THE ROLE OF THUNDERSTORM FOR HUMAN HEALTH

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THE ROLE OF THUNDERSTORM FOR HUMAN HEALTH

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Medical Research in Biblical Times
Examination of Passages from the Bible, Exactly as Written

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I am grateful to my husband for his ideas, wisdom and courage that made this Research possible.

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Severe weather, including tornadoes, thunderstorms, wind, and hail annually cause significant loss of life and property.

In this research, the Biblical verses dealing with the thunderstorms are described. Therefore, the research deals with the characteristics of thunder, the lightening effect, health effects of thunder and lightning, and coping with these negative nature effects.

This research indicates that the thunderstorms, including the lightening manifestations, has accompanied humans during the long years of our existence. With years, the scientific study validated the numerous negative effects associated with the thunderstorm that can help to cope with this nature disaster in human life.

CONTENTS

INTRODUCTION

McGovern & al. (1) mentioned that severe weather, including tornadoes, thunderstorms, wind, and hail annually cause significant loss of life and property. The Authors are developing spatiotemporal machine learning techniques that will enable meteorologists to improve the prediction of these events by improving their understanding of the fundamental causes of the phenomena and by building skillful empirical predictive models. In this paper, significant enhancements of the Spatiotemporal Relational Probability Trees enable autonomous discovery of spatiotemporal relationships as well as learning with arbitrary shapes. The evaluation was focused on two real-world case studies using the technique: predicting tornadoes in Oklahoma and predicting aircraft turbulence in the United States. It was also discussed how to evaluate success for a machine learning algorithm in the severe weather domain, which will enable new methods such as ours to transfer from research to operations, provide a set of lessons learned for embedded machine learning applications, and discuss how to field our technique **(1)**.

According to **Harlfinger (2)**, the most important studies on weather-related pain have been analyzed and their results compared. Since different medicometeorological classifications were used, and individual reactions to the weather vary considerably, it is possible to recognize unequivocal, universally valid relationships only with difficulty. Rheumatic pain arises mainly in a cold front area, in unstable polar air, and in thunderstorms. Amputation- and scar-related pain is similarly dependent upon changes in the weather. Headaches and migraine are typical signs of an imminent change in the weather. The question as to whether or not the endorphin concentration is of significance for meteorogenic pain is discussed, and possible influences of atmospherics activity noted **(2)**.

According to **Hatemi & McDermott (3)**, previous work proposes that dispositional fear exists predominantly among political conservatives, generating the appearance that fears align strictly along party lines. This view obscures evolutionary dynamics because fear evolved to protect against myriad threats, not merely those in the political realm. It is suggested that prior work in this area has been biased by selection on the dependent variable, resulting from an examination of exclusively politically oriented fears that privilege conservative values. Because the adaptation regulating fear should be based upon both universal and ancestral-specific selection pressures combined with developmental and individual differences, the elicitation of it should prove variable across the ideological continuum dependent upon specific combinations of fear and value domains. In a sample of ~ 1,600 Australians assessed with a subset of the Fear Survey Schedule II, the Authors find fears not infused with political content are differentially influential across the political spectrum. Specifically, those who are more fearful of sharp objects, graveyards, and urinating in public are more socially conservative and less supportive of gay rights. Those who are more fearful of death are more supportive of gay rights. Those who are more fearful of

suffocating and swimming alone are more concerned about emissions controls and immigration, while those who are more fearful of thunderstorms are also more anti-immigration. Contrary to existing research, both liberals and conservatives are more fearful of different circumstances, and the role of dispositional fears are attitude-specific **(3)**.

Cherington (4) mentioned that it is a little-known fact that lightning casualties often involve travel or transportation. López and colleagues, in their studies on the epidemiology of lightning injuries, have reported that 10% of lightning injuries are categorized under transportation. In the majority of their cases, victims were struck while standing outside or near their vehicles during a thunderstorm. During the review of the neurologic complications of lightning injuries, the Author was impressed by the number of case reports in which the victim was struck while either in or near a vehicle, airplane or vessel. In this article, forth information was put on four aspects of lightning that relate to the danger to people traveling in vehicles, boats, and airplanes. First, the Author shall deal with lightning safety on ships and boats. People who enjoy recreational sailing, including the "weekend sailor" and those who enjoy fishing from a boat, should be fortified with knowledge about lightning protection. Second, the Author shall consider the matter of lightning strikes to aircraft. In the third section, the question of lightning safety is discussed in automobiles. Fourth, the Author shall review those cases found in my literature review in which the victim was struck while in or near a vehicle, boat, or airplane **(4)**.

Thus, severe weather, including tornadoes, thunderstorms, wind, and hail annually cause significant loss of life and property.

In this research the Biblical verses dealing with the thunderstorms are described. Therefore, the research deals with the characteristics of thunder, the lightening effect, health effects of thunder and lightning, and coping with these negative nature effects.

References

1. McGovern A, Gagne 2nd DJ, Williams JK, et al. Enhancing understanding and improving prediction of severe weather through spatiotemporal relational learning. Mach Learn. 2014;95(1):27-50.

2. Harlfinger O. Weather-induced effects on pain perception. Fortschr Med. 1991;109(32):647-50.

3. Hatemi PK, McDermott R. Dispositional fear and political attitudes. Hum Nat. 2020;31(4):387-405.

4. Cherington M. Lightning and transportation. Semin Neurol. 1995; 15(4):362-6.

BIBLICAL VERSES

Among the numerous verses, these were chosen as the most appropriate:

"*When he made a decree for the rain, and a way for the lightning of the thunder*" **(Job 28:26).**

"W*ho hath divided a watercourse for the overflowing of waters, or a way for the lightning of thunder*" **(Job 38:25)**.

"*..and the Lord sent thunder and hail,…*" **(Exodus 9:23).**

" **..***there were thunders and lightnings, a thick cloud upon the mountain…***(Exodus 19:16).**

"**…***out of heaven shall he thunder upon them***…" (1 Sam 2:10).**

"**..** *but the LORD thundered with a great thunder on that day upon the Philistines…***" (1 Sam 7:10).**

"**..** *and he shall send thunder and rain.***." (1 Sam 12:17).**

"*The Lord thundered from the heavens..*" **(2 Sam 22:14).**

" *After it a voice roareth; he thundereth with the voce of his excellency…***" (Job 37:4).**

" *at the voice of thy thunder they hasted away*" **(Psalm 104:7).**

"**…***He makes lightning with rain….* " **(Jeremiah 10:13) .**

"*And the living creatures ran and returned as the appearance of flash of lightening* " **(Ezekiel 1:14).**

DESCRIPTION

Thunder is the sound caused by lightning **(1-3)**. Depending upon the distance from and nature of the lightning, it can range from a long, low rumble to a sudden, loud crack. The sudden increase in temperature and hence pressure caused by the lightning produces rapid expansion of the air in the path of a lightning bolt. In turn, this expansion of air creates a sonic shock wave, often referred to as a "thunderclap" or "peal of thunder". The study of thunder is known as brontology **(4)**.

References

1. Severe Weather 101: Lightning Basics. Available at www.nssl.noaa.gov/education//svrwx101/lightning/faq/.

2. Thunder Facts. Available at www.factsjustforkids.com/weather-facts/thunder- facts-for-kids/.

3. The Sound of Thunder. Available at www.weather.gov/jetstream

4. Thunder. Available at en.wikipedia.org/wiki/Thunder.

ETYMOLOGY

The d in Modern English thunder (from earlier Old English þunor) is epenthetic, and is now found as well in Modern Dutch donder (cf. Middle Dutch donre; also Old Norse þorr, Old Frisian þuner, Old High German donar, all ultimately descended from Proto-Germanic *þunraz). In Latin the term was tonare" to thunder". The name of the Nordic god Thor comes from the Old Norse word for thunder **(1)**.

The shared Proto-Indo-European root is *tón-r̥ or *tar-, also found in Gaulish Taranis **(2)**.

References

1. thunder. Oxford English Dictionary (2 ed.). Oxford, England: Oxford University Press. 1989.

2. Matasovic, Ranko. Etymological Dictionary of Proto Celtic. Leiden, The Netherlands: Brill. 2009. p. 384. ISBN978-90-04-17336-1.

CAUSE

The cause of thunder has been the subject of centuries of speculation and scientific inquiry **(1)**. Early thinking was that it was made by deities, but the ancient Greek philosophers attributed it to natural causes, such as wind striking clouds (Anaximander, Aristotle) and movement of air within clouds (Democritus) **(2)**. The Roman philosopher Lucretius held it was from the sound of hail colliding within clouds **(2)**.

In the mid-19th century, the accepted theory was that lightning produced a vacuum and that the collapse of that vacuum produced what is known as thunder **(1)**.

In the 20th century a consensus evolved that thunder must begin with a shock wave in the air due to the sudden thermal expansion of the plasma in the lightning channel **(2,3)**. The temperature inside the lightning channel, measured by spectral analysis, varies during its 50 µs existence, rising sharply from an initial temperature of about 20,000 K to about 30,000 K, then dropping away gradually to about 10,000 K. The average is about 20,400 K (20,100 °C; 36,300 °F) **(4)**. This heating causes a rapid outward expansion, impacting the surrounding cooler air at a speed faster than sound would otherwise travel. The resultant outward-moving pulse is a shock wave **(5)**, similar in principle to the shock wave formed by an explosion, or at the front of a supersonic aircraft. In close proximity to the source, the sound pressure level of thunder is usually 165–180dB, but can exceed 200 dB in some cases **(6)**.

Experimental studies of simulated lightning have produced results largely consistent with this model, though there is continued debate about the precise physical mechanisms of the process **(3,7)**. Other causes have also been proposed, relying on electrodynamic effects of the enormous current acting on the plasma in the bolt of lightning **(8)**.

References

1. Vavrek RJ, Kithil R, Holle RL, Allsopp J, & Cooper MA. (n.d.). The science of thunder. Available at lightningsafety.com/nlsi_info/thunder2.html.

2. Heidorn KC. Thunder: Voice of the heavens. 1999. Available at www.islandnet.com/~see/weather/elements/thunder1.htm.

3. Rakov Vladimir A, Uman Martin A. Lightning: Physics and Effects. Cambridge, England: Cambridge University Press. 2007, p. 378. ISBN 978-0-521-03541-5.

4. Cooray Vernon. The lightning flash. London: Institution of Electrical Engineers. 2003, pp. 163–164. ISBN 978-0-85296-780-5. Available at archive.org/details/lightningflashpo00/ w1808e0l.htm.

5. Thunder. Encyclopædia Britannica. Available at web.archive.org/web/20080607020659/http://www.britannica.com/EBchecked/topic/ 594339/thunder.

6. Ultimate Sound Pressure Level Decibel Table. Available at makeitlouder.com/Decibel%20Level%20 Chart.txt.

7. MacGorman, Donald R, Rust W David. The Electrical Nature of Storms. Oxford University Press. 1998, pp. 102–104. ISBN 978-0195073379. Available at web.archive.org/web/20140628073642/ http://books.google.com/books?id=_ NbHNj7KJecC.

8. Graneau P. The cause of thunder. J Phys D: Appl. Phys. 1989;22 (8):1083–1094. Bibcode:1989JPhD...22.1083G. doi:10.1088/0022-3727/22/8/012.

TYPES

Vavrek et al. (n.d.) reported that the sounds of thunder fall into categories based on loudness, duration, and pitch **(1)**. Claps are loud sounds lasting 0.2 to 2 seconds and containing higher pitches. Peals are sounds changing in loudness and pitch. Rolls are irregular mixtures of loudness and pitches. Rumbles are less loud, last for longer (up to more than 30 seconds), and of low pitch **(2)**.

Inversion thunder results when lightning strikes between cloud and ground occur during a temperature inversion; the resulting thunder sounds have significantly greater acoustic energy than from the same distance in a non-inversion condition. In an inversion, the air near the ground is cooler than the higher air; inversions often occur when warm moist air passes above a cold front. Within a temperature inversion, the sound energy is prevented from dispersing vertically as it would in a non-inversion and is thus concentrated in the near-ground layer **(3)**.

References

1. Vavrek RJ, Kithil R, Holle RL, Allsopp J, & Cooper MA. (n.d.). The science of thunder. Available at lightningsafety.com/nlsi_info/thunder2.html.

2. Thunder. Available at en.wikipedia.org/wiki/Thunder.

3. Pollet DA, Micheal M. Kordich MA. User's guide for the Sound Intensity Prediction System (SIPS) as installed at the Naval Explosive Ordnance Disposal Technology Division (Naveodtechdiv). Systems Department February 2000. dtic.mil. 2013. Available at web.archive.org/web/20130408130804/http://www.dtic.mil/CGI-bin/GetTRDoc?Location=U2&doc=GetTRDoc.pdf&AD= ADA477220.

CHARACTERISTICS

Joshi & al. (1) mentioned that human-to-human transmission of the Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) occurs most often when people are in the incubation stage of the disease or are carriers and have no symptoms. SARS-CoV-2 transmission on different levels showed that the cold and dry climate, hot wind and relative humid wind, maximum wind speed, turbulent wind, intensified recirculating flow were causing transmission higher than factors. The role of environmental factors described in Ayurveda like air, water, soil, season, frequent earthquakes, sunlight exposure, frequent thunderstorm with lightening, and factors from arthropods were revalidated in perspective of COVID-19 transmission. The Authors searched the information regarding epidemic diseases in Ayurveda textbooks. Pubmed, Science Direct, Wikipedia, Elsevier, Lancet, and Springer were approached for the latest knowledge relating to SARS-CoV-2 and COVID-19. Google Scholar search engine was thoroughly checked upon for scientific evidence regarding the Ayurveda drugs. Various environmental factors like soil, air, water, frequent earthquake disasters, wildlife animals, aquatic birds, space, inevitable disastrous factors, weather or seasonal hazards, violent thunderstorm with lightning, intermediate hosts, sunlight exposure etc. were considered for their role in the genesis of the disease. The Ayurvedic concepts behind the etiology and development of epidemics are the same as modern epidemiological theories. The mysteries of many aspects of the current pandemic might be deciphered by traditional medicine knowledge and thus adding upon to the integrative medicine concept **(1)**.

Tippett & al. (2) emphasized that tornadoes and severe thunderstorms kill people and damage property every year. Estimated U.S. insured losses due to severe thunderstorms in the first half of 2016 were $8.5 billion (US). The largest U.S. effects of tornadoes result from tornado outbreaks, which are sequences of tornadoes that occur in close succession. Here, using extreme value analysis, it was found that the frequency of U.S. outbreaks with many tornadoes is increasing and that it is increasing faster for more extreme outbreaks. This behavior was modeled by extreme value distributions with parameters that are linear functions of time or of

some indicators of multidecadal climatic variability. Extreme meteorological environments associated with severe thunderstorms show consistent upward trends, but the trends do not resemble those currently expected to result from global warming **(2)**.

Peterson & al. (3) emphasized that the organization and structure of thunderstorms determines the extent and severity of their hazards to the general public and their consequences for the Earth system. Distinguishing vigorous convective regions that produce heavy rain and hail from adjacent regions of stratiform or overhanging anvil clouds that produce light-to-no rainfall is valuable in operations and physical research. Cloud type algorithms that partition convection from stratiform regions have been developed for space-based radar, passive microwave, and now Geostationary Operational Environmental Satellites (GOES) Advanced Baseline Imager (ABI) multi-spectral products. However, there are limitations for each of these products including temporal availability, spatial coverage, and the degree to which they based on cloud microphysics. A cloud type algorithm was developed for GOES Geostationary Lightning Mapper (GLM) observations that identifies convective/non-convective regions in thunderstorms based on signatures of interactions with non-convective charge structures in the lightning flash data. The GLM sensor permits a rapid (20-s) update cycle over the combined GOES-16/GOES-17 domain across all hours of the day. Storm regions that do not produce lightning will not be classified by the algorithm, however. The GLM cloud type product is intended to provide situational awareness of electrified anvils and to complement other cloud type retrievals by providing a contemporary assessment tied to lightning physics. A future combined ABI / GLM cloud type algorithm would be a valuable product that could draw from the strengths of each instrument and approach **(3)**.

Winckler (4) dealt with a luminous electric discharge that forms in the mesospheric region between thundercloud tops and the ionosphere at 90-km altitude. These cloud-ionosphere discharges (CIs), following visual reports dating back to the 19th century, were finally imaged by a low-light TV camera as part of the "SKYFLASH" program at the University of Minnesota in 1989. Many observations were made by various groups in the period 1993-1996. The characteristics of CIs are that they have a wide range of sizes from a few kilometers up to 50 km horizontally; they extend from 40 km to nearly 90 km vertically, with an intense region near 60-70 km and streamers extending down toward cloud tops; the CIs are partly or entirely composed of vertical luminous filaments of kilometer size. The predominate color is red. The TV images show that the CIs usually have a duration less than one TV field (16.7 ms), but higher-speed photometric measurements show that they last about 3 ms and are delayed 3 ms after an initiating cloud-ground lightning stroke; 95% of these initiating strokes are found to be "positive"- i.e., carry positive charges from clouds to ground. The preference for positive initiating strokes is not understood. Theories of the formation of CIs are briefly reviewed **(4)**.

Gurevich & al. (5) reported here for the first time about the registration of an extraordinary high flux of low-energy neutrons generated during thunderstorms. The measured neutron count rate enhancements are directly connected with thunderstorm discharges. The low-energy neutron flux value obtained in the work is a challenge for the photonuclear channel of neutron generation in thunderstorm: the estimated value of the needed high-energy γ-ray flux is about 3 orders of magnitude higher than that one observed **(5)**.

Houtkooper & al. (6) mentioned that Sferics are electromagnetic impulses generated by electrical discharges during thunderstorms (lightning). One category is comprised of very low frequency electromagnetic waves, traveling over distances up to a thousand kilometers. Sferics have been shown to affect biological responses such as pain syndromes, reaction times, and power in the alpha band of the EEG. In the present study, in which 100 subjects took part, sferics have been studied in their relation to performance on a forced-choice extrasensory perception (ESP) task and to several secondary variables. The general finding is a negative correlation between ESP performance and sferics activity around the time of the session, most notably 24-48 hours prior to the session. Secondary variables appear to modulate this correlation, as has been found in previous research on sferics: the correlation tended to be stronger for persons who scored lower on Neuroticism and higher on the Openness scale of a Five-Factor Personality Questionnaire **(6)**.

Østgaard al. (7) emphasized that in the spring of 2017 an ER-2 aircraft campaign was undertaken over continental United States to observe energetic radiation from thunderstorms and lightning. The payload consisted of a suite of instruments designed to detect optical signals, electric fields, and gamma rays from lightning. Starting from Georgia, USA, 16 flights were performed, for a total of about 70 flight hours at a cruise altitude of 20 km. Of these, 45 flight hours were over thunderstorm regions. An analysis of two gamma ray glow events that were observed over Colorado at 21:47 UT on 8 May 2017 is presented. The charge structure of the cloud system, as well as possible mechanisms that can produce the gamma ray glows were explored. The thundercloud system was passed during the gamma ray glow observation had strong convection in the core of the cloud system. Electric field measurements combined with radar and radio measurements suggest an inverted charge structure, with an upper negative charge layer and a lower positive charge layer. Based on modeling results, the production mechanism was not unambiguously determined. Possible mechanisms are either an enhancement of cosmic background locally (above or below 20 km) by an electric field below the local threshold or an enhancement of the cosmic background inside the cloud but then with normal polarity and an electric field well above the Relativistic Runaway Electron Avalanche threshold **(7)**.

Wada & al. (8) reported that during a winter thunderstorm on 24 November 2017, a strong burst of gamma rays with energies up to ∼10 MeV was detected coincident with a lightning discharge, by scintillation detectors installed at the Kashiwazaki-Kariwa Nuclear

Power Station at sea level in Japan. The burst had a subsecond duration, which is suggestive of photoneutron production. The leading part of the burst was resolved into four intense gamma-ray bunches, each coincident with a low-frequency radio pulse. These bunches were separated by 0.7-1.5 ms, with a duration of ≪1 ms each. Thus, the present burst may be considered as a "downward" terrestrial gamma-ray flash (TGF), which is analogous to upgoing TGFs observed from space. Although the scintillation detectors were heavily saturated by these bunches, the total dose associated with them was successfully measured by ionization chambers, employed by nine monitoring posts surrounding the power plant. From this information and Monte Carlo simulations, the present downward TGF is suggested to have taken place at an altitude of 2500±500 m, involving 8_{-4}^{+8}×10^{18} avalanche electrons with energies above 1 MeV. This number is comparable to those in upgoing TGFs **(8)**.

Ringuette & al. (9) mentioned that terrestrial gamma-ray flashes (TGFs) - very short, intense bursts of electrons, positrons, and energetic photons originating from terrestrial thunderstorms have been detected with satellite instruments. TGF and Energetic Thunderstorm Rooftop Array (TETRA), an array of NaI (Tl) scintillators at Louisiana State University, has been used to detect similar bursts of 50 keV to over 2 MeV gamma-rays at ground level. After 2.6 years of observation, 24 events with durations 0.02-4.2 ms have been detected associated with nearby lightning, three of them coincident events observed by detectors separated by ∼1000 m. Nine of the events occurred within 6 ms and 5 km of negative polarity cloud-to-ground lightning strokes with measured currents in excess of 20 kA. The events reported here constitute the first catalog of TGFs observed at ground level in close proximity to the acceleration site **(9)**.

Su & al. (10) mentioned that transient luminous events in the atmosphere, such as lighting-induced sprites and upwardly discharging blue jets, were discovered recently in the region between thunderclouds and the ionosphere. In the conventional picture, the main components of Earth's global electric circuit include thunderstorms, the conducting ionosphere, the downward fair-weather currents, and the conducting Earth. Thunderstorms serve as one of the generators that drive current upward from cloud tops to the ionosphere, where the electric potential is hundreds of kilovolts higher than Earth's surface. It has not been clear, however, whether all the important components of the global circuit have even been identified. Here, the Authors reported observations of five gigantic jets that establish a direct link between a thundercloud (altitude approximately 16 km) and the ionosphere at 90 km elevation. Extremely-low-frequency radio waves in four events were detected, while no cloud-to-ground lightning was observed to trigger these events. The result indicates that the extremely-low-frequency waves were generated by negative cloud-to-ionosphere discharges, which would reduce the electrical potential between ionosphere and ground. Therefore, the conventional picture of the global electric

circuit needs to be modified to include the contributions of gigantic jets and possibly sprites **(10)**.

Pasko & al. (11) noticed that for over a century, numerous undocumented reports have appeared about unusual large-scale luminous phenomena above thunderclouds and, more than 80 years ago, it was suggested that an electrical discharge could bridge the gap between a thundercloud and the upper atmosphere. Since then, two classes of vertically extensive optical flashes above thunderclouds have been identified sprites and blue jets. Sprites initiate near the base of the ionosphere, develop very rapidly downwards at speeds which can exceed 107 m s-1 (ref. 15), and assume many different geometrical forms. In contrast, blue jets develop upwards from cloud tops at speeds of the order of 105 m s-1 and are characterized by a blue conical shape. But no experimental data related to sprites or blue jets have been reported which conclusively indicate that they establish a direct path of electrical contact between a thundercloud and the lower ionosphere. Here a video recording of a blue jet propagating upwards is reported from a thundercloud to an altitude of about 70 km, taken at the Arecibo Observatory, Puerto Rico. Above an altitude of 42 km-normally the upper limit for blue jets and the lower terminal altitude for sprites-the flash exhibited some features normally observed in sprites. As this phenomenon was observed above a relatively small thunderstorm cell, it was speculated that it may be common and therefore represent an unaccounted for component of the global electric circuit **(11)**.

Boggs & al. (12) emphasized that gigantic jets are atmospheric electrical discharges that propagate from the top of thunderclouds to the lower ionosphere. They begin as lightning leaders inside the thundercloud, and the thundercloud charge structure primarily determines if the leader is able to escape upward and form a gigantic jet. No observationally verified studies have been reported on the thundercloud charge structures of the parent storms of gigantic jets. Here meteorological observations and lightning simulation results are presented to identify a probable thundercloud charge structure of those storms. The charge structure features a narrow upper charge region that forms near the end of an intense convective pulse. The convective pulse produces strong storm top divergence and turbulence, as indicated by large values of storm top radial velocity differentials and spectrum width. The simulations show the charge structure produces leader trees closely matching observations. This charge structure may occur at brief intervals during a thunderstorm's evolution due to the brief nature of convective pulses, which may explain the rarity of gigantic jets compared to other forms of atmospheric electrical discharges **(12)**.

Enoto & al. (13) mentioned that lightning and thunderclouds are natural particle accelerators. Avalanches of relativistic runaway electrons, which develop in electric fields within thunderclouds, emit bremsstrahlung γ-rays. These γ-rays have been detected by ground-based observatories, by airborne detectors and as terrestrial γ-ray flashes from space. The energy of the γ-rays is sufficiently high that

they can trigger atmospheric photonuclear reactions that produce neutrons and eventually positrons via β^+ decay of the unstable radioactive isotopes, most notably ^{13}N, which is generated via $^{14}N + \gamma \rightarrow {}^{13}N + n$, where γ denotes a photon and n a neutron. However, this reaction has hitherto not been observed conclusively, despite increasing observational evidence of neutrons and positrons that are presumably derived from such reactions. Here ground-based observations of neutron and positron signals after lightning are reported. During a thunderstorm on 6 February 2017 in Japan, a γ-ray flash with a duration of less than one millisecond was detected at the monitoring sites 0.5-1.7 kilometers away from the lightning. The subsequent γ-ray afterglow subsided quickly, with an exponential decay constant of 40-60 milliseconds, and was followed by prolonged line emission at about 0.511 megaelectronvolts, which lasted for a minute. The observed decay timescale and spectral cutoff at about 10 megaelectronvolts of the γ-ray afterglow are well explained by de-excitation γ-rays from nuclei excited by neutron capture. The center energy of the prolonged line emission corresponds to electron-positron annihilation, providing conclusive evidence of positrons being produced after the lightning **(13)**.

Peterson & al. (14) reported that intense heating by wildfires can generate deep, smoke-infused thunderstorms, known as pyrocumulonimbus (pyroCb), which can release a large quantity of smoke particles above jet aircraft cruising altitudes. Injections of pyroCb smoke into the lower stratosphere have gained increasing attention over the past 15 years due to the rapid proliferation of satellite remote sensing tools. Impacts from volcanic eruptions and other troposphere-to-stratosphere exchange processes on stratospheric radiative and chemical equilibrium are well recognized and monitored. However, the role of pyroCb smoke in the climate system has yet to be acknowledged. Here, the mass of smoke aerosol particles injected into the lower stratosphere from five near-simultaneous intense pyroCbs occurring in western North America on 12 August 2017 was comparable to that of a moderate volcanic eruption, and an order of magnitude larger than previous benchmarks for extreme pyroCb activity. The resulting stratospheric plume encircled the Northern Hemisphere over several months. By characterizing this event, it is concluded that pyroCb activity, considered as either large singular events, or a full fire season inventory, significantly perturb the lower stratosphere in a manner comparable with infrequent volcanic intrusions **(14)**.

Franz & al. (15) mentioned that an image of an unusual luminous electrical discharge over a thunderstorm 250 kilometers from the observing site has been obtained with a low-light-level television camera. The discharge began at the cloud tops at 14 kilometers and extended into the clear air 20 kilometers higher. The image, which had a duration of less than 30 milliseconds, resembled two jets or fountains and was probably caused by two localized electric charge concentrations at the cloud tops. Large upward discharges may create a hazard for aircraft and rocket launches and, by penetrating into the ionosphere, may initiate whistler waves and other effects on

a magnetospheric scale. Such upward electrical discharges may account for unexplained photometric observations of distant lightning events that showed a low-rise rate of the luminous pulse and no electromagnetic sferic pulse of the type that accompanies cloud-to-earth lightning strokes. An unusually high rate of such photometric events was recorded during the night of 22 to 23 September 1989 during a storm associated with hurricane **(15).**

Peterson & al. (16) emphasized that optical lightning observations from space reveal a wide range of flash structure. Lightning imagers such as the Geostationary Lightning Mapper and Lightning Imaging Sensor measure flash appearance by recording transient changes in cloud top illumination. The spatial and temporal optical energy distributions reported by these instruments depend on the physical structure of the flash and the distribution of hydrometeors within the thundercloud that scatter and absorb the optical emissions. This study explores how flash appearance changes according to the scale and organization of the parent thunderstorms with a focus on mesoscale convective systems. Clouds near the storm edge are frequently illuminated by large optical flashes that remain stationary between groups. These flashes appear large because their emissions can reflect off the exposed surfaces of nearby clouds to reach the satellite. Large stationary flashes also occur in small, isolated thunderstorms. Optical flashes that propagate horizontally, meanwhile, are most frequently observed in electrified stratiform regions where extensive layered charge structures promote lateral development. Highly radiant "superbolts" occur in two scenarios: embedded within raining stratiform regions or in nonraining boundary/anvil clouds where optical emissions can take a relatively clear path to the satellite **(16)**.

Peterson (17) mentioned that the optical energy emitted by lightning flashes interacts with the surrounding cloud medium through scattering and absorption. The optical signals recorded by space-based lightning imagers describe a convolution of lightning flash energetics and radiative transfer effects in the intervening cloud layer. A thundercloud imaging technique is presented that characterizes cloud regions based on how they are illuminated by lightning. This technique models the spatial distribution of optical energy in radiant lightning pulses to determine whether and to what extent each illuminated cloud pixel behaves like a homogeneous planar cloud layer. A gridded product is constructed that differentiates flashes that illuminate convective cells from stratiform flashes with long horizontal channels and anvil flashes whose optical emissions reflect off of nearby cloud surfaces. Producing this imagery with a rolling 15-min window allows us to visualize changes in connection with a rapid (20 s) update cycle **(17)**.

Dowdy & Catto (18) mentioned that phenomena such as cyclones, fronts and thunderstorms can cause extreme weather in various regions throughout the world. Although these phenomena have been examined in numerous studies, they have not all been systematically examined in combination with each other, including in relation to extreme precipitation and extreme winds throughout the

world. Consequently, the combined influence of these phenomena represents a substantial gap in the current understanding of the causes of extreme weather events. Here, a systematic analysis of cyclones, fronts, and thunderstorms in combination with each other is presented, as represented by seven different types of storm combinations. The results highlight the storm combinations that most frequently cause extreme weather in various regions of the world. The highest risk of extreme precipitation and extreme wind speeds is found to be associated with a triple storm type characterized by concurrent cyclone, front, and thunderstorm occurrences. The findings reveal new insight on the relationships between cyclones, fronts and thunderstorms and clearly demonstrate the importance of concurrent phenomena in causing extreme weather **(18)**.

Boyd (19) emphasized that general aviation (comprised mainly of noncommercial, light aircraft) accounts for 94% of civil aviation fatalities in the United States. Although thunderstorms are hazardous to light aircraft, little research has been undertaken on in-flight pilot decision-making regarding their avoidance. The study objectives were: 1] to determine if the thunderstorm accident rate has declined over the last two decades; and 2] assess in-flight (enroute/landing) airman decision-making regarding adherence to FAA separation minima from thunderstorms. Thunderstorm-related accidents were identified from the NTSB database. To determine en route/arriving aircraft real-time thunderstorm proximity/relative position and airplane location, using a flight-tracking (Flight Aware®) website, were overlaid on a graphical weather image. Statistics employed Poisson and Chi-squared analyses. The thunderstorm-related accident rate was undiminished over the 1996-2014 period. In a prospective analysis the majority (enroute 77%, landing 93%) of flights violated the FAA-recommended separation distance from extreme convection. Of these, 79 and 69% (en route and landing, respectively) selected a route downwind of the thunderstorm rather than a less hazardous upwind flight path. Using a mathematical product of binary (separation distance, relative aircraft-thunderstorm position) and nominal (thunderstorm-free egress area) parameters, airmen were more likely to operate in the thunderstorm hazard zone for landings than en route operations. The thunderstorm-related accident rate, carrying a 70% fatality rate, remains unabated, largely reflecting nonadherence to the FAA-recommended separation minima and selection of a more hazardous route (downwind) for circumnavigation of extreme convective weather. These findings argue for additional emphasis in ab initio pilot training/recurrency on thunderstorm hazards and safe practices (separation distance and flight path). Boyd DD. In-flight decision-making by general aviation pilots operating in areas of extreme thunderstorms **(19)**.

Kelley & al. (20) mentioned that gamma-ray 'glows' are long duration (seconds to tens of minutes) X-ray and gamma-ray emission coming from thunderclouds. Measurements suggest the presence of relativistic runaway electron avalanches (RREA), the same process underlying terrestrial gamma-ray flashes. Here, it was demonstrated

that glows are relatively a common phenomenon near the tops of thunderstorms, when compared with events such as terrestrial gamma-ray flashes. Examining the strongest glow measured by the airborne detector for energetic emissions, it was shown that this glow is measured near the end of a downward RREA, consistent with occurring between the upper positive charge layer and the negative screening layer above it. The glow discharges the upper positive layer by ≥9.6 mA, strong enough to be an important charging mechanism of the storm. For this glow, the gamma-ray flux observed is close to the value at which relativistic feedback processes become important, with an avalanche multiplication factor of 4,500 **(20)**.

Tilles & al. (21) emphasized that thunderstorms are natural laboratories for studying electrical discharges in air, where the vast temporal, spatial, and energy scales available can spawn surprising phenomena that reveal deficiencies in the understanding of dielectric breakdown. Recent discoveries, such as sprites, jets, terrestrial gamma ray flashes, and fast positive breakdown, highlight the diversity of complex phenomena that thunderstorms can produce, and point to the possibility for electrical breakdown/discharge mechanisms beyond dielectric breakdown theory based mainly on laboratory experiments. Here, the Authors present one such confounding discovery, termed fast negative breakdown, that does not fit with the current understanding of dielectric breakdown. The adaptation of radio astronomy imaging techniques to study extremely transient lightning-associated events confirms that electrical breakdown in thunderstorms can begin with oppositely directed fast breakdown of negative polarity, similar and in addition to fast positive breakdown expected from conventional dielectric theory and recent observations. The discovery of fast negative breakdown calls for an addendum to the physical description of electrical discharges in air **(21)**.

Diffenbaugh & al. (22) noticed that although severe thunderstorms are one of the primary causes of catastrophic loss in the United States, their response to elevated greenhouse forcing has remained a prominent source of uncertainty for climate change impacts assessment. The Coupled Model Intercomparison Project, Phase 5, global climate model ensemble indicates robust increases in the occurrence of severe thunderstorm environments over the eastern United States in response to further global warming. For spring and autumn, these robust increases emerge before mean global warming of 2 °C above the preindustrial baseline. Days with high convective available potential energy (CAPE) and strong low-level wind shear increase in occurrence, suggesting an increasing likelihood of atmospheric conditions that contribute to the most severe events, including tornadoes. In contrast, whereas expected decreases in mean wind shear have been used to argue for a negative influence of global warming on severe thunderstorms, it was found that decreases in shear are in fact concentrated in days with low CAPE and therefore do not decrease the total occurrence of severe environments. Further, the shift toward high CAPE is most concentrated in days with low convective inhibition, increasing the

occurrence of high-CAPE/low-convective inhibition days. The fact that the projected increases in severe environments are robust across a suite of climate models, emerge in response to relatively moderate global warming, and result from robust physical changes suggests that continued increases in greenhouse forcing are likely to increase severe thunderstorm occurrence, thereby increasing the risk of thunderstorm-related damage **(22)**.

Singh & al. (23) mentioned that intense thunderstorms produce rapid cloud updrafts and may be associated with a range of destructive weather events. An important ingredient in measures of the potential for intense thunderstorms is the convective available potential energy (CAPE). Climate models project increases in summertime mean CAPE in the tropics and subtropics in response to global warming, but the physical mechanisms responsible for such increases and the implications for future thunderstorm activity remain uncertain. Here, high percentiles of the CAPE distribution (CAPE extremes) also increase robustly with warming across the tropics and subtropics in an ensemble of state-of-the-art climate models, implying strong increases in the frequency of occurrence of environments conducive to intense thunderstorms in future climate projections. The increase in CAPE extremes is consistent with a recently proposed theoretical model in which CAPE depends on the influence of convective entrainment on the tropospheric lapse rate, and the importance of this influence was demonstrated for simulated CAPE extremes using a climate model in which the convective entrainment rate is varied. It was further shown that the theoretical model is able to account for the climatological relationship between CAPE and a measure of lower-tropospheric humidity in simulations and in observations. The results provide a physical basis on which to understand projected future increases in intense thunderstorm potential, and they suggest that an important mechanism that contributes to such increases may be present in Earth's atmosphere **(23)**.

Liu & al. (24) described narrow bipolar events (NBEs) as signatures in radio signals from thunderstorms observed by ground-based receivers. NBEs may occur at the onset of lightning, but the discharge process is not well understood. Here, spectral measurements was presented by the Atmosphere-Space Interactions Monitor (ASIM) on the International Space Station that are associated with nine negative and three positive NBEs observed by a ground-based array of receivers. Both polarities NBEs are associated with emissions at 337 nm with weak or no detectable emissions at 777.4 nm, suggesting that NBEs are associated with streamer breakdown. The rise times of the emissions for negative NBEs are about 10 μs, consistent with source locations at cloud tops where photons undergo little scattering by cloud particles, and for positive NBEs are ~1 ms, consistent with locations deeper in the clouds. For negative NBEs, the emission strength is almost linearly correlated with the peak current of the associated NBEs. The findings suggest that ground-based observations of radio signals provide a new means

to measure the occurrences and strength of cloud-top discharges near the tropopause **(24)**.

Kirschenstein & al. (25) presented an assessment of the long-term variability of storm activity in the aspect of potential threats to aircraft. The analysis of data from the period 1970-2018 was conducted for selected airports in Poland: Gdańsk Lech Wałęsa Airport, IATA code: GDN, ICAO code: EPGD (54°22'39"N 18°27'59"E, altitude above sea level 149 m above sea level); Solidarity Szczecin-Goleniow Airport, IATA code: SZZ, ICAO code: EPSC (53°35'05" N 14°54'08" E, altitude above sea level 47 m above sea level); Poznań-Ławica Henryk Wieniawski Airport, IATA code: POZ, ICAO code: EPPO (52°25'16" N 16°49'35" E, altitude above sea level 94 m above sea level); Warsaw Chopin Airport, IATA code: WAW, ICAO code: EPWA (52°09'57" N 20°58'02" E, altitude above sea level 110 m above sea level); Copernicus Airport Wrocław, IATA code: WRO, ICAO code: EPWR (51°06'10" N 16°53'10" E, altitude above sea level 123 m above sea level); John Paul II International Airport Kraków-Balice, IATA code: KRK, ICAO code: EPKK (50°04'40" N 19°47'06" E, altitude above sea level 241 m above sea level). The purpose of this paper is to assess the long-term variability of storm activity in the aspect of potential threats to air operations in Poland with the examples of six selected airports. In order to achieve the goal, an analysis of the frequency of storm phenomena in Poland was carried out both in annual and long- term terms. The analysis will allow the assessment of the geographical diversity of the distribution of storm phenomena and their variability in the years 1970-2018. The next stage of the work will be to determine the climatic conditions that exert the greatest impact on the formation of storms. The important factors include atmospheric circulation, which, over the Polish territory, is shaped by the influence of air masses from the Atlantic Ocean, the Baltic Sea and in addition, from the vast continental area. All these air masses clash over the area of Poland causing large variability in the frequency of occurrence of hazardous atmospheric phenomena. For this reason, the Polish climate is defined as a moderate warm climate with transitory features. The important factors affecting regional diversity are local conditions, such as terrain, nature of the land, and distance from water reservoirs. The thermal, humidity and aerodynamic properties of the substrate, which are components of radiation processes, determine the exchange of energy at the interface between the atmosphere and the earth, and largely determine the intensity of selected hazardous atmospheric phenomena. Each occurrence of a storm is a potentially dangerous meteorological event that threatens the environment and human activities, including all types of transport. The studied phenomenon of storms is particularly dangerous for air transport. Literature shows that storm phenomena in Poland are characterized by a large regional diversity, both during the year and over many years. The greatest threat of storm phenomena occurs in the warm period of the year-spring and summer **(25)**.

Dowdy (26) mentioned that thunderstorms are convective systems characterized by the occurrence of lightning. Lightning and

thunderstorm activity has been increasingly studied in recent years in relation to the El Niño/Southern Oscillation (ENSO) and various other large-scale modes of atmospheric and oceanic variability. Large-scale modes of variability can sometimes be predictable several months in advance, suggesting potential for seasonal forecasting of lightning and thunderstorm activity in various regions throughout the world. To investigate this possibility, seasonal lightning activity in the world's tropical and temperate regions is examined here in relation to numerous different large-scale modes of variability. Of the seven modes of variability examined, ENSO has the strongest relationship with lightning activity during each individual season, with relatively little relationship for the other modes of variability. A measure of ENSO variability (the NINO3.4 index) is significantly correlated to local lightning activity at 53% of locations for one or more seasons throughout the year. Variations in atmospheric parameters commonly associated with thunderstorm activity are found to provide a plausible physical explanation for the variations in lightning activity associated with ENSO. It is demonstrated that there is potential for accurately predicting lightning and thunderstorm activity several months in advance in various regions throughout the world **(26)**.

Weber (27) noticed that although prevalent weather helps define climate, individual weather conditions, such as rain, humidity, wind speed and direction, temperature, or amount of sunshine, may have direct and indirect effects on bioaerosols. Effects may be immediate or cumulative. Precipitation and humidity acutely decrease particle air burden, but sufficient preseason moisture is necessary to assure proper growth of flower buds on perennials and trees and growth of annuals in general. Ambient temperature increase is necessary for anthesis in many plants, and cumulative heat above a threshold value has been linked to onset and intensity of pollination in grasses, weeds, and trees. Wind direction only impacts if there is lack of uniformity in the pollen sources that surround sampling sites. Wind speed may factor in re-entrainment of settled particles or may act to scour the air. Thunderstorms provide a unique sum of factors that greatly may increase aeroallergen burden. Dispersal of mold spores is linked intimately to precipitation and humidity. The effects may be opposed diametrically, however, depending on the type of fungi. Certain ascospores and basidiospores require active rainfall for release of spores, whereas other Deuteromycetes are suppressed by precipitation **(27)**.

Pattiaratchi & Wijeratne (28) mentioned that meteotsunamis are generated by meteorological events, particularly moving pressure disturbances due to squalls, thunderstorms, frontal passages and atmospheric gravity waves. Relatively small initial sea-level perturbations, of the order of a few centimeters, can increase significantly through multi-resonant phenomena to create destructive events through the superposition of different factors. The global occurrence of meteotsunamis and the different resonance phenomena leading to amplification of meteotsunamis are reviewed. Results from idealized numerical modelling and field measurements

from southwest Australia are presented to highlight the relative importance of the different processes. It is shown that the main influence that leads to amplification of the initial disturbance is due to wave shoaling and topographic resonance. Although meteotsunamis are not catastrophic to the extent of major seismically induced basin-scale events, the temporal and spatial occurrence of meteotsunamis is higher than those of seismic tsunamis as the atmospheric disturbances responsible for the generation of meteotsunamis are more common. High-energy events occur only for very specific combinations of resonant effects. The rareness of such combinations is perhaps the main reason why destructive meteotsunamis are exceptional and observed only at a limited number of sites globally **(28)**.

Holmes & al. (29) mentioned that Mercury (Hg) wet deposition, transfer from the atmosphere to Earth's surface by precipitation, in the United States is highest in locations and seasons with frequent deep convective thunderstorms, but it has never been demonstrated whether the connection is causal or simple coincidence. Rainwater samples were used from over 800 individual precipitation events to show that thunderstorms increase Hg concentrations by 50% relative to weak convective or stratiform events of equal precipitation depth. Radar and satellite observations reveal that strong convection reaching the upper troposphere (where high atmospheric concentrations of soluble, oxidized mercury species (Hg(II)) are known to reside) produces the highest Hg concentrations in rain. As a result, precipitation meteorology, especially thunderstorm frequency and total rainfall, explains differences in Hg deposition between study sites located in the eastern United States. Assessing the fate of atmospheric mercury thus requires bridging the scales of global transport and convective precipitation **(29)**.

Pante & Knippertz (30) emphasized that the summertime West African Sahel has the worldwide highest degree of thunderstorm organization into long-lived, several hundred-kilometer elongated, fast propagating systems that contribute 90% to the annual rainfall. All current global weather prediction and climate models represent thunderstorms using simplified parameterization schemes which deteriorates the modelled distribution of rainfall from individual storms and the entire West African monsoon circulation. It is unclear how this misrepresentation of Sahelian convection affects forecasts globally. The study is the first to demonstrate how a computationally feasible increase of model resolution over West Africa - allowing to avoid convection parameterization - yields a better representation of organized convection in the Sahel and of moisture within the monsoon system, ultimately improving 5-8-day tropical and mid-latitude weather forecasts. An operational use of a modelling strategy similar to the one presented here is advocated for a cost-effective improvement of global weather prediction and potentially even (sub-)seasonal and climate simulations **(30)**.

This chapter (1-30) shows numerous characteristics of thunderstorms in different countries. An analysis of thunderstorms by different types of storms is presented.

References

1. Joshi N, Dash MK, Jayakumar R. Transmission modes of COVID-19 disease pandemic in the light of ancient wisdom of Ayurveda medicine: a review. J Complement Integr Med. 2021 May 17.

2. Tippett MK, Lepore C, Cohen JE. More tornadoes in the most extreme U.S. tornado outbreaks. Science. 2016;354(6318):1419-23.

3. Peterson M, Rudlosky S, Zhang D. Thunderstorm cloud-type classification from space-based lightning imagers. Mon Weather Rev. 2020;148(5):1891-8.

4. Winckler JR. The cloud-ionosphere discharge: a newly observed thunderstorm phenomenon. Proc Natl Acad Sci U S A. 1997;94(20): 10512-9.

5. Gurevich AV, Antonova VP, Chubenko AP, et al. Strong flux of low-energy neutrons produced by thunderstorms. Phys Rev Lett. 2012 Mar 23;108(12):125001.

6. Houtkooper JM, Schienle A, Stark R, Vaitl D. Geophysical variables and behavior: LXXXVIII. Atmospheric electromagnetism: the possible disturbing influence of natural sferics on ESP. Percept Mot Skills. 1999;89(3 Pt 2):1179-92.

7. Østgaard N, Christian HL, Grove JE, et al. Gamma ray glow observations at 20-km altitude. J Geophys Res Atmos. 2019; 124(13):7236-54.

8. Wada Y, Enoto T, Nakazawa K, et al. Downward terrestrial gamma-ray flash observed in a winter thunderstorm. Phys Rev Lett. 2019;123(6):061103.

9. Ringuette R, Case GL, Cherry ML et al. TETRA observation of gamma-rays at ground level associated with nearby thunderstorms. J Geophys Res Space Phys. 2013;118(12):7841-9.

10. Su HT, Hsu RR, Chen AB, et al. Gigantic jets between a thundercloud and the ionosphere. Nature. 2003;423(6943):974-6.

11. Pasko VP, Stanley MA, Mathews JD, et al. Electrical discharge from a thundercloud top to the lower ionosphere. Nature. 2002;416(6877):152-4.

12. Boggs LD, Liu N, Riousset JA, et al. Thunderstorm charge structures producing gigantic jets. Sci Rep. 2018 Dec 27;8(1):18085.

13. Enoto T, Wada Y, Furuta Y, et al. Photonuclear reactions triggered by lightning discharge. Nature. 2017;551(7681):481-4.

14. Peterson DA, Campbell JR, Hyer EJ, et al. Wildfire-driven thunderstorms cause a volcano-like stratospheric injection of smoke. NPJ Clim Atmos Sci. 2018;1:10.1038/s41612-018-0039-3.

15. Franz RC, Nemzek RJ, Winckler JR. Television image of a large upward electrical discharge above a thunderstorm system. Science. 1990;249(4964):48-51.

16. Peterson M, Rudlosky S, Zhang D. Changes to the appearance of optical lightning flashes observed from space according to thunderstorm organization and structure. J Geophys Res Atmos. 2020 Feb 27;125(4):10.1029/2019jd031087.

17. Peterson M. Using lightning flashes to image thunderclouds. J Geophys Res Atmos. 2019;124(17-18):10175-85.

18. Dowdy AJ, Catto JL. Extreme weather caused by concurrent cyclone, front and thunderstorm occurrences. Sci Rep. 2017 Jan 11;7:40359.

19. Boyd DD. In-flight decision-making by general aviation pilots operating in areas of extreme thunderstorms. Aerosp Med Hum Perform. 2017;88(12):1066-72.

20. Kelley NA, Smith DM, Dwyer JR, et al. Relativistic electron avalanches as a thunderstorm discharge competing with lightning. Nat Commun. 2015 Aug 12;6:7845.

21. Tilles JN, Liu N, Stanley MA, et al. Fast negative breakdown in thunderstorms. Nat Commun. 2019 Apr 9;10(1):1648.

22. Diffenbaugh NS, Scherer M, Trapp RJ. Robust increases in severe thunderstorm environments in response to greenhouse forcing. Proc Natl Acad Sci U S A. 2013;110(41):16361-6.

23. Singh MS, Kuang Z, Maloney ED, et al. Increasing potential for intense tropical and subtropical thunderstorms under global warming. Proc Natl Acad Sci U S A. 2017;114(44):11657-62. Erratum in: Proc Natl Acad Sci U S A. 2018;115(2):E342.

24. Liu F, Lu G, Neubert T, et al. Optical emissions associated with narrow bipolar events from thunderstorm clouds penetrating into the stratosphere. Nat Commun. 2021 Nov 17;12(1):6631.

25. Kirschenstein M, Krasuski K, Kozuba J, Kelemen M. Assessment of the variability of many years of thunderstorm activity in the aspect of potential threats to aircraft at selected airports in Poland. Int J Environ Res Public Health. 2019 Dec 24;17(1):144.

26. Dowdy AJ. Seasonal forecasting of lightning and thunderstorm activity in tropical and temperate regions of the world. Sci Rep. 2016 Feb 11;6:20874.

27. Weber RW. Meteorologic variables in aerobiology. Immunol Allergy Clin North Am. 2003;23(3):411-22.

28. Pattiaratchi CB, Wijeratne EMS. Are meteotsunamis an underrated hazard? Philos Trans A Math Phys Eng Sci. 2015 Oct 28;373(2053):20140377.

29. Holmes CD, Krishnamurthy NP, Caffrey JM, et al. Thunderstorms increase mercury wet deposition. Environ Sci Technol. 2016;50(17):9343-50.

30. Pante G, Knippertz P. Resolving Sahelian thunderstorms improves mid-latitude weather forecasts. Nat Commun. 2019 Aug 2;10(1):3487.

THUNDERSTORMS

HEALTH EFFECTS

This section deals with the features of thunderstorms, involving emergency medical services and hospital admissions, epidemiology, etiology, general practice perspective, bronchial asthma, asthma and leukemia risk, spontaneous pneumothorax, subarachnoid hemorrhage, suicide attempts, and community responses.

EMERGENCY MEDICAL SERVICES/HOSPITAL ADMISSIONS

Kearns & al. (1) reported that during the early afternoon of June 29, 2012, a line of destructive thunderstorms producing straight line winds known as a derecho developed near Chicago (Illinois, USA). The storm moved southeast with wind speeds recorded from 100 to 160 kilometers per hour (kph, 60 to 100 miles per hour [mph]). The storm swept across much of West Virginia (USA) later that evening. Power outage was substantial as an estimated 1,300,000 West Virginians (more than half) were without power in the aftermath of the storm and approximately 600,000 citizens were still without power a week later. This was one of the worst storms to strike this area and occurred as residents were enduring a prolonged heat wave. The wind damage left much of the community without electricity and the crippling effect compromised or destroyed critical infrastructure including communications, air conditioning, refrigeration, and water and sewer pumps. This report describes utilization of Emergency Medical Services (EMS) and hospital resources in West Virginia in response to the storm. Also reported is a review of the weather phenomena and the findings and discussion of the disaster and implications **(1)**.

Villeneuve & al. (2) evaluated associations between meteorological conditions and the number of emergency department visits for asthma in a children's hospital in Ottawa, Canada. A case-crossover study design was used. Hospital emergency department visits for asthma between 1992 and 2000 were identified based on patients' presenting complaints. Hourly measures were obtained for the following meteorological variables: wind speed, temperature, atmospheric pressure, relative humidity, and visibility. Particular emphasis was placed on exploring the association between asthma visits and fog, thunderstorms, snow, and liquid and freezing forms of precipitation. In total, there were 18,970 asthma visits among children between 2 and 15 years of age. The number of visits and weather characteristics were grouped into 6 h case and control intervals. The occurrence of fog or liquid precipitation was associated with an increased number of asthma visits, while snow was associated with a reduced number ($p<0.05$). Stratified analyses by season found no association in any of the four calendar intervals between the number of asthma visits and visibility, change in relative humidity and change in temperature. In contrast, summertime thunderstorm activity was associated with an odds ratio of 1.35 (95% CI 1.02-1.77) relative to summer periods with no activity. Models that incorporate calendar and meteorological data may help emergency departments to more efficiently allocate resources needed to treat children presenting with respiratory distress **(2)**.

Silver & al. (3) examined the seasonality of asthma-related hospital admissions in Melbourne, Australia, in particular the contribution and predictability of episodic thunderstorm asthma. Using a time-series ecological approach based on asthma admissions to Melbourne metropolitan hospitals, we identified seasonal peaks in asthma admissions that were centered in late February, June, and

mid-November. These peaks were most likely due to the return to school, winter viral infections and seasonal allergies, respectively. Non-linear statistical regression was performed to predict daily admission rates as functions of the seasonal cycle, weather conditions, reported thunderstorms, pollen counts and air quality. Important predictor variables were the seasonal cycle and mean relative humidity in the preceding two weeks, with higher humidity associated with higher asthma admissions. Although various attempts were made to model asthma admissions, none of the models explained substantially more variation above that associated with the annual cycle. A list of high asthma admissions days (HAADs) was identified. Most HAADs fell in the late-February return-to-school peak and the November allergy peak, with the latter containing the greatest number of daily admissions. Many HAADs in the spring allergy peak may represent episodes of thunderstorm asthma, as they were associated with rainfall, thunderstorms, high ambient grass pollen levels and high humidity, a finding that suggests thunderstorm asthma is a recurrent phenomenon in Melbourne that occurs roughly once per five years. The rarity of thunderstorm asthma events makes prediction challenging, underscoring the importance of maintaining high standards of asthma management, both for patients and health professionals, especially during late spring and early summer **(3)**.

Xu & al. (4) reported that an epidemic of thunderstorm asthma in pediatric patients occurred in Yulin, a northwest city of China, on 11 September 2018. The epidemic was described, and the demographic and clinical aspects of the involved children were retrospectively analyzed. The caseload data of patients were collected from the hospital information system in Yulin Pediatric Hospital. The detailed document of hospitalized children with thunderstorm asthma was sourced from the medical records. The mean number of daily visits to emergency/outpatient department and the daily admission to hospital were 2.7 and 16 times, respectively, than on the other days of September. A gender prominence of males was observed in both emergency/outpatient and inpatient department. Among the 51 hospitalized children with detailed medical records, 56% of them had never experienced or were diagnosed with asthma and 25% had confirmed diagnosis of asthma. Sixty-seven percent had a history of allergic rhinitis during August and September. Seventy-six percent of the hospitalized children presented as moderate asthma. Ninety-four percent of the pediatric patients had positive IgE against mugwort pollen and 78% were monosensitized to pollen. The data show that thunderstorm asthma can affect children, especially who has allergic rhinitis or asthma without preventive management. Mugwort is also an aeroallergen in thunderstorm asthma attacks. Thunderstorm can induce asthma attacks in children with allergic rhinitis owing to mugwort and aggravate symptoms in children with confirmed diagnosis of asthma. Children with mugwort allergy are susceptible to thunderstorm asthma and a preponderance of boys was observed. Better identification of allergic children to mugwort, giving suitable protective measures during thunderstorm and standard therapy to

existing allergic situation could be a benefit for children at risk of thunderstorm asthma **(4)**.

Darvall & al. (5) investigated the environmental precipitants, treatment and outcome of critically ill patients affected by the largest and most lethal reported epidemic of thunderstorm asthma. This was a retrospective multicenter observational study. Meteorological, airborne particulate and pollen data, and a case series of 35 patients admitted to 15 intensive care units (ICUs) due to the thunderstorm asthma event of 21-22 November 2016, in Victoria, Australia, were analyzed and compared with 1062 total ICU-admitted Australian patients with asthma in 2016. Main outcome measures were characteristics and outcomes of total ICU versus patients with thunderstorm asthma, the association between airborne particulate counts and storm arrival, and ICU resource utilization. All 35 patients had an asthma diagnosis; 13 (37%) had a cardiac or respiratory arrest, five (14%) died. Compared with total Australian ICU-admitted patients with asthma in 2016, patients with thunderstorm asthma had a higher mortality (15% *v* 1.3%, p<0.001), were more likely to be male (63% *v* 34%, p<0.001), to be mechanically ventilated, and had shorter ICU length of stay in survivors (median, 31.8 hours [interquartile range (IQR), 14.8-43.6 hours] *v* 40.7 hours [IQR, 22.3-75.1 hours]; p=0.025). Patients with cardiac arrest were more likely to be born in Asian or subcontinental countries (5/10 [50%] *v* 4/25 [16%]; relative risk, 3.13; 95% CI 1.05-9.31). A temporal link was demonstrated between airborne particulate counts and arrival of the storm. The event used 15% of the public ICU beds in the region. The data show that arrival of a triggering storm is associated with an increase in respirable airborne particles. Affected critically ill patients are young, have a high mortality, a short duration of bronchospasm, and a prior diagnosis of asthma is common **(5)**.

Joshi & al. (6) mentioned that Melbourne, Australia, witnessed a thunderstorm asthma outbreak on 21 November 2016, resulting in over 8,000 hospital admissions by 6 P.M. This is a typical acute disease event. Because the time to respond is short for acute disease events, an algorithm based on time between events has shown promise. Shorter the time between consecutive incidents of the disease, more likely the outbreak. Social media posts such as tweets can be used as input to the monitoring algorithm. However, due to the large volume of tweets, a large number of alerts may be produced. This problem was referred as alert swamping. A four-step architecture is presented for the early detection of the acute disease event, using social media posts (tweets) on Twitter. To curb alert swamping, the first three steps of the algorithm ensure the relevance of the tweets. The fourth step is a monitoring algorithm based on time between events. It was experimented with a dataset of tweets posted in Melbourne from 2014 to 2016, focusing on the thunderstorm asthma outbreak in Melbourne in November 2016. Out of our 18 experiment combinations, three detected the thunderstorm asthma outbreak up to 9 hours before the time mentioned in the official report, and five were able to detect it before the first news report. The data demonstrate that with

appropriate checks against alert swamping in place and the use of a monitoring algorithm based on time between events, tweets can provide early alerts for an acute disease event such as thunderstorm asthma **(6)**.

References

1. Kearns RD, Wigal MS, Fernandez A, et al. The 2012 derecho: emergency medical services and hospital response. Prehosp Disaster Med. 2014;29(5):542-5.

2. Villeneuve PJ, Leech J, Bourque D. Frequency of emergency room visits for childhood asthma in Ottawa, Canada: the role of weather. Int J Biometeorol. 2005;50(1):48-56.

3. Silver JD, Sutherland MF, Johnston FH, et al. Seasonal asthma in Melbourne, Australia, and some observations on the occurrence of thunderstorm asthma and its predictability. PLoS One. 2018 Apr 12;13(4):e0194929.

4. Xu Y-Y, Xue T, Li H-R, Guan K. Retrospective analysis of epidemic thunderstorm asthma in children in Yulin, northwest China. Pediatr Res. 2021;89(4):958-61.

5. Darvall JN, Durie M, Pilcher D, et al. Intensive care implications of epidemic thunderstorm asthma. Crit Care Resusc. 2018;20(4):294-303.

6. Joshi A, Sparks R, McHugh J, et al. Harnessing tweets for early detection of an acute disease event. Epidemiology. 2020;31(1):90-97.

EPIDEMIOLOGY

Venables & al. (1) mentioned that a large epidemic of asthma occurred following a thunderstorm in southern and central England on 24/25 June 1994. A collaborative study group was formed. The objective was to describe the epidemic and the meteorological, aerobiological, and other environmental characteristics associated with it. Collation of data were from the Meteorological Office, the Pollen Research Unit, the Department of the Environment's Automatic Urban Network, from health surveillance by the Department of Health and the National Poisons Unit, from clinical experience in general practice and hospitals, and from an immunological study of some of the affected cases from north east London. The thunderstorm was a Mesoscale Convective System, an unusual and large form of storm with several centers and severe wind gusts. It occurred shortly after the peak grass pollen concentration in the London area. A sudden and extensive epidemic occurred within about an hour affecting possibly several thousand patients. Emergency services were stretched but the epidemic did not last long. Cases had high serum levels of IgE antibody to mixed grass pollen. This study supports the view that patients with specific IgE to grass pollen are at risk of thunderstorm-related asthma. The details of the causal pathway from storm to asthma attack are not clear. Case-control and time series studies are being carried out **(1)**.

Wardman & al. (2) mentioned that thunderstorm-associated asthma epidemics have been documented in the literature, but no Canadian experience has been reported. On July 31, 2000, a thunderstorm-associated epidemic of asthma or shortness of breath

occurred in Calgary, Alberta. The Calgary Health Region investigated the event using diagnostic data from emergency departments, an urgent care medical clinic and patient interviews, in addition to bioaerosol counts, pollutant data and weather data reflecting atmospheric conditions at that time. On July 31, 2000 and August 1, 2000, 157 people sought care for asthma symptoms. The expected number of people to seek care for such symptoms in a 48-h period in Calgary is 17. Individuals with a personal or family history of asthma, allergies or hay fever who were not taking regular medication for these conditions and who were outdoors before the storm appeared to have been preferentially affected. A stagnant air masses the day before the thunderstorm may have resulted in declining bioaerosol concentrations, and the possible accumulation of spore and pollen reservoirs within mold and plant structures. The elevated bioaerosol concentrations observed on the day of the thunderstorm may be attributed to the sudden onset of high winds during the thunderstorm, which triggered a sudden release of spores and pollens into the atmosphere, which was probably responsible for the epidemic. Several pollutant levels slightly increased on the day of the storm and possibly also played a role in symptom development. It is unclear whether an atmospheric pressure drop contributed to the release of spores and pollen **(2).**

Straub & al. (3) reported that higher incidences of asthma during thunderstorms can pose a serious health risk. In this study, the thunderstorm asthma risk was estimated using statistical methods, with special focus on Bavaria, Southern Germany. In this approach, a dataset of asthma-related emergency cases for the study region is combined with meteorological variables and aeroallergen data to identify statistical relationships between the occurrence of asthma (predictand) and different environmental parameters (set of predictors). On the one hand, the results provide evidence for a weak but significant relationship between atmospheric stability indices and asthma emergencies in the region, but also show that currently thunderstorm asthma is not a major concern in Bavaria due to overall low incidences. As thunderstorm asthma can have severe consequences for allergic patients, the presented approach can be important for the development of emergency strategies in regions affected by thunderstorm asthma and under present and future climate change conditions **(3)**.

Newson & al. (4) mentioned that recent epidemics of acute asthma have caused speculation that, if their causes were known, early warnings might be feasible. In particular, some epidemics seemed to be associated with thunderstorms. The Authors wondered what risk factors predicting epidemics could be identified. Daily asthma admissions count during 1987-1994, for two age groups (0-14 yrs and ≥15 yrs), were measured using the Hospital Episodes System (HES). Epidemics were defined as combinations of date, age group and English Regional Health Authority (RHA) with exceptionally high asthma admission counts compared to the predictions of a log-linear autoregression model. They were compared with control days 1 week before and afterwards, regarding seven meteorological

variables and 5-day average pollen counts for four species. Fifty-six asthma epidemics were identified. The mean density of sferics (lightning flashes), temperature and rainfall on epidemic days were greater than those on control days. High sferics densities were overrepresented in epidemics. Simultaneously high sferics and grass pollen further increased the probability of an epidemic, but only to 15% (95% confidence interval 2-45%). Two thirds of epidemics were not preceded by thunderstorms. Thunderstorms and high grass pollen levels precede asthma epidemics more often than expected by chance. However, most epidemics are not associated with thunderstorms or unusual weather conditions, and most thunderstorms, even following high grass pollen levels, do not precede epidemics. An early warning system based on the indicators examined here would, therefore, detect few epidemics and generate an unacceptably high rate of false alarms **(4)**.

Celenza & al. (5) sought associations between meteorological factors, concentrations of air pollutants or pollen, and an asthma epidemic which occurred in London on 24 and 25 June 1994 after a thunderstorm. A retrospective study of patients' accident and emergency department records was conducted, with bivariate and multivariate analysis of environmental factors and data were collected for the two months surrounding the epidemic. Setting: The accident and emergency department of St Mary's Hospital in west central London. Subjects included 148 patients presenting with asthma between 1 June and 31 July 1994, of whom 40 presented in the 24 hours after the storm. The asthma epidemic was significantly associated with a drop in air temperature six hours previously and a high grass pollen concentration nine hours previously. Non-epidemic asthma was significantly associated with lightning strikes, increase in humidity or sulphur dioxide concentration, a drop in temperature or high rainfall the previous day, and a decrease in maximum air pressure or changes in grass pollen counts over the previous two days. The data show that new episodes of asthma during the epidemic on 24 and 25 June 1994 were associated with a fall in air temperature and a rise in grass pollen concentration. Non-epidemic asthma was significantly associated with a greater number of environmental changes. This may indicate that the patients with thunderstorm associated asthma were a separate population, sensitive to different environmental stimuli **(5)**.

Davidson & al. (6) investigated the time course of an epidemic of asthma after a thunderstorm, characteristics of patients affected, and the demand on emergency medical resources. This was study of registers and records in accident and emergency departments and questionnaire to staff conducted at London area. Subjects included all patients presenting at 12 accident and emergency departments with asthma or other airway disease. Main outcome measures were numbers of patients, clinical features, information on shortage of resources--equipment, drugs, and staff. The epidemic had a sudden onset on 24 June 1994; 640 patients with asthma or other airways disease attended during 30 hours from 1800 on 24 June, nearly 10 times the expected number. Over half (365) the patients were aged

21 to 40 years. A history of hay fever was recorded in 403 patients; for 283 patients this was the first known attack of asthma; a history of chronic obstructive airways disease was recorded in 12 patients. In all, 104 patients were admitted (including five to an intensive care unit). Several departments ran out of equipment or drugs, called in additional doctors, or both. This study supports the view that this epidemic was larger than previously reported epidemics and the hypothesis that "thunderstorm associated asthma' is related to aeroallergens. Demands on resources were considerable; a larger proportion of patients needing intensive care would have caused greater problems **(6)**.

Spina & al. (7) mentioned that thunderstorm asthma is a rare event: in this letter we describe two cases observed during the same month of 2018 at an Italian Emergency department, assessed by the same medical team and according to the same methodology and approach. Given the infrequency of such a phenomenon and the debate around its nature, frequency, and - at times - existence, it is strongly believed it is important for all specialists who observe such cases to report them, building an evidence base to expand its knowledge and understanding **(7).**

According to **Rabiee & al. (8)**, previous studies that described thunderstorm asthma, which is a rare event, are not being well explained. This study was conducted, to describe the patient perspective on their asthma attack experience during Ahvaz post-rain phenomenon. Patients present in the Naft clinic of Ahvaz, during 28th October and the first week of November 2015 were interviewed. Recruitment was continued as saturation ensued by 33 participants. An inductive content analysis was used to evaluate the interviews. The key finding indicated a climatic condition, direct or indirect contact with rain, history of allergy, and physical conditions are the main categories. The patient emphasized the importance of dust, humidity, first autumn rainfall, and environmental air pollution in occurrences of the event. When exposed to further rains (third rainfall onward), they were less likely to experience dyspnea or shortness of breath. However, being indoor or out at the time of rainfall reported not to be related to the onset of asthma exacerbation. This study yielded that patients' asthma outbreak is a climate-related health impact and many individual factors triggering this issue. Patients concerns need future investigation and public health emergency planning and response arrangements **(8)**.

Ali & al. (9) mentioned that reports of thunderstorm asthma in the Middle East are few. This study is the first to report on cases of near-fatal and fatal thunderstorm asthma in Kuwait on December 1, 2016. A chart review and interview were conducted with adult patients admitted to Mubarak Al-Kabir Hospital with near-fatal asthma, defined as an exacerbation requiring intubation and mechanical ventilation or hypercapnia with a $PaCO_2 \geq 6$ kPa. Information, including patient age, gender, occupation, asthma history, medication usage, and clinical outcome, was collected. For fatal asthma cases, patients' data were collected from the Forensic Department at the Kuwait Ministry of Interior. A total of 17 patients

were admitted with near-fatal asthma. Fifteen patients (93.8%) had a prior history of asthma, with an average duration of 9 years. Five patients (33.3%) reported receiving a corticosteroid inhaler from their physician. Fifteen patients (93.8%) reported relying on a short-acting β2-agonist alone to manage their asthma. Eleven patients (68.8%) reported being outdoors during the storm. Eleven patients were diagnosed with fatal asthma. The study is the first to report on a thunderstorm-associated asthma epidemic in Kuwait and emphasizes the potential dangers associated with this entity **(9)**.

Forouzan & al. (10) reported the characteristics and treatment strategies of all patients with acute bronchospasm who were presented to the emergency departments of Ahvaz, Iran, following the occurrence of a thunderstorm on November 2, 2013. A total of 2000 patients presenting with asthma attacks triggered by thunderstorm were interviewed and an initial questionnaire was completed for each individual. After twenty days, patients were asked to complete a supplementary questionnaire, but only 800 of them accepted to do so. The majority of subjects was aged 20-40 years (60.5%) and had no history of asthma in most cases (60.0%). The symptoms had started outdoors for 60.0% of the participants. In most patients, the onset of the condition was on November 2. Short-acting β 2-agonist (salbutamol) and aminophylline were the most commonly prescribed medications in the emergency department. Upon the second interview, 85.3% of the patients were still symptomatic. Overall, 63.6% did not have a follow-up visit after hospital discharge, although all of them were referred to the specialist. The findings of the present study suggest that thunderstorm-associated asthma could affect young adults with no gender priority, with or without asthma history, which put a strain on emergency medical services **(10)**.

Girgis & al. (11) characterized patients at risk of asthma exacerbation during spring thunderstorms and identify potential measures to ameliorate the impact of those events. A case-control study was conducted among patients aged 7-60 yrs, who attended Wagga Hospital (NSW, Australia) for asthma during the period of 1 June 1997 to 31 October 1997. One hundred and eighty-three patients who attended on 30 and 31 October 1997 were the cases, and the remaining 121 patients were the controls. Questionnaire data were obtained from 148 (81%) cases and 91 (75%) controls. One hundred and thirty-eight (95%) cases who attended during the thunderstorm gave a history of hay fever prior to the event compared to 66 (74%) controls who attended at other times (odds ratio (OR) 6.01, 95% confidence interval [CI] 2.55-14.15); 111 (96%) cases were allergic to rye grass pollen compared to 47 (64%) controls (OR 23.6, 95% CI 6.6-84.3). Among subjects with a prior diagnosis of asthma (64% cases and 82% controls), controls (56%) were more likely to be taking inhaled steroids at time of the thunderstorm than cases (27%, OR 0.3, 95% CI 0.16-0.57). History of hay fever and allergy to rye grass are strong predictors for asthma exacerbation during thunderstorms in spring. The lower rate of inhaled steroid use

in thunderstorm cases suggests that this treatment may be effective in preventing severe attacks during thunderstorms **(11)**.

Foo & al. (12) reported that epidemic thunderstorm asthma (ETSA) severely affected Melbourne, Australia in November 2016. There is scant literature on the natural history of individuals affected by ETSA. A multicenter 12-month prospective observational study was conducted assessing symptomatology and behaviors of ETSA-affected individuals. A structured phone questionnaire was used to assess asthma symptom frequency, inhaled preventer use, asthma action plan ownership and healthcare utilization over 12 months since the ETSA. Analysis of results included subgroup analyses of the "current," "past," "probable," and "no asthma" subgroups defined according to their original 2016 survey responses. Four hundred forty-two questionnaires were analyzed. Eighty percent of individuals reported ongoing asthma symptoms at follow-up, of which 28% were affected by asthma symptoms at least once a week. Risk of persistent asthma symptoms was significantly higher in those with prior asthma diagnosis, current asthma, and probable undiagnosed asthma (all $p<0.01$). Of 442 respondents, 53% were prescribed inhaled preventers, of which 51% were adherent at least 5 days a week. Forty-two percent had a written asthma action plan and 16% had sought urgent medical attention for asthma in the preceding year. The data show that following an episode of ETSA, patients experience a pivotal change in asthma trajectory with both loss of asthma control and persistence of de novo asthma. Suboptimal rates of inhaled preventer adherence and asthma action plan ownership may contribute to asthma exacerbation risk and susceptibility to future ETSA episodes. Longer-term follow-up is needed to determine the extent and severity of this apparent change **(12)**.

Foo & al. (13) mentioned that the world's most catastrophic epidemic thunderstorm asthma event (ETSA) affected Melbourne in 2016. Little is known about the natural history of individuals affected by such extreme events. In this single center prospective 3-year longitudinal study, symptomatology and behaviors of individuals affected by ETSA were assessed. Standardized telephone questionnaire was used to evaluate frequency of asthma symptoms, inhaled corticosteroid preventer use, asthma action plan ownership, and healthcare utilization. Questionnaires were administered at 12, 24, and 36 months after 2016 ETSA. Subgroup analyses of the 'current', 'past', 'possible,' and 'no asthma' subgroups were also conducted. Two hundred and eight, 164, and 112 completed questionnaires were analyzed in 2017, 2018, and 2019, respectively. Seventy to eighty five percent of respondents reported ongoing asthma symptoms in any given year, of which 20%-28% experienced weekly symptoms. Nearly 50% of respondents were prescribed preventers, with approximately 45% adherent at least 5 days a week. Less than 40% had an asthma action plan and 15%-20% sought urgent medical attention for asthma over the follow-up period. Among 106 individuals with 3 consecutive years of completed questionnaires, those with no prior doctor diagnosis of asthma were

significantly more likely to be asymptomatic on follow-up than those with a prior doctor diagnosis of asthma (p=0.02). Subgroup analyses suggest that large proportions of respondents with 'past' and 'no asthma' continue to remain symptomatic throughout the 36-month period. The data demonstrate that in individuals affected by ETSA, evidence of ongoing loss of asthma control was found in those with previously well controlled asthma, and the persistence of symptoms suggestive of asthma in those with no history or symptoms suggestive of prior asthma, even after 36 months from initial ETSA. Low rates of inhaler adherence and asthma action plan ownership may contribute to increased morbidity and mortality from future ETSA events. Further research is required to confirm these findings **(13)**.

Severe Weather, Heavy Rain & Excessive Heat - YouTube.
YouTube|480 × 360 jpeg. wallpapersafari.co.

Rangamuwa & al. (14) emphasized that on 21st November 2016, Melbourne experienced an epidemic of 'thunderstorm asthma.' Although previously described in the literature, risk factors and natural history remain incompletely understood. The aim was to follow up those presenting to the 3 Emergency Departments (EDs) in our health service during the epidemic, and assess their history for previous asthma, rhinitis, and allergies. ED notes of all respiratory presentations within 48 hours of the thunderstorm event were reviewed and patients with acute asthma included. A standardized questionnaire was devised encompassing asthma diagnosis, undiagnosed asthma symptoms and rhinitis severity. Patients were contacted by phone within 30 days of the event. Three hundred forty-four patients were identified overall; 263 patients were contactable and completed a phone or mail questionnaire. The mean age was 32.7 ± 19.2 years (range, 6 months-87 years; 25% < 18 years) with 58% male sex. A previous diagnosis of asthma was present in 42% (n=111), and there was no previous asthma diagnosis in 58% (n=152). Of those who had no asthma diagnosis, 53% had probable undiagnosed asthma. Overall, rhinitis prevalence was 88%, of which 72% were moderate or severe (Allergic Rhinitis and its Impact on Asthma guidelines) and 51% (n=133) reported a history of grass

pollen allergy. The data highlights the importance of atopy and rhinitis as risk factors for epidemic thunderstorm asthma. Better identification of undiagnosed asthma and implementing treatment of asthma and rhinitis may be important **(14).**

Bellomo & al. (15) documented the clinical impact and identify the meteorological and environmental circumstances surrounding two epidemics of asthma exacerbations associated with thunderstorms in the city of Melbourne and to find a possible etiology for these events. Collection of meteorological and environmental data from the Victorian Bureau of Meteorology and the Environment Protection Authority; collection of clinical data from metropolitan emergency departments and the Victorian Ambulance Service; and study of a cohort of affected patients with asthma and a control group of asthmatics who were not affected by the storms were carried out at a tertiary institution. Patient**s** included twelve storm-affected patients with asthma and 16 asthmatics not affected by the storms. Interventions were administration of a questionnaire, medical interview, pulmonary function tests and skin prick tests with common allergens. Both epidemics caused a major increase in the number of hospital attendances and admissions because of asthma exacerbation (five-to-ten-fold rise) were analyzed. These events could not be related to atmospheric pollution or specific meteorological features of the storms. Patients affected by the second storm were significantly more likely to suffer from hay fever ($p<0.05$), rye grass pollen allergy ($p<0.05$) and allergy to rainfall released rye grass starch granules ($p<0.025$). The data show that late spring thunderstorms in the city of Melbourne can trigger epidemics of asthma attacks. The seasonal nature of the phenomenon and the pattern of allergic responses found in affected patients suggest a possible etiological role for rye grass pollen **(15)**.

Hew & al. (16) mentioned that the world's most catastrophic and deadly thunderstorm asthma epidemic struck Melbourne, Australia, on November 21, 2016. Among thunderstorm-affected patients presenting to emergency rooms (ERs), risk factors predicting severe attacks requiring admission to hospital were investigated. Thunderstorm-affected patients were identified from ER records at the eight major Melbourne health services and interviewed by telephone. Risk factors for hospital admission were analyzed. Of thunderstorm-affected patients, 1,435/2,248 (64%), of whom 164 (11.4%) required hospital admission. Overall, rhinitis was present in 87%, and current asthma was present in 28%. Odds for hospital admission were higher with increasing age (odds ratio 1.010, 95% CI 1.002, 1.019) and among individuals with current asthma (adjusted odds ratio [aOR] 1.87, 95% CI 1.26-2.78). Prior hospitalization for asthma in the previous 12 months further increased the odds for hospital admission (aOR 3.16, 95% CI 1.63-6.12). Among patients of Asian ethnicity, the odds for hospital admission were lower than for non-Asian patients (aOR 0.59, 95% CI 0.38-0.94), but higher if born in Australia (OR 5.42, 95% CI 1.56, 18.83). The data show that in epidemic thunderstorm asthma patients who presented to the ER, higher odds for hospital admission among patients with known

asthma were further amplified by recent asthma admission, highlighting the vulnerability conferred by suboptimal disease control. Odds for hospital admission were lower in Asian patients born overseas, but higher in Asian patients born locally, than in non-Asian patients; these observations suggest susceptibility to severe thunderstorm asthma may be enhanced by gene-environment interactions **(16)**.

References

1. Venables KM, Allitt U, Collier CG, et al. Thunderstorm-related asthma - the epidemic of 24/25 June 1994. Clin Exp Allergy. 1997;27(7):725-36.

2. Wardman AED, Stefani D, MacDonald JC. Thunderstorm-associated asthma or shortness of breath epidemic: a Canadian case report. Can Respir J. 2002;9(4):267-70.

3. Straub A, Fricke V, Olschewski P, et al. The phenomenon of thunderstorm asthma in Bavaria, Southern Germany: a statistical approach. Int J Environ Health Res. 2021 Oct 4;1-17.

4. Newson R, Strachan D, Archibald E, et al. Acute asthma epidemics, weather and pollen in England, 1987-1994. Eur Respir J. 1998;11(3):694-701.

5. Celenza A, Fothergill J, Kupek E, Shaw RJ. Thunderstorm associated asthma: a detailed analysis of environmental factors. BMJ. 1996;312(7031):604-7.

6. Davidson AC, Emberlin J, Cook AD, Venables KM. A major outbreak of asthma associated with a thunderstorm: experience of accident and emergency departments and patients' characteristics. Thames Regions Accident and Emergency Trainees Association. BMJ. 1996;312(7031):601-4.

7. Spina MF, Banfi PI, Nicolini A. Thunderstorm-asthma, two cases observed in Northern Italy. Multidiscip Respir Med. 2020 Sep 11;15(1):679.

8. Rabiee S, Mousavi H, Khafaie MA. Thunderstorm asthma outbreak, a rare phenomenon in southwest Iran: patients' perspectives. Environ Sci Pollut Res Int. 2018;25(36):36158-62.

9. Ali F, Behbehani N, Alomair N, Taher A. Fatal and near-fatal thunderstorm asthma epidemic in a desert country. Ann Thorac Med. 2019;14(2):155-60.

10. Forouzan A, Masoumi K, Shoushtari MH, et al. An overview of thunderstorm-associated asthma outbreak in southwest of Iran. J Environ Public Health. 2014;2014:504017.

11. Girgis ST, Marks GB, Downs SH, et al. Thunderstorm-associated asthma in an inland town in south-eastern Australia. Who is at risk? Eur Respir J. 2000;16(1):3-8.

12. Foo CT, Yee EL, Young A, et al. Continued loss of asthma control following epidemic thunderstorm asthma. Asia Pac Allergy. 2019 Oct 17;9(4):e35.

13. Foo CT, Fernando S, Cohen N, et al. Natural history of asthma symptoms after epidemic thunderstorm asthma: a 3-year longitudinal study. Asia Pac Allergy. 2020 Jul 21;10(3):e30.

14. Rangamuwa KB, Young AC, Thien F. An epidemic of thunderstorm asthma in Melbourne 2016: asthma, rhinitis, and other previous allergies. Asia Pac Allergy. 2017;7(4):193-8.

15. Bellomo R, Gigliotti P, Treloar A, et al. Two consecutive thunderstorm associated epidemics of asthma in the city of Melbourne. The possible role of rye grass pollen. Med J Aust. 1992; 156(12):834-7.

16. Hew M, Lee J, Susanto NH, et al. The 2016 Melbourne thunderstorm asthma epidemic: risk factors for severe attacks requiring hospital admission. Allergy. 2019;74(1):122-30.

FATALITIES

According to CDC (1), On March 1, 1997, approximately nine tornadoes originating from two separate thunderstorms swept across Arkansas, from Hempstead County in the southwest to Clay County in the northeast (approximately 260 miles). The tornadoes caused 26 deaths and an estimated $115 million in property damage, reflecting damage to residences, nonresidential buildings, bridges, and roads and agriculture and timber losses. The strongest tornadoes touched down southwest of Little Rock in Clark, Saline, and Pulaski counties; the estimated widths of the tornado paths ranged from 1/2 to 1 mile, and wind speeds were > 200 miles per hour (National Weather Service [NWS], unpublished data, 1997). This report summarizes circumstances of the tornado-associated fatalities from information collected by the American Red Cross (ARC); 14 of the 26 fatalities occurred among persons who were in mobile homes (1).

CDC (2) mentioned that on June 29, 2012, a rapidly moving line of intense thunderstorms with high winds swept across the midwestern and eastern United States, causing widespread damage and power outages. Afterward, the area experienced extreme heat, with maximum temperatures exceeding 100°F (37.8°C). This report describes 32 heat-related deaths in Maryland, Ohio, Virginia, and West Virginia that occurred during the 2 weeks following the storms and power outages. Median age of the decedents was 65 years, and most of the excessive heat exposures occurred within homes. During 1999-2009, an annual average of 658 heat-related deaths occurred in the United States. Heat-related deaths are preventable, and heat response plans should be in place before an extreme heat event (EHE). Interventions should focus on identifying and limiting heat exposure among vulnerable populations (2).

References

1. Centers for Disease Control and Prevention (CDC). Tornado-associated fatalities - Arkansas, 1997. MMWR Morb Mortal Wkly Rep. 1997;46(19):412-6. Erratum in MMWR Morb Mortal Wkly Rep. 1997;46(39):928.

2. Centers for Disease Control and Prevention (CDC). Heat-related deaths after an extreme heat event--four states, 2012, and United States, 1999-2009. MMWR Morb Mortal Wkly Rep. 2013;62(22): 433-6.

BRONCHIAL ASTHMA

ETIOLOGY

Harun & al. (1) mentioned that thunderstorm-triggered asthma (TA) is the occurrence of acute asthma attacks immediately following

a thunderstorm. Epidemics have occurred across the world during pollen season and have the capacity to rapidly inundate a health care service, resulting in potentially catastrophic outcomes for patients. TA occurs when specific meteorological and aerobiological factors combine to affect predisposed patients. Thunderstorm outflows can concentrate aeroallergens, most commonly grass pollen in TA, at ground level to release respirable allergenic particles after rupture by osmotic shock related to humidity and rainfall. Inhalation of high concentrations of these aeroallergens by sensitized individuals can induce early asthmatic responses which are followed by a late inflammatory phase. Other environmental factors such as rapid temperature change and agricultural practices contribute to the causation of TA. The most lethal TA event occurred in Melbourne, Australia, in 2016. Studies on the affected individuals found TA to be associated with allergic rhinitis, ryegrass pollen sensitization, pre-existing asthma, poor adherence to inhaled corticosteroid preventer therapy, hospital admission for asthma in the previous year and outdoor location at the time of the storm. Patients without a prior history of asthma were also affected. These factors are important in extending our understanding of the etiology of TA and associated clinical indicators as well as possible biomarkers which may aid in predicting those at risk and thus those who should be targeted in prevention campaigns. Education on the importance of recognizing asthma symptoms, adherence to asthma treatment and controlling seasonal allergic rhinitis is vital in preventing TA. Consideration of allergen immunotherapy in selected patients may also mitigate risk of future TA. Epidemic TA events are predicted to increase in frequency and severity with climate change and identifying susceptible patients and preventing poor outcomes is a key research and public health policy priority **(1)**.

Higham & al. (2) described the areas affected and the scale of an epidemic of thunderstorm associated asthma on the night of 24/25 June 1994 and to explore the spatial and temporal relationship between the thunderstorm and the associated epidemic. Setting**:** The 29 offices of a deputising service for general practitioners' (GP) out of hours calls (Healthcall). At the time of the storm the deputising service provided out of hours cover for about 8500 out of about 30000 GPs in England, Scotland, and Wales. Patients who phoned the Healthcall offices to request a home visit were categorized as "asthma" or "other causes" based on their presenting complaint. The number of calls on the night of 24/25 June 1994 was compared in areas affected by thunderstorms and areas not affected by thunderstorms and with the night of 17/18 June 1994, when there were no thunderstorms. A large area of the south and east of England was affected by an epidemic of asthma closely related both temporally and spatially with the thunderstorms on 24/25 June 1994. The pooled Mantel-Haenszel estimate for the risk of asthma in thunderstorm affected areas compared with the control night was 6.36 (95% confidence interval [CI] 4.97-8.32) compared with a value of 1.01 (0.80-1.27) for those not exposed. Extrapolation suggests about 1500 extra patients were likely to have requested a visit from a

GP that night because of epidemic asthma. The data indicate that under certain circumstances thunderstorms are associated with asthma and can affect many patients. Deputizing services are a useful source of data for the investigation of epidemics in primary care **(2)**.

D'Amato & al. (3) emphasized that the fifth report issued by the Intergovernmental Panel on Climate Change forecasts that greenhouse gases will increase the global temperature as well as the frequency of extreme weather phenomena. An increasing body of evidence shows the occurrence of severe asthma epidemics during thunderstorms in the pollen season, in various geographical zones. The main hypotheses explaining association between thunderstorms and asthma claim that thunderstorms can concentrate pollen grains at ground level which may then release allergenic particles of respirable size in the atmosphere after their rupture by osmotic shock. During the first 20-30 min of a thunderstorm, patients suffering from pollen allergies may inhale a high concentration of the allergenic material that is dispersed into the atmosphere, which in turn can induce asthmatic reactions, often severe. Subjects without asthma symptoms but affected by seasonal rhinitis can also experience an asthma attack. All subjects affected by pollen allergy should be alerted to the danger of being outdoors during a thunderstorm in the pollen season, as such events may be an important cause of severe exacerbations. In light of these observations, it is useful to predict thunderstorms and thus minimize thunderstorm-related events **(3)**.

Abbott & Cronin (4) noticed that cloud-aerosol interactions remain a major obstacle to understanding climate and severe weather. Observations suggest that aerosols enhance tropical thunderstorm activity; past research, motivated by the importance of understanding aerosol impacts on clouds, has proposed several mechanisms that could explain that observed link. High-resolution atmospheric simulations can reproduce the observed link between aerosols and convection. However, previously proposed mechanisms are unable to explain the invigoration. Examining underlying processes reveals that, in the simulations, high aerosol concentrations increase environmental humidity by producing clouds that mix more condensed water into the surrounding air. In turn, higher humidity favors large-scale ascent and stronger convection. The results provide a physical reason to expect invigorated thunderstorms in high-aerosol regions of the tropics **(4)**.

Douglass (5) reported that over recent years, Australians have been subject to an unprecedented number of environmental events materially and visibly affecting air quality, including thunderstorm asthma and bushfire smoke. There is increasing evidence that poor air quality adversely affects health with consequences for mortality and morbidity with measured particulates (PM2.5) in January 2019 frequently exceeding World Health Organization standards. Biological factors can also impact air quality with thunderstorm asthma epidemics evidence of a prime example, the 2016 event being associated with severe impacts on health services. Given these

events, consideration needs to be given to environmental health literacy which will support individuals with pre-existing illness to recognize and mitigate as far as possible the effects of adverse air quality. Recognizing the impact of poor air quality should also urge physicians to advocate for clean air as a necessity for good health **(5)**.

According to **D'Amato & al. (6)**, an increasing body of evidence shows the occurrence of asthma epidemics, sometimes also severe, during thunderstorms in the pollen season in various geographical zones. The main hypothesis explaining association between thunderstorms and asthma claims that thunderstorms can concentrate pollen grains at ground level; these grains may then release allergenic particles of respirable size in the atmosphere after their rupture by osmotic shock. During the first 20-30 minutes of a thunderstorm, patients suffering from pollen allergy may inhale a high concentration of the allergenic material dispersed into the atmosphere, which can, in turn, induce asthmatic reactions, often severe. Subjects without asthma symptoms but affected by seasonal rhinitis can also experience an asthma attack. All subjects affected by pollen allergy should be alerted to the danger of being outdoors during a thunderstorm in the pollen season, as such events may be an important cause of severe bronchial obstruction. Considering this background, it is useful to predict thunderstorms during pollen season and, thus, to prevent thunderstorm-related clinical event. However, it is also important to focus on therapy, and it is not sufficient that subjects at risk of asthma follow a correct therapy with bronchodilators, but they also need to inhale corticosteroids, using both in case of emergency **(6)**.

D'Amato & al. (7) mentioned that thunderstorm-triggered asthma (TA) can be defined as the occurrence of acute asthma attacks immediately following a thunderstorm during pollen seasons. Outbreaks have occurred across the world during pollen season with the capacity to rapidly inundate a health care service, resulting in potentially catastrophic outcomes for allergic patients. TA occurs when specific meteorological and aerobiological factors combine to affect predisposed atopic patients with IgE-mediated sensitization to pollen allergens. Thunderstorm outflows can concentrate aeroallergens, most commonly grass pollen but also other pollens such as Parietaria and moulds in TA, at ground level to release respirable allergenic particles after rupture by osmotic shock related to humidity and rainfall. Inhalation of high concentrations of these aeroallergens by sensitized individuals can induce early asthmatic responses which can be followed by a late inflammatory phase. There is evidence that, during pollen season, thunderstorms can induce allergic asthma outbreaks, sometimes also severe asthma crisis and sometimes deaths in patients suffering from pollen allergy. It has been observed that changes in the weather such as rain or humidity may induce hydratation of pollen grains during pollen seasons and sometimes also their fragmentation which generates atmospheric biological aerosols carrying allergens. Asthma attacks are induced for the high concentration at ground level of pollen grains which may release allergenic particles of respirable size after

rupture by osmotic shock. In other words, it is a global health problem observed in several cities and areas of the world that can strike without sufficient warning, inducing sometimes severe clinical consequences also with deaths of asthma patients. Due to constant climate change, future TA events are likely to become more common, more disastrous, and more unpredictable, as a consequence it is important to have deep knowledge on this topic to prevent asthma attacks. Other environmental factors, such as rapid changes in temperature and agricultural practices, also contribute to causing TA **(7)**.

D'Amato & al. (8) emphasized that thunderstorms have been linked to asthma epidemics, especially during the pollen seasons, and there are descriptions of asthma outbreaks associated with thunderstorms, which occurred in several cities, prevalently in Europe (Birmingham and London in the UK and Napoli in Italy) and Australia (Melbourne and Wagga Wagga). Pollen grains can be carried by thunderstorm at ground level, where pollen rupture would be increased with release of allergenic biological aerosols of paucimicronic size, derived from the cytoplasm and which can penetrate deep into lower airways. In other words, there is evidence that under wet conditions or during thunderstorms, pollen grains may, after rupture by osmotic shock, release into the atmosphere part of their content, including respirable, allergen-carrying cytoplasmic starch granules (0.5-2.5 microm) or other paucimicronic components that can reach lower airways inducing asthma reactions in pollinosis patients. The thunderstorm-asthma outbreaks are characterized, at the beginning of thunderstorms by a rapid increase of visits for asthma in general practitioner or hospital emergency departments. Subjects without asthma symptoms but affected by seasonal rhinitis can experience an asthma attack. No unusual levels of air pollution were noted at the time of the epidemics, but there was a strong association with high atmospheric concentrations of pollen grains such as grasses or other allergenic plant species. However, subjects affected by pollen allergy should be informed about a possible risk of asthma attack at the beginning of a thunderstorm during pollen season **(8)**.

Al-Rubaish (9) emphasized that acute episodes of bronchial asthma are associated with specific etiological factors such as air pollutants and meteorological conditions including thunderstorms. Evidence suggests that thunderstorm-associated asthma (TAA) may be a distinct subset of asthmatics, and, epidemics have been reported, but none from Saudi Arabia. The trigger for this review was the TAA epidemic in November 2002, Eastern Saudi Arabia. The bulk of patients were seen in the King Fahd Hospital of the University, Al-Khobar. The steady influx of acute cases was managed effectively and involved all neighboring hospitals, without evoking any "Major Incident Plan". Three groups of factors are implicated as causes of TAA: pollutants (agrobiologic or chemical) and meteorological conditions. Aerobiological pollutants include air-borne allergens: pollen and spores of molds. Their asthma-inducing effect is augmented during thunderstorms. Chemical pollutants include

greenhouse gases, heavy metals, ozone, nitrogen dioxide, sulfur dioxide, fumes from engines and particulate matter. Their relation to rain-associated asthma is mediated by sulfuric and nitric acid. Outbreaks of non-epidemic asthma are associated with high rainfall, drop in maximum air temperature and pressure, lightning strikes and increased humidity. Thunderstorm can cause all of these, and it seems to be related to the onset of asthma epidemic. Patients in epidemics of TAA are usually young atopic adults not on prophylaxis steroid inhalers. The epidemic is usually their first known attack. These features are consistent with the hypothesis that TAA is related to both aero-allergens and weather effects. Subjects allergic to pollen who are in the path of thunderstorm can inhale air loaded with pollen allergen and so have acute asthmatic response. TAA runs a benign course Doctors should be aware of this phenomenon and the potential outbreak of asthma during heavy rains. A & E departments and ICU should be alert for possible rush of asthmatic admissions and reinforce ventilators and requirements of cardio-pulmonary resuscitation. Scientific approach should be adopted to investigate such outbreaks in the future and must include meteorological, bio-aerosol pollutants and chemical pollutant assessment. Regional team work is mandatory **(9)**.

Sabih & al. (10) reported that thunderstorm asthma is induced by specific weather conditions causing breakdown and widespread distribution of allergens. Thunderstorm asthma had previously been considered unlikely to occur in New Zealand (NZ), given its local weather patterns. Storm events on 2 December 2017 led to increased asthma presentations at Waikato Hospital in Hamilton. Analyses of patient presentations led us to conclude that these presentations were similar to international descriptions of thunderstorm asthma. This is the first time such presentations have been reported in NZ. Documenting these events accurately is important as this is the first step to making a plan that would enable paramedics and emergency facilities across NZ to respond to any larger scale thunderstorm asthma events in the future **(10)**.

D'Amato & al. (11) mentioned that there are observations in various geographical areas that thunderstorms occurring during pollen seasons can induce severe asthma attacks in pollinosis patients. An accredited hypothesis explaining the association between thunderstorms and asthma suggests that storms can concentrate pollen grains at ground level, which may then release allergenic particles of respirable size in the atmosphere after their imbibition of water and rupture by osmotic shock. During the first 20-30 min of a thunderstorm, patients affected by pollen allergy may inhale a high quantity of the allergenic material that is dispersed into the atmosphere as a bioaerosol of allergenic particles, which can induce asthmatic reactions, often severe. Subjects without asthma symptoms but affected by seasonal rhinitis can also experience an asthma attack. A key message is that all subjects affected by pollen allergy should be alerted to the danger of being outdoors during a thunderstorm in the pollen season, as such events may be an important cause of severe asthma exacerbations. In light of these

observations, it is useful to predict thunderstorms and thus minimize thunderstorm-related events. Patients with respiratory allergy induced by pollens and molds need to be informed about a correct therapeutic approach of bronchial asthma by inhalation, including the use of bronchodilators and inhaled corticosteroids. The purpose of this review is to focalize epidemiological, etiopathogenetic, and clinical aspects of thunderstorm-related asthma **(11)**.

Clayton-Chubb & al. (12) mentioned that epidemic thunderstorm asthma (ETSA) refers to large-scale acute bronchospasm events associated with thunderstorm. The most serious episode ever recorded occurred in Melbourne, Australia, in November 2016, where more than 3,500 patients were treated in hospitals and 10 died. Previous work has been focused primarily on patient presentations to emergency departments. The prevalence of individuals with milder, non-emergent symptoms and who may be at risk of more serious episodes in the future has not previously been explored. The aim was to characterize the nature and extent of respiratory symptoms in healthcare workers during the Melbourne ETSA event. A survey was conducted among staff and volunteers across Eastern Health, distributed on the intranet homepage, by email and by word of mouth. Anonymous survey questions were constructed to assess prior and current diagnoses of relevance, symptoms, and demography. There were 515 participants (80% female, n=411) of approximately 9000 potential respondents (~6% response rate) who completed the survey; 132 (25.6%) had symptoms suggestive of asthma during the Melbourne ETSA event, the majority of whom did not seek professional medical help. Notably, of those with ETSA-like symptoms, only 58 (43.9%) had a history of asthma, while 97 (73.5%) had a history of allergic rhinitis. Specifically, a history of allergic rhinitis (OR 2.77, $p<0.001$), a history of asthma (OR 1.67, $p=0.037$) and being of self-identified Asian ethnicity (OR 3.24, $p<0.001$) were all strong predictors of ETSA-like symptoms. Being predominantly indoors was not protective. The study provides evidence of the presence of a large cohort of sufferers during the Melbourne ETSA event of 2016 that did not come to the attention of medical services, implying a potentially hidden and significant susceptible population. Further research should help clarify the true prevalence of vulnerability in the general population, with important public health implications **(12).**

D'Amato & al. (13) reported that thunderstorm-triggered asthma (TA) can be defined as the occurrence of acute asthma attacks immediately following a thunderstorm during pollen seasons. Outbreaks have occurred across the world during pollen season with the capacity to rapidly inundate a health care service, resulting in potentially catastrophic outcomes for allergic patients. TA occurs when specific meteorological and aerobiological factors combine to affect predisposed atopic patients with IgE-mediated sensitization to pollen allergens. Thunderstorm outflows can concentrate aeroallergens, most commonly grass pollen but also other pollens such as Parietaria and molds in TA, at ground level to release respirable allergenic particles after rupture by osmotic shock related

to humidity and rainfall. Inhalation of high concentrations of these aeroallergens by sensitized individuals can induce early asthmatic responses which can be followed by a late inflammatory phase. There is evidence that, during pollen season, thunderstorms can induce allergic asthma outbreaks, sometimes also severe asthma crisis and sometimes deaths in patients suffering from pollen allergy. It has been observed that changes in the weather such as rain or humidity may induce hydratation of pollen grains during pollen seasons and sometimes also their fragmentation which generates atmospheric biological aerosols carrying allergens. Asthma attacks are induced for the high concentration at ground level of pollen grains which may release allergenic particles of respirable size after rupture by osmotic shock. In other words, it is a global health problem observed in several cities and areas of the world that can strike without sufficient warning, inducing sometimes severe clinical consequences also with deaths of asthma patients. Due to constant climate change, future TA events are likely to become more common, more disastrous, and more unpredictable, as a consequence it is important to have deep knowledge on this topic to prevent asthma attacks. Other environmental factors, such as rapid changes in temperature and agricultural practices, also contribute to causing TA **(13)**.

Dabrera & al. (14) mentioned that thunderstorm asthma is a term used to describe an observed increase in acute bronchospasm cases following the occurrence of thunderstorms in the local vicinity. The roles of accompanying meteorological features and aeroallergens, such as pollen grains and fungal spores, have been studied in an effort to explain why thunderstorm asthma does not accompany all thunderstorms. Despite published evidence being limited and highly variable in quality due to thunderstorm asthma being a rare event, this article reviews this evidence in relation to the role of aeroallergens, meteorological features, and the impact of thunderstorm asthma on health services. This review has found that several thunderstorm asthma events have had significant impacts on individuals' health and health services with a range of different aeroallergens identified. This review also makes recommendations for future public health advice relating to thunderstorm asthma on the basis of this identified evidence **(14)**.

D'Amato & al. (15) mentioned that the observational evidence indicates that recent regional changes in climate, particularly temperature increases, have already affected a diverse set of physical and biological systems in many parts of the world. Allergens patterns are also changing in response to climate change and air pollution can modify the allergenic potential of pollen grains especially in the presence of specific weather conditions. Although genetic factors are important in the development of asthma and allergic diseases, their rising trend can be explained only by changes occurring in the environment and urban air pollution by motor vehicles has been indicated as one of the major risk factors responsible for this increase. Despite some differences in the air pollution profile and decreasing trends of some key air pollutants, air quality is an

important concern for public health in the cities throughout the world. Due to climate change, air pollution patterns are changing in several urbanized areas of the world with a significant effect on respiratory health. The underlying mechanisms of all these interactions are not well known yet. The consequences on health vary from decreases in lung function to allergic diseases, new onset of diseases, and exacerbation of chronic respiratory diseases. In addition, it is important to recall that an individual's response to pollution exposure depends on the source and components of air pollution, as well as meteorological conditions. Indeed, some air pollution-related incidents with asthma aggravation do not depend only on the increased production of air pollution, but rather on atmospheric factors that favor the accumulation of air pollutants at ground level. Associations between thunderstorms and asthma morbidity of pollinosis-affected people have also been identified in multiple locations around the world. A factor clouding the problem is that laboratory evaluations do not reflect what happens during natural exposition. Considering these aspects, governments worldwide, international organizations, and cooperation such as the World Health Organization (WHO) and the European Health Policy of the European Union (EU) are facing a growing problem of the respiratory effects induced by gaseous and particulate pollutants arising from motor vehicle emissions **(15)**.

Pulimood & al. (16) mentioned that after July 29, 2002, an epidemic of asthma admissions was associated with a thunderstorm in the United Kingdom. The cause of epidemics of asthma associated with thunderstorms was studied. A case-control study was performed of 26 patients presenting to Cambridge University Hospital with asthma after the thunderstorm. Control subjects were 31 patients with summer seasonal asthma. Subjects underwent skin tests and specific IgE serology to inhaled aeroallergens. Meteorologic and aerobiological data correlated with asthma admissions were analyzed. Twenty-three of 26 cases had IgE sensitization to Alternaria species. Eleven of 31 control subjects gave a history of asthma exacerbation during thunderstorms. Ten of these 11 control subjects were sensitive to Alternaria species on skin testing, but Alternaria species sensitivity was only identified in 4 of the 20 remaining control subjects who did not report thunderstorm-related asthma symptoms. The odds ratio of having epidemic thunderstorm-related asthma if sensitive to Alternaria species was 9.31 (95% CI 2.305-37.601; $p=0.0008$) and 63.966 (95% CI 3.577-1143.9; $p<0.0001$) if sensitive to Alternaria species, Cladosporium species, or both. Poisson regression analysis showed that counts of broken Alternaria species and Didymella and Cladosporium species were significantly correlated with each other and with asthma admissions. The thunderstorm was associated with increased levels of Alternaria, Cladosporium, and Didymella species. The data indicate that Alternaria alternata sensitivity is a compelling predictor of epidemic asthma in patients with seasonal asthma and grass pollen allergy and is likely to be the important factor in thunderstorm-related asthma. Alternaria species sensitization in asthmatic subjects with grass

pollen sensitivity predicts susceptibility to thunderstorm-associated asthma **(16)**.

Grinn-Gofroń & Strzelczak (17) mentioned that fungal spores are known to cause allergic sensitization. Recent studies reported a strong association between asthma symptoms and thunderstorms that could be explained by an increase in airborne fungal spore concentrations. Just before and during thunderstorms the values of meteorological parameters rapidly change. Therefore, the goal of this study was to create a predictive model for hourly concentrations of atmospheric Alternaria and Cladosporium spores on days with summer storms in Szczecin (Poland) based on meteorological conditions. For this study all days of June, July, and August (2004-2009) were chosen with convective thunderstorms. There were statistically significant relationships between spore concentration and meteorological parameters: positive for air temperature and ozone content while negative for relative humidity. In general, before a thunderstorm, air temperature and ozone concentration increased, which was accompanied by a considerable increase in spore concentration. During and after a storm, relative humidity increased while both air temperature ozone concentration along with spore concentrations decreased. Artificial neural networks (ANN) were used to assess forecasting possibilities. Good performance of ANN models in this study suggest that it is possible to predict spore concentrations from meteorological variables 2 h in advance and, thus, warn people with spore-related asthma symptoms about the increasing abundance of airborne fungi on days with storms **(17)**.

Campbell & al. (18) reported that epidemic thunderstorm asthma (ETA) is an emerging public health threat in Australia, highlighted by the 2016 event in Melbourne, Victoria, that overwhelmed health services and caused loss of life. However, there is limited understanding of the regional variations in risk. The public health risk of ETA in the nearby state of Tasmania was evaluated by quantifying the frequency of potential ETA episodes and applying a standardized natural disaster risk assessment framework. Using a case control approach, emergency presentations was analyzed in Tasmania's public hospitals from 2002 to 2017. Cases were defined as days when asthma presentations exceeded four standard deviations from the mean, and controls as days when asthma presentations were less than one standard deviation from the mean. Four controls were randomly selected for each case. Independently, a meteorologist identified the dates of potential high-risk thunderstorm events. No case days coincided with thunderstorms during the study period. ETA was assessed as a very low risk to the Tasmanian population, with these findings informing risk prioritization and resource allocation. This approach may be scaled and applied in other settings to determine local ETA risk. Furthermore, the identification of hazards using this method allows for critical analysis of existing public health systems **(18)**.

Matisoff & al. (19) mentioned that the downslope transport of rare earth element-tagged soil particles remobilized during a spring thunderstorm was studied on both a natural prairie and an

agricultural field in southwestern Iowa (U.S.A.). A technique was developed for tagging natural soils with the rare earth elements Eu, Tb, and Ho to approximately 1,000 ppm via coprecipitation with MnO2. Tagged material was replaced in target locations; surficial soil samples were collected following precipitation and runoff; and rare earth element concentrations were determined by inductively coupled plasma mass spectrometry. Diffusion and exponential models were applied to the concentration-distance data to determine particle transport distances. The results indicate that the concentration-distance data are well described by the diffusion model, but the exponential model does not simulate the rapid drop-off in concentrations near the tagged source. Using the diffusion model, calculated particle transport distances at all hillside locations and at both the cultivated and natural prairie sites were short, ranging from 3 to 73 cm during this single runoff event. This study successfully demonstrates a new tool for studying soil erosion **(19)**.

Cecchi & al. (20) reported that the so-called "thunderstorm asthma" (TA) is an uncommon but dramatic outbreak of asthma attacks occurring during a thunderstorm in the pollen and moulds season. Mechanisms which make the pollen able to enter the deeper airways and provoke severe asthma symptoms are still unclear. The objective was to test the hypothesis that sub-pollen particles (SPPs) originated from the rupture by an osmotic shock of pollen associated with TA contain allergens. After hydration, SPPs released from pollen grains of grass, pellitory, olive, cypress, ragweed and birch were isolated and determined by microscopy. Allergens were determined by in vitro ELISA inhibition tests indirectly using the sera from 10 polyreactive patients. An inhibition <50% was considered as negative, 50%-75% moderate and > 75% complete. The inhibition experiments showed that the SPPs from birch and cypress were unable to inhibit serum IgE reactivity to Bet v 1 and Cup a 1, respectively. Ragweed SPPs inhibited ragweed pollen extract and Amb a 1 by 75.8 ± 0.11% and 81.2 ± 0.15%, respectively. Olive and pellitory SPPs retained almost the whole IgE-binding capability in all cases tested. Grass SPPs inhibited 32 ± 0.06% of Lolium perenne Lol p 1 and 65% of Phleum pratense extracts, but results were highly variable for individual allergens (97.5%-0.03% for Phl p 2, 45.3 ± 0.12% for Phl p 5, 24.7 ± 0.22% for Phl p 6, and 38.3 ± 0.2% for Phl p 1). The data indicate that inhibition experiments confirm the hypothesis that SSPs obtained after the osmotic shock of pollen involved in TA, namely grass, pellitory and olive tree pollen, contain allergens and therefore they can induce severe asthma attacks during thunderstorms **(20)**.

Sultana & al. (21) identified risk factors for thunderstorm asthma (TA) in subjects ≥15 years of age from information available in routine clinical records. Retrospective and hospital-based case-control study of various clinical factors in all TA cases (n=53) who presented to a single-site ED in November 2016 (TA16) and in a control group of patients (n=156) who presented to the same ED with asthma during the pollen season over eight non-TA years. Bivariate analysis and multivariable logistic regression modelling were

performed to calculate the odds of TA asthma in the presence of potential risk factors. A logistic regression model revealed that the odds of TA were lower for age (odds ratio [OR] 0.97, 95% confidence interval [CI] 0.95-0.99), higher for Asian country of birth (OR 4.09, 95% CI 1.40-11.95) and higher for oral beta-blocker use (OR 6.43, 95% CI 1.58-26.33) compared to controls. No difference was found between TA16 cases and controls for allergies (to medication, grass pollen, animal), hayfever, smoking, oral non-steroidal anti-inflammatory drugs, or aspirin. Newly diagnosed asthma was higher in TA16 cases versus controls (32.1% vs 12.2%, p=0.001). The data indicate that oral beta-blocker medications, younger age and Asian-born heritage are risk factors for TA. Further study is required to explore the potential association between beta-blockers and TA **(21)**.

Gupta & al. (22) mentioned that a major characteristic of the hydrometeorology of semi-arid regions is the occurrence of intense thunderstorms that develop very rapidly and cause severe flooding. In summer, monsoon air mass is often of subtropical origin and is characterized by convective instability. The existing observational network has major deficiencies for those regions in providing information that is important to run-off generation. Further, because of the complex interactions between the land surface and the atmosphere, mesoscale atmospheric models are currently able to reproduce only general features of the initiation and development of convective systems. In the research, several interrelated components including the use of satellite data to monitor precipitation, data assimilation of a mesoscale regional atmospheric model, modification of the land component of the mesoscale model to better represent the semi-arid region surface processes that control run-off generation, and the use of ensemble forecasting techniques to improve forecasts of precipitation and run-off potential are investigated. This presentation discusses the ongoing research in this area; preliminary results including an investigation related to the unprecedented flash floods that occurred across the Las Vegas valley (Nevada, USA) in July of 1999 are discussed **(22)**.

Ščevková & al. (23) described a thunderstorm as a risk factor for severe respiratory allergy or asthma attacks in patients suffering from pollen/spore allergy. This study aimed to investigate the changes in the spectrum and quantity of pollen and fungal spores in the air of Bratislava during summer storms as well as the impact of selected environmental parameters on these changes. Pollen/spore samples were collected using a Burkard volumetric aero spore trap during summer 2016. To identify those types of pollen/spores that may harm human health during the storm episodes, the Authors analyzed how the concentration of individual bioparticles in the air changed during pre-storm/storm/post-storm periods. The effect of environmental variables on the concentration of selected pollen/spore types was evaluated through Spearman's correlation analysis. The results of the study suggest that thunderstorm-related respiratory allergy symptoms in the study area may be caused by 1] spores of Myxomycetes, the airborne concentration of which increases due to an increase in wind speed during the pre-storm

period; 2] ruptured pollen and Diatripaceae spores, the concentration of which increases due to increase in precipitation and relative air humidity, respectively, during the storm period; and 3] spores of Fusarium and Leptosphaeria, the concentration of which increases due to increase in precipitation and air temperature, respectively, during the post-storm period **(23)**.

Dales & al. (24) documented the existence and investigate the etiology of "thunderstorm asthma," which has been reported sporadically over the past 20 years. The relationship was assessed between thunderstorms, air pollutants, aeroallergens, and asthma admissions to a children's hospital emergency department over a 6-year period. During thunderstorm days (n=151 days) compared to days without thunderstorms (n=919 days), daily asthma visits increased from 8.6 to 10 ($p<0.05$), and air concentrations of fungal spores doubled (from 1,512 to 2,749/m(3)), with relatively smaller changes in pollens and air pollutants. Daily time-series analyses across the 6 years of observation, irrespective of the presence or absence of thunderstorms, demonstrated that an increase in total spores, equivalent to its seasonal mean, was associated with a 2.2% (0.9% SE) increase in asthma visits. The results support a relationship between thunderstorms and asthma and suggest that the mechanism may be through increases in spores that exacerbate asthma. Replication in other climates is suggested to determine whether these findings can be generalized to other aeroallergen mixes **(24)**.

Xie & al. (25) emphasized that seasonal allergic asthma prevalence has been increasing over the last decades and is one of global health concerns now. Pollen is one of the main reasons to cause seasonal allergic asthma and influenced by multiple risk factors. Thunderstorm-related asthma is a typical type of seasonal allergic asthma that thunderstorms occurring can induce severe asthma attacks during pollen season. The diagnosis of seasonal allergic asthma relies on precise medical history, skin prick tests (SPT) and specific IgE detection. Component resolved diagnosis is greatly significant in determining the complex situation. Allergen specific immunotherapy (AIT) is the only disease-modifying therapy that can change the natural course from seasonal allergic rhinitis to seasonal allergic asthma **(25).**

Rabe (26) noticed that Alternaria alternata spores are important allergens causing "hayfever". Outdoor fungal exposure is primarily associated with increased asthma symptoms and increased risk of asthma exacerbations. In the outpatient-clinic, patients who presented with symptoms of allergic conjunctivitis and respiratory symptoms were investigated in the summertime. A sensitization to Alternaria alternata was found in about 6% of the investigated patients. Especially in children and teenagers, the sensitization is clinically important. The spores of Alternaria alternata are responsible for the development and persistence of nonspecific airway hyperresponsiveness and in a group of patients also for a difficult-to-treat asthma in the summer. We should always bear in mind that prolonged symptoms (after end of June) in grass pollen allergic patients might be caused by additional sensitization to

Alternaria alternata spores or mugwort pollen. In the patients, the Authors were able to show a sensitization to Alternaria alternata in grass pollen allergic patients rather frequently. In the summertime, high counts of Alternaria spores and pollen often appear simultaneously. The findings show a considerable effect of Alternaria sensitization on the asthma morbidity and exacerbations. In this article it is referred to the necessity of keeping a patient diary of allergic symptoms and the importance of information from regional pollen traps about the counts of pollen and Alternaria spores. Only then we will be able to differentiate, which allergen is responsible for the severe "hay fever", especially in patients with severe asthma episodes. Before the start of a specific immunotherapy with Alternaria alternata it is recommended to perform a mucosal provocation test, to prove the clinical significance of the sensitization. It has been shown that also in Germany, there are high counts of Alternaria spores in the summer. The results of the pollen and alternaria count in the year 2009, measured in the regional pollen trap (Treuenbrietzen), are shown in Abb. 1, 2, 3, 4, 5. Broken Alternaria spores were also found. They are associated with increased asthma exacerbations and appear often during thunderstorms and harvesting. An allergen-specific immunotherapy with Alternaria alternata is a safe treatment and it is effective in improving respiratory function. The safety and efficacy is comparable to the one found in the allergen-specific immunotherapy with pollen **(26)**.

Taylor & Jonsson (27) emphasized that thunderstorms have often been linked to epidemics of asthma, especially during the grass flowering season; however, the precise mechanisms explaining this phenomenon are unknown. Evidence of high respirable allergen loadings in the air associated with specific meteorologic events combined with an analysis of pollen physiology suggests that rupture of airborne pollen can occur. Strong downdrafts and dry, cold outflows distinguish thunderstorm rain from frontal rain. The weather system of a mature thunderstorm likely entrains grass pollen into the cloud base, where pollen rupture would be enhanced, then transports the respirable-sized fragments of pollen debris to ground level where outflows distribute them ahead of the rain. The conditions occurring at the onset of a thunderstorm might expose susceptible people to a rapid increase in concentrations of pollen allergens in the air that can readily deposit in the lower airways and initiate asthmatic reactions **(27)**.

Marks & al. (28) mentioned that a study was undertaken to assess the importance of thunderstorms as a cause of epidemics of asthma exacerbations and to investigate the underlying mechanism. A case control study was performed in six towns in south eastern Australia. Epidemic case days (n=48) and a random sample of control days (n=191) were identified by reference to the difference between the observed and expected number of emergency department attendances for asthma. The occurrence of thunderstorms, their associated outflows and cold fronts were ascertained, blind to case status, for each of these days. In addition, the relation of hourly

pollen counts to automatic weather station data was examined in detail for the period around one severe epidemic of asthma exacerbations. The main outcome measure was the number of epidemics of asthma exacerbations. Thunderstorm outflows were detected on 33% of epidemic days and only 3% of control days (odds ratio 15.0, 95% confidence interval 6.0 to 37.6). The association was strongest in late spring and summer. Detailed examination of one severe epidemic showed that its onset coincided with the arrival of the thunderstorm outflow and a 4-12-fold increase in the ambient concentration of grass pollen grains. These findings are consistent with the hypothesis that some epidemics of exacerbations of asthma are caused by high concentrations of allergenic particles produced by an outflow of colder air, associated with the downdraught from a thunderstorm, sweeping up pollen grains and particles and then concentrating them in a shallow band of air at ground level. This is a common cause of exacerbations of asthma during the pollen season **(28)**.

Wark & al. (29) mentioned that epidemics of acute asthma associated with thunderstorms occur intermittently worldwide, though airway inflammation during these acute episodes has not been characterized. The aim of this study was to characterize airway inflammation in thunderstorm asthma. Cases were recruited after presentation to the emergency room with acute asthma immediately following a thunderstorm (n=6). They were compared to two control groups: a group of atopic asthmatics that had presented with acute asthma to the emergency room prior to the thunderstorm (n=12), and a second group of corticosteroid naive asthmatics who presented to the emergency room in the prior 12 months (n=6). Subjects had spirometry, sputum induction and allergy skin tests acutely and at review 4 weeks later. Thunderstorm (TS) cases were more likely to have a history of hay fever and grass pollen allergy, and less likely to be on inhaled corticosteroids (ICS) prior to presentation. Cases and control groups had a similar degree of moderate to severe acute airway obstruction (p=1.0). TS cases had elevated sputum eosinophils (14.8% of total cell count) compared to controls (1%, 2.6%, p<0.01). TS cases had higher sputum eosinophil cationic protein (ECP; 11,686 ng/mL) compared to controls (1,883, 3,300, p=0.02) acutely. TS cases had more cells positive for IL-5 (30%) compared to controls (1, 1.5%, p=0.02). When adjusted for ICS use, TS cases had a risk ratio for elevated sputum eosinophils of 2.4 (1.23-4.69). The data indicate that thunderstorm asthma is characterized by airway inflammation with IL-5-mediated sputum eosinophilia and eosinophil degranulation. These results are consistent with allergen exposure as the cause of the exacerbation and are consistent with the thunderstorm-induced grass pollen deluge as the cause of epidemic asthma after thunderstorms **(29)**.

References

1. Harun NS, Lachapelle P, Douglass J. Thunderstorm-triggered asthma: what we know so far. J Asthma Allergy. 2019;12:101-8.

2. Higham J, Venables K, Kupek E, Bajekal M. Asthma and thunderstorms: description of an epidemic in general practice in Britain using data from a doctors' deputising service in the UK. J Epidemiol Community Health. 1997;51(3):233-8. Erratum in J Epidemiol Community Health. 1998;52(5):340.

3. D'Amato G, Vitale C, D'Amato M, et al. Thunderstorm-related asthma: what happens and why. Clin Exp Allergy. 2016;46(3):390-6.

4. Abbott TH, Cronin TW. Aerosol invigoration of atmospheric convection through increases in humidity. Science. 2021;371(6524):83-5.

5. Douglass JA. How can air quality affect health? Intern Med J. 2020;50(11):1403-4.

6. D'Amato M, Annesi-Maesano A, Molino A, et al. Thunderstorm and asthma outbreaks during pollen season. Epidemiol Prev. 2017;41(3-4):208-11.

7. D'Amato G, Annesi-Maesano I, Urrutia-Pereira M, et al. Thunderstorm allergy and asthma: state of the art. Multidiscip Respir Med. 2021 Dec 2;16(1):806.

8. D'Amato G, Liccardi G, Frenguelli G. Thunderstorm-asthma and pollen allergy. Allergy. 2007;62(1):11-6.

9. Al-Rubaish AM. Thunderstorm-associated bronchial asthma: a forgotten but very present epidemic. J Family Community Med. 2007;14(2):47-51.

10. Sabih A, Russell C, Chang CL. Thunderstorm-related asthma can occur in New Zealand. Respirol Case Rep. 2020;8(7):e00655.

11. D'Amato G, Annesi-Maesano I, Vaghi A, et al. How do storms affect asthma? Curr Allergy Asthma Rep. 2018 Mar 24;18(4):24.

12. Clayton-Chubb D, Con D, Rangamuwa K, et al. Thunderstorm asthma: revealing a hidden at-risk population. Intern Med J. 2019; 49(1):74-78.

13. D'Amato G, Annesi-Maesano I, Urrutia-Pereira M, et al. Thunderstorm allergy and asthma: state of the art. Multidiscip Respir Med. 2021 Dec 2;16(1):806.

14. Dabrera G, V Murray V, Emberlin, J & al. Thunderstorm asthma: an overview of the evidence base and implications for public health advice QJM. 2013;106(3):207-17.

15. D'Amato G, Bergmann KC, Lorenzo Cecchi L, et al. Climate change and air pollution: effects on pollen allergy and other allergic respiratory diseases. Allergo J Int. 2014;23(1):17-23.

16. Pulimood TB, Corden JM, Bryden C, et al. Epidemic asthma and the role of the fungal mold Alternaria alternata. J Allergy Clin Immunol. 2007;120(3):610-7.

17. Grinn-Gofroń A, Strzelczak A. Changes in concentration of Alternaria and Cladosporium spores during summer storms. Int J Biometeorol. 2013;57(5):759-68.

18. Campbell SL, Fox-Hughes PD, Jones PJ, et al. Evaluating the risk of epidemic thunderstorm asthma: lessons from Australia. Int J Environ Res Public Health. 2019 Mar 7;16(5):837.

19. Matisoff G, Ketterer ME, Wilson CG, et al. Transport of rare earth element-tagged soil particles in response to thunderstorm runoff. Environ Sci Technol. 2001;35(16):3356-62.

20. Cecchi L, Scala E, Caronni S, et al. Allergenicity at component level of sub-pollen particles from different sources obtained by osmolar shock: a molecular approach to thunderstorm-related asthma outbreaks. Clin Exp Allergy. 2021;51(2):253-61.

21. Sultana RV, McKenzie DP, Fahey MT, et al. Beta-blocker use is an independent risk factor for thunderstorm asthma. Emerg Med Australas. 2019;31(6):955-60.

22. Gupta H, Sorooshian S, Gao X et al. The challenge of predicting flash floods from thunderstorm rainfall. Philos Trans A Math Phys Eng Sci. 2002;360(1796):1363-71.

23. Ščevková J, Dušička J, Tropeková M, Kováč J. Summer storms and their effects on the spectrum and quantity of airborne bioparticles in Bratislava, Central Europe. Environ Monit Assess. 2020 Jul 21;192(8):537.

24. Dales RE, Cakmak S, Judek S, et al. The role of fungal spores in thunderstorm asthma. Chest. 2003;123(3):745-50.

25. Xie Z-J, Guan K, Yin J. Advances in the clinical and mechanism research of pollen induced seasonal allergic asthma. Am J Clin Exp Immunol. 2019;8(1):1-8.

26. Rabe U. Are fungal spores relevant outdoor allergens? Laryngorhinootologie. 2020;99(5):292-8.

27. Taylor PE, Jonsson H. Thunderstorm asthma. Curr Allergy Asthma Rep. 2004;4(5):409-13.

28. Marks GB, Colquhoun JR, Girgis ST, et al. Thunderstorm outflows preceding epidemics of asthma during spring and summer. Thorax. 2001;56(6):468-71.

29. Wark PAB, Simpson J, Hensley MJ, Gibson PG. Airway inflammation in thunderstorm asthma. Clin Exp Allergy. 2002;32(12): 1750-6.

ASTHMA AND LEUKEMIA

According to **Redmayne (1)**, thunderstorm asthma and increased childhood leukemia risk near high-voltage power lines (HVPL) are occurrences whose mechanism of effect is not fully understood. This paper proposes and discusses a key similarity: both thunderstorms and HVPL generate a high enough electrical field in the environment to ionize nearby air and air-borne particles. It is argued that the repeatedly demonstrated acute asthma response to pollen-laden air during thunderstorms is largely due to ionization of air-borne allergens, which adhere more readily and in greater quantity in the lungs than non-ionized particles. If these bind to mucous or phagocytic cells, it would enhance immune response. A rapid temperature drop, and high ozone also seem to be drivers of thunderstorm asthma. This causal nexus provides strong support for the parallel situation of prolonged exposure to ionized particles near HVPL and an increased rate of childhood leukemia. Here, it is proposed that upwind carcinogens are ionized when passing HVPL and then residential and business areas. Published evidence for most steps are presented but have not previously been published as a coherent whole, nor has it been suggested that the inhaled ionized micro-particle explanation for acute asthma may also explain development of childhood leukemia over time. The demonstrated series of events leading to increased deposition and retention of ionized particles in airways provides support for explaining both adverse health outcomes: acute thunderstorm asthma and increased risk of childhood leukemia near HVPL. Further support for this

explanation of both outcomes is provided by effects of on-going proximity to highways **(1)**.

Reference

1. Redmayne M. A proposed explanation for thunderstorm asthma and leukemia risk near high-voltage power lines: a supported hypothesis. Electromagn Biol Med. 2018;37(2):57-65.

SPONTANEOUS PNEUMOTHORAX

Bertolaccini & al. (1) mentioned that primary spontaneous pneumothorax (PSP) tends to cluster. Previous studies have found a correlation between PSP and atmospheric pressure variations or thunderstorms. This study was conducted to analyze the PSP correlations with meteorological variables and the concentrations of air pollutants in the city of Cuneo in Italy (IT). Totally, 451 consecutive PSP patients treated between 2004 and 2010 were evaluated prospectively. For each day within the period analyzed, the meteorological parameters and pollutants data were recorded. Statistical analyses on PSP were done for distribution characteristics, spectral autocorrelation, and spectral analysis. Multivariate regression analyses were performed using artificial neural networks. Analysis of annual, seasonal, and monthly distributions showed no significant correlation between PSP and the time series. The spectral analysis showed that PSP events were not random. Correlations between meteorological and environmental variables confirmed that PSP was significantly more likely to occur on warm windy days with high atmospheric pressure and high mean nitrogen dioxide concentration. The data indicate that meteorological parameters and atmospheric pollutants might explain the cluster onset of PSP **(1)**.

Poole & Erickson (2) mentioned that as the Thoroughbreds race for the final stretch, 44 hooves flash and thunder creating a cacophony of tortured air and turf. Orchestrated by selective breeding for physiology and biomechanics, expressed as speed, the millennia-old symphony of man and beast reaches its climax. At nearly 73 kilometers per hour (45 mph) over half a ton of flesh and bone dwarfs its limpet-like jockey as, eyes wild and nostrils flaring, their necks stretch for glory. Beneath each resplendent livery-adorned, latherin-splattered coat hides a monstrous heart trilling at 4 beats per second, and each minute, driving over 400 L (105 gallons) of oxygen-rich blood from lungs to muscles. Matching breath to stride frequency, those lungs will inhale 16 L (4 gallons) of air each stride moving >1,000 L/min in and out of each nostril - and yet failing. Engorged with blood and stretched to breaking point, those lungs can no longer redden the arterial blood but leave it dusky and cyanotic. Their exquisitely thin blood-gas barrier, a mere 10.5 µm thick (1/50,000 of an inch), ruptures, and red cells invade the lungs. After the race is won and lost, long after the frenetic crowd has quieted and gone, that blood will clog and inflame the airways. For a few horses, those who bleed extensively, it will overflow their lungs and spray from their nostrils incarnadining the walls of their stall: a

horrifically poignant canvas that strikes at horse racing's very core. That exercise-induced pulmonary hemorrhage (EIPH) occurs is a medical and physiological reality. That every reasonable exigency is not taken to reduce/prevent it would be a travesty. This review is not intended to provide an exhaustive coverage of EIPH for which the reader is referred to recent reviews, rather, after a brief reminder of its physiologic and pathologic bases, focus is brought on the latest developments in EIPH discovery as this informs state-of-the-art knowledge, the implementation of that knowledge and recommendations for future research and treatment **(2)**.

References

1. Bertolaccini L, Viti A, Boschetto L, et al. Analysis of spontaneous pneumothorax in the city of Cuneo: environmental correlations with meteorological and air pollutant variables. Surg Today. 2015;45(5):625-9.

2. Poole DC, Erickson HH. Exercise-induced pulmonary hemorrhage: where are we now? Vet Med (Auckl). 2016;7:133-48.

SUBARACHNOID HEMORRAGE

Beseoglu & al. (1) reported that a number of publications suggest that there are seasonal influences on the incidence of subarachnoid hemorrhage (SAH). Most series agree on a peak incidence during springtime. Meteorological influences have been assumed to be obvious explanations for seasonal variations. Furthermore, the perceived clustering of the incidence of subarachnoid hemorrhage is also intuitively related to meteorological influences. The present study was initiated to determine whether specific meteorological conditions are related to the occurrence of SAH in the mild climatic zone of North Rhine Westphalia. The Authors retrospectively examined 183 patients (107 women and 76 men) treated at the department between January 2003 and June 2005 for SAH that had occurred within the Düsseldorf metropolitan area. The date of SAH (Day 0) and of the week preceding the incident (Days -1, -3, -5, and -7) were correlate with the meteorological key parameters from Düsseldorf International Airport. Parameters analyzed were mean daily temperature (7C), relative humidity (%), barometric pressure (hPa), and weather condition (divided into 6 groups: clear, cloudy, rain, thunderstorms, snow, and not available). A relative peak incidence of SAH was found for the month of April. In addition, a diurnal rhythm with two peaks during morning and in the evening, and a statistically significant nadir during forenoon and midday was evident ($p<0.002$). None of the average meteorological key parameters of the day of SAH differed from the annual average, and no general trends during the days preceding hemorrhage could be identified. Apparent clustering of the occurrence of SAH could not be related to short-term meteorological trends. The results of the present study demonstrate a trend toward a seasonal distribution in the incidence of SAH with a peak during spring in the metropolitan area of Düsseldorf. Furthermore, weather variables, such as temperature, barometric pressure, and humidity, were shown to be

without influence on aneurysm rupture within the patient population. Therefore, the result indicates the need to validate further parameters in detail to isolate risk circumstances to achieve a risk pattern for patients with SAH **(1)**.

Reference

1. Beseoglu K, Hänggi D, Stummer W, Hans-Jakob Steiger H-J. Dependence of subarachnoid hemorrhage on climate conditions: a systematic meteorological analysis from the Dusseldorf metropolitan area. Neurosurgery. 2008;62(5):1033-8; discussion 1038-9.

SUICIDE ATTEMPTS

Breuer & al. (1) analyzed a sample of 151 patients, admitted to an Intensive Care Unit after attempted suicide by poisoning with regard to age, drugs consumed, possible causal factors and influence of weather. The German Weather Service provided the meteorological data. Mean age of the patients was 37.6 years. The patients had taken barbiturates, aggressive chemicals, tranquillizers, or a combination of drugs (47%). Alcohol had been taken in addition to the drugs in 24%, which might indicate a trigger function. The main provoking causes for the suicide attempts were conflicts in partnerships and occupational problems. Some 15% of the patients had previously diagnosed psychiatric disorders. There was a significant positive correlation between the time of attempted suicide and the weather parameters "stable upslide, labile upslide, fog, thunderstorm, warm air, upslide and weather drier than on the 2 preceding days". Significantly fewer attempts than expected occurred with "low pressure and trough situation, labile ground layer-upslide above, subsidence or downslide motion". Apart from individual provoking factors, such as the reaction to conflicts and the spectrum of reactions, exogenous factors like weather must be considered as important for the timing of suicide attempts. These results may be of relevance for suicide prevention **(1)**.

Trepińska et al. (2) presented a certain biometeorological problem. The evaluation of influence of weather factors on frequency of suicidal cases by hanging in the area of Cracow City during 1991-2002 was examined. Rapid changes of air pressure, air temperature, hot, sweltering, and sultry days, very frosty days, days with strong or foehn wind, days with thunderstorms, fog and haze were selected as unfavorable weather factors. They give an occasion for strong psychical stress. The results of detailed investigations are next: more frequency of cases of suicide during the advance of cold fronts, rapid decreases of air pressure during hot, sweltering, and sultry days, days with thunderstorms and foehn winds in the Tatra Mountains **(2)**.

Breuer & al. (3) analyzed retrospectively 151 patients, admitted to an intensive care unit after attempted suicide, the possible influence of weather at the time of the attempt. The "biosynoptic daily analysis" of the German Weather Service provided the weather data. There was a 5% and 1%, respectively, significant level for the positive

correlation between the time of the attempted suicide and the weather parameters "stable upslide, labile upslide, fog and thunderstorm" and the summarized parameters "warm air, upslide and weather drier than on the two preceding days". Significantly fewer attempts than expected occurred when the weather description was "low pressure and trough situation, labile ground layer - upslide above" and the summarized parameters "subsidence or downslide motion". Besides the individual factors such as the reaction to conflicts and the spectrum of reactions, exogenous factors like weather must be considered as important for the time of suicidal attempt **(3).**

References

1. Breuer HW, Breuer J, Fischbach-Breuer BR. Social, toxicological and meteorological data on suicide attempts. Eur Arch Psychiatry Neurol Sci. 1986;235(6):367-70.

2. Trepińska J, Piotrowicz K, Bakowski R, et al. Influence of weather factors on suicidal hangings. Przegl Lek. 2005;62(8):788-94.

3. Breuer HW, Fischbach-Breuer BR, Breuer J, et al. Suicide and weather. Dtsch Med Wochenschr. 1984;109(45):1716-20.

GENERAL PRACTICE PERSPECTIVE

Farouque & al. (1) reported that Thunderstorm asthma (TA) epidemics have been recognized globally as a rare phenomenon, producing a rapid surge of acute asthma presentations leading to an increased demand on emergency medical services and healthcare resources. General practitioners (GPs) are well placed in the community to contribute to healthcare during TA epidemics and similar disaster events. The aim of this review was to synthesize current evidence of the experiences of GPs during TA epidemics and similar surge events. A comprehensive systematic search of eleven electronic databases, including ancestry searching for peer-reviewed studies and grey literature published in English was conducted. Quantitative and qualitative study designs were included, and a quality assessment conducted. Of the 125 records identified, 16 were included for synthesis. During TA epidemics and surge events, GPs experience an increased demand for services, yet it is not known if general practice clinics experience resource limitations from this patient surge. While GPs express a willingness to help, few structures are in place to liaise, support and provide information to GPs during surge events. Following most surge/disaster events, no GP data is collected so it is not known how to improve coordination and communication between general practice services and emergency services. GPs have well-functioning adaptive management systems, and resources of space, supplies and staff thus the ability to increase surge capacity of their clinics **(1)**.

Hajat & al. (2) mentioned that evidence shows that asthma attacks can be brought on by adverse weather conditions such as those experienced during a thunderstorm; a prime example of such an occasion being a thunderstorm episode on 24 June 1994, which

resulted in a well-documented increase in medical attendances made by those suffering with asthma and respiratory disorders. However, most of these studies have concerned admissions to accident and emergency departments. The aim of this paper was to ascertain whether a similar increase in consultations was observed in the primary care setting **(2)**.

References

1. Farouque A, Walker R, Erbas B. Thunderstorm asthma epidemic-a systematic review of the general practice perspective. Int J Environ Res Public Health. 2020 May 27;17(11):3796.

2. Hajat S, Goubet SA, Haines A. Thunderstorm-associated asthma: the effect on GP consultations. Br J Gen Pract. 1997;47(423):639-41.

COMMUNITY RESPONSES

AlQuran & al. (1) reported that the most severe thunderstorm asthma (TA) event occurred in Melbourne on the 21st November 2016 and during this period, daily pollen information was available and accessible on smart devices via an App. An integrated survey within the App allows users to self-report symptoms. The objective was to explore patterns of symptom survey results during the period when the TA event occurred. Symptom data from the Melbourne Pollen Count and Forecast App related to asthma history, hay fever symptoms, and medication use was explored. A one-week control period before and after the event was considered. Chi-square tests and logistic regression were used to assess associations between sex, age, symptoms, and medication use. Of the 28,655 responses, during the 2016 pollen season, younger (18 to 40 years) males, with no hay fever and no asthma were the most single and regular responders. During the TA event for new users, sex was only significantly associated with hay fever (p=0.008) of which 60.2% of females' responses reported having hay fever, while 43% of males' responses did not. Those with mild symptoms peaked during the TA event. The data indicate that many individuals completed the survey on the app for the first time during the TA event indicating the potential of digital technologies to be used as indicators of health risk among populations at risk of TA events **(1)**.

Reference

1. AlQuran A, Batra M, Susanto NH, et al. Community response to the impact of thunderstorm asthma using smart technology. Allergy Rhinol (Providence). 2021 Apr 26;12:21526567211010728.

MANAGEMENT

Chatelier & al. (1) mentioned that epidemic thunderstorm asthma (ETSA) occurs following a thunderstorm due to the interaction of environmental and immunologic factors. Whilst first reported in the 1980s, the world's largest event in Melbourne, Australia, on November 21, 2016, has led to a wealth of clinical literature seeking

to identify its mechanisms, susceptibility risk factors, and management approaches. Thunderstorm asthma (TA) typically presents during an aeroallergen season in individuals sensitized to perennial rye grass pollen (RGP) in Australia, or fungus in the United Kingdom, in combination with meteorological factors such as thunderstorms and lightning activity. It is now well recognized that large pollen grains, which usually lodge in the upper airway causing seasonal allergic rhinitis (SAR), are ruptured during these events, leading to sub-pollen particles respirable to the lower respiratory tract causing acute asthma. The identified risk factors of aeroallergen sensitization, specifically to RGP in Australians with a history of SAR, and individuals born in Australia of South-East Asian descent as a risk factor for TA has been key in selecting appropriate patients for preventative management. Moreover, severity-determining risk factors for ETSA-related asthma admission or mortality, including pre-existing asthma or prior hospitalization, poor inhaled corticosteroid adherence, and outdoor location at the time of the storm are important in identifying those who may require more aggressive treatment approaches. Basic treatments include optimizing asthma control and adherence to inhaled corticosteroid therapy, treatment of SAR, and education regarding TA to increase recognition of at-risk days. Precision treatment approaches may be more beneficial in select individuals, including the use of allergen immunotherapy and even biologic treatment to mitigate asthma severity. Finally, the importance of environmental health literacy was discussed in the context of concerns surrounding the increased frequency of ETSA due to climate change and its implications for the frequency and severity of future events **(1)**.

Thien & al. **(2)** described epidemic thunderstorm asthma (ETSA) is due to a complex interaction of environmental and individual susceptibility factors, with outbreaks reported globally over the last four decades. Australia has been particularly susceptible with nearly half of episodes reported internationally, culminating in the catastrophic Melbourne 2016 event. Reported ETSA episodes are reviewed for common environmental and meteorological risk factors. Allergen aerobiology interaction with thunderstorm activity and rapid weather condition changes is examined. Assessment of the clinical and immunological data highlights risk factors for ETSA presentation, hospital admission, and intensive care admission. Risk factors associated with ETSA deaths are evaluated. Public health strategies, as well as pharmacological and immunological management approaches to reduce individual susceptibility and prevent ETSA are discussed. Improved understanding of the specific meteorological factors predisposing to the greatest risk of ETSA to improve forecasting is required. Better monitoring of aeroallergen levels in areas of greatest geographic risk, with further research into allergen aerobiology underpinning mechanisms of allergen exposure is needed. The role of climate change in increasing the risk of ETSA outbreaks requires further research. Public awareness and education are required to reduce exposure, and to improve uptake of

pharmacological and immunological risk reduction and preventive strategies **(2)**.

Farouque & al. (3) wanted to understand the challenges faced by general practice (GP) services in terms of personnel, materials, secondary support services, and discharge and communication obstacles during the thunderstorm asthma (TA) epidemic in 2016. This was a qualitative study using semi-structured interviews and focus groups between September and October 2017. Participants were general practitioners (GPs), practice nurses, and administrative staff working on the TA epidemic days in the northern region of Melbourne, Australia. Eighteen participants contributed to the study from six clinic sites. Both daytime and evening clinics experienced a surge in respiratory patient presentations. After-hours clinics were inundated with asthma patients during the night of the thunderstorm. Consistent themes emerged about the challenges encountered by participants the most significant being limitation of medication, equipment, space, and personnel. The extraordinary influx of patients necessitated participants innovate solutions including recycling equipment, procuring medications from hospitals and community pharmacies, triage, altering management strategies and extending clinic hours. Participants were limited by the paucity of information from local services during the TA epidemic. This study supports the view that GP services made a substantial contribution to the emergency response on the evening of the TA epidemic that occurred in Melbourne in 2016. Demands on resources were considerable during and after the epidemic yet GP staff showed great resilience increasing clinic surge capacity. The findings indicate significant barriers at an organizational level including resource limitations, inadequate operational information, and the absence of timely communication channels that impaired the response of GP services during a TA event **(3).**

References

1. Chatelier J, Chan S, Tan JA, et al. Managing exacerbations in thunderstorm asthma: current insights. J Inflamm Res. 2021 Sep 8; 14:4537-50.

2. Thien F, Davies JM, Hew M, et al. Thunderstorm asthma: an overview of mechanisms and management strategies. Expert Rev Clin Immunol. 2020;16(10):1005-17.

3. Farouque AS, Walker R, Erbas B. Thunderstorm asthma epidemic - management challenges experienced by general practice clinics. J Asthma. 2021;58(4):423-9.

LIGHTNING

MECHANISMS OF DEVELOPMENT

Rison & al. (1) mentioned that a long-standing but fundamental question in lightning studies concerns how lightning is initiated inside storms, given the absence of physical conductors. The issue has revolved around the question of whether the discharges are initiated

solely by conventional dielectric breakdown or involve relativistic runaway electron processes. Here, observations are reported of a relatively unknown type of discharge, called fast positive breakdown, that is the cause of high-power discharges known as narrow bipolar events. The breakdown is found to have a wide range of strengths and is the initiating event of numerous lightning discharges. It appears to be purely dielectric in nature and to consist of a system of positive streamers in a locally intense electric field region. It initiates negative breakdown at the starting location of the streamers, which leads to the ensuing flash. The observations show that many or possibly all lightning flashes are initiated by fast positive breakdown **(1).**

Update on ignitia's thunderstorm tracker.
ignitia.se|1000 × 501 jpeg.

Chilingarian & al. (2) mentioned that the relationship of lightning and elementary particle fluxes in the thunderclouds is not fully understood to date. Using the particle beams (the so-called Thunderstorm Ground Enhancements - TGEs) as a probe the characteristics of the interrelated atmospheric processes were investigate. The well-known effect of the TGE dynamics is the abrupt termination of the particle flux by the lightning flash. With new precise electronics, it can be seen that particle flux decline occurred simultaneously with the rearranging of the charge centers in the cloud. The analysis of the TGE energy spectra before and after the lightning demonstrates that the high-energy part of the TGE energy spectra disappeared just after lightning. The decline of particle flux coincides on millisecond time scale with first atmospheric discharges and can be conclude that Relativistic Runaway Electron Avalanches (RREA) in the thundercloud assist initiation of the negative cloud to ground lightning. Thus, RREA can provide enough ionization to play a significant role in the unleashing of the lightning flash **(2)**.

Almendarez & al. (3) emphasized that the prevalence rates of diabetes in communities of color are higher than in Caucasian populations. Social marketing can be an effective approach to educating communities and encouraging visits to health care providers. This article describes Thunder and Lightning and Rain, a diabetes media awareness campaign implemented in a 5-county area in central Washington State with a large Latino/Hispanic population.

The Washington State Department of Health's Diabetes Prevention and Control Program, along with national and community partners and focus groups, used a social marketing model to reach those with uncontrolled diabetes. A telephone survey-based evaluation, conducted in Spanish, provided data on demographics, media access, calls to a toll-free information line, provider visits, and recall of the campaign's central message: "Control your diabetes. For Life" **(3).**

Friday & al. (4) mentioned that known since antiquity, ball lightning is a natural, long-lived plasma-like phenomenon associated with thunderstorms and is not well understood due to its rarity and unpredictability. A recently discovered laboratory phenomenon with striking similarity to ball lightning is observed when a high-power spark is discharged from a cathode protruding from a grounded electrolyte solution. Whereas several investigations of these long-lived plasmas have been reported over the past decade, the underlying chemical and physical processes are still unknown. The present work attempts to gain further insight into this phenomenon by examining the effect of electrolyte pH on the plasmoid and observing the chemical and physical structure of the plasmoid using high-speed schlieren videography and FTIR absorption spectroscopy. The results indicate that the lifetime and size of the plasmoid slightly increase as the pH of isoohmic electrolyte solutions deviate from neutrality. The observed absorption spectra of the plasmoids exhibit absorption cross sections in the 620-700, 1500-1560, 2280-2390, and 3650-4000 cm(-1) ranges, the last attributed to the presence of water clusters. Finally, schlieren images revealed a single, sharp density gradient at the boundary layer of the top and sides of the expanding ball-shaped plasmoid, and turbulent mixing below the ball **(4)**.

Fill & al. (5) noticed that trends in average annual or seasonal precipitation are insufficient for detecting changes in the climatic fire season, especially in regions where the fire season is defined by wet-dry seasonal cycles and lightning activity. Using an extensive dataset (1897-2017) in the Coastal Plain of the southeastern United States, we examined changes in annual dry season length, total precipitation, and (since 1945) the seasonal distribution of thunder-days as a correlate of lightning activity. across the entire region, the dry season has lengthened by as much as 156 days (130% over 120 years), both starting earlier and ending later with less total precipitation. Less rainfall over a longer dry season, with no change in seasonal thunderstorm patterns, likely increases both the potential for lightning-ignited wildfires and fire severity. Global climate change could be having a hitherto undetected influence on fire regimes by altering the synchrony of climatic seasonal parameters **(5)**.

Hunt (6) described a dataset of videos of lightning flashes to and around a tall tower (the Brixton tower) in Johannesburg, South Africa. The videos were collected during the 2015-2016 South African thunderstorm season and a total of 3623 .mp4 videos are available in the dataset. Three different cameras were used, two in a similar location and the third at a different location giving a 90-degree perspective. Each video is timestamped and labelled depending on the type of event seen (attachment to the tower,

nearby the tower, far from the tower, intracloud etc.). This dataset provides ground-truth, timestamped evidence of lightning events a known location and of differing types and can benefit atmospheric research scientists as well as lightning detection operators, particularly with regards to evaluating detection networks operating in the area. As the dataset contains a significant number of labelled videos, it also of use to pattern or image recognition supervised machine learning techniques and researchers **(6).**

According to **Montanyà & al. (7)**., lightning flashes are known to initiate in regions of strong electric fields inside thunderstorms, between layers of positively and negatively charged precipitation particles. For that reason, lightning inception is typically hidden from sight of camera systems used in research. Other technology such as lightning mapping systems based on radio waves can typically detect only some aspects of the lightning initiation process and subsequent development of positive and negative leaders. It is reported here a serendipitous recording of bidirectional lightning initiation in virgin air under the cloud base at ~11,000 images per second, and the differences in characteristics of opposite polarity leader sections during the earliest stages of the discharge. This case reveals natural lightning initiation, propagation, and a return stroke as in negative cloud-to-ground flashes, upon connection to another lightning channel - without any masking by cloud **(7)**.

Davis & Johnson (8) mentioned that a connection between thunderstorms and the ionosphere has been hypothesized since the mid-1920s. Several mechanisms have been proposed to explain this connection, and evidence from modelling as well as various types of measurements demonstrate that lightning can interact with the lower ionosphere. It has been proposed, on the basis of a few observed events, that the ionospheric 'sporadic E' layer - transient, localized patches of relatively high electron density in the mid-ionosphere E layer, which significantly affect radio-wave propagation - can be modulated by thunderstorms, but a more formal statistical analysis is still needed. Here we identify a statistically significant intensification and descent in altitude of the mid-latitude sporadic E layer directly above thunderstorms. Because no ionospheric response to low-pressure systems without lightning is detected, this localized intensification of the sporadic E layer can be attributed to lightning. It is suggested that the co-location of lightning and ionospheric enhancement can be explained by either vertically propagating gravity waves that transfer energy from the site of lightning into the ionosphere, or vertical electrical discharge, or by a combination of these two mechanisms **(8)**.

Bates & al. (9) carried out an exploratory analysis of lightning-ignited wildfire data for the Warren Region of Western Australia out for the period from April 1976 to December 2016. Temporal patterns in the series were examined in terms of characterizing the seasonal cycle and detecting long-term trends and changes in seasonality over time. A generalized additive modelling approach was used to ensure that temporal features were determined by the data rather than a priori assumed mathematical forms (e.g., linear, or low-order

polynomial functions). The spatial organization of the data was evaluated using concepts from the theory of stochastic point processes. Results indicate a strong seasonality in the monthly lightning ignition series, the presence of a long-term trend and an interaction between trend and seasonality. There is also strong evidence of spatial variation in the number of ignitions per unit area in terms of location and distance from nearest ignition. Within the Warren Region, observation platforms for fire detection and reporting protocols have remained stable over the period of record, and changes in land use are unlikely to have altered the pattern of lightning ignition. Thus, the above results might reflect an interplay between landscape attributes (e.g., vegetation classes, elevation, slope, aspect); changes in rainfall and fuel moisture; changes in fuel management practices; and, perhaps, an increase in the frequency of dry thunderstorms and fire weather conditions **(9)**.

Koshak & Solakiewicz (10) mentioned that the design, alignment, calibration, and field deployment of a solid-state lightning detector is described. The primary sensing component of the detector is a potassium dihydrogen phosphate electro-optic crystal that is attached in series to a flat-plate aluminum antenna; the antenna is exposed to the ambient thundercloud electric field. A semiconductor laser diode (lambda = 685 nm), polarizing optics, and the crystal are arranged in a Pockels cell configuration. Lightning-caused electric field changes are related to small changes in the transmission of laser light through the optical cell. Several hundred lightning electric field change excursions were recorded during five thunderstorms that occurred in the summer of 1998 at the NASA Marshall Space Flight Center in northern Alabama **(10).**

Vorpahl & al. (11) mentioned the analysis of the positions of nighttime thunderstorms as determined from the detection of optical radiation by satellite OSO-B reveals that ten times as many lightning storms occur over land areas as over the sea **(11)**.

This chapter (1-11) deals with various mechanisms involved in the development of lightning.

References

1. Rison W, Krehbiel PR, Stock MG, et al. Observations of narrow bipolar events reveal how lightning is initiated in thunderstorms. Nat Commun. 2016 Feb 15;7:10721.

2. Chilingarian A, Chilingaryan S, Karapetyan T, et al. On the initiation of lightning in thunderclouds. Sci Rep. 2017 May 2;7(1): 1371.

3. Almendarez IS, Boysun M, Clark K. Thunder and lightning and rain: a Latino/Hispanic diabetes media awareness campaign. Fam Community Health. 2004;27(2):114-22.

4. Friday DM, Broughton PB, Lee TA, et al. Further insight into the nature of ball-lightning-like atmospheric pressure plasmoids. J Phys Chem A. 2013;117(39):9931-40.

5. Fill JM, Davis CN, Crandall RM. Climate change lengthens southeastern USA lightning-ignited fire seasons. Glob Chang Biol. 2019; 25(10):3562-9.

6. Hunt HGP. Dataset of photographed lightning events attaching to and around the Brixton tower, Johannesburg, South Africa for the 2015-2016 thunderstorm season. Data Brief. 2020 Apr 29;30:105630.

7. Montanyà J, van der Velde O, Williams ER. The start of lightning: evidence of bidirectional lightning initiation. Sci Rep. 2015 Oct 16;5:15180.

8. Davis CJ, Johnson CG. Lightning-induced intensification of the ionospheric sporadic E layer. Nature. 2005;435(7043):799-801.

9. Bates BC, McCaw L, Dowdy AJ. Exploratory analysis of lightning-ignited wildfires in the Warren Region, Western Australia. J Environ Manage. 2018;225:336-45.

10. Koshak WJ, Solakiewicz RJ. Electro-optic lightning detector. Appl Opt. 1999;38(21):4623-34.

11. Vorpahl JA, Sparrow JG, Ney EP. Satellite observations of lightning. Science. 1970;169(3948):860-2.

EPIDEMIOLOGY

Williams & al. (1) reported that during 2008-2017, a total of 241 service members had incident lightning-related medical encounters with ICD-9 or ICD-10 codes that documented specific lightning-associated injuries or illnesses. The crude overall incidence rate of lightning strike injury during the surveillance period was 1.9 cases per 100,000 person-years. Compared to their respective counterparts, overall rates of lightning strike injury were higher among males, those aged 20-29 years, non-Hispanic whites, Army members, enlisted service members, those in combat-specific occupations, and those stationed in the Southern region of the U.S. During the surveillance period, there was a peak in incidence of lightning strike injury during 2015, as well as two smaller peaks in 2011 and 2013. "Disturbance of skin sensation," headache, limb pain, and burns were the four most frequent diagnoses during medical encounters for incident lightning strike injuries. The largest numbers of incident lightning strike injuries occurred in June, July, August, and September. Service members who routinely train and work outdoors should be vigilant about the dangers of lightning, especially in field settings during summer months **(1)**.

Thompson & al. (2) emphasized that although lightning strikes are a rare occurrence, their significance cannot be ignored given military operations in the field during all types of weather. With proper medical management, patients with lightning injuries can return to duty. Information for this case report comes from eyewitness account at the 6th Ranger Training Battalion and from review of physician documentation from the 96th Medical Group, Eglin Air Force Base, Florida. A lightning strike injured 44 Ranger School participants during a training exercise on August 12, 2015, at Camp Rudder, Florida. These patients were triaged in the field and transported to emergency department of Eglin Air Force Base. Of the 44 casualties, 20 were admitted. All were returned to duty the following day. One patient had cardiac arrest. This patient, along with two others, was admitted to the intensive ca re unit. Seventeen other patients were admitted for observation for rhabdomyolysis

and/or cardiac arrhythmias. One patient was admitted with suspected acute kidney injury indicated by an elevated creatinine. All patients, including those admitted to the intensive care unit, were released on the day following the lightning strike without restrictions and were allowed to return to duty with increased medical monitoring. This case report highlights the need for proper triage and recognition of lightning strike injury, coordination of care between field operations and emergency department personnel, and close follow-up for patients presenting with lightning injury. Symptoms, physical exam, and laboratory findings from rigorous training can be difficult to distinguish from those resulting from lightning injury. Secondary injuries resulting from blunt trauma from falls may have been prevented by the use of the lightning strike posture. Further analysis of procedures and standard operating protocols to mitigate risk during thunderstorms may be required to prevent lightning's effects on large groups of military personnel **(2)**.

Huss & al. (3) emphasized that there are several misconceptions even among hospital personnel regarding damages and injuries caused by lightning. Few health care providers have experience from lightning injuries as they are rare and different (DC) from the more common high-voltage (AC) injuries. Furthermore, fatalities are uncommon. Burns do occur but are usually minor. Most lightning injuries occur in the summer season during outdoor leisure activities and in the vicinity of a tree or other large structures. In Sweden, on average, approximately seventeen persons per year are hospitalized and 0.2-0.8 persons per million inhabitants and year die due to lightning injuries. The primary treatment follows the general guidelines for other trauma, electrical, and burn injuries, i.e., as is described in the standardized ATLS, ABLS, or A-HLR programs. However, there are some minor points that are different and may be stressed for a favorable outcome. In this paper these are addressed together with the epidemiology, effects and treatment of lightning injuries that are specific for Sweden. Unfortunately, little is known, apart from what is described in smaller case series, of the long-time sequelae experienced by this patient population and further research is therefore particularly warranted in this respect **(3)**.

Sleiwah & al. (4) reported that lightning injuries are uncommon in Northern Ireland (NI) with scarce reports detailing incidence and local experience. The Authors present a case study of 3 patients involved in a single lightning strike with a review of the incidence of similar injuries in the province. Data from TORRO's National Lightning Incidents Database between 1987 and 2016 (30 years) were searched to identify victims of lightning injuries in NI. Information on 3 patients with lightning injuries that were managed in thew regional burns and plastic surgery service was collected and examined. A supplementary search in hospital records was conducted over the last 20 years to identify additional data. Prior to the study, 6 victims of lightning injuries were identified of whom 5 survived and 1 died. Three ptients comprised of 2 children and 1 accompanying adult. All survived but the adult suffered cardiac arrest and required a prolonged period of cardiopulmonary resuscitation. The data show while lightning

injuries are rare in NI, this is the first report of more than one person affected by a single lightning incident in the province. In the limited experience, immediate public response and prolonged cardiopulmonary resuscitation efforts facilitated by automated defibrillators result in a favorable outcome **(4)**.

Ströhle & al. (5) stressed that lightning strikes are rare but potentially lethal. The risk for suffering a lightning strike in a mountain environment is unknown. The aim of this nationwide study was to analyze all lightning accidents in the Austrian Alps from 2005 to 2015, to assess the circumstances of the accident, the injury pattern as well as the outcome. From 2005 to 2015, data from the national Austrian Alpine Police database as well as the Clinical Information System of Innsbruck Medical University Hospital were searched for the keywords lightning injury, lightning strike, lightning as well as ICD-10 Code T75.0. Additionally, the archive data of Innsbruck Medical University Hospital was searched manually. The Austrian Alpine Police database, containing 109.168 patients for the years 2005-2015, was screened for lightning accidents. Sixty-four patients had been hit by lightning in the Austrian Alps, 54 were male. Four persons died on scene; survival rate was 93.8%. Two deceased persons were hunters, who were killed by the same lightning strike. Sixty-three patients suffered a lightning strike while doing a recreational activity, mostly hiking (n=55), a few hunting and only one doing occupational timberwork. Sixty-three patients suffered a lightning strike between June and August with nearly half (46.9%) of the accidents happening on a Saturday or Sunday, and mainly (95.3%) between 12:00 and 22:00 h. Persons who perform recreational outdoor and occupational activities in an alpine environment during summer and after noon incur a higher risk of sustaining a lightning strike. The primary risk group includes young male mountaineers and hunters. The mortality rate was low **(5)**.

This chapter (1-5) shows various prevalence rates of lightening in different countries.

References

1. Williams VF, Oetting AA, Stahlman S. Update: lightning strike injuries, active component, U.S. Armed Forces, 2008-2017. MSMR. 2018;25(9):20-24.

2. Thompson SN, Wilson ZW, Cole CB, et al. Case report: mass casualty lightning strike at Ranger Training Camp. Mil Med. 2017; 182(5):e1803-e1806.

3. Huss F, Erlandsson U, Cooray V, et al. et al. Lightning injuries - a mixture of electrical, thermal and multiple trauma. Lakartidningen. 2004;101(28-29):2328-31.

4. Sleiwah A, Baker J, Gowers C, et al. Lightning injuries in Northern Ireland. Ulster Med J. 2018;87(3):168-72.

5. Ströhle M, Wallner B, Lanthaler M, et al. Lightning accidents in the Austrian alps - a 10-year retrospective nationwide analysis. Scand J Trauma Resusc Emerg Med. 2018 Sep 10;26(1):74.

HEALTH EFFECTS

This section deals with lightning effects on humans including lightning-related mortality that is relatively uncommon, ranging between 10% and 30% after a lightning strike, various injuries, cardiovascular complications, autonomic nervous system dysfunction, neurological diseases, neurorehabilitation of cerebral disorders, transportation, ophthalmic manifestations, cutaneous manifestations, burns, Lichtenberg figures, acute lung injury, acute renal failure, burns, gastric perforation, and auricular accidents.

MORTALITY

Hinkelbein & al. (1) emphasized that up to 32.2% of patients in a burn center suffer from electrical injuries. Of these patients, 2-4% present with lightning injuries. In Germany, approximately 50 people per year are injured by a lightning strike and 3-7 fatally. Typically, people involved in outdoor activities are endangered and affected. A lightning strike usually produces significantly higher energy doses as compared to those in common electrical injuries. Therefore, injury patterns vary significantly. Especially in high voltage injuries and lightning injuries, internal injuries are of special importance. Mortality ranges between 10% and 30% after a lightning strike. Emergency medical treatment is similar to common electrical injuries. Patients with lightning injuries should be transported to a regional or supraregional trauma center. In 15% of all cases multiple people may be injured. Therefore, it is of outstanding importance to create emergency plans and evacuation plans in good time for mass gatherings endangered by possible lightning **(1)**.

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Langley & al. (2) mentioned that individuals who are outdoors during thunderstorms are at risk for death from direct and indirect lightning hits. Death is more likely from 3:00 p.m. to 8:00 p.m. during the months of May through September. The fatality pattern in North Carolina is similar to that reported for the nation as a whole. Physicians are urged to discuss with their patients' simple strategies for reducing exposure to lightning **(2)**.

According to **Centers for Disease Control and Prevention [CDC] (3)**, after flooding, lightning is the second leading cause of weather-related death in the United States; approximately 300 injuries and 100 deaths are associated annually with lightning strikes in the United States. To characterize lightning-associated injuries and deaths among U.S. Armed Forces personnel, the U.S. Army and CDC analyzed data from the Defense Medical Surveillance System (DMSS). This that the highest lightning-related injury rates during 1998-2001 occurred among male U.S. military members who were aged <40 years, single, with a high school education or less, stationed near the Gulf of Mexico or the East Coast, and in the U.S. Army. The findings suggest that the risk for lightning-associated injury depends primarily on the frequency, timing, duration, and nature of outdoor exposure to thunderstorms. Military personnel should be aware of severe weather onset and take reasonable precautions to protect themselves and their companions from exposure to lightning **(3).**

According to **CDC (4)**, a lightning strike can cause death or various injuries to one or several persons. The mechanism of injury is unique, and the manifestations differ from those of other electrical injuries. In the United States, lightning causes more deaths than do most other natural hazards (e.g., hurricanes and tornadoes), although the incidence of lightning-related deaths has decreased since the 1950s. The cases described in this report illustrate diverse circumstances in which deaths attributable to lightning can occur. This report also summarizes data from the Compressed Mortality File of CDC's National Center for Health Statistics on lightning fatalities in the United States from 1980 through 1995, when 1,318 deaths were attributed to lightning **(4)**.

Duclos & al. **(5)** reviewed cases of lightning-related deaths and injuries that occurred in Florida in 1978-87 to determine the factors involved, to quantify the morbidity and mortality related to lightning strikes, and to describe epidemiologically the injuries and circumstances involved. Statewide information on deaths was obtained from death certificates, autopsy reports, and investigative reports. Information about morbidity was obtained from the Florida Hospital Cost Containment Board data base and the National Climatic Data Center data base for all Florida counties, as well as from hospitals in selected counties. Lightning-related deaths totaled 101 in Florida during the period 1978-87, an annual average of 10.1. Eight percent of the victims were from other States. The overall yearly death rate for State residents was 0.09 per 100,000 population, with the highest rate being that for men aged 15-19 years, 0.38 per 100,000. Thirteen percent of victims were females. The ratio of lightning-related injuries to deaths in Florida was estimated at about four to one. Thirty percent of all deaths were occupationally related. The first strikes of lightning from a thunderstorm may be the most dangerous, not in terms of impact, but because of the element of surprise. During thunderstorms, people may seek shelter under isolated trees because they believe erroneously that a tree offers protection from lightning, or perhaps because their top priority is to escape from rain rather than lightning.

People may not seek adequate shelter during thunderstorms because they do not know the dangers of remaining outdoors or their judgment is impaired by drugs or alcohol **(5)**.

Adekoya & Nolte (6) examined the epidemiologic characteristics of struck-by-lightning deaths. Using data from both the National Centers for Health Statistics (NCHS) multiple-cause-of-death tapes and the Census of Fatal Occupational Injuries (CFOI), which is maintained by the Bureau of Labor Statistics, the authors calculated numbers and annualized rates of lightning-related deaths for the United States. They used resident estimates from population microdata files maintained by the Census Bureau as the denominators. Work-related fatality rates were calculated with denominators derived from the Current Population Survey of employment data. Four illustrative investigative case reports of lightning-related deaths were contributed by the New Mexico Office of the Medical Investigator. It was found that a total of 374 struck-by-lightning deaths had occurred during 1995-2000 (an average annualized rate of 0.23 deaths per million persons). The majority of deaths (286 deaths, 75 percent) were from the South and the Midwest. The numbers of lightning deaths were highest in Florida (49 deaths) and Texas (32 deaths). A total of 129 work-related lightning deaths occurred during 1995-2002 (an average annual rate of 0.12 deaths per million workers). Agriculture and construction industries recorded the most fatalities at 44 and 39 deaths, respectively. Fatal occupational injuries resulting from being struck by lightning were highest in Florida (21 deaths) and Texas (11 deaths). In the two national surveillance systems examined, incidence rates were higher for males and people 20-44 years of age. In conclusion, three of every four struck-by-lightning deaths were from the South and the Midwest, and during 1995-2002, one of every four struck-by-lightning deaths was work-related. Although prevention programs could target the entire nation, interventions might be most effective if directed to regions with the majority of fatalities because they have the majority of lightning strikes per year **(6)**.

According to **Blumenthal (7)**, a review of the Southern Africa medical literature shows a paucity of published data regarding lightning fatalities. The South African Highveld has a lightning ground flash density of 6 to 9 flashes/km/year, with a high incidence of thunderstorm days per year (some 40-70). The Highveld has a largely urban population, many of whom have low socioeconomic status and poor education, housing, and other infrastructures and hence (possibly) are at greater exposure risk. Thirty-eight victims of lightning-related death were identified from the records of the 6 large medicolegal mortuaries on the South African Highveld, serving a population of approximately 7 million, for the period 1997 to 2000. Analysis of the records revealed that 95% of all victims were black, 79% were male, and the average age was 36 years. Lightning strikes occurred from September through to April (normal summer rainfall period), and the most strikes took place in the late afternoon (3:00 pm to 6:00 pm). All except 1 case occurred outdoors. In the autopsy

reports, mention was made of singeing of hair in 68% of cases, and mention of damage to clothing was made in 26% of cases. Cutaneous thermal injuries were noted in 34 of the 38 cases, with apparent electrothermal injuries of the feet noted in 4 cases. Fifty-two percent of victims sustained some form of associated blunt-force injury (including abrasions, contusions, etc.). Specific keraunopathologic injuries were described in only 2 of the cases. Twenty-one cases had some form of internal organ injury. This study serves to illustrate the relatively high incidence of lightning strikes in the region and calls for a more systematic and detailed investigative protocol in lightning-related deaths **(7)**.

Murty & al. (8) described lightning strike as a natural phenomenon with potentially devastating effects and represents one of the important causes of deaths from environmental phenomena. Almost every organ system may be affected as lightning current passes through the human body taking the shortest pathways between the contact points. A 10-year retrospective study (1996-2005) was conducted at University Hospital Kuala Lumpur (20 cases) also including cases during last 3 years from Hospital Tengku Ampuan Rahimah, Klang (7 cases) from the autopsy reports at Forensic Pathology Units of these 2 hospitals. Both these hospitals are attached to University of Malaya. There were 27 fatal cases of lightning strike with male preponderance (92.59%) and male to female ratio of 12.5:1. Majority of victims of lightning strike were from the age group between 30 and 39 years old. Most of the victims were foreign workers. Indonesians' workers contributed to 59.26% of overall cases. Majority of them were construction workers who attributed i.e., 11 of 27 cases (40.74%). Most of the victims were brought in dead (37.04%). In majority of the cases the lightning incidence occurred in the evenings, with the frequency of 15 of 27 cases (62.5%). The month of December represented with the highest number of cases (5 cases of 23 cases); 2004 had the highest incidence of lightning strike which was 5 (19.23%). Lightning strike incidence occurred when victims had taken shelter (25.9%) under trees or shades. Lightning strike in open areas occurred in 10 of 27 cases (37.0%). Head and neck were the most commonly affected sites with the incidence of 77.78% and 74% respectively in all the victims. Only 29.63% of the cases presented with ear bleeding **(8)**.

Cherington & Mathys (9) mentioned that aircraft are at risk of being struck by lightning or triggering lightning as they fly through clouds. Commercial and private airplanes have been struck, with resultant deaths and injuries to passengers and crew. The Authors were interested in learning how large a problem existed to the American public from lightning strikes to airplanes. Data were analyzed from the National Transportation Safety Board (NTSB) on lightning-related accidents in the United States from 1963-89. NTSB recorded 40 lightning-related aircraft accidents. There were 10 commercial airplane accidents reported, 4 of which were associated with 260 fatalities and 28 serious injuries. There were 30 private aircraft accidents that accounted for 30 fatalities and 46 serious injuries. While lightning remains a potential risk to aircraft passenger

s and crew, modern airplanes are better equipped to lessen the dangers of accidents due to lightning **(9)**.

Ventura & al. (10) mentioned that death due to lightning strikes is infrequent, above all indoors. Some cases may take on a medical legal interest due to the unusual and uncommon circumstances in which they occur. The Authors report an extremely rare case of electrocution occurred inside a house in a rural area. A 53-year-old man was reached by an electrical discharge originating from lightning while he was doing renovation work on a cottage. In this case, the correct interpretation of the autopsy and histological aspects and the attentive analysis of the circumstantial and environmental data led to the correct diagnosis of death and to the reconstruction of the dynamics with which it occurred. It was in fact possible to reconstruct that during a violent thunderstorm, lightning, discharging from the bottom upward formed an electric arc. The victim, who was close to metal objects (sawhorses), was struck on the left foot and the current exited from the right hand passing through the heart causing immediate death **(10)**.

Blanco-Pampín & al. (11) mentioned that lightning-related deaths are relatively uncommon, especially indoors. Some cases, involving unusual circumstances, may be of medicolegal relevance. A highly infrequent case of fulguration occurring inside a house is reported in a country area. The deceased, a 55-year-old man, was struck by lightning while he was in his bed. Scene investigation and autopsy findings were equally important in finding out the cause of death. The present case is of interest to forensic pathologists because what occurred might be difficult to clarify **(11)**.

References

1. Hinkelbein J, Spelten O, Wetsch WA. Lightning strikes and lightning injuries in prehospital emergency medicine. Relevance, results, and practical implications. Unfallchirurg. 2013;116(1):74-9.

2. Langley RL, Dunn KA, Esinhart JD. Lightning fatalities in North Carolina 1972-1988. N C Med J. 1991;52(6):281-4.

3. Centers for Disease Control and Prevention (CDC). Lightning-associated injuries and deaths among military personnel - United States, 1998-2001. MMWR Morb Mortal Wkly Rep. 2002;51(38):859-62.

4. Centers for Disease Control and Prevention (CDC). Lightning-associated deaths - United States, 1980-1995. MMWR Morb Mortal Wkly Rep. 1998;47(19):391-4.

5. Duclos PJ, Sanderson LM, Klontz KC. Lightning-related mortality and morbidity in Florida. Public Health Rep. 1990;105(3):276-82.

6. Adekoya N, Nolte KB. Struck-by-lightning deaths in the United States. J Environ Health. 2005;67(9):45-50, 58.

7. Blumenthal R. Lightning fatalities on the South African Highveld: a retrospective descriptive study for the period 1997 to 2000. Am J Forensic Med Pathol. 2005;26(1):66-9.

8. Murty OP, Kian CK, Husin MHA, et al. Fatal lightning strikes in Malaysia. Am J Forensic Med Pathol. 2009;30(3):246-51.

9. Cherington M, Mathys K. Deaths and injuries as a result of lightning strikes to aircraft. Aviat Space Environ Med. 1995;66(7):687-9.

10. Ventura F, Barranco R, Bonsignore A, De Stefano F. A unusual lightning death in an indoor setting: a case report. Am J Forensic Med Pathol. 2017;38(1):1-4.

11. Blanco-Pampín JM, Peñaranda JM, Boquete RR, Carro LC. An unusual case of death by lighting. J Forensic Sci. 1997;42(5):942-4.

VARIOUS INJURIES

Tribble & al. (1) mentioned that lightning causes more deaths than any other weather phenomenon. It is an electrical current that will choose the shortest paths between the contact points of the human body and may involve vital structures in its pathway. Almost every organ system can be injured by the electrical current of lightning. A broad spectrum of complications resulting from damage to the various organ systems has been reported. The sequelae peculiar to this specific type of injury will dictate the choice of therapy **(1)**.

According to **Mistovich & al. (2)**, it is estimated that a lightning flash occurs approximately 8 million times per day throughout the world. Most strikes are benign and cause little damage to property and physical structures; however, when lightning strikes a person or group of people, it is a significant medical and potentially traumatic event that could lead to immediate death or permanent disability. By understanding some basic physics of lightning and pathophysiology of injuries associated with lightning strikes, EMS providers will be better prepared to identify assessment findings, anticipate complications, and provide effective emergency care **(2)**.

Stütz & al. (3) noticed that lightning injury is one of the most frequent injuries caused by a natural phenomenon, but the risk of being struck by lightning is low. The most vulnerable subjects for lightning injuries are individuals who work in open fields. Although lightning injuries may involve all organ systems, injuries to the cardiovascular system and central nervous system are the most frequent. Burns, tinnitus, blindness and secondary blunt trauma have also been reported. Even though immediate death through lightning-induced cardiac arrest is well documented, the majority of cases reported in the literature describe infrequent and enormously disparate sequelae. A 17-year-old man was admitted to the hospital approximately 3 h after a lightning strike. The Glasgow coma scale was recorded as 15/15 and partial thickness burns totaling of 11% were present on the chest, stomach and right and left lower leg. The entry point was approximately the right side of the neck and the current exited through the right foot. On arrival, the patient's vital signs were normal. Cardiac and pulmonary examinations were within normal limits. The patient suffered transient symptoms, including pain, loss of consciousness, tinnitus, iritis, and paresthesia. The laboratory data obtained on admission were within normal limits except serum for WBC, CK, CK-MB, troponin, and CRP. The mechanism by which lightning caused injury to this patient was a flash discharge (side splash). During his stay in hospital, a debridement of the burn surface following graft coverage and Z-

plasty to close the dehiscent wound on the right neck was performed. The patient was discharged from the hospital after 14 days **(3)**.

Blumenthal (4) mentioned that the explosive effects of lightning have been known to exist for some time; however, the precise risks associated with it have been generally unknown. This curious injury phenomenon has existed historically under many different names in the literature: "lightning's pressure blast wave," "arc blast," "shattering effects of lightning," "pressures developed by arcs," "thunder generation of shock waves," and "the sixth mechanism of lightning injury" are but a few of the many divergent and disparate terminologies used in the past to describe this invisible blast phenomenon. Blunt force trauma injuries and barotrauma injuries are often identified on lightning strike victims. Lightning's pressure blast wave and its associated overpressure does appear to have significant injury implications associated with it. This paper takes an in-depth look at the explosive effects of lightning and the main blast-related pathologies seen on lightning strike victims. Knowledge and insight into this phenomenon may help forensic pathologists and those working in the fields of lightning injury and lightning protection. A general literature search of the medical, the electrical engineering, and the mechanical engineering literature was conducted. By looking exclusively at the pathology of barotrauma in the human body, forensic pathologists may now get a relatively good idea as to the possible overpressures and distances involved with regards to lightning's explosive effects **(4)**.

Patten (5) mentioned that lightning and electrical injuries are similar in that both produce immediate tissue injury from burn and trauma induced by fall and both can arrest the heart and respiratory center. Immediate support of circulation and respiration is lifesaving. Subsequently the nervous system may show signs of injury, and seizures, cerebral edema, and muscle and nerve lesions should be handled as the indications arise. Prevention of the injury is more effective than any postinjury treatment. Outdoors's hikers and campers must take shelter to minimize their exposure; indoors properly installed equipment and attention to the relation of the equipment user to the electrical ground are the key elements in avoiding electrocution **(5)**.

Blount (6) noticed that lightning kills or injures thousands of people in the United States each year. Injuries are caused by the effects of electrical, thermal, and mechanical energy, and a wide range of clinical results, involving multiple body systems, is possible. Important differences exist between lightning victims and patients injured by fire or by other forms of electricity. In lightning victims, successful resuscitation is highly likely, even among patients with conventional signs of brain death. With proper management, long-term physical and psychologic sequelae of lightning injury are rare **(6)**.

Yigit (7) mentioned that lightning strikes especially occur during spring and summer months in the afternoons when there is heavy rain. In deaths resulting from lightning strike, there may either be no

evidence on the dead person's clothes or body, or there may be burnt or torn patches on their clothes and Lichtenberg figures specific to lightning strikes on their bodies. In such cases that also have a comorbid of cognitive dysfunction, since there is generally amnesia, having these figures during the physical examination has a valuable place in early diagnosis and quick treatment. This paper presents a case of lightning strike that was found to have Lichtenberg figures on the back and right leg after secondary examination **(7)**.

Browne & Gaasch (8) noticed that prolonged cardiopulmonary resuscitation is key to the resuscitation of lightning strike victims. Multiple accounts exist of successful revival of victims thought to be "dead" or in patients who have what is often believed to be unresuscitatable cardiac dysrhythmia. Victims of lightning injury may, in addition to their electrical injury, have secondary injuries that require expedient care if significant morbidity is to be avoided. They should be treated as any victim of trauma, that is, with a complete and thorough evaluation including hospitalization if warranted. In the absence of a cardiac arrest or serious secondary injury, care for the lightning strike victim is generally supportive in nature **(8)**.

Fontanarosa (9) described cardiac arrest from electrical shock or lightning strike that is associated with significant mortality and requires modification and extension of standard advanced life support measures to achieve successful resuscitation. Patients who experience electrical shock or lightning strike may sustain cardiac and respiratory arrest secondary to the direct effects of current. However, the majority of victims have associated multisystem involvement, including neurologic complications, cutaneous burns, and associated blunt trauma. As a result, a combination of advanced cardiac life support measures and advanced trauma life support techniques is indicated. Victims with cardiac arrest from electrical shock or lightning strike require prompt, aggressive resuscitation using standard methods for airway control, ventilation, and chest compressions, as well as usual measures for defibrillation and cardiac pharmacotherapy. Unique considerations include vigorous fluid resuscitation and spinal immobilization for victims of electrical shock and reversal of normal multiple casualty triage priorities when managing several lightning strike victims. Because the majority of victims are relatively young and seldom have significant underlying cardiac disease, the chance for successful resuscitation may be greater for patients who experience sudden death from electrical shock or lightning strike than for those with other causes of cardiac arrest, even among patients with initial rhythms traditionally unresponsive to therapy. Although numerous specialized aspects are required for the successful management of victims of electrical shock and lightning strike, the following article focuses on the unique considerations necessary for immediate care of cardiac arrest victims, with emphasis on the underlying mechanisms of sudden death and currently recommended guidelines for resuscitation **(9)**.

Muehlberger et al. (10) mentioned that the risk of being struck by lightning is extremely low. Although dying instantly through lightning-induced cardiac arrest is a well-documented cause of death,

the majority of cases reported in the literature describe infrequently occurring and enormously disparate sequelae of this injury. A total number of 12 patients were treated in the burn intensive care unit following a lightning accident within a period of 12 years. The incidence of cardiac, muscular, and sensory disturbances, keraunographic skin markings and significant laboratory results were analyzed, as well as episodes of audiovisual dysfunction and amnesia at the time of the initial admission. In order to determine possible long-term complications, ten of these 12 patients were evaluated at an average time of 6.7 years following the injury (range, 1 month-12.3 years). Considering specific findings during their hospital stay (average length, 1.58+/-0.23 days), patients were assessed for residual neurologic, ocular, oto-vestibular or psychological deficits. The outcome showed that none of the patients suffered from any deficits or long-term problems that could be related to the original lightning injury. Based on these findings and a literature review, the Authors believe that the overall outcome of lightning injuries is more favorable than generally reported **(10)**.

Shipman (11) reported that lightning strikes to people are rare events that cause significant injuries and mortality when they do occur. An uncommon case of a storm chaser is described in Oklahoma who was struck by lightning who suffered cutaneous burns, bilateral tympanic membrane ruptures, as well as pulmonary edema, which is an atypical finding in survivors. This case report highlights several injury patterns seen in lightning strike cases and provides evidence that these patients should be managed at a center with multidisciplinary services available **(11)**.

References

1. Tribble SG, Persing JA, Morgan RF, et al. Lightning injuries. Compr Ther. 1985;11(2):32-40.

2. Mistovich JJ, Krost WS, Limmer DD. Beyond the basics: lightning-strike injuries. EMS Mag. 2008;37(3):82-7; quiz 88-9.

3. Stütz N, Weiss D, Reichert B. Lightning injuries: case report of a 17-year-old man and a brief review of the literature]. Unfallchirurg. 2006;109(6):495-8.

4. Blumenthal R. The explosive effects of lightning: what are the risks? Acad Forensic Pathol. 2016;6(1):89-95.

5. Patten BM. Lightning and electrical injuries. Neurol Clin. 1992; 10(4):1047-58.

6. Blount BW. Lightning injuries. Am Fam Physician. 1990; 42(2):405-15.

7. Yigit M, Tanrikulu N, Ahmet KA, Yigit E. Pathognomonic symptom associated with lightning strike: Lichtenberg figure. J Pak Med Assoc. 2015;65(2):218-9.

8. Browne BJ, Gaasch WR. Electrical injuries and lightning. Emerg Med Clin North Am. 1992;10(2):211-29.

9. Fontanarosa PB. Electrical shock and lightning strike. Ann Emerg Med. 1993;22(2 Pt 2):378-87.

10. Muehlberger T, Vogt PM, Munster AM. The long-term consequences of lightning injuries. Burns. 2001;27(8):829-33.

11. Shipman J, Carver B, Painter K, Shipman S The dangerous life of a storm chaser: a lightning strike injury causing serious injury. J Investig Med High Impact Case Rep. 2020;8:2324709620925566.

CARDIOVASCULAR COMPLICATIONS

McIntyre & al. (1) mentioned that lightning strike is a rare natural phenomenon, which carries a risk of dramatic medical complications to multiple organ systems and a high risk of fatality. The known complications include but are not limited to myocardial infarction, arrhythmia, cardiac contusion, stroke, cutaneous burns, respiratory disorders, neurological disorders, acute kidney injury and death. A case of a healthy young man who suffered a lightning injury is reported and the cardiovascular complications of lightning injury, ranging from ECG changes to death are discuss. The patient, a 27-year-old previously healthy male, developed a syndrome of rhabdomyolysis and symptomatic cardiogenic pulmonary edema. Electrocardiographic findings included transient T-wave inversions, late transition shift and long QT. His clinical condition improved with supportive measures. Early recognition of lightning injury syndromes and anticipation of complications may help us improve outcomes for these patients. Evaluation of patients having experienced a lightning injury should include a minimum of a detailed history and physical examination, 12-lead ECG and drawing of baseline troponins. Prolonged electrocardiographical monitoring (for monitoring of ventricular arrhythmias) and assessment for signs and symptoms of hemodynamic compromise may be warranted **(1).**

Rotariu & Manole (2) mentioned that lightning strike injuries, although less common than electrical injuries, have a higher morbidity rate because of critical alterations of the circulatory system, respiratory system, and central nervous system. Most lightning-related deaths occur immediately after injury because of arrhythmia or respiratory failure. The case of a pediatric patient is described who experienced cardiorespiratory arrest secondary to a lightning strike, where the Advanced Cardiac Life Support and Basic Life Support chain of survival was well executed, leading to return of spontaneous circulation and intact neurological survival. The pathophysiology of lightning injuries, prognostic factors of favorable outcome after cardiac arrest, including bystander cardiopulmonary resuscitation, shockable rhythm, and automatic external defibrillator use, and the importance of temperature management are reviewed **(2)**.

Courtman & al. (3) mentioned that lightning strikes kill 1,000 people per year worldwide. Cardiac arrests resulting from lightning strikes have good survival rates but there is a significant degree of morbidity amongst the survivors. This is the case report of a 13-year-old boy who had a cardiac arrest following a direct lightning strike, and his subsequent management **(3)**.

Ruiz Ruiz & al. (4) mentioned that lightning strike is one of the most frequent causes of death due to natural phenomena. In such cases, cardiac injury is the main cause of death, with type of lesion

varying by type of impact. The case is reported of a 29-year-old woman who was struck indirectly by lightning. Upon hospital admission, she showed both the echocardiographic disturbances characteristic of direct impact and electrocardiographic disturbances. Both types of change resolved spontaneously. After describing the case, the literature is briefly reviewed on echo and electrocardiographic disturbances after lightning strike **(4)**.

Akın & al. (5) mentioned that lightning strikes may cause injury to the heart, ranging from slight electrocardiographic changes to fatal damage. As heart injury is the most important cause of mortality in these patients, cardiac monitoring is crucial. Even though various ECG changes have been reported, published data on pathologic ST-segment changes is scarce. Herein, a seven-year-old patient is presented with ST-segment elevation following a lightning strike. There is not sufficient data regarding lightning-related myocardial ischemia. However, because of the similar effects of lightning strikes and high-voltage electric shocks, it is believed myocardial injury related to lightning may be managed in the same manner as is cardiac involvement associated with electric shock **(5)**.

Lichtenberg & al. (6) mentioned that the purpose of this study was to investigate the effects of lightning strikes on the cardiovascular system. A lightning strike can attack its victims in one of three ways: direct hit, splash, or ground strike. The cardiovascular system can be affected directly by mechanical or electrical trauma during a direct hit or can be indirectly affected through effects on the total body with extensive catecholamine release or autonomic stimulation. Reported effects include hypertension, tachycardia, nonspecific electrocardiographic (ECG) changes including prolongation of the corrected QT (QTc) interval, transient T wave inversion and myocardial necrosis with creatine kinase-MB (CK-MB) fraction release. Nineteen victims from five separate lightning strikes were studied over a 2-month period. Each patient was evaluated by serial ECG, CK-MB determinations, and echocardiography. The early (0 to 72 h) effects of lightning were demonstrated on the ECG by ST segment elevation consistent with acute current of injury, prolonged QTc interval with direct hits and nonspecific ST and T wave changes. On echocardiography, segmental or global ventricular dysfunction was seen, and pericardial effusion was also detected. During the intermediate (3- to 14-day) period, new and often marked ECG changes consistent with pericarditis or ischemia were seen. No new echocardiographic changes were detected, however, and the early abnormalities including severe left ventricular dysfunction with cardiogenic shock have reversed. The late (1 to 12 months) period revealed only one patient with long-term sequelae (recurrent pericarditis that persisted for 5 months). The data show that unless both entrance and exit sites are limited to the lower limbs, direct and splash lightning strikes cause myocardial damage as assessed by abnormal serum enzyme determinations or abnormal echocardiographic findings. Only direct hits resulted in echocardiographic abnormalities or a prolonged QTc interval. The

degree of myocardial injury can be severe with left and right ventricular ejection fraction < 15% and can be reversible **(6)**.

Eber & al. (7) reported a 27-year-old woman, who was struck by lightning behind the left ear, the ECG showed signs of an acute posterior-lateral myocardial infarction after 1 h of unconsciousness and loss of memory. Her serum enzymes were increased as is typical of myocardial infarction, but the patient did not complain of cardiac symptoms. Besides clear signs of lightning injury, the patient showed a hemorrhage throughout the left breast and transient pericardial effusion was observed by echocardiography. In the course of two months, the ECG revealed a regression to unspecific ST-T-deviations and serum enzymes became normal. TI-201-myocardial-scintigraphy (SPECT), done six days and two months after lightning injury, excluded reversible and irreversible perfusion defects **(7)**.

Christophides & al. (8) emphasized that lightning strikes are a common and leading cause of morbidity and mortality. Multiple organ systems can be involved, though the effects of the electrical current on the cardiovascular system are one of the main modes leading to cardiorespiratory arrest in these patients. Cardiac effects of lightning strikes can be transient or persistent, and include benign or life-threatening arrhythmias, inappropriate therapies from cardiac implantable electronic devices, cardiac ischemia, myocardial contusion, pericardial disease, aortic injury, as well as cardiomyopathy with associated ventricular failure. Prolonged resuscitation can lead to favorable outcomes especially in young and previously healthy victims **(8)**.

Zack & al. (9) described a 27-year-old male who was standing in a tent and was injured by lightning as it struck a tree about 1.5 m away. He immediately lost consciousness and exhibited ventricular fibrillation when the emergency physician arrived. A clinical picture of hypoxemic brain damage emerged after initially successful resuscitation. Brain death was diagnosed on the fifth day after injury. The discrete external findings (remaining arborescent skin marks) contrasted markedly with the severe thermal damage to the pectoral muscle and cardiac musculature found during the autopsy. The histological cardiac findings indicated severe acute myocardial infarction affecting virtually all parts of the myocardium **(9)**.

Alyan & al. (10) mentioned that lightning strike is a natural phenomenon with potentially devastating effects and represents one of the leading causes of cardiac arrest and death from environmental phenomena. Almost every organ system may be impaired as lightning passes through the human body taking the shortest pathways between the contact points. In this paper, the Authors report a 38-year-old man who was injured by lightning, a typical example of side splash, and had transient electrocardiographic changes **(10)**.

George & al. (11), emphasized that lightning strikes are a relatively uncommon emergency department presentation, and due to the very high energy involved, can present quite dramatically, including cardiac arrest. However, as with many chief complaints, sometimes these patients can be discharged home after a benign

emergency department evaluation. One such case of a male was struck to the ground by lightning outside his truck, which subsequently caught on fire. He demonstrated the classic Lichtenberg figures associated with a lightning injury that evolved over time but was otherwise hemodynamically stable. After an unremarkable laboratory evaluation and electrocardiogram, he was safely discharged home **(11)**.

References

1. McIntyre WF, Simpson CS, Redfearn DP, et al. The lightning heart: a case report and brief review of the cardiovascular complications of lightning injury. Indian Pacing Electrophysiol J. 2010;10(9):429-34.

2. Rotariu EL, Manole MD. Cardiac arrest secondary to lightning strike: case report and review of the literature. Pediatr Emerg Care. 2020 Jan;36(1):e18-e20.

3. Courtman SP, Wilson PM, Mok Q. Case report of a 13-year-old struck by lightning. Paediatr Anaesth. 2003;13(1):76-9.

4. Ruiz Ruiz FJ, Ruiz Laiglesia FJ, Lobo Escolar A et al. Cardiac injury after indirect lightning strike. Rev Esp Cardiol. 2002; 55(7):768-70.

5. Akın A, Bilici M, Demir F, et al. ST-segment elevation following lightning strike: case report and review of the literature. Turk J Pediatr. 2015;57(2):186-8.

6. Lichtenberg R, Dries D, Ward K, et al. Cardiovascular effects of lightning strikes. J Am Coll Cardiol. 1993;21(2):531-6.

7. Eber B, Himmel G, Schubert B, et al. Myocardial damage following lightning injury. Z Kardiol. 1989;78(6):402-4.

8. Christophides T, Khan S, Ahmad M, et al. Cardiac effects of lightning strikes. Arrhythm Electrophysiol Rev. 2017;6(3):114-7.

9. Zack F, Hammer U, Klett I, Wegener R. Myocardial injury due to lightning. Int J Legal Med. 1997;110(6):326-8.

10. Alyan O, Ozdemir O, Tufekcioglu O, et al. Myocardial injury due to lightning strike - a case report. Angiology. 2006;57(2):219-23.

11. George N, Bandi S, Ganti L, et al. Bounced off a truck out of the blue: a case report of a lightning strike during a thunderstorm. Cureus. 2020;12(11):e11534.

MYOCARDIAL INFARCTION. Aydin & al. (1) mentioned that lightning strike is an infrequent natural phenomenon with serious medical complications, like multiple organ damage, and it is associated with increased risk of mortality. Cardiovascular complications are among the most hazardous complications of lightning strike. Lightning strike can cause various serious consequences ranging from electrocardiographic changes to death. A 21-year-old patient is reported with no cardiovascular risk factors struck by lightning and presented by inferior ST elevated myocardial infarction (MI). The patient was followed up in the intensive care unit and MI complication did not develop during follow-up. The patient was lost due to multi-organ failure after 20 hours. AydinF, Turgay YildirimO, DagtekinE, Huseyinoglu AydinA, AksitE. Acute inferior myocardial infarction caused by lightning strike **(1)**.

Karadas & al. (2) mentioned that cardiac events due to lightning strike and their severity vary according to the strength of the electric

current and the duration of exposure. The electrophysiological effects of lightning on the heart can result in ventricular fibrillation, asystole, QT prolongation, supraventricular tachycardia, and non-specific ST-T wave changes. In this report, a case of a patient who suffered myocardial infarction due to lightning strike is presented, which is a rare complication **(2)**.

Saglam & al. (3) mentioned that lightning strike is a natural phenomenon with potentially devastating effects and represents one of the leading causes of cardiac arrest and death from environmental phenomena. Almost every organ system may be impaired as lightning passes through the human body preferring the pathways that the lowest resistance between the contact points. Lightning can also have widespread effects on the cardiovascular system, producing extensive catecholamine release or autonomic stimulation. The victim may develop hypertension, tachycardia, nonspecific electrocardiographic changes (including prolongation of the QT interval and transient T-wave inversion), and myocardial necrosis with release of creatine phosphokinase-MB fraction. The case of a 13-year-old boy with acute myocardial infarction secondary to an indirect lightning strike is presented **(3).**

Schwab & al. (4) reported a 17-year-old man who was resuscitated after being struck by lightning. The ECG showed a development similar to anterior infarction. The patient died on the 12th day due to irreversible brain damage. Autopsy showed normal myocardium **(4)**.

References

1. Aydin F, Yildirim OT, Dagtekin E, et al. Acute inferior myocardial infarction caused by lightning strike. Prehosp Disaster Med. 2018; 33(6):658-59.

2. Karadas S, Vuruskan E, Dursun R, et al. Myocardial infarction due to lightning strike. J Pak Med Assoc. 2013;63(9):1186-8.

3. Saglam H, Yavuz Y, Yurumez Y, et al. A case of acute myocardial infarction due to indirect lightning strike. J Electrocardiol. 2007;40(6):527-30.

4. Schwab M, Wiegand H, Bentsen P, Hochrein H. Infarct ECG following a lightning accident. Z Kardiol. 1989 (9):611-4.

PACING SYSTEM MALFUNCTION. Obszański & al. (1) mentioned that atmospheric electrical discharge is an extremely powerful natural phenomenon which can have dangerous and lethal effects on the human body. However, there is no evidence to indicate whether and, if so, to what extent the electric current travelling through the body can affect proper pacemaker function. An 80-year-old patient admitted to emergency department after being struck by a lightning bolt while riding a bike. The patient had a DDD pacemaker implanted 4 years prior to the incident. The ECG on admission depicted pacemaker spikes and native sinus rhythm at 50-60 b.p.m. On the 3rd day after admission the patient developed recurrent pacing-induced tachycardia. Pacemaker interrogation showed high pacing thresholds (failure to pace in the atrial channel).

When the patient's condition stabilized, she was transferred to the tertiary hospital for transcutaneous lead extraction. The extracted pacing system was sent to Biotronik for thorough evaluation. Injuries due to a lightning strike are considered a rare occurrence but being struck by lightning with a pacemaker or an ICD is even less common. In the present case, the cause of cardiac arrhythmia was most probably electrical burn at the endocardial-electrode interface and a sudden elevation of the pacing threshold leading to transient pacing failure in both PM channels. To the best of the Authors' knowledge, in this case presentation, permanent lightning-induced pacemaker dysfunction is first described **(1)**.

Reference

1. Obszański B, Tułecki Ł, Kutarski A, Kleinrok A. Lightning-induced pacing system malfunction: a case report. Eur Heart J Case Rep. 2019 Jun 1;3(2):ytz092.

TAKOTSUBO CARDIOMYOPATHY. Dundon & al. (1) mentioned that lightning strike is the most common environmental cause of sudden cardiac death but may also be associated with a myriad of injuries to various organ systems. Direct myocardial injury may be manifest as electrocardiographic alterations or elevation in cardiac-specific isoenzymes; however, significant electrical cardiac trauma appears uncommon. A case is presented of severe acute cardiomyopathy in a "Takotsubo" distribution causing cardiogenic shock following lightning strike in a previously healthy 37-year-old woman. Although rarely identified in this context, Takotsubo cardiomyopathy (also known as "transient left ventricular apical ballooning syndrome") is characterized by transient cardiac dysfunction, electrocardiographic changes that may mimic acute myocardial infarction and minimal release of cardiac-specific enzymes in the absence of obstructive coronary artery disease. The condition is associated with a substantial female bias (up to 90% of cases) in reported series, and despite occasionally dramatic presentations recovery of left ventricular function is almost universal over days to weeks. In rare instances, however, the syndrome has been associated with more catastrophic complications such as papillary muscle or cardiac free wall rupture, necessitating emergency surgical intervention to preserve life. In clinical practice, non-lethal lightning strike-induced cardiac injury is frequently associated with small elevations of cardiac isoenzymes without overt clinical sequelae; however, the incidence of silent myocardial mechanical dysfunction remains unknown. Cases such as the one presented highlight the potential for serious, albeit usually transient, cardiac sequelae from lightning strike injury and remind us that the mothers' advice to remain indoors during thunderstorms is probably worth heeding **(1)**.

References

1. Dundon BK, Puri R, Leong DP, Worthley MI. Takotsubo cardiomyopathy following lightning strike. Emerg Med J. 2008;25(7):460-1.

AUTONOMIC NERVOUS SYSTEM DYSFUNCTION

Jost & al. (1) emphasized that Autonomic nervous system (ANS) dysfunction is a serious complication of lightning and electrical trauma (L/ET). The ANS regulates the normal vegetative functioning of many organ systems. When ANS is compromised after lightning and electric trauma, patients are vulnerable to serious medical problems. Three conditions of ANS dysfunction of particular concern for L/ET patients are complex regional pain syndrome (CRPS), cardiovascular abnormalities, and keraunoparalysis (KP). The patient with CRPS presents with pain, hyperpathia, sweating, and edema hours to days after trauma. Neurorehabilitation is exceedingly important. A primary goal is to keep the affected extremity mobile and functional. Some patients benefit from sympathetic blockade. Cardiovascular abnormalities associated with lightning and electrical trauma can be life threatening. Care for these patients require a multidisciplinary team including a cardiologist. Keraunoparalysis is a frightening and distressing complication of lightning strikes. The syndrome consists of limb paralysis, sensory symptoms, pallor, coolness, and absent pulses. Release of excessive catecholamines is said to be responsible for these findings. Fortunately, the condition is transient **(1)**.

Cohen (2) mentioned that both lightning and electrical injuries can cause autonomic nervous system (ANS) symptoms and signs. Published descriptions of ANS involvement occurring with lightning and electrical injuries are rare. The most often reported neurologic complications of lightning injuries involve the central nervous system. ANS abnormalities have been documented with lightning, although the descriptions are scant. There is a lack of complete clinical information or ANS testing data in these cases. This is usually a result of the transient nature of ANS complications. In electrical injuries, ANS involvement is less well described than for lightning. Electrical injuries can be associated with peripheral nerve damage. As a result of peripheral nerve damage, reflex sympathetic dystrophy (RSD) may occur in patients with electrical injuries. Various treatment strategies for RSD associated with electrical injuries are found in single case reports. This article summarizes ANS involvement, predominantly in lightning injuries, and describes RSD and its treatment, predominantly in electrical injuries **(2)**.

References

1. Jost WH, Schönrock LM, Cherington M. Autonomic nervous system dysfunction in lightning and electrical injuries. NeuroRehabilitation. 2005;20(1):19-23.

2. Cohen JA. Autonomic nervous system disorders and reflex sympathetic dystrophy in lightning and electrical injuries. Semin Neurol. 1995;15(4):387-90.

NEUROLOGICAL DISEASES

Gruhn & al. (1) mentioned that lightning strikes rarely occur but 85 % of patients have lightning-related neurological complications. This report provides an overview about different modes of energy transfer and neurological conditions related to lightning strikes. Moreover, two case reports demonstrate the importance of interdisciplinary treatment and the spectrum of neurological complications after lightning strikes **(1)**.

Thunderstorm Night View Photo from Sanatorio in Kavala. greece.com.

Cherington (2) mentioned that the bicycle, an invention that provides joy and transportation to millions of people, can also be a source of disabling injuries and death. The victims of bicycle accidents are usually in good health and often young. Most of the fatal head injury cases are teenagers. In this article, four areas of bicycle trauma that frequently brings the bicycle patient to the attention of a neurologist was chosen. These areas are 1] head trauma as a consequence of road collisions; 2] compressive ulnar neuropathy; 3] impotence, probably due to compression of the pudendal nerve or its branches; and 4] lightning-related bicycle injuries. The one thing that all four categories have in common is that they are often preventable. Helmet usage and common sense would lower the number of serious head trauma cases by 50%. Compressive ulnar and pudendal neuropathies can be prevented or reduced if the cyclist would frequently change his or her position in relation to the handlebar and saddle. In the majority of cases of compressive neuropathies, the symptoms improve if the patient takes a holiday from bike riding. Lightning injuries can be avoided or lessened if the cyclist takes proactive measures to limit his or her exposure during thunderstorms. These proactive measures include knowing the climate patterns of the area and knowing where the nearest safe shelter is located **(2)**.

Kleinschmidt-DeMasters (3) mentioned that when a person is struck by lightning a spectrum of neurologic damage can result. Approximately one third of the strikes prove to be fatal. The possibility of damage to the CNS relates to the type of lightning injury (direct strike, stride potential, or side flash), the intensity and

duration of the current, the pathway of the current within the body, and secondary injuries to brain either from cardiac arrest and hypoxia or from physical trauma. Direct strikes to the head have a high degree of fatality and often result in petechiae or larger brain hemorrhages. Although there may be some predilection for the petechiae to occur in the brainstem, the larger hemorrhages may be particularly located near the pathway of the electrical current and result from direct damage to brain vasculature. Enlarged perivascular spaces seen histologically are relatively subtle; they have been attributed to the effects of gas bubbles from electrolysis, heat formation, or both. Small vessel thrombi and neuronal changes may be present nearby. Some brain tissue softening, and edema may be direct effects of passage of current. Often, however, hypoxic encephalopathy and cerebral edema occur following cardiopulmonary arrest when the passage of the current through the body presumably generates cardiac arrhythmias. Considerably less is known about the spinal cord injuries in lightning strike, although one detailed recent study suggests that demyelination may be an underlying mechanism. Similarly, myelin damage appears to be a feature of electrical and possibly lightning injury to the peripheral nervous system **(3)**.

Cherington & al. **(4)** mentioned that over the past ten years, the Authors have cared for 13 patients who suffered serious neurologic complications after being struck by lightning. The spectrum of neurologic lesions includes the entire neuraxis from the cerebral hemispheres to the peripheral nerves. These various neurologic disorders were described with regard to the site of the lesion, severity of the deficit, and the outcome. Damage to the nervous system can be a serious problem for patients struck by lightning. Fatalities are associated with hypoxic encephalopathy in patients who suffered cardiac arrests. Patients with spinal cord lesions are likely to have permanent sequelae and paralysis. New technology for detecting lightning with wideband magnetic direction finders is useful in establishing lightning-flash densities in each state. Florida and the Gulf Coast states have the highest densities. Colorado and the Rocky Mountain states have the next highest **(4)**.

Lakshminarayanan & al. (5) presented 2 patients in whom the predominant neurological complication following lightning strike was spinal cord injury. One patient, who was followed for 5 years, showed clinical, electrophysiologic and MRI evidence of cervical spinal cord injury. This patient had significant recovery, which in part, may be related to early and intense rehabilitation. The second patient presented with the symptoms and signs of spinal shock which then evolved into a myelopathy. Follow-up several months later showed almost complete resolution of symptoms. These patients demonstrate that the prognosis of spinal cord injury complicating a lightning strike may not be uniformly poor **(5)**.

Cherington (6) noticed that lightning is responsible for a wide spectrum of neurologic complications. Many of the persistent symptoms require long-term neurorehabilitation. The lightning-related neurologic conditions are divided into four categories.

Category I consists of signs and symptoms that are temporary and usually benign. Category II conditions are prolonged or permanent produced by significant central nervous system lesions. Two of the most devastating complications are lightning-related encephalopathy and myelopathy. The disabilities that accompany these lesions call for concentrated neurorehabilitