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LIGHTNING—SOME OF ITS EFFECTS*

BY CASPAR FRANK HEGNER, M.D.

OF DENVER, COLO.

EVERY action, chemical or physical, within the universe is accompanied by the generation of electricity.

Atmospheric electricity is generated by the friction of the wind and currents of air upon the vapor in the atmosphere, and by the molecular changes in this vapor, whereby they are converted into positive and negative electric ions (*Scientific American*, No. 106). The generation is more active when the vapor temperature is raised by the heat of the sun and later cooled by currents of air (*Scientific American*, No. 625; *Henry, U. S. Bulletin*, No. 30).

The earth is in a state of permanent electrification. The vapor in the atmosphere in condensing forms clouds, which in passing over other clouds and over the earth become charged by induction with electricity of opposite polarity to that of the earth.

Under ordinary conditions electricity in the atmosphere is neutralized by the insensible interchange with the electricity of the earth. This takes place in the form of usually invisible discharges, from the top of every mountain, hill, building, tree or metallic object. Discharges of this character take place from the human body, and when in high altitudes or on mountain peaks it may cause muscular rigidity and discomfort.

The electrical tension of the atmosphere may become very great. When the charges attain sufficient intensity that insensible neutralization becomes inadequate, the insulating air space is broken. The charges rush together and neutralize each other by a series of flashes, accompanied by the generation of light, heat and sound. Lightning is the term applied to this visible discharge of electricity.

The zone of danger may extend beyond the storm area (*Sc. Am.*, No. 625). Any upright or prominent object, being a better conductor

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of electricity than air, is liable to be struck. The electrical strain is taken up by every object in contact with the ground in proportion to its conduction and insulation.

Guerike, in 1650, was the first to discover the means of producing the electric spark (Flamarion). Nothing was known of the nature of lightning or of its relation to electricity until 1708, when Wall drew attention to the similarity of lightning and the sparks obtained by rubbing a piece of amber. Franklin in 1750 proved that the atmosphere was constantly in a state of electrification and with others demonstrated that lightning and electricity are identical. The degree of atmospheric electricity increases with the distance from the surface of the earth (Flamarion).

Lightning tends to obey the laws governing electricity. It is of such incomprehensible strength and the factors incident to its development are so imperfectly understood, that the laws controlling its dissipation have not been fully determined.

A flash of lightning is a rapid succession of (15-40) distinct sparks ($1/5000$ to $1/500$ second duration) of progressively increasing length, projected along the same general path. The succession of sparks gives to lightning its flickering appearance. The entire flash varies from $1/1000$ to $1/2$ second duration.

The direction of the flash is a matter of dispute. It may take place to or from the earth.

The discharge usually takes place between the most prominent or proximal points. It follows the line of greatest conductivity or of least resistance. The charge may be so great that the main path is insufficient for its conduction. It may jump out of the main course, or form numerous branches (*Sc. Am.*, vol. 80). The course taken is determined by the intensity of the current and by the conduction or resistance encountered. The path may be altered by the wind or by the hygrometrical state of the atmosphere (Flamarion). These conditions account for the sinuous, spiral or irregular appearance of lightning.

Unsuccessful attempts have been made to determine the current-intensity, the frequency and the amperage of lightning. These have been variously estimated—voltage as high up in the millions (5000 millions). The frequency as medium (5000 to 300,000, *Emede Sc. Am. Supp.*, No. 697). The amperage upward of 10,000 (Brockels).

So long as resistance is not offered lightning is harmless (*Virchow's Archives*, vol. xx). Lightning will leap over a non-conducting surface

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more readily than through air. Insulation afforded by auto tires, etc., and the safety thereby conferred is a fallacy (*Sc. Am.*, November 7, 1914). *Protection does not lie in providing insulation or resistance, but in establishing a path of greater conductivity and of less resistance than the body.* Conducting bodies or objects are more liable to be struck but are damaged less than resisting bodies (*U. S. Bull.*, No. 56).

There is an uncertain periodicity associated with the frequency and the severity of electrical storms. They are more frequent in the temperate zones during the summer months and in rainy seasons. They are five times more frequent east than west of the Rocky Mountains, more frequent in high mountains and on open plateaus than along the coast, or in low altitudes, in wet, marshy districts more than in dry districts.

