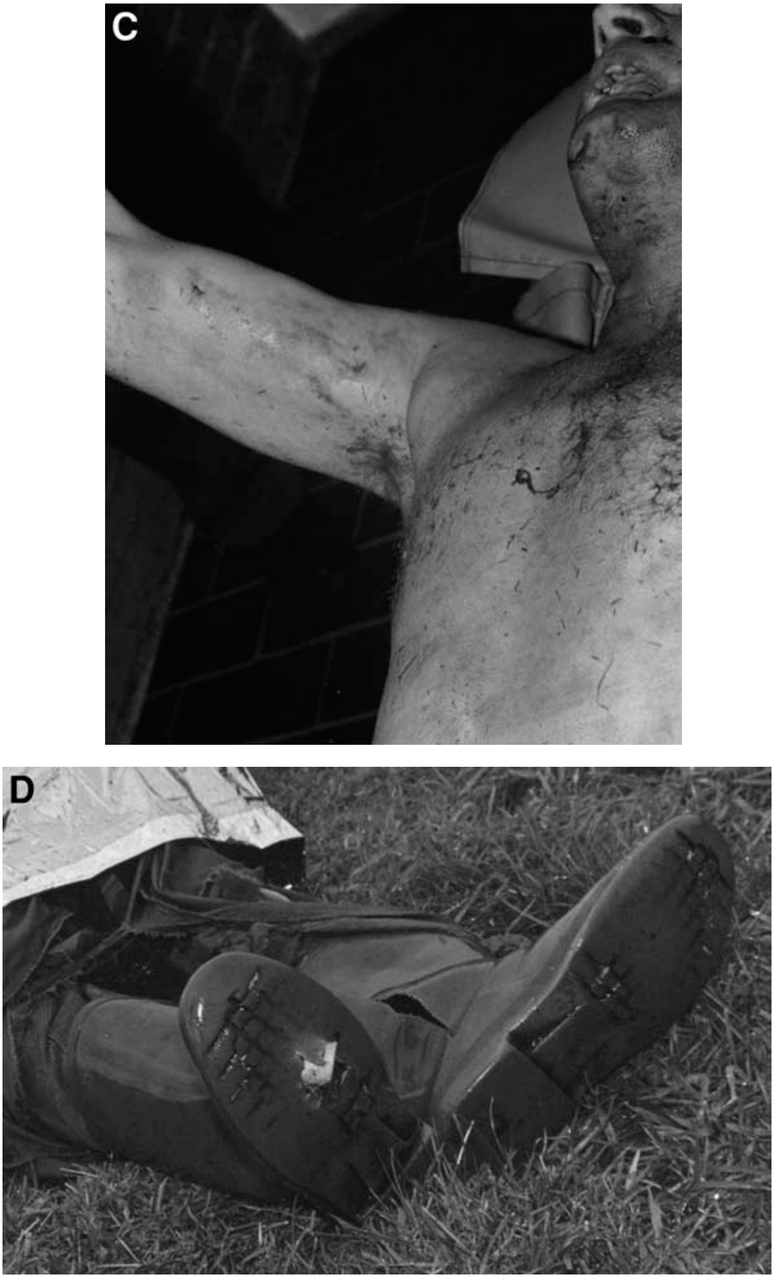

Fig. 1. *(continued)*

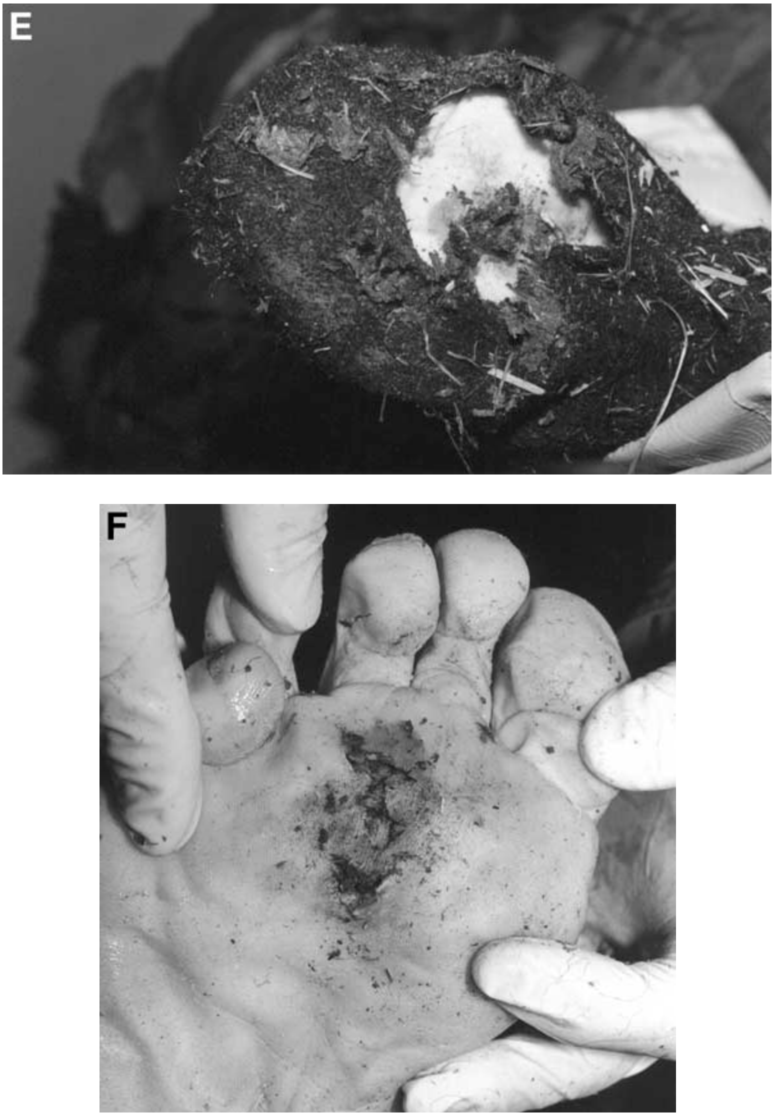

Fig. 1. *(continued)*

direct contact with the object *(2,19,23,24,27,28)*. The lightning may be conducted down the tree or it may jump to a path of less resistance, such as the person or persons standing under or near the tree *(19)*. The side splash seems to be the most frequent form of lightning strike *(22)*. As with ground strikes, the side splash often leads to injuries of several people *(23,26)*.

2.4. Ground Strike

Ground strike (also known as "stride potential" and "step voltage") occurs when lightning strikes the ground and a person is standing or walking nearby. An electrode voltage is encountered between the victim's two legs, and lightning can travel up one leg of a victim and down the other, causing a current to flow through the lower extremities and trunk *(2,12,20,23)*. Ground strikes are less severe because the force of the lightning dissipates rapidly when it travels through soil *(25)*. The heart and brain are usually spared by this type of injury, but the victims are frequently rendered transiently paraplegic and show severe burns on both legs *(12,23)*.

2.5. Wire-Mediated Lightning

People may rarely be struck by lightning indoors while using a telephone or an electrical appliance *(18,29,30)*. In these cases, the lightning surge may energize the structure of a house, causing current to flow through the victim into the grounded telephone or appliance. Likewise, lightning may strike a cable, causing connected telephones to become electrically charged *(18,31)*. Morgan and colleagues *(32)* reported the case of a 52-year-old man who was struck by lightning via the telephone line. They assumed that lightning passed through the man from head to toe and grounded via arcs from the right big toe and left scapular region. Qureshi *(33)* described the case of a 27-year-old woman who was indirectly struck by lightning while using the telephone during a thunderstorm. She heard a loud bang mediated through the telephone into her left ear and was thrown across the room. She was briefly unable to speak and hear. The left half of her face and body felt numb and she suffered from temporary left-sided hemiparalysis.

3. Effects of Lightning Strikes on the Human Body

Lightning injuries result from electrical energy, thermal energy, or the enormous blast force of a thunderous lightning strike *(23)*. Although lightning is essentially a high-voltage direct current, the effects of lightning are much different than those caused by other types of high-voltage electricity *(18)*. Whereas high-voltage electricity usually produces charring of tissue, a lightning strike is characterized by an extremely short duration of electrical contact. Although it is just a small proportion of the current that passes through the victim's body, the magnetic field that is formed is high enough to affect the neuromuscular, cardiovascular, and central nervous systems *(9,15,34)*. Lightning strikes result in multisystem dysfunction, and survivors may experience prolonged disability following their recovery from the initial strike *(14)*. Electrical energy affects the permeability of cell membranes, can denature active intracellular proteins, and cause muscular spasm and necrosis, thrombosis, blood vessel tears, unconsciousness, motor and sensory function abnormalities, such as transient paraplegia and aphasia, amnesia, burns, contusions, edema, cataracts, decreased renal clearance with myoglobinuria, necrosis, and other injuries, including cerebral bleeding, skull fractures, or heart contusion *(3,4,8,14,15,27,35,36)*. However, lightning is anything but invariably fatal: cases have been reported of one person who was struck by lightning and merely stunned, whereas his companion, who was struck with the discharge after it emerged from the elbow of the original target, was killed. Other authors reported electrocutions of entire crowds, with some killed, others burned, and others merely showing various minor or major neurological sequelae *(37,38)*. The degree of injury is dependent on many factors, including current strength, resistance of the conducting tissue, current pathway, and duration of current flow.

3.1. Skin Injury

The vast majority of lightning injuries are first- and second-degree burns to the skin, covering between 1 and 20% of the body *(13,14,39,40)*. However, the points at which the current enters and leaves the body by arcing usually show third-degree burns *(32,37)*. Most of the current flows along the outside of the body, thus decreasing the extent of internal burning and tissue damage *(13,38,41)*. Immediately after the strike, lightning victims may be too hot to touch *(14)*. Burns associated with lightning appear in several forms: feathering, linear, punctuate, thermal (from the ignition of clothing), contact (from metal objects, such as jewellery or zippers [Fig. 2]), and flash *(1,4)*. Celiköz and colleagues reported the case of a 21-year-old man who had taken shelter under a thick nylon cover in the center of a group of five soldiers. While the soldiers sheltered themselves from heavy rain, lightning struck the nylon cover and a flash discharge with full-thickness scalp burn 12 cm in diameter occurred in the victim *(1)*. Most lightning burns, however, are superficial and require only local care, such as dry gauze dressings *(2,14)*; sometimes they reach from the entry point nearly to the exit point, where full-thickness burns are often found *(14,40,42,43)*. In contrast to electrical skin injuries from alternating current, significant myonecrosis is only rarely seen *(42)*. The feathering, arborescent, or fern-like pattern of skin injury is a transient, hyperpigmented mark that appears within an hour of the strike, radiates outward from a central spot, and disappears after several hours *(8,27,33,38)*. This so-called "Lichtenberg figure" (Figs. 3 and 4) is thought to be a fractal pattern of positive electrical discharge,

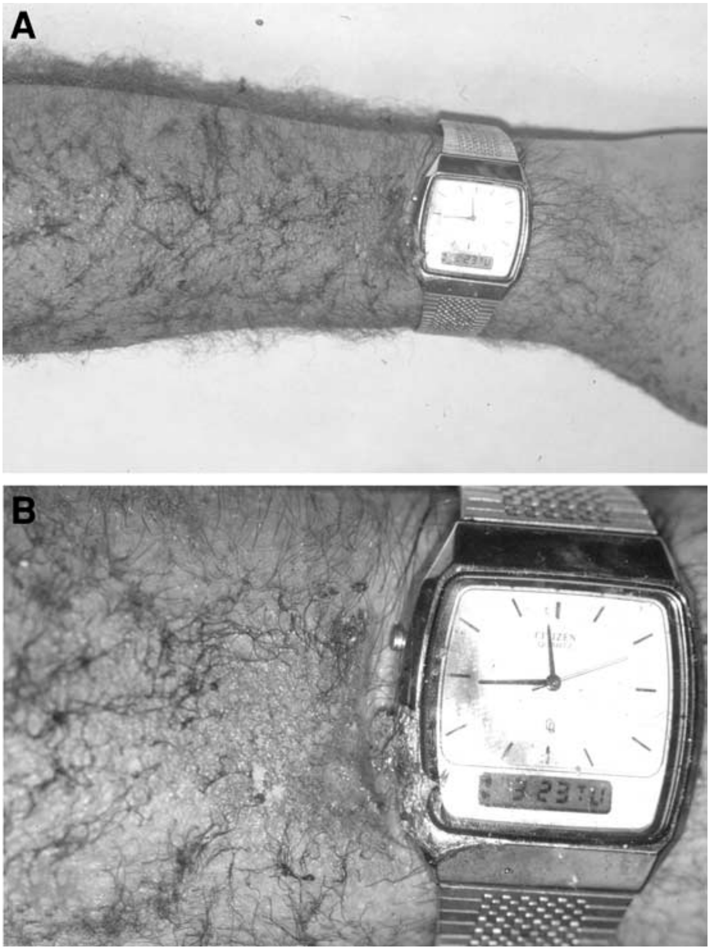

Fig. 2. (A) Contact burn at the left forearm caused by a partially melted watch following a lightning strike. **(B)** Detail. (Courtesy of Dr. Roland Hausmann, Erlangen, Germany.)

and has been reported in approx 30% of lightning strike cases *(4,8,14,38,44)*. Histological examination of the arborizing pattern revealed normal epidermis and dermis. An extravasation of red blood cells in the subcutaneous fatty tissue, as proposed by Resnik and Wetli *(38)*, is not mandatory. Other authors described only a dilatation of small blood vessels in the corium, sometimes combined with an elongation and nuclear streaming (palisading) of the cells of the basal epidermal layer *(45)*.

Fig. 3. Fatal direct lightning strike of a 52-year-old man. An arborescent pattern of skin injury is clearly visible at the left loin region. (Courtesy of Dr. Roland Hausmann, Erlangen, Germany.)

Jonas et al. *(46)* reported the case of a couple who was hit by a lightning strike. Both survived the thunderbolt without permanent injury. However, whereas the man was unconscious for only a few minutes, his wife fell into a coma for 24 hours. The lightning, which entered her body behind the left ear and went out at her left shoe, caused a partial evaporation of a gold ornamental chain on her neck. After recovery, the woman got a tattoo on her neck. Two skin biopsies taken 6 months later showed particles of different shapes and sizes up to 2 mm deep in the skin that accumulated in histiocytes, multinucleated giant cells, and, to a small extent, in fibroblasts. Element analysis by electron energy loss spectroscopy, energy-dispersive X-ray analysis, and atomic absorption spectroscopy showed that the detected particles were gold (70%), silver (21%), and copper (9%).

