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Keraunoparalysis

An Explanation for the More Severe Lightning Injuries Reported in Developing Countries

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***Abstract*— While lightning injuries in developed countries seldom show significant burns, those killed by lightning in developing countries are often characterized as 'charred' or 'burned beyond recognition'. Keraunoparalysis, the usually immediate but temporary paralysis of one or more limbs after lightning injury, may be the reason that even healthy individuals cannot escape from thatched buildings and why these findings are reported.**

Keywords—Keraunoparalysis, paralysis, lightning injury, lightning death, hemiplegia, monoplegia, paraplegia

I. INTRODUCTION

Lightning is a natural phenomenon whose nature is mainly electric with energy and temperatures sufficient to cause fires and burns. In developed countries, most incidents involve single deaths, lightning burns tend to be superficial and at least one third of survivors have no skin damage or burns [1]. However, news reports in Latin America and Africa often describe lightning incidents with multiple victims, some of whom have burns so severe that identification of victims may be difficult [2, 3]. This paper investigates why these injuries vary so markedly between developing and developed countries.

Lightning discharge exerts an electrical effect at the multisystem level which can compromise the central nervous, cardiac and pulmonary systems [1]. One nervous system injury that lightning may cause immediately is peculiar as it may prevent victims inside a less substantial building from moving or escaping if it catches fire [4]. Although unconsciousness or immediate death are also logical explanations, another plausible explanation is the little known and much less understood phenomenon called keraunoparalysis, temporary paralysis that frequently occurs with lightning injury [5].

The aim of the paper was to gain a better understanding of this phenomenon. The Authors conducted a systematic search in the US National Library of Medicine National Institutes of Health (PubMed), using the term 'keraunoparalysis' in both titles and abstracts [6]. Only 10 relatively recent articles were found, with the oldest from 1985. For this reason, a more extensive search was made based on clinical cases or case series references of lightning injuries to learn the different presentations and clinical aspects related to this event.

II. HISTORY OF THE TERM 'KERAUNOPARALYSIS'

Several authors [7, 8] attribute the term keraunoparalysis to Charcot, a French neurologist, who was said to have coined it in two classic articles published at the end of the 19th century that described the paralysis [9, 10]. However, Cherington [11], a well-known authority on the neurological aspects of lightning and electrical injuries, affirms that the term was not introduced until 1932 by Critchley, a statement ratified by Kumar et al. [12].

The first publication related to lightning injuries registered in PubMed was published in 1800 [13]. In early texts, neurological manifestations from lightning were not documented until 1848 when Orton described a transient paralysis involving weakness and paralysis of the right upper limb with a very slow recovery [14]. In 1875, Vincent presented a review remarking about the lack of information that existed in Europe on lightning effects and their possible treatment. Throughout the review's four chapters, he discusses several cases of injuries by lightning, among them a case of numbness and coldness of the right leg for 3 days, in addition to other cases of hemiplegia or paraplegia without further information [15].

In 1883, in an article describing the first photographic images of Lichtenberg figures, paralysis, weakness and coldness of both upper limbs were also mentioned without further analysis or information [16].

Only a decade later, a series of documents from the French Medical School attempted to explain the phenomenon of lightning paralysis, not only from the anatomical aspect, but also from the observed behavior. Hysterical hemiplegia (l'hémiplégie hystérique), meaning physical complaints without a physiological explanation, is described as a condition caused by multiple triggers with lightning being among them. In 1894, Bardonnet described it as hemiplegia, usually flaccid, often accompanied by a sensory disturbance (hemianesthesia) [17]. In the thesis made by the outstanding neurologist Guinon, the 'l'hystéri' is the consequence of multiple external causes, among which is the so-called 'le shock nerveux', a more general term to explain the multiple symptoms and neurological and behavioral findings presented by lightning victims [18].

However, publication of the clinical presentations by Charcot in 1889 makes a differentiation between hysterical paralysis and the so-called paralysis of thunderbolts, 'paralysies des foudroyes' or 'kerauno-paralysies'. After describing and analyzing several cases of people struck by lightning, Charcot affirms that "the paralyses produced immediately after the shock, are marked (1) by the disorders of sensibility, namely: cutaneous and deep anesthesia; (2) by more or less pronounced motor paralysis, with a temporary diminution of the electrical excitability. One of the characters of these paralyses is that, whatever one does, they are not durable" [19].