The geologic as well as the topographic character of a region exerts an influence upon the site and the severity of a lightning stroke (*Sc. Am. Supp.*, No. 24; *U. S. Bull.*, No. 15). Loam, sand, clay, marl, and chalk predispose in the order named. Rocks are not often struck. They may be split, moved in great masses, or their surface vitrified. Fulgurites may be formed when lightning strikes dry soil rich in silica. Any tree may be struck, in order of their frequency, poplar, oak, elm, conifer, walnut, ash and beech. The richer in starches and the poorer in oils the more susceptible are trees. When struck the tree may be split, separated into layers, splintered, broken off obliquely or transversely. It may be stripped of limbs or bark. The bark may be grooved vertically or spirally, may be ignited (2 per cent.), may be stunted or stimulated in its growth.

Buildings are susceptible in proportion to their size, height, nature of their construction and insulation.

Lightning is more frequent (five times) in rural than in urban districts. The more thickly settled and the better built a section is, the less frequent and destructive will be the lightning.

Occupations which keep one in the open, especially in sparsely settled or open districts, increase liability—cattlemen, woodmen, farmers, etc. Animals are more frequently struck than men. All species, even fish in ponds and streams, have been affected. When animals are struck they rarely survive.

No accurate statistics of lightning casualties are available. Most fatalities and the greatest property damage occur during the months of June and July. The largest number of deaths occur in the Mid-Atlantic states. The greatest proportionate mortality is noted in the

mountain states of Colorado, Montana and Wyoming. Over sixteen hundred cases of lightning accidents are recorded yearly in the United States. One-third of these result in death. Nine-tenths of the deaths occur in rural sections.

Lightning has a tearing or explosive effect. It has a greater tendency to bend or break than to burn or fuse. The effects are largely mechanical, the result of pressure fluctuations. The disassociation of gases (*Virchow's Archives*, vol. xx) or the generation of steam by the current are claimed to explain many of these mechanical effects (*Lancet*, 1879-1909). The charge in passing through the body is not evenly distributed. It may remain superficial, follow channels, such as blood- or lymph-vessels, or be transmitted through bones and nerves.

The body may not be visibly affected, may be left in the same posture as before the stroke or thrown more or less violently many feet, and not injured (*Lancet*, 1909, vol. 1). Mutilation in varying degrees to complete dismemberment or incineration may result.

The clothing may not be affected in any way. It may be stripped or burned in part or entirely, shredded to ribbons, either warp or woof may be destroyed. Seams may be ripped, linings or undergarments destroyed leaving the outer garments and the skin intact (Flamarion). Metallic objects in or of the clothing are bent, broken, more or less fused or not affected. The shoes most constantly show the effects of the current. People are usually standing when struck, the current then enters or leaves the body through the feet. The shoes, especially when dry or only partially damp, interpose a substance of increased resistance. One or both shoes may be affected. They may be gently removed, or violently thrown many feet, be punctured or have a large hole torn in any part, shredded, split, reduced to lint or disappear entirely. The soles may disappear with or without the heels. Any of the foregoing may occur and the person not injured or only slightly shocked.

The amount of damage to the clothing or to the surface of the body is no index to the extent or the severity of the injuries sustained within the body. Either may be disproportionately great or small.

As lightning travels faster than sensory impulses, or the tracts are blocked, the injuries at the time of their infliction are usually painless.

The symptoms may be divided into (1) external or mechanical, (2) internal or essential, (3) mental or psychical.

External or mechanical signs are most marked at the points of

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entrance or exit of the current. The nature of the injuries is determined by the position of the body, the condition of the skin, the character and condition of the clothing, the presence of constricting bands of metallic parts and the proximity of conductors and contacts.

The skin offers greater resistance than any other tissue. The resistance is five hundred times greater when dry or oily than when wet. This difference accounts for the wide variation in the character and degree of its injuries, which are burns, lacerations and contusions.

Burns range in degree, from singeing of the lanugo and mildest erythemas to complete incineration. They vary in extent from minute punctate to extensive irregular areas. Burns which at first appear small and superficial may later assume a more extensive and deep character. They may partially heal and later break down, not only in the scar but in the adjacent apparently healthy tissue. They take longer to heal than ordinary burns.