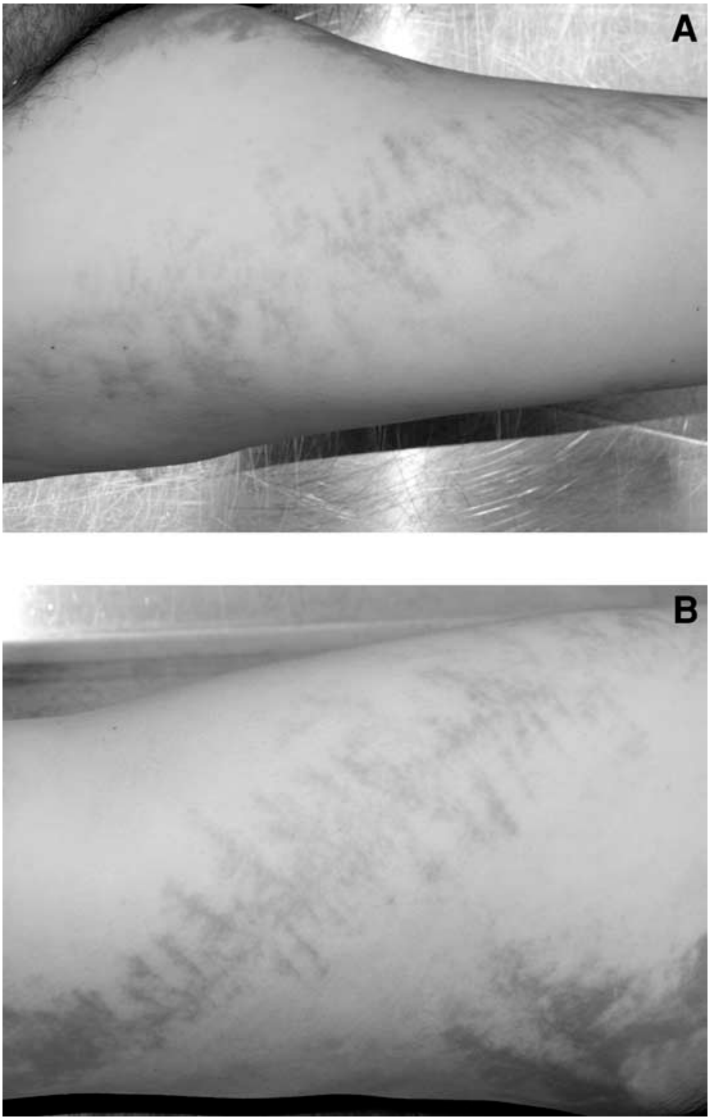

Fig. 4. Fatal direct lightning strike of a 42-year-old woman. **(A,B)** Fern-like patterns ("Lichtenberg figures") are visible on the thigh. (Courtesy of Dr. Wolfgang Huckenbeck, Düsseldorf, Germany.)

3.2. Heart Injury

Most deaths following lightning strikes occur because of primary cardiac arrest or are the result of hypoxia-induced secondary cardiac arrest *(2,14)*. Because lightning is direct current, it has the effect of cardioversion and induces ventricular standstill, as opposed to atrial and ventricular fibrillation *(2,4,8,14,32,41,47,48)*. Despite the fact that 50 to 75% of those who have cardiac arrest will die, cardiopulmonary resuscitation (CPR) can be successful in lightning victims far longer after the initial strike than in other types of injury *(2,4,18,37,49)*.

Other cardiovascular effects of lightning are transient hypertension and tachycardia, both thought to be secondary to adrenal stimulation with excess catecholamine release or autonomic stimulation *(19,49)*. Chia *(39)* reported the case of a 24-year-old woman who was struck by lightning and was found to be in congestive cardiac failure at the time of hospital admission. Kleiner and Wilkin portrayed the case of an 18-year-old man with T-wave inversion in electrocardiograph (ECG) showing a rapidly developing severe bilateral pulmonary edema 3 hours after admission *(49)*. Even in cases of primary cardiac arrest, ECG abnormalities are not necessarily seen *(14)*. If ECG changes occur, they consist of deep T-wave inversions in multiple leeds and patterns of ischemic changes, myocardial infarction, or subepicardial injury that normally resolve within several months *(19,39,41,48–50)*. These changes are explained by epicardial hemorrhages, muscle fiber necrosis, and a peculiar spiral malformation of the myocardial fibers *(41,51)*. Animal experiments by Karobath et al. *(47)* confirmed the existence of myocardial necroses owing to lightning strikes. Zack and colleagues *(35)* portrayed a case of side splash where a 27-year-old man showed severe acute myocardial infarction, affecting virtually all parts of the myocardium. Lichtenberg and colleagues *(19)*, however, showed that the potential for, and mechanisms of, injury to the cardiovascular system obviously differ in each type of lightning strike. They found in 19 cases that a direct lightning strike results in a high incidence of severe cardiac injury that can be manifested early as life-threatening pericardial effusion or severe global cardiac dysfunction. ST elevation and prolonged QTc intervals in the ECG were limited to direct strikes, whereas myocardial injuries manifesting as creatine kinase-MB release can be seen in any type of strike; this occurred in 75% of victims of a direct hit, 66% of victims of a side splash, and 12% of victims of a ground strike. ECG changes after splash and ground strikes were limited to nonspecific ST-T-wave changes *(19)*.

3.3. Central Nervous System

The most serious injuries from lightning strikes involve the cardiovascular and central nervous systems *(2,9,16)*. Because of their clinical course, the effects of direct strikes to the head can be divided into the following four groups:

1. Fatal coma from hypoxic encephalopathy.
2. Global encephalopathy with partial recovery.
3. Slow resolution of focal neurological dysfunction.
4. Transient neurological symptoms with rapid complete recovery *(9, 18)*.

