Injury 53 (2022) 3070–3077

Contents lists available at ScienceDirect

Injury

journal homepage: www.elsevier.com/locate/injury

Review

A shocking injury: A clinical review of lightning injuries highlighting pitfalls and a treatment protocol

Rick van Ruler[a,*], Ties Eikendal[b], Fabian O. Kooij[c], Edward C.T.H. Tan[a]

[a] Department of Traumasurgery, Radboud University Medical Center, Geert Grooteplein Zuid 10, GA, Nijmegen 6525, the Netherlands
[b] Department of Emergency Medicine, Department of Emergency Medicine, Radboud University Medical Center, Geert Grooteplein Zuid 10, GA, Nijmegen 6525, the Netherlands
[c] Department of Anesthesiology, Amsterdam UMC, Meibergdreef 9, AZ, Amsterdam 1105, the Netherlands

ARTICLE INFO

Article history:
Revised 7 August 2022
Accepted 10 August 2022

Keywords:
Lightning injuries
Reversed triage system
Cardiopulmonary resuscitation
Lightning burns
Treatment protocol
Wilderness medicine

ABSTRACT

Introduction: Lightning strikes have high morbidity and mortality rates. Thousands of fatalities are estimated to be caused by lightning worldwide, with the number of injuries being 10 times greater. However, evidence of lightning injuries is restricted to case reports and series and nonsystematic reviews. In this clinical review, we systematically select, score, and present evidence regarding lightning injuries.
Material and methods: We performed a systematic search for reviews and guidelines in the PubMed, Embase (OvidSP), MEDLINE (OvidSP), and Web of Science databases. All publications were scored according to the Levels of Evidence 2 Table of the Oxford center for Evidence-Based Medicine. The reviews were also scored using the scale for the quality assessment of narrative review articles (SANRA) and guidelines from the Appraisal of Guidelines for Research & Evaluation (AGREE II).
Results: The search yielded 536 articles. Eventually, 56 articles were included, which consisted of 50 reviews, five guidelines and one overview. The available reviews and guidelines were graded as low to moderate evidence. Most damage from lightning injuries is cardiovascular and neurological, although an individual can experience complications with any of their vital functions. At the scene, initial treatment and resuscitation should focus on those who appear to be dead, which is called the reverse triage system. We proposed an evidence-based treatment protocol for lightning strike patients.
Conclusion: It is vital that every lightning strike patient is treated according to standard trauma guidelines, with a specific focus on the possible sequelae of lighting injuries. All emergency healthcare professionals should acknowledge the risks and particularities of treating lighting strike injuries to optimize the care and outcomes of these patients. Our evidence-based treatment protocol should help prehospital and in-hospital emergency healthcare practitioners to prevent therapeutic mismanagement among these patients.

Introduction

Lightning strikes an estimated 50–100 times per second worldwide, of which 20% result in actual ground strikes [1–3]. Thousands of fatalities are estimated to occur annually due to lightning, with the number of injuries being 10 times greater [1–4]. Data on lightning mortality rates in India support these estimations, where 1755 lightning deaths occur on average each year [5]. Nevertheless, presentation at a healthcare facility seems rare. Retrospective studies of large hospitals have indicated that each year, approximately 1 in 35,000–40,000 patients is hospitalized due to lightning [6–8]. With the current data, it remains difficult to conclude anything regarding the exact number of lightning strike patients, who eventually present at the emergency department.

Why lightning injuries are underreported remains unknown. However, lightning can inflict serious damage on victims. Lightning can expose the body to over 1000,000 Vs and 10,000–200,000 As, which is classified as a high voltage injury [1,9,10]. The most critical difference from other high voltage injuries is the duration of exposure. A person's exposure to lightning is very short, typically lasting from 1/1000 s to 1/10 s [4,10,11]. Because of this short exposure period, only a small amount of energy is transferred internally, while the majority of the energy flows externally over the victim's body, which is also known as the "flashover" effect [4,10,12]. Due to the flashover effect, a person can actually survive

* Corresponding author.
E-mail address: Rick.vanruler@radboudumc.nl (R. van Ruler).

https://doi.org/10.1016/j.injury.2022.08.024

Table 1
Types of lightning strike mechanisms.

Mechanism	
1 Direct strike	Lightning strikes the victim and the current passes through the body. Entry and exit wounds are often found.
2 Contact injury	Lightning strikes an object that is touched by the victim.
3 Side flash injury	Lightning strikes a nearby object (e.g., a tree) and flashes over to the victim.
4 Ground strike (most common)	Lightning strikes the ground and passes to the victim. The current enters the body through one leg and exits through the other.
5 Upward stream	Current flows through the body from the ground upwards.
6 Blast injury	Such injuries occur through a blast wave, through an explosion of nearby structures (which can cause penetrating injuries), or through the victim falling or being thrown.
7 Phone electrocution	A bolt of lightning that strikes a telephone line can cause an electrical surge to shoot through the wires and enter a handset. Nowadays, the odds of this are extremely small due to the use of wireless phones.

a lightning strike. However, this effect also causes a much more serious injury pattern compared with other high voltage injuries, and lightning injuries have a 5–10 times higher estimated morbidity rate [13,14].

In addition to the electrical current, patients can be injured by the extreme temperature of lightning or through a blast wave [9]. Strike temperatures are reported to rise as high as 30,000 °C [1,9]. A blast wave causes injury through an explosion occurring in the air around the lightning channel. The electrical current often contributes to severe damage in patients, whereas severe injuries caused by blast waves or high temperature are rarer [12].