Erythema may be the only manifestation of lightning stroke, or may accompany burns—as a circumscribed area or as irregular, narrow or broad, more or less branching bands—the resemblance to trees, ferns, etc., giving rise to the popular fallacy of lightning photographs. It has been asserted that these peculiar configurations are due to vasomotor paralysis, and to disintegration of the blood in the superficial vessels and capillaries. They are not confined to the distribution of these vessels. Rindfleisch (*Virchow's Archives*, vol. xxv) proved they are due to the effect of the current on the tissues, the irregular and branching distribution being caused by the difference in resistance.

Vesication and pigmentation may accompany burns and erythemas as brownish areas, hard dry parchment-like or soft, with vesicles containing more or less altered blood.

Contusions, from the mildest, with slight ecchymosis, to the most severe degree, with extensive hæmatomas, may occur.

Lacerations may be single or multiple, clean cut or irregular. They may be superficial, confined to the skin, or deep, involving not only the subcutaneous tissues but also the muscles, fascias, vessels, nerves and bones. Either may be extensively involved without the other.

Joints may be dislocated, bones may be fractured. Fractures are direct, caused by the lightning, or indirect, due to muscular contraction, the throwing of the body, or by objects falling on the body. When direct they are usually comminuted or complex and occur at joints, particularly where several bones enter into the formation of the joints, *e.g.*, ankle and spine. A break in the continuity of the bony tract

conducting the electric charge increases the resistance and admirably illustrates the law—damage is in proportion to the resistance.

Important vessels may be ruptured, cause alarming or fatal hemorrhage or irreparable damage. Any viscus may be lacerated or ruptured with or without damage to the overlying tissues. Eye injuries may result promptly in cataract. The choroid or choroidal vessels may be ruptured, retinal hemorrhage or detachment, paralyses of the muscular apparatus and of accommodation or atrophy of the optic nerve may occur (*Medical News*, 1888). Ear may be torn off, membrana tympani ruptured, or the auditory nerve injured.

The actual destruction of tissue resulting from the purely mechanical effects is of secondary importance, so far as life is concerned, to the interruption or the destruction of the physiology of the vital centres. This pathological physiology explains many of the internal or essential symptoms.

The internal or essential symptoms may be divided into primary and secondary.

Primary symptoms may be very slight: a mild sensation of giddiness or blunting of intellectual faculties. Loss of consciousness more or less complete, lasting from a few moments to days, may terminate in death. Return to consciousness may be sudden or by stages. Collapse with pale clammy skin, difficult, slow and irregular respiration, irregular feeble pulse, dilated pupils, may enter a state of suspended animation, during which there is neither respiration nor pulse. This lasts a variable period, usually short and if not promptly treated by artificial respiration deepens into death. Lastly and most awe-inspiring is instantaneous death without macroscopic lesion.

Secondary symptoms are in all probability dependent upon some tissue change. Loss of memory complete or confined to the accident, temporary or permanent. Aphasias of any kind may result. Growth of the affected part may be permanently stunted.

Motor.—Tonic or clonic contractures, rhythmical or irregular, general or confined to the injured part. Paralysis—mono, hemi, para or quadriplegia with or without involving the sphincters. Difficult mastication, deglutition or phonation. Vertigo, ataxia or loss of coördination. Convulsions, true epilepsy or epileptiform.

Sensory.—Pains, general or confined to the area affected, sharp, severe darting or paroxysmal in character or a dull ache. Hyper, para or anæsthesia.

Special sense—deafness, dulling of hearing or buzzing in the ears.

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Blindness, blurring of vision, double vision, loss of color sense, lachrymation, photophobia, ptosis, loss of accommodation.

Mental or psychological neuroses may have a pathological basis. Functional traumatic neuroses, mental or intellectual impairment, insomnia, delirium, mania. Hypersensitive to electrical storms ranging from fear to positive pain.

Prognosis should always be guarded. When symptoms have no demonstrable pathological basis they are usually temporary but may last for months. Death may be instantaneous, a direct effect of the lightning upon the myocardium (fibrillation) or upon the respiratory centre, or both; more or less sudden, due to shock following the stroke or to gross lesion of the vital centres; slow, from delayed shock of the injuries, as a direct result of the injuries or consequent exhaustion.