Mechanisms of neuronal damage in lightning strikes include prolonged depolarization, direct neuronal damage (heat and blunt trauma) as well as secondary tissue damage from edema, ischemia, and reperfusion injury *(10,52)*. It has been well-described that lightning strikes cause intense vasospasms and ischemia *(10,53)*. Whereas skull fractures are mostly linked to falls, brain lesions are common in the absence of falls. In fact, most neurological lesions in lightning-strike patients are not linked to trauma from falls, but occur as a result of hypoxia caused by paralysis of the respiratory musculature or failure of the medullary respiratory center *(14,36)*. Comparable to other tissues, brain damage of lightning victims is triggered thermally or electrically *(54)*. Subarachnoid and intraventricular hemorrhages often follow a particular pattern with regard to the location in the brain *(12,36,55)*. The most vulnerable sites are the basal ganglia and brainstem. Although small petechial hemorrhages are seen in the brainstem, larger hemorrhages are found in the basal ganglia *(12,36,56,57)*. The pathophysiology of basal ganglia hemorrhages related to lightning is not likely a product of either mechanical trauma or intense peripheral vasoconstriction resulting in acute hypertension, but may reflect the path of current flow in the brain *(36)*. Ozgun and Costillo *(56)* pointed out that electrical conductivity is highest in the cerebrospinal fluid (CSF), and heating of the CSF to 145°F has been recorded after legal electrocution. Additionally, blood vessels and neural tissue have been found to carry more current per area than other tissues, and to become damaged before surrounding tissues in an animal model *(56,58)*. Ozgun and Costillo concluded that preferential conduction along Virchow-Robin spaces in the anterior perforated substance plays a major role in the production of basal ganglia injury following lightning strikes *(56)*.

Severe head trauma can occur as a consequence of falling, being thrown to the ground by the enormous blast force of a thunderous lightning strike, or as a direct effect of the lightning strike *(8,25,32,36)*. Blunt head trauma patients often present with subarachnoid and intraventricular hemorrhages, as well as mass lesions of epidural and subdural hematomas *(32,36)*.

Ongoing neurological deficit following a lightning strike is an important issue. The majority of sequelae following a lightning strike are neurological, as seen in 70% of survivors *(14,43)*. Injuries arise as a result of the primary strike (hemorrhages, edema, or neuronal injury) or are owing to a hypoxic insult from the cardiac arrest *(14)*. Nearly 80% of lightning-strike survivors suffer from amnesia, loss of consciousness, or confusion, and 50% are afflicted with paraplegia, which is normally transient and resolves within hours to days *(14,40,43)*. Persisting neurological deficits, however, indicate spinal cord damage, which is a rare but well-documented phenomenon following lightning strikes *(14,59)*. Freeman and colleagues *(59)* reported the case of a 58-year-old man who was struck by lightning while sleeping in a tent:

> After short-term loss of consciousness, he was unable to move his arms and legs. Over the next few hours, he gradually noticed some return of movement and feeling in the fingers, arms, and legs. … Two days after admission, the patient was discharged with no persistent sensory loss or paresthesias. The only remaining deficit was some difficulty in walking.

Approximately 6 weeks after the lightning strike hit the man, he began to notice numbness, tingling, and dysesthesia in both hands.

> Over the next week, the paresthesia gradually migrated into his forearms to the elbows and became noticeable in his feet. He also complained of weakness in his hands and legs. Finally, the patient described severe shock going through his arms, trunk, and feet elicited by minor neck flexion.

CSF analysis revealed a moderate elevation in protein (0.89 g/L) with normal cell count. Nerve conduction studies were normal. Magnetic resonance imaging (MRI) revealed hyperintense signals within the posterolateral region of the spinal cord from C1 to C3 bilaterally. Clinically, the symptoms were consistent with a diagnosis of delayed myelopathy secondary to electric injury with predominant dorsal column involvement. The abnormal spinal cord signal had resolved at a follow-up MRI performed 6 weeks later. At this time, the patient described some improvement with less stiffness in his hands, improved sensation, and improved grip *(59)*.

Marleschki *(60)* portrayed the case of a lightning strike during the fourth month of pregnancy. Aside from skin burns and transitory symptoms of left ventricular ischemia, the 27-year-old woman suffered from temporary hypoesthesia, muscular hypotonia, and palsy of the right arm and both legs. As movements of the fetus were not palpable for 12 hours, Marleschki assumes that the lightning stroke caused a reversible palsy of the child *(60)*.

Van Zomeren and colleagues *(61)* tried to objectify neuropsychological impairments in six survivors of lightning stroke between 1 and 4 years after injury. Patients reported fatigue and lack of energy as their main complaints. In addition, poor concentration, irritability, and emotional lability were mentioned often. Neuropsychological tests disclosed mild impairments in memory, attention, and visual reaction times. The authors speculated that most complaints of these survivors are caused by a vegetative dysregulation, a disorder that has often been noted in the literature as an aftermath of electrical injury to the nervous system *(61)*.

3.4. Other Injuries

Victims of lightning strikes may also suffer ophthalmic, otological, psychiatric, pulmonary, renal, gastrointestinal, musculoskeletal, and peripheral neurovascular complications *(18)*. Dilated, unreactive pupils are usually a short-term effect of autonomic nervous system involvement *(14)*.