Lightning injuries can be classified through seven mechanisms, which are presented in Table 1 [4,9,12,15–17].

Which type of injury will occur in a lightning strike victim is determined by the type of mechanism, current (A), path of current flow across the body, duration of contact, and individual vulnerability [16]. Due to the many determinants, injuries vary significantly between individuals. Therefore, it is crucial to have a clear overview and sound understanding of these injuries. Considering the low documented incidence (some case reports and case series), assessing lighting strike patients and treating their injuries are challenging. The guidelines for treating lightning injuries remain poor and hardly any contain recommendations based on a systematic review of existing evidence. Therefore, the aim of this clinical review is to present the best available evidence regarding the epidemiology, clinical presentation, treatment, and sequalae of lightning injuries from the past 30 years as well as to highlight pitfalls in the approaches to these patients. Then, this clinical review provides an evidence-based treatment protocol, which could be of great use to all emergency healthcare professionals in the prehospital and in-hospital setting.

Materials and methods

Search strategy and study selection

We performed a systematic database search for reviews and guidelines in the PubMed, Embase (OvidSP), MEDLINE (OvidSP), and Web of Science databases. The search strategies are listed in Appendix A. Furthermore, a global search was performed on Google Scholar and UpToDate using the terms “lightning injuries,” “lightning injuries review,” and “medical aspects lightning injuries” to find additional articles. One author (RR) performed this screening. Articles with publication dates after January 1990 up to April 2022 were reviewed if written in Dutch, English, or German. Because of the many case reports and series, which varied significantly in injury presentation, the search was limited to reviews and guidelines. Articles were screened based on their title, abstract, and full-text and were discussed with a second author (ET). Articles were included if they contained relevant information regarding the epidemiology, clinical presentation, treatment, or sequalae of lightning injuries. Additional articles were screened for inclusion through cross-referencing the shortlisted articles.

Article quality assessment

The quality of the articles was assessed according to the Levels of Evidence 2 Table of the Oxford center for Evidence-Based Medicine (OCEBM) [18]. With the exception of two articles, all reviews were nonsystematic narrative reviews. These reviews could be considered level 5 evidence or even as nonevidence because of the lack of a systematic methodology. Only one set of included guidelines contained recommendations based on a systematic literature review (published in 2018), and therefore, it was scaled as level 1 evidence. Because of the low evidence quality of the articles, the recommendations in this articles should be used with caution. To provide a more detailed description of the quality of the included reviews and guidelines, reviews were also scored using the scale for the quality assessment of narrative review articles (SANRA) [19] and guidelines from the Appraisal of Guidelines for REsearch & Evaluation (AGREE II) [20]. All scores, as well as the most critical characteristics of each article, are listed in Appendix B. When different articles presented conflicting information, their total included references and their quality scores were used as a tool to decide the quality of the information and their contribution to this review.

Results

In total, 536 articles were found through the systematic literature search. After duplicates were removed, 231 articles were screened. Eventually, 56 articles were included. Fig. 1 presents a PRISMA chart of the literature search.

Prevention of and misconceptions about lightning

For the sake of prevention, we wish to address some misconceptions about lightning as well as to provide safety tips, which we gleaned from the reviewed articles. Table 2 shows an overview of the misconceptions and safety tips. We feel that this is important to do because misconceptions could lead to inadequate risk mitigation before a lightning strike as well as inadequate treatment after one occurs.

Epidemiology

Based on patient data, men are four to five times more likely to be struck by lightning than women and victims are mostly healthy young individuals [1,12,16,22,25,29,30]. Worldwide, most