The diagnosis of death due to lightning depends upon the presence or absence of positive findings at autopsy and upon the conditions and circumstances attending the finding of the body at the site of the accident. The post-mortem changes may be negative. Evidence of violence may be entirely absent. Body temperature may be elevated for a considerable period. Rigidity sets in early and passes rapidly. Putrefaction may set in early and progress rapidly.

Brain and nerve tissue being better conductors are more easily affected, but show less macroscopic damage than other tissues.

Findings may be those of asphyxia, congestion with or without ecchymosis of the cerebrum medulla or cord and their membranes. Heart is flaccid, right heart filled with fluid blood, the large venous trunk and veins congested, arteries contracted and nearly empty. Blood not coagulated or poorly coagulable. Ecchymosis beneath the pericardium, pleura or in the lungs. Evidence of violence or injuries before mentioned in the skin, muscle, bones or viscera. There are no reliable or constant cytologic changes in the material obtained from cases of death by lightning.

CASE I.—On August 3, 1916, Miss V. and Miss A. were sitting on the porch of their cottage which was located among the pine trees on the slope of a hill near Grand Lake, Colorado. A severe storm began and they went into the cottage.

Miss V., noticing the rain coming in the window of her room, closed it, but not before the floor became wet. She then sat on a commode. The commode was several feet from the bed near the living room partition, on the opposite side of which was a

stove with a metallic flue leading through the roof. The next thing she knew she was lying partly under the bed near a large hole in the floor. She experienced no pain, did not know what had happened or how long she had been unconscious. She says it could not have been long, probably a few minutes. When she tried to get up she noticed the front of her shoe was torn and the sole and heel entirely gone. The little toe was gone and her foot was bleeding badly. She called to Miss A., but received no response.

Miss A., who had been sitting in a chair near the middle of the living room, heard Miss V. close the window and remark about the storm. She heard nothing after this, but saw the stove lid fly across the room and heard it fall on the floor. Above the stove appeared a huge round flash of bright light the size of the sun. She tried to get up but was lifted from her position and thrown several feet through the open door to the floor of her room. She was dazed, her ears felt shut. She was aroused after a brief period by the cries of Miss V, which she heard as if in a dream. She could not move. By supreme effort, being unable to get up, she crawled to Miss V's room and found her sitting on the floor holding her foot. The sight of blood all over the floor brought her out of her dazed condition. She laid Miss V. on the floor, who on looking up through a hole torn by the lightning in the ceiling saw the cottage was on fire. The cottage burned completely. The nearby pine trees were also burned. Miss V. was carried to the adjacent ranch house and attended by Dr. H. L. Buxton who rendered efficient service, stopping the hemorrhage which seemed to threaten her life. Her watch stopped at 2.10 p.m., the exact time of the stroke.

I was sent to Grand Lake by Dr. G. W. Holden, and arrived the next a.m. Miss A. was entirely recovered though still very nervous, a state easily accounted for by the precarious condition of her friend Miss V. Miss V. was in a state of shock, under the influence of opiates. Lips cyanotic, skin pale, giving face a peculiar expression. Pulse 140, respiration 14 and irregular. Her left labia showed a superficial laceration the size of a quarter. Her left foot had a laceration, the surface of which appeared as if seared by heat, extending through the web between the big and second toe from the dorsum to the plantar surface of the foot back to and exposing the first row of tarsal bones. A second laceration through the web between the second and third toe through the entire thickness of the foot joining the first laceration near the base of the metatarsal bones. A third laceration 2 inches long through the web between third and

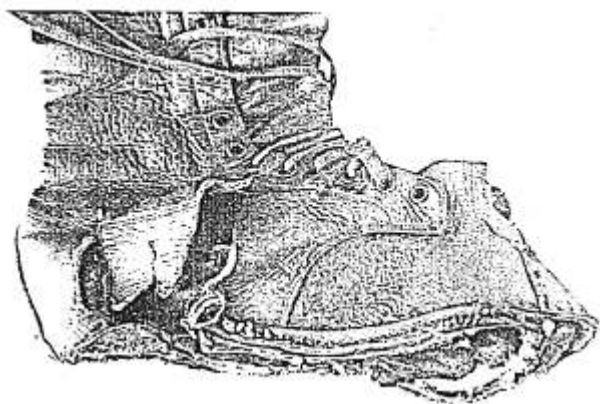


FIG. 1.—Internal aspect.