Paralysis is presented as hemiplegia (one side), paraplegia (lower extremities) or monoplegia (any one extremity) and with different degrees of severity from partial (incomplete) paralysis and weakness to complete paralysis.

III. PATHOPHYSIOLOGY

Lightning produces a multi-organ compromise, affecting mainly the cardiovascular and nervous systems [20]. At the neurological level, lightning can compromise all three components of the nervous system: central nervous system (CNS – brain and spinal cord), peripheral nervous system (PNS) and autonomic nervous system (ANS – responsible for automatic functions such as breathing and digestion). Keraunoparalysis, according to Cherington's classification [21], belongs to Class I neurological lesions (immediate and transitory), occurring in about one half to two thirds of reported lightning cases [22, 23], and typically consisting of limb paralysis, sensory symptoms, coolness, pallor and pulselessness. (Table I).

The study of keraunoparalysis is not an easy issue. While frequently reported by survivors, physical manifestations are transient and, on many occasions, the symptoms and signs have improved or resolved by the time the patient arrives at a medical institution. Multiple theories have been proposed to explain this phenomenon [Table II]. It has been hypothesized to be from vascular circulatory compromise of the injured limb [24], or to a differential effect according to the route of the discharge (entry or exit) [25, 26].

TABLE I. CHERINGTON'S CLASSIFICATION OF NEUROLOGICAL SYMPTOMS FROM LIGHTNING INJURY

Group	***Characterization***	***Examples***
Group 1	Immediate and transient symptoms.	Loss of consciousness, amnesia, confusion, keraunoparalysis, weakness, headache
Group 2	Immediate and prolonged or permanent	Intracranial hemorrhage, cerebral infarction, post hypoxic-ischemic encephalopathy, cerebellar syndromes
Group 3	Possible delayed neurologic syndromes	Movement disorders
Group 4	Lightning-linked secondary trauma from falls or blast.	Ruptured eardrums, damage consistent with falls or being thrown a distance

TABLE II. THEORIES ON THE CAUSATION OF KERAUNOPARALYSIS

Factor	***Corroboration***
Vascular spasm	Plausible – but from what cause?
Autonomic nervous system dysfunction	Other autonomic effects should be seen – hypertension, fast or slow pulse, etc
Catecholamine release (adrenaline, etc)	Effect would be generalized, not limited to specific limbs
Lightning pathway	Nearly impossible to test or document
Release of other chemicals or hormones?	Andrews hypothesis

In 1934, the British neurologist Critchley proposed that sensory and neurological symptoms may be related to vasoconstriction caused by a "massive autonomic stimulation", similar to that in Raynaud's disease [27-29]. Current explanation considers a high discharge of adrenaline and other catecholamines as the cause of vasoconstriction [8, 30]. However, questions arise which may be interesting ideas to investigate in the future:

1) if the weakness, numbness and paralysis is directly related to vasoconstriction, why do neurological symptoms occur in the absence of vascular compromise [31-33]?

2) if the phenomenon is produced by the effect of circulating catecholamines throughout the body, why don't the vascular and neurological findings occur in all 4 limbs?

For this reason, the Authors agree with Andrews et al. [34] regarding the involvement of several mechanisms simultaneously and capable of producing different manifestations in each limb of the same patient [34, 35].

IV. PHYSICAL EXAM

Keraunoparalysis occurs frequently. In a classic study performed by Cooper, the largest series of lightning injury cases reported to date (66 patients), paralysis was found in 43.9%, with about 2/3 affecting the legs and 1/3 the arms [5].

The initial presentation of victims by lightning is summarized by Critchley as follows: "immediately on recovering consciousness the patient usually notices an immobility and loss of feeling in the legs and lower part of the trunk" [7]. Subsequently, the survivors manifest keraunoparalysis as a weakness or flaccid paralysis associated with variable alteration in sensation. These symptoms must be accompanied by severe vasoconstriction (the classic description is 'the legs are white or livid, the toes often bluish, and the limbs are deadly cold') but the clinical manifestation is to be transitory [19, 30].

Motor involvement can affect from one to all four extremities. Therefore, it can be manifested as monoplegia (a single limb compromised) [36, 37], paraplegia (both lower limbs) [12, 39, 40], hemiplegia (left or right side of the body) [31, 32, 38], or quadriplegia (all four limbs compromised) [41, 42].

As autonomic dysfunction has been considered a cause of keraunoparalysis [27], other autonomic manifestations may be found on physical exam such as bradycardia or tachycardia, profuse sweating, or usually transient arterial hypertension [21, 43, 44], among others.