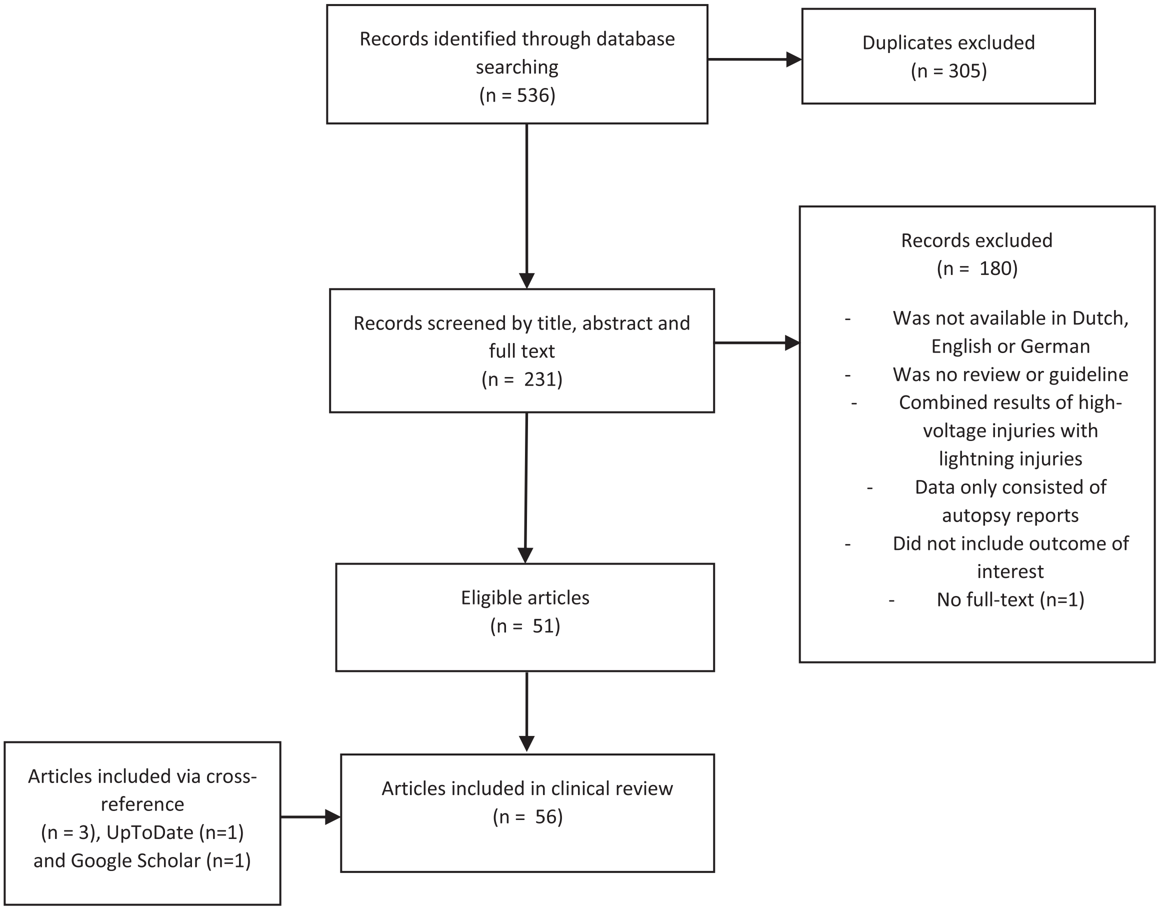

Fig. 1. PRISMA chart of the literature search.

Table 2
Lightning facts and safety tips.

Lightning facts	Lightning safety tips
- Lightning *can* strike the same place twice [11]. - Lightning *can* strike with blue skies overhead, also known as 'a bolt from the blue' [3,12,16,21,22]. - Lightning cannot occur without thunder [16]. - A ball lightning is an actual phenomenon. It is described as a mixture of fire and lightning, which can move in any direction after a strike and suddenly disappears [23]. - Lightning does not always hit the highest object [12,16,24]. - If there are no external signs of lightning injury, the damage/injury can still be serious [4,16,24].	- It is not dangerous to touch a lightning victim, because victims do not remain charged [2,11,13,16,21,22,25]. - The best spots to seek shelter are inside away from windows and wiring or, when outside, in a car with a metal roof [16,21,26,27]. - The "30–30″ rule is recommended for safety. This rule states that you should seek shelter when the thunder is heard within 30 s of seeing a lightning strike and activity should not resume for 30 min after the last thunder is heard or the last lightning seen [2,11,14,15,25,27,28].

incidents occur during the summer months and in the afternoon or early evening [1,12,16,25,29–32]. Furthermore, 9–30% of injuries are multi-casualty incidents [10,25,30,33]. Most injuries occur outdoors where ground strikes or side flash injuries are most common. With ground strikes injuries the lightning strikes the ground and passes to the victim. The current enters the body through one leg and exits through the other. With side flash injuries the lighting strikes a nearby object and flashes over to the victim. About 50% of injuries are ground strike injuries, while side flash injuries contribute from 30% to ≤50% of total injuries. Direct strikes contribute from 3% to 5% of injuries and contact injuries only 1–2% [3,15,22,34]. With a direct strike the lightning hits the victim instantly, while with contact injuries the lightning strikes an object that is touched by the victim. Although direct strike injuries are uncommon, they have the highest mortality rates [3,35,36]. Approximately 10–30% of all lightning injuries result in death [4,10,12,13,16,24,25,31,34–39]. Worldwide, mortality is estimated to be 0.2–1.7 deaths per million people per year, but the incidence differs per region [12,37]. A recent study by Holle presented published data of mortality rates per country [5]. Africa topped the list with mortality rates up to 84 deaths per million people per year, followed by countries in Asia and North and South America. Mortality rates in Europe were the lowest with an average of 0.1–0.4 deaths per million people per year. This discrepancy in mortality rates is due to the lack of lightning-safe facilities and fewer fully enclosed metal-topped vehicles, higher rates of labor-intensive agriculture, lack of awareness, and poor medical treatment in less developed countries [5].

Fig. 2. Lichtenberg figure. Used with permission from Mahajan AL, Rajan R, Regan PJ. Lichtenberg figures: cutaneous manifestation of phone electrocution from lightning. Journal of Plastic, Reconstructive & Aesthetic Surgery. 2008;61:111–3. © Elsevier.

Clinical presentation

Although clinical presentation in lightning strike victims varies greatly per individual, signs and symptoms of lightning strike victims are explained by the current following the path of least resistance. Nerves have the least resistance, followed by blood, muscles, skin, fat, and bones [22,27,31,35,37,40]; this may explain why neurological and cardiovascular damage are the most common and severe forms among these patients. In contrast to other high voltage injuries, burns are mostly not severe due to the short exposure time of patients [29,31]. Table 3 presents which injuries are observed.

Treatment

Given the highly variable clinical presentation of a lightning strike victim, treatment should follow standard trauma guidelines according to Advanced Trauma Life Support (ATLS) [2,34,37,38]. Additionally, it is crucial to present the risks and particularities in the treatment of these patients.

Diagnosis at scene

When diagnosis is unclear, critical clues pointing to lightning injuries are unexplained burns, specific sequelae such as Lichtenberg figures (Fig. 2), singed hair, torn clothes, molten metal, and tympanic membrane ruptures [4,9,14,25,47].