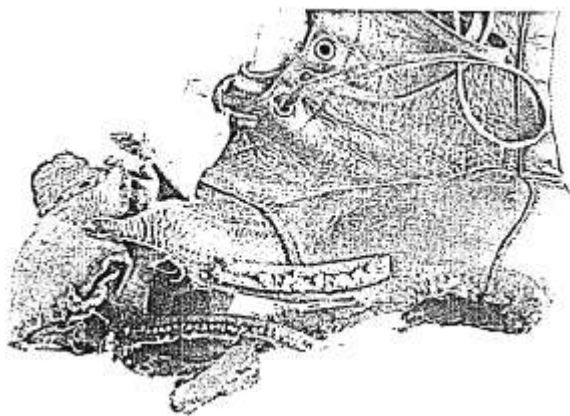


FIG. 2.—External aspect.

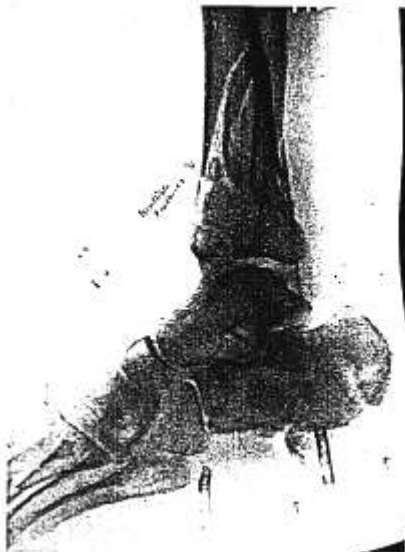


FIG. 3.—Comminuted fractures resulting from direct explosive (lightning) violence.

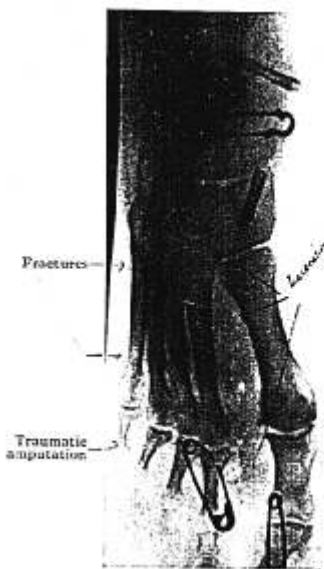


FIG. 4.—Extensive laceration through entire foot, exposing the tarsal bones, illustrating explosive or tearing effect of lightning.

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fourth toe involved the dorsum of the foot and the intermetatarsal tissues. A fourth laceration through the web between the fourth and fifth toes extended across the base of the little toe, completely amputating it, leaving only a fragment of the proximal phalanx. On the dorsum of the foot near the base of the second and third toes was a nearly circular burn of second degree the size of a silver half dollar. On the corresponding area of the sole was a burn of the same size and degree. Extending from two inches below the internal malleolus under the heel to its outer margin was an irregular laceration through which could be felt fragments of the fractured os calcis. One of these fragments had the posterior end of the badly shredded plantar fascia attached to it; two others were removed. There was a comminuted fracture of the lower end of the tibia and fibula, compound comminuted fracture of the os calcis and fracture of the third and fourth metatarsal bones, as shown on the accompanying X-rays by Drs. Childs and Crosby.

Without anaesthesia the wounds were gently wiped free of coagula with dry gauze. The plantar fascia which was reduced to a bundle of strings and the deeper tissues were united by tiers of interrupted catgut sutures, two catheter drains inserted, skin loosely approximated with interrupted silkworm sutures, leg placed on posterior splint. Patient withstood the ordeal with wonderful fortitude. She was sent to Denver the next day. For three days her temperature was 100, but never higher. She had severe darting pains in her back, leg and foot. Tactile sensation in foot and leg was normal. At the end of a week I sent her to her home in Chicago and reports tell of her favorable progress. She can now bear considerable weight on her foot which is practically healed.