Ear lesions may vary from mild burns of the auricle to complete destruction of the hearing organ. Absence of the organ of Corti, rupture and collapse of Reissner´s membrane, strial degeneration, and decreased spiral ganglion cell population were reported *(17,62,63)*. Sound pressure levels of 150 to 160 dB have been recorded thus, ruptured tympanic membranes are common in lightning-strike patients, but no case of auditory ossicle injury following lightning strike has been reported so far *(3,14,17,25,33,64–66)*. Symptoms related to the inner ear following lightning strike may be cochlear, such as hearing loss, or vestibular, such as temporary vertigo, positional vertigo, and endolymphatical hydrops *(15)*. A case of hearing loss caused by a lightning strike was reported by Cankaya and colleagues *(16)*. Aside from a first-degree burn of the auricle, the 33-year-old man showed two perforations with hemorrhagic edges on the right tympanic membrane that were attributed to the blast effect of lightning. The middle-ear mucosa was hyperemic and edema was present. At pure-tone audiometry, a 40-dB conduction-type hearing loss was detected, which resolved within 6 months. Sensorineural hearing loss caused by lightning strike, however, does not have a high rate of resolution *(15)*. In the case of a lightning strike via a telephone wire mentioned earlier, the 27-year-old woman complained of tinnitus and deafness in her left ear *(33)*. Although the tinnitus improved, deafness persisted at a re-examination 6 months later.

Todd and Meyers *(17)*, as well as Silbergleit and Trenkner *(67)*, reported cases of lightning strike-induced dysphagia that persisted several months and was attributed to an isolated central nervous system defect.

As the lens of the eye seems to be very sensitive to electrical current or the heat set free by the current, the most common permanent ocular sequela of lightning is cataract *(10,29)*. The cataract can occur soon after a lightning strike or it may develop over many months *(2,68)*. Problems with vision may be a sign of retinal detachment. Burns of the periorbita and the eyelids, keratitis, iritis, papillary abnormalities, cornea lesions, lens dislocations, retina damages, and thermal optic nerve papillitis were reported in patients injured by lightning *(10)*.

The muscular effects of electricity consist of muscular contraction in response to electric stimulation *(32)*. Because lightning is a modified form of alternating current, consisting of a brief, highly damped discharge, no injury is usually associated with this contraction. Indeed, a rupture of muscles may occur occasionally as sometimes observed in cases of electrocution *(69)*, or the victim may fall, receiving secondary injuries *(32)*. In contrast with other electrical injuries, muscle necrosis with resulting renal impairment is rarely seen after lightning strikes *(14)*. The myoglobinuria from lightning injury results from tissue damage caused by heat generation and coagulation necrosis. Myoglobinuria has clearly been shown to precipitate acute tubular necrosis, which progresses in some cases to renal failure *(70)*.

4. First Aid After Lightning Strike

Anyone struck by lightning should have a complete physical examination, including ophthalmological and otological check-up. Care for these patients with multisystem involvement requires a team approach and attention to the whole patient *(19)*. Multiple lightning victims have to be treated in the opposite way from those involved in other disaster situations *(2)*: the recommendation of the American Heart Association is that after a lightning strike, all attention should be given to the most sick, particularly to those who appear moribund or even dead, because these persons may be in respiratory arrest and in need of immediate CPR *(2–4,18,37,49,70)*.

5. Conclusions for the Forensic Pathologist

In regions with high lightning-strike densities, lightning strikes should always be considered as a potential differential diagnosis when investigating unexpected, unwitnessed deaths, especially when they occurred outdoors *(66)*. The diagnosis of a lightning fatality should be considered even when witnesses report that the sky was cloudless and they heard no thunder *(66)*. Because knowledge of the weather conditions, even in the surrounding area, is of obvious value, further information is available from meteorological services like the National Lightning Detection Network of the United States *(8)*.

Fig. 5. Fatal direct lightning strike of a 52-year-old man. Because of an effect called "flashover," **(A)** the cap, **(B)** the trousers, and **(C)** a sock exploded into shreds. (Courtesy of Dr. Roland Hausmann, Erlangen, Germany.)

If there are no or no reliable witnesses, a diligent search for evidence at the scene of death is needed *(18)*. Externally visible forensic clues that suggest lightning strike at the scene include damage to nearby trees, such as splitting or removal of bark, or charred arc marks on the walls of nearby structures *(18)*. The ground may display a keraunographic fern-like pattern in the grass resembling the cutaneous changes (Lichtenberg figures) observed in some victims *(8,18)*. If the scene of death is inside a building, nearby electrical and telephone equipment should be examined for signs of lightning damage *(18)*. The clothing of lightning-strike victims may be burned, the trouser legs, for example, may be exploded into shreds, and the shoes may be melted or "exploded" *(8,14)* (Fig. 5). Clothing of lightning-strike victims, particularly shoes, may have been torn by the lightning energy. Finding a victim in a remote location with the clothing in disarray may even suggest a sexual attack *(18)*. Skin observations of burns and fern-like cutaneous patterns, as well as singed hair, may then point to the true cause of death *(66)*.

In any case of death attributed to lightning, a thorough autopsy is mandatory. Besides the lightning injuries mentioned, such as skin burns or fern-like injuries, the forensic pathologist has to look for fractures that may have been caused by the lightning strike's explosive effects or by electrically induced muscular contractions *(18)*. Further points of interest are the tympanic membranes, aortic injury (mostly consisting of endothelial elevations and tearing of a portion of the media *[8]*), cardiac injury (such as heart contusions or myocardial ischemia), and head injury, including cerebral hemorrhages.

REFERENCES

1. Celiköz B, Isik S, Türegün M, Selmanpakoglu N (1996) An unusual case of lightning strike: full-thickness burns of the cranial bones. Burns 22, 417-419.
2. Fulde GW, Marsden SJ (1990) Lightning strikes. Med J Aust 153, 496-498.
3. Blount BW (1990) Lightning injuries. Am Fam Physician 42, 405-415.
4. Gibbs NF, Keel DM (2003) Burns from out of the blue. Lightning strike. Postgrad Med 113, 67-68, 85.
5. Myers F (1931) Lightning from clear sky. Monthly Weather Rev 59, 39.
6. McCaughan ZA (1926) A lightning stroke far from the thunderstorm cloud. Monthly Weather Rev 54, 344.
7. Gisborne HF (1928) Lightning from clear sky. Monthly Weather Rev 56, 108.
8. Wetli CV (1996) Keraunopathology. An analysis of 45 fatalities. Am J Forensic Med Pathol 17, 89-98.
9. Cherington M, Krider EP, Yarnell PR, Breed DW (1997) A bolt from the blue: lightning strike to the head. Neurology 48, 683-686.
10. Norman ME, Albertson D, Younge BR (2001) Ophthalmic manifestations of lightning strike. Surv Ophthalmol 46, 19-24.
11. Jain S, Bandi V (1999) Electrical and lightning injuries. Crit Care Clin 15, 319-331.
12. Stanley LD, Suss RA (1985) Intracerebral hematoma secondary to lightning stroke: case report and review of the literature. Neurosurgery 16, 686-688.
13. Craig SR (1986) When lightning strikes: pathophysiology and treatment of lightning injuries. Postgrad Med 79, 109-124.
14. Courtman SP, Wilson PM, Mok Q (2003) Case report of a 13-year-old struck by lightning. Paediatr Anaesth 13, 76-79.
15. Cankaya H, Egeli E, Evliyaoglu Z (2002) Hearing loss caused by lightning strike: case report and review of the literature. J Otolaryngol 31, 181-183.
16. Cooper MA (1984) Electrical and lightning injuries. Emerg Med Clin North Am 2, 489-501.
17. Todd DH, Meyers A (1994) An unusual otolaryngologic manifestation of lightning strike. Otolaryngol Head Neck Surg 110, 126-130.
18. Lifschultz BD, Donoghue ER (1993) Deaths caused by lightning. J Forensic Sci 38, 353-358.
19. Lichtenberg R, Dries D, Ward K, Marshall W, Scanlon P (1993) Cardiovascular effects of lightning strikes. J Am Coll Cardiol 21, 531–536.
20. Cooper MA (1980) Lightning injuries: prognostic signs for death. Ann Emerg Med 9, 134–138.

21. Cooper MA (1983) Lightning injuries. Emerg Med Clin North Am 1, 639–641.
22. Epperly TD, Stewart JR (1989) The physical effects of lightning injury. J Fam Pract 29, 267–272.
23. Zack F, Schniers E, Wegener R (2004) Blitzunfall. Vorschlag einer Klassifizierung der verschiedenen Energieübertragungen auf den Menschen. Rechtsmedizin 14, 396–401.
24. Cwinn AA, Cantrill SV (1985) Lightning injuries. J Emerg Med 2, 379–388.
25. Tibesar RJ, Roy S, Hom DB (2000) Bilateral Le Fort I fracture from a lightning strike injury to the face. Otolaryngol Head Neck Surg 123, 647–649.
26. Volinsky JB, Hanson JB, Lustig JV, Tunnessen WW Jr (1994) Clinical picture. Lightning burns. Arch Fam Med 3, 657–658.
27. Anders S, Tsokos M, Püschel K (2002) Nachweis der Stromwirkung und des Stromweges im Körper. Rechtsmedizin 12, 1–9.
28. Browne BJ, Gaasch WR (1992) Electrical injuries and lightning. Emerg Med Clin North Am 10, 211–229.
29. Dinakaran S, Desai SP, Elsom DM (1998) Telephone–mediated lightning injury causing cataract. Injury 29, 645–646.
30. Schneider R (1956) Blitzschlag als Telefonunfall (unter besonderer Berücksichtigung der unterschiedlichen Bedeutung von Blitzfigur und Blitzauftreffstelle). Med Klin (Munich) 51, 2208–2210.
31. Johnstone BR, Harding DL, Hocking B (1986) Telephone-related lightning injury. Med J Aust 144, 706–709.
32. Morgan ZV Jr, Headley RN, Alexander EA, Sawyer CG (1958) Atrial fibrillation and epidural hematoma associated with lightning stroke; report of a case. N Engl J Med 259, 956–959.
33. Qureshi NH (1995) Indirect lightning strike via telephone wire. Injury 26, 629–630.
34. Lee MS, Gunton KB, Fischer DH, Brucker AJ (2002) Ocular manifestations of remote lightning strike. Retina 22, 808–810.
35. Zack F, Hammer U, Klett I, Wegener R (1997) Myocardial injury due to lightning. Int J Legal Med 110, 326–328.
36. Cherington M (2002) Two Lancet lightning articles: Clark and Brigham, 1872; Knaggs, 1894—A commentary. Wilderness Environ Med 13, 158–162.
37. Ravitch MM, Lane R, Safar P, Steichen FM, Knowles P (1961) Lightning stroke. Report of a case with recovery after cardiac massage and prolonged artificial respiration. N Engl J Med 264, 36–38.
38. Resnik BI, Wetli CV (1996) Lichtenberg figures. Am J Forensic Med Pathol 17, 99–102.
39. Chia BL (1981) Electrocardiographic abnormalities of congestive cardiac failure due to lightning stroke. Cardiology 68, 49–53.
40. Fahmy FS, Brinsden MD, Smith J, Frame JD (1999) Lightning: the multisystem group injuries. J Trauma 46, 937–940.
41. Burda CD (1966) Electrocardiographic changes in lightning stroke. Am Heart J 72, 521–524.
42. Matthews MS, Fahey AL (1997) Plastic surgical considerations in lightning injuries. Ann Plast Surg 39, 561–565.

43. Lewis AM (1997) Understanding the principles of lightning injuries. J Emerg Nurs 23, 535–541.
44. ten Duis HJ, Klasen HJ, Nijsten MW, Pietronero L (1987) Superficial lightning injuries—their "fractal" shape and origin. Burns Incl Therm Inj 13, 141–146.
45. Pollak S (2003) Blitzschlag (Fulguration). In Madea B, ed., Praxis Rechtsmedizin. Springer, New York, pp. 190–191.
46. Jonas L, Fulda G, Nizze H, et al. (2002) Detection of gold particles in the neck skin after lightning stroke with evaporation of an ornamental chain. Ultrastruct Pathol 26, 153–159.
47. Karobath H, Redtenbacher M, Hofecker G, Walde I, Syre G (1977) Zur Frage der Todesursache Beim Blitzunfall. MMW Munch Med Wochenschr 119, 29–32.
48. Stolle R (1968) Infarktähnliche EKG—Veränderungen nach blitzschlag. Z Gesamte Inn Med 23, 603–606.
49. Kleiner JP, Wilkin JH (1978) Cardiac effects of lightning stroke. JAMA 240, 2757–2759.
50. Schmidt W, Grutzner A, Schoen HR (1957) Beobachtungen bei Blitzschlagverletzungen unter Berücksichtigung von EKG und EEG. Dtsch Arch Klin Med 204, 307–324.
51. Hughes JPW (1956) Electric shock and associated injuries. Br Med J 1, 852.
52. Kleinschmidt–DeMasters BK (1995) Neuropathology of lightning-strike injuries. Semin Neurol 15, 323–328.
53. Fontanarosa PB (1993) Electrical shock and lightning strike. Ann Emerg Med 22, 378–387.
54. Thaventhiran J, O'Leary MJ, Coakley JH, Rose M, Nagendran K, Greenwood R (2001) Pathogenesis and recovery of tetraplegia after electrical injury. J Neurol Neurosurg Psychiatry 71, 535–537.
55. Mann H, Kozic Z, Boulos MI (1983) CT of lightning injury. AJNR Am J Neuroradiol 4, 976–977.
56. Ozgun B, Castillo M (1995) Basal ganglia hemorrhage related to lightning strike. AJNR Am J Neuroradiol 16, 1370–1371.
57. Thomas M, Pillai M, Krishna Das KV (1991) Intracranial haematoma resulting from lightning stroke. J Assoc Physicians India 39, 421–422.
58. Cherington M, Yarnell P, Hallmark D (1993) MRI in lightning encephalopathy. Neurology 43, 1437–1438.
59. Freeman CB, Goyal M, Bourque PR (2004) MR imaging findings in delayed reversible myelopathy from lightning strike. AJNR Am J Neuroradiol 25, 851–853.
60. Marleschki V (1965) Blitzschlag während der Schwangerschaft. Zentralbl Gynakol 87, 1512–1514.
61. van Zomeren AH, ten Duis HJ, Minderhoud JM, Sipma M (1998) Lightning stroke and neuropsychological impairment: cases and questions. J Neurol Neurosurg Psychiatry 64, 763–769.
62. Bergstrom L, Neblett LW, Sando I, Hemenway WG, Harrison GD (1974) The lightning-damaged ear. Arch Otolaryngol 100, 117–121.

63. Youngs R, Deck J, Kwok P, Hawke M (1988) Severe sensorineural hearing loss caused by lightning. A temporal bone case report. Arch Otolaryngol Head Neck Surg 114, 1184–1187.
64. Wright JW, Silk KL (1974) Acoustic and vestibular defects in lightning survivors. Laryngoscope 84, 1378–1386.
65. Redleaf MI, McCabe BF (1993) Lightning injury of the tympanic membrane. Ann Otol Rhinol Laryngol 102, 867–869.
66. Cherington M, Kurtzman R, Krider EP, Yarnell PR (2001) Mountain medical mystery. Unwitnessed death of a healthy young man, caused by lightning. Am J Forensic Med Pathol 22, 296–298.
67. Silbergleit AK, Trenkner SW (1988) Dysphagia following lightning strike. Dysphagia 2, 228–229.
68. Dinakaran S, Desai SP, Elsom DM (2002) Ophthalmic manifestations of lightning strikes. Surv Ophthalmol 47, 292; author reply 292–293.
69. Ander S, Schulz F, Tsokos M (2000) Ausgeprägte intramuskuläre Hämorrhagien vitaler Genese bei letaler suizidaler Strombeibringung. Rechtsmedizin 10, 105–109.
70. Yost JW, Holmes FF (1974) Myoglobinuria following lightning stroke. JAMA 228, 1147–1148.