Reverse triage

Apart from immediate cardiac arrest, lightning strike does not usually cause any immediately life-threatening injuries. This suggests that victims who are not in cardiac arrest upon arrival will most likely not die within the next 30–60 min [16,41,43,57]. Initial treatment and resuscitation should therefore be focused on those who appear dead, which is called reverse triage [1,2,9,13–16,21,24,25,27,28,32,33,39,42,43,45–47,56–58].

Initial assessment

Initial assessment can proceed as usual. However, prehospital providers should keep in mind a few important aspects of the prehospital trauma care of a lightning strike patient:

- Every patient should be treated as a polytrauma patient and undergo spinal immobilization at the scene [2,13,31,32,42,45,57].
- Airway management is essential, because primary and secondary hypoxic cardiac arrest is a major cause of death in lightning strike patients. Management can include oral and nasal airway adjuncts, and bag-mask ventilation [1–3,24,30,38,42–44].
- One should always check central pulse due to peripheral vasospasm [2,3,15].
- Hemorrhage control and management of long-bone fractures is mostly not necessary in lightning strike patients, due to the low incidence of blunt injuries [9,12,21,31].
- Dilated and fixed pupils should never be interpreted as a sign of death because of autonomic dysfunction [9,16,24,27,32,36,39,40,42,47,59].
- Presentation of full-thickness burns are rare. However, a prehospital provider should always determine the severity and extent (total body surface area) of burns on a lightning strike patient. Aggressive fluid resuscitation should start immediately for patients with major burns [1,3,4,10–12,15,16,27,28,30,35,37,40,45,48,53].

Hospitalization

All patients should be presented to a hospital to rule out morbidity [16,25,31,32,48,58]. Furthermore, all patients should have an ECG, blood test and urinalysis. One should look specifically for QT prolongation, T-wave inversion and ST alteration. Minimum laboratory examinations should include a complete blood count, myoglobin, electrolytes, blood urea nitrogen, creatinine, creatine phosphokinase, creatine kinase-MB, coagulation panel, troponin and urinalysis, including a test for myoglobin on fresh urine [10,11,15,16,34,37,41,58]. Lightning survivors with normal vital functions (i.e. heart rate, blood pressure and saturation), normal ECG, normal blood tests and normal urinalysis can safely be discharged after 12–24 h [1,36,41,60]. However, patients with high-risk findings should stay for at least 24 h and be closely monitored in either a Medium Care Unit (MCU) or Intensive Care Unit (ICU) [1,3,4,29,35]. High-risk findings are suspected direct strike, loss of consciousness, chest pain, dyspnea, cranial burns, leg burns, burns $>10\%$ of total body surface area (TBSA), persisting neurological damage, and pregnancy. In hospital, treatment should mainly focus on repeated and ongoing assessments, as the physical findings and mental state of lightning strike patients tend to change considerably over the first few hours. Alteration in mental state or new focal neurologic deficit indicates the need to obtain additional imaging studies, like CT. Lab studies that were abnormal upon admission should be repeated. Other laboratories are obtained based upon diagnosis. Hyponatremia may result in brain edema. As lightning strike patients are already at risk of developing cerebral edema, close monitoring of the serum sodium levels and immediate correction of electrolyte abnormalities are therefore necessary. Lightning strike patients with traumatic brain injury may have indications for intracranial pressure monitoring. Furthermore, it is important to monitor fluid status in the severely burned lightning strike patient. Clinical signs of volume status, such as blood pressure, capillary refill, heart rate, color and turgor of the skin should be closely monitored for the first 24 h [1,3,9,10,16,47,54].

Transient injuries

Many victims exhibit transient and benign ECG changes. ST elevation is often not related to stenosis, but rather to transient vasospasm. Invasive therapy should therefore be avoided in young and previously healthy individuals [22,41,61].

Table 3
Clinical characteristics of a lightning victim.

ORGAN SYSTEM	INJURIES	IMPORTANT NOTES
Cardiovascular	Often: Cardiac and respiratory arrest, hypertension, tachycardia, and non-specific ECG changes (QT prolongation, T-wave inversion and ST alteration) [1–3,10,15,30,32,37,38,41]. Rare: Myocardial infarction, necrosis, reduced ejection fractions, and myocardial contusion [2,3,10,15,16,28,32,37,38,42].	- Primary and secondary hypoxic cardiac arrest is a major cause of death and is usually asystole [1–3,24,30,38,42–44]. - Return of spontaneous circulation (ROSC) is rather the rule then the exception, but respiratory arrest outlasts cardiac arrest. This states that apnea is the critical factor in mortality. So artificial respiration must be continued after ROSC [16,30,33,39,40,45–47]. - ECG changes might be delayed for as long as 1 week. Most ECG changes resolve within a few days, but some might persist for months [16,28]. - Self-limited vasospasm can mimic neurologic, cardiac, and gastrointestinal ischemia as well as compartment syndrome [10,48].
Neurologic	1 Immediate and transient: loss of consciousness (75%); amnesia and headache (86%); paraesthesias (67%); muscle weakness (80%), and keraunoparalysis (67%). Keraunoparalysis is a temporary paralysis of the extremities (lower more common than upper) that are blue, mottled, cold, and pulseless [12,29,37,42,44,49,50]. 2 Immediate and prolonged or permanent: hypoxic ischemic injury encephalopathy (HIE), intracranial hemorrhage, post-arrest cerebral infarction, edema, and cerebellar syndromes. Spinal and peripheral nerve injuries are uncommon [13,29,35,37,49]. 3 Delayed: Motor neuron diseases and movement disorders [12,13,27,29,35,37,49]. 4 Trauma from fall or blast: epidural, subdural or subarachnoid haemorrhages [10,12,13,29,37,40].	- 85% of patients present with neurological damage [25,31,35]. - Keraunoparalysis usually lasts for several hours and then resolves [28,30,41,42,50,51]. - Keraunoparalysis can mimic spinal cord injury or compartment syndrome. Diagnostic imaging should be performed if neurologic deficits persist despite resolution of pallor or pulselessness [3,12,40]. - The neuropathological findings in group 2–4 associated with central nervous system (CNS) injuries can be seen on CT or MRI [25,30,52]. - Long-term disability is seen in 70–75% of all patients [10,32,36,37].
Dermatologic	Burns are mostly superficial and only 5–10% are full-thickness burns. Burns are classified as: 1 Linear: occurs when sweat is vaporized as lighting travels over the skin resulting in typically partial thickness burns. 2 Punctiform: shown as clustered circular burns due to current passing out from deep tissue as it exits the body. 3 Thermal: metal or synthetic fabric can be heated and burn the skin.Feathering/Lichtenberg figure (Fig. 2) [1,3,4,10–12,15,16,27,28,30,35,37,40,45,48,53].	- Full-thickness burns present as an entry wound, at the feet as an exit wound (also called "tip-toe sign"), or are caused via molten metal or a ball lightning [10,14,17,22,24,36,40,54]. - Lichtenberg figure is not a burn, but the origin remains unclear. It typically presents after an hour and resolves within 24 h [2,11,22,26,28]. - Be aware of cranial burns, because they are related to a 3–4 times increase in mortality and 2 times increase in suffering a cardiac arrest [2,3,12,16,28,40,45]. Leg burns are also associated with increased mortality rates [12]. - Due to heavy sweat concentrations, burns are more common in skin folds, creases and joints [1,28,48].
Renal	Acute renal failure (ARF) due to rhabdomyolysis/myoglobinuria and muscle breakdown is rare but must be excluded [1,2,11,17,27,34,48,52].	- 3–15% of those suffering major strike injuries develop ARF [4].
Ear	>50% of patients have auditory and/or balancing organ damage with (bilateral) tympanic membrane rupture in >50% as well [1–4,9,10,14,16,22,25,27,29,31,40]. Transient vertigo is the most frequent vestibular symptom [55]. Inner ear damage is more rare, but can cause sensorineural hearing loss [55].	- Always check the tympanic membrane.
Ocular	50% of patients have eye injuries with (bilateral) cataract as most present injury [11,12,14,31,36,40,56].	- Delayed eye injuries are reported between 2 days and 4 years [11,17,38,40].
Fetal	The low number of cases reported and their poor monitoring does not allow the drawing of conclusions [1,3,14,30].	- There are no important notes, because no conclusions can be drawn from the literature regarding fetal injury.
Blunt	Fractures and internal organ damage are rare [9,21,31].	- Persistent hypotension should alert to underlying blunt injuries to the chest, heart, lungs, intestines or spine [10,16,36].

Keraunoparalysis is a frequent but transient effect of lightning (Table 3) [2,12,16,29,36,37,56]. Keraunoparalysis is a temporary paralysis of the extremities (lower more common than upper) that are blue, mottled, cold, and pulseless. Severe vascular damage to the extremities, spinal cord injury, and compartment syndrome should only be considered if the affected extremity exhibits no signs of recovery over time or if intracompartmental tissue pressures are elevated [16,34,41,56].

Neurological assessment

Prompt neurological assessment is essential [1,16,24,25]. All patients should receive repeated neurological examinations since

Table 4
Sequelae of a lightning strike patient.

Category	Sequelae	Timespan	Follow-up
Cardiac	Hypertension, ECG changes, and cardiac arrhythmias. Pacemakers can stop working, so function must be checked [3,9,22,25–27,36].	Days	Patients with arrhythmias or ECG changes should return to the hospital after 1 week to have their ECG alterations and blood pressure checked.
Neuropsychological	Lack of energy, poor concentration, sleep disturbance, emotional liability, pain and irritability, post-traumatic stress disorder (30%), cognitive dysfunction, and depression [9,12,15–17,22,29,37,40,47,62].	Years	Early neuropsychiatric treatment is recommended [12,16,17,22,29,37,40].
Ocular	Cataracts are most common. Other eye injuries can evolve [10,15,36,42].	Days-Years	General practitioner
Other	Endocrine and sexual dysfunction [16]. Children present with more cardiac sequelae and with prolonged severe muscle pain [63]. Sensorineural hearing loss can persist [55].	Unknown	General practitioner

they are at risk of developing cerebral edema several hours after being struck by lightning [10,47,54]. Additionally, this risk indicates that intravenous fluid therapy should only be considered in patients with full-thickness burns, muscle necrosis, and rhabdomyolysis resulting in acute renal failure [16,28,31,32,39,41].

Late inpatient treatment

When a patient is stabilized, otoscopic and ophthalmic examination is required [1,4,12,24,35,40]. The focus should be on assessing tympanic membrane ruptures, hearing loss, and reduced vision [1,35].

Prolonged resuscitation

Given that the majority of lightning strike victims tend to be relatively young and previously healthy, the possibility of successful resuscitation is high even if the interval before the resuscitative attempt is prolonged [9,30–32,38,44,46,59]. Moreover, a substantial amount of the included literature suggests that these patients can benefit from prolonged resuscitation even up to an hour [24,26,27,31,36,42,44,47,51,58].

An evidence-based treatment protocol based on the clinical presentation, risks, and particularities of treating lightning strike patients is presented in Appendix C.

Sequelae

Approximately 75% of all lightning strike victims suffer from permanent disabilities [1,4,10,12,25,27,32,34,37,57]. Table 4 indicates which sequelae can present and whether follow-up is required.

It is crucial to inform lightning strike victims about the possible delayed onset of symptoms and persisting sequelae; this will make patients more aware and result in the earlier diagnosis of comorbidities through general practitioners. The cause–effect relationship between lightning and all subsequent delayed neurological complications is still open to question.

Quality of presented information

All 56 articles were scored using the OCEBM method [48]. With the exception of two articles, all articles were scored as level 5 evidence, which equates to a recommendation score of D.

To provide a more detailed quality score, all of the reviews were scored using the SANRA tool and subjected to statistical analysis [49]. The mean sum score of all reviews ($N = 50$) was 5.8 out of 12 points (SD 1.9, range 2–9, median 6), which indicated that the overall quality of the included reviews was moderate. Furthermore, all guidelines were scored using the AGREE II tool and scores were used for statistical analysis [50]. The mean sum score of all guidelines ($N = 5$) was 28% (SD 15.8, range 9–45), which indicated that the overall quality of the included guidelines was low (see Appendix B).

The overall quality of the reviewed evidence was low to moderate. The lack of a systematic methodology in the included articles was the most critical factor behind this limited score.

Discussion

Evidence-based guidelines regarding lighting strike injuries are limited. By systematically selecting and grading reviews and guidelines, we have presented an up-to-date overview concerning lightning injuries. This clinical review has presented the risks and particularities in treating these patients and emphasized the importance of follow-up as the sequelae of lightning injuries can be delayed. We combined the key points into an evidence-based protocol for the treatment of every lightning strike victim. Burns can be quickly observed and help in the diagnostic process if it is unclear whether a patient has been involved in a lightning strike. The presence of a Lichtenberg figure can be used as a perfect diagnostic tool. Emergency care practitioners must realize that this phenomenon is not an actual burn and should be treated with expectant treatment for at least 24 h. In the absence of a Lichtenberg figure, linear, punctiform, and thermal burns can contribute to the diagnostic process. One should examine the whole patient as deep burns can be small and may be overlooked. Leg and head burns should alarm emergency healthcare professionals and patients should not be discharged too early, as doing so would cause unnecessary risks.

Discussions continue regarding the benefit of prolonged resuscitation for lightning strike patients. A few reviews have mentioned case reports of successful resuscitation attempts, even up to an hour [24,26,31,47]. With ROSC being the rule rather than the exception, and knowing that victims mostly have no cardiac history, this observation is plausible. However, no evidence suggests that emergency care practitioners should deviate from the standard resuscitation guidelines published by the European Resuscitation Council (ERC) or the American Heart Association in case of a lightning injury [64,65].

The limitation of this study is the exclusion of case reports and case series. By only considering reviews and guidelines, this article has tended to cover the majority of all available evidence on lightning injuries published in the last 30 years. However, interesting information on rare injuries could have been missed based on this exclusion. Furthermore, the literature has mentioned that injuries could be underreported by 50% and deaths by 11% when comparing databases of mainly newspaper reports with those of medical and death certificates [12,29]. The underreporting of lightning cases may lead to a bias in the relative incidences of specific injuries. Moreover, the used evidence from almost all of the selected reviews and guidelines was limited due to the lack of a systematic methodology. Because of the low quality of the included evidence, the recommendations in this article should be used with caution when applied in healthcare facilities.

Future research must determine the exact beneficial effect of prolonged resuscitation in lightning strike victims. The incidence of lightning strike patients at a single trauma center is limited to a maximum of one or two patients per year. Thus, assembling a significant amount of data about these patients is challenging. The founding of an international online database with systematic reporting of lightning injuries could establish a more sound treatment protocol as well as aid in understanding the effects of prolonged resuscitation. A more specific and detailed reporting of injuries and treatment will benefit the analysis and evidence quality level regarding these injuries. This may also allow more accurate delineation of the exact correlation between lightning and delayed neurological complications, which to date remains unclear. Last of all, our search strategy focused on literature written in English, Dutch or German. However, lightning strike injuries have a much higher incidence in Asia, Africa and North and South America. Future research should include other (non-European) language publications as a useful source of information as well.

Conclusion

The available reviews and guidelines concerning lightning injuries were graded as low to moderate evidence. Our clinical review regarding lightning injuries aggregated the available evidence published over the past 30 years. Lightning burns can help in the diagnostic process if it is unclear whether a patient has been involved in a lightning strike. Most damage from lightning injuries is cardiovascular and neurological, although an individual can experience complications with any of their vital functions. Therefore, it is vital that every lightning strike patient is treated according to standard trauma guidelines, with a specific focus on the possible sequelae of lighting injuries. All emergency healthcare professionals should acknowledge the risks and particularities of treating lighting strike injuries to optimize the care and outcomes of these patients. Our evidence-based treatment protocol should help prehospital and in-hospital emergency healthcare practitioners to prevent therapeutic mismanagement among these patients.

Source of funding

No funding was received.

Declarations of Competing Interest

None.

Acknowledgments

Not applicable.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.injury.2022.08.024.

References

[1] Jensen JD, Thurman J, Vincent AL. Lightning injuries. statpearls, Treasure Island (FL): StatPearls Publishing LLC; 2021. StatPearls Publishing Copyright © 2021.
[2] Geary SP, Spencer T, Tilney PV. A 26-year-old man struck by lightning. Air Med J 2015;34:8–11.
[3] Davis C, Engeln A, Johnson EL, McIntosh SE, Zafren K, Islas AA, et al. Wilderness medical society practice guidelines for the prevention and treatment of lightning injuries: 2014 update. Wilderness Environ Med 2014;25:S86–95.
[4] Okafor UV. Lightning injuries and acute renal failure: a review. Ren Fail 2005;27:129–34.
[5] Holle RL. A summary of recent national-scale lightning fatality studies. Weather Clim Soc 2016;8:35–42.
[6] Pfortmueller CA, Yikun Y, Haberkern M, Wuest E, Zimmermann H, Exadaktylos AK. Injuries, sequelae, and treatment of lightning-induced injuries: 10 years of experience at a swiss trauma center. Emerg Med Int 2012;2012:167698.
[7] Tolouie M, Farzan R. A six-year study on epidemiology of electrical burns in Northern Iran: is it time to pay attention? World J Plast Surg 2019;8:365–71.
[8] Glatstein MM, Ayalon I, Miller E, Scolnik D. Pediatric electrical burn injuries: experience of a large tertiary care hospital and a review of electrical injury. Pediatr Emerg Care 2013;29:737–40.
[9] Zack F, Rothschild MA, Wegener R. Blitzunfall – Energieübertragungsmechanismen und medizinische Folgen. Dtsch Arztebl Int 2007;104 A-3545.
[10] Whitcomb D, Martinez JA, Daberkow D. Lightning injuries. South Med J 2002;95:1331–4.
[11] Roberts S, Meltzer JA. An evidence-based approach to electrical injuries in children. Pediatr Emerg Med Pract 2013;10:1–16 quiz -7.
[12] Ritenour AE, Morton MJ, McManus JG, Barillo DJ, Cancio LC. Lightning injury: a review. Burns 2008;34:585–94.
[13] Rotariu EL, Manole MD. Cardiac arrest secondary to lightning strike: case report and review of the literature. Pediatr Emerg Care 2020;36:e18–20.
[14] Koumbourlis AC. Electrical injuries. Crit Care Med 2002;30:S424–SS30.
[15] Thomson EM, Howard TM. Lightning injuries in sports and recreation. Curr Sports Med Rep 2013;12:120–4.
[16] O'Keefe Gatewood M, Zane RD. Lightning injuries. Emerg Med Clin N Am 2004;22:369–403.
[17] Blumenthal R. Lightning and the forensic pathologist. Acad Forensic Pathol 2018;8:98–111.
[18] OCEBM Levels of Evidence Working Group*. "The Oxford Levels of Evidence 2". Oxford Centre for Evidence-Based Medicine. http://www.cebm.net/index.aspx?o=5653. * OCEBM Levels of Evidence Working Group = Jeremy Howick, Iain Chalmers (James Lind Library), Paul Glasziou, Trish Greenhalgh, Carl Heneghan, Alessandro Liberati, Ivan Moschetti, Bob Phillips, Hazel Thornton, Olive Goddard and Mary Hodgkinson (2011).
[19] Baethge C, Goldbeck-Wood S, Mertens S. SANRA—A scale for the quality assessment of narrative review articles. Res Integr Peer Rev 2019;4:5. doi:10.1186/s41073-019-0064-8.
[20] AGREE Next Steps Consortium (2017). The AGREE II Instrument [Electronic version]. Retrieved from http://www.agreetrust.org.
[21] Zimmermann C, Cooper MA, Holle RL. Lightning safety guidelines. Ann Emerg Med 2002;39 660-A1.
[22] Schlein SM, Marcolini PG, Marcolini EG. Wilderness neurology. Semin Neurol 2019;39:137–48.
[23] Selvaggi G, Monstrey S, von Heimburg D, Hamdi M, Van Landuyt K, Blondeel P. Ball lightning burn. Ann Plast Surg 2003;50:541–4.
[24] Zafren K, Durrer B, Herry JP, Brugger H. Lightning injuries: prevention and on-site treatment in mountains and remote areas. official guidelines of the International Commission for Mountain Emergency Medicine and the Medical Commission of the International Mountaineering and Climbing Federation (ICAR and UIAA MEDCOM). Resuscitation 2005;65:369–72.
[25] Hinkelbein J, Spelten O, Wetsch WA. [Lightning strikes and lightning injuries in prehospital emergency medicine. relevance, results, and practical implications]. Unfallchirurg 2013;116:74–9.
[26] Christophides T, Khan S, Ahmad M, Fayed H, Bogle R. Cardiac effects of lightning strikes. Arrhythm Electrophysiol Rev 2017;6:114–17.
[27] Mason AD, Crockett RK. When lighting strikes... a case report and review of the literature. Int Pediatr 2000;15:173–8.
[28] Galster K, Hodnick R, Berkeley RP. Lightning strike in pregnancy with fetal injury. Wilderness Environ Med 2016;27:287–90.
[29] Cherington M. Neurologic manifestations of lightning strikes. Neurology 2003;60:182–5.
[30] García Gutiérrez JJ, Meléndez J, Torrero JV, Obregón O, Uceda M, Gabilondo FJ. Lightning injuries in a pregnant woman: a case report and review of the literature. Burns 2005;31:1045–9.
[31] Lederer W, Kroesen G. [Emergency treatment of injuries following lightning and electrical accidents]. Anaesthesist 2005;54:1120–9.
[32] Lederer W, Wiedermann FJ, Cerchiari E, Baubin MA. Electricity-associated injuries II: outdoor management of lightning-induced casualties. Resuscitation 2000;43:89–93.
[33] Fontanarosa PB. Electrical shock and lightning strike. Ann Emerg Med 1993;22:378–87.
[34] DeFranco MJ, Baker CL, DaSilva JJ, Piasecki DP, Bach BR. Environmental issues for team physicians. Am J Sports Med 2008;36:2226–37.
[35] Gruhn KM, Knossalla F, Schwenkreis P, Hamsen U, Schildhauer TA, Tegenthoff M, et al. [Neurological diseases after lightning strike : lightning strikes twice]. Nervenarzt 2016;87:623–8.

[36] Cooray V, Cooray C, Andrews CJ. Lightning caused injuries in humans. J Electrostat 2007;65:386–94.
[37] Forster SA, Silva IM, Ramos ML, Gragnani A, Ferreira LM. Lightning burn–review and case report. Burns 2013;39:e8–12.
[38] Part 8: advanced challenges in resuscitation section 3: special challenges in ECC: 3G: electric shock and lightning strikes. Resuscitation 2000;46:297–9.
[39] Spies C, Trohman RG. Electrocution and life-threatening electrical injuries. Ann Intern Med 2006;145:531–7.
[40] Edlich RF, Farinholt HM, Winters KL, Britt LD, Long WB. Modern concepts of treatment and prevention of lightning injuries. J Long Term Eff Med Implants 2005;15:185–96.
[41] Cooper MA. Emergent care of lightning and electrical injuries. Semin Neurol 1995;15:268–78.
[42] Browne BJ, Gaasch WR. Electrical injuries and lightning. Emerg Med Clin N Am 1992;10:211–29.
[43] Blancher M, Albasini F, Elsensohn F, Zafren K, Hölzl N, McLaughlin K, et al. Management of multi-casualty incidents in mountain rescue: evidence-Based guidelines of the International Commission for Mountain Emergency Medicine (ICAR MEDCOM). High Alt Med Biol 2018;19:131–40.
[44] Graber J, Ummenhofer W, Herion H. Lightning accident with eight victims: case report and brief review of the literature. J Trauma 1996;40:288–90.
[45] Jain S, Bandi V. Electrical and lightning injuries. Crit Care Clin 1999;15:319–31.
[46] Guidelines for cardiopulmonary resuscitation and emergency cardiac care. Emergency cardiac care committee and subcommittees, American Heart Association. Part IV. Special resuscitation situations. JAMA 1992;268:2242–50.
[47] Conrad L. Clinical update on lightning injuries. Wilderness Environ Med 1998;9:217–22.
[48] Gentges J, Schieche C. Electrical injuries in the emergency department: an evidence-based review. Emerg Med Pract 2018;20:1–20.
[49] Cherington M. Central nervous system complications of lightning and electrical injuries. Semin Neurol 1995;15:233–40.
[50] Wilbourn AJ. Peripheral nerve disorders in electrical and lightning injuries. Semin Neurol 1995;15:241–55.
[51] Rescorl D. Environmental emergencies. Crit Care Nurs Clin N Am 1995;7:445–56.
[52] Fish RM. Electric injury, part III: cardiac monitoring indications, the pregnant patient, and lightning. J Emerg Med 2000;18:181–7.
[53] Cohen MA. Clinical pearls: struck by lightning. Cutaneous manifestation of lightning strike ("splash"). Acad Emerg Med 2001;8(893):929–31.
[54] Arnoldo BD, Purdue GF. The diagnosis and management of electrical injuries. Hand Clin 2009;25:469–79.
[55] Modayil PC, Lloyd GW, Mallik A, Bowdler DA. Inner ear damage following electric current and lightning injury: a literature review. Eur Arch Otorhinolaryngol 2014;271:855–61.
[56] Kumar A, Srinivas V, Sahu BP. Keraunoparalysis: what a neurosurgeon should know about it? J Craniovertebr Junction Spine 2012;3:3–6.
[57] Lewis AM. Understanding the principles of lightning injuries. J Emerg Nurs 1997;23:535–41.
[58] Schissler K, Pruden C. Pediatric electrical injuries in the emergency department: an evidence-based review. Pediatr Emerg Med Pract 2021;18:1–24.
[59] Patten BM. Lightning and electrical injuries. Neurol Clin 1992;10:1047–58.
[60] Duane S Pinto P.F.C. Environmental and weapon-related electrical injuries. 2020.
[61] Shaw PK, Brouwer RE, Spaander PJ, Tjandra YI. Nature's high-voltage injuries: sometimes a deadly consequence. Neth J Med 1996;49:153–9.
[62] Primeau M, Engelstatter GH, Bares KK. Behavioral consequences of lightning and electrical injury. Semin Neurol 1995;15:279–85.
[63] Nield LS, Kamat D. Long-term sequelae of lightning strike in a child: a case report and review. Clin Pediatr 2004;43:563–7 (Phila).
[64] Perkins GD, Gräsner JT, Semeraro F, Olasveengen T, Soar J, Lott C, et al. European Resuscitation Council Guidelines 2021: executive summary. Resuscitation 2021;161:1–60.
[65] Merchant RM, Topjian AA, Panchal AR, Cheng A, Aziz K, Berg KM, et al. Part 1: executive summary: 2020 American Heart Association guidelines for cardiopulmonary resuscitation and emergency cardiovascular care. Circulation 2020;142 S337-S57.