V. TREATMENT

Lightning injuries often involve multiple systems injuries [1, 20]. but because we are focusing on keraunoparalysis, only the aspects related to keraunoparalysis and how this phenomenon can affect the physical examination and the treatment of lightning victims will be discussed.

In the primary evaluation, it is important to take into account that the presence of keraunoparalysis, manifested by absence of pulse, coldness and distal pallor, could be associated with dilation and absence of pupillary reaction [1], which can lead to an incorrect diagnosis of cardiac arrest, initiating CPR maneuvers in a patient that does not require them [31. 45]. In the recognition of cardiac arrest by health professionals, the standard basic life support (BLS) course recommends the evaluation of signs of life and central pulse (carotid) [45], while for lay personnel, inexperienced at finding pulses, delay for pulse evaluation is not recommended before starting CPR in an unconscious, non-breathing person.

The hemodynamic status in all four extremities should always be evaluated by pulse quality, distal perfusion and temperature [1]. If all four limbs show coldness, pallor, and absence of pulses, health personnel must also consider a cardiogenic, hypovolemic or neurological shock cause and treat appropriately instead of assuming quadriplegic keraunoparalysis, which is extremely rare.

Because keraunoparalysis can mimic spinal cord injury, spinal alignment and immobilization is always required. In addition, barotrauma, a well-known lightning injury mechanism similar to being near an explosion where the person can be thrown a distance, should be expected and spinal precautions taken. Other causes of trauma must always be considered, especially if there are no observers or reporters of the event.

In many cases, neurological symptoms of lightning injury are transient [46, 47], which may lead some physicians to wait a period of watchful observation, delaying expensive or difficult to obtain diagnostic images which often take the patient to a radiology suite away from skilled care and quick intervention [31]. However, if neurologic findings do NOT resolve or change despite the improvement of vascular symptoms (improvement of pallor, perfusion and pulse), neurologic damage at the medullary or spinal cord level should be ruled out with radiologic studies such as magnetic resonance imaging (MRI) [12,42,45]. Keraunoparalysis should only be adopted as a diagnosis after all other more serious causes are excluded.

Burns are commonly reported in only about 1/3 of lightning injury events and are usually superficial. It is important to emphasize that these burns are dissimilar to those from high voltage injuries [20, 47-50]. Circular and deep burns are rarely seen, so it is unlikely that vascular symptoms are secondary to elevated pressures as in muscle compartment syndromes. Rhabdomyolysis (muscle destruction) in lightning injuries are also uncommon [23. 40, 44, 51, 52]. Fasciotomy or emergency escharotomy is not recommended [8, 53], except in cases where elevation of the pressure in the extremity compartment is confirmed [49]. Avoiding unnecessary surgical procedures is always a priority.

In cases of hypertension, another frequent but transient finding in lightning cases, there is no specific recommendation on which antihypertensive to use [21, 43, 44]. However, the elevation of blood pressure is usually transient and can be treated expectantly with no continued treatment usually needed. Although anticoagulation was considered at one time, there is no current evidence to support its use [8, 53].

While many would recommend discharge to outpatient care, waiting for recovery of deficits, some authors recommend a prudent observation time due to cases of readmissions after a few days without recovery [54]. Some studies have found that persistent symptoms are related to neuropraxia and axonal lesions per se¸ so they belong to other injury groups in the Cherington classification [21].

VI. CONCLUSIONS

News reports in developing countries often describe people with lightning injury as ‘burned beyond recognition’ or ‘charred’. Researchers did not know if these reports were true or if they were written by reporters who may not have had personal contact with the victims or the scene of injury but who expected these findings. However, the authors and others have collected news report indicating first person quotes and pictures showing complete conflagration of thatched roofs and buildings “Fig 1”. It was unclear why inhabitants of the buildings might be screaming but unable to escape until keraunoparalysis was considered, a phenomenon that may explain why victims cannot escape from burning buildings

While frequently reported by survivors, keraunoparalysis has had little study, perhaps because of its often-transitory nature. In this extensive review of the literature, most reports of keraunoparalysis are of isolated clinical cases with a few case series. Given this lack of information, the Authors recommend returning to laboratory studies, with a multidisciplinary collaboration (including medicine, bioengineering, physics, social disciplines, among others), to clarify this and other pathologies related to lightning injury.

Fig. 1. Eleven members from the indigenous Wiwa ethnic group died when the thatch building they were meeting in was ignited by a lightning strike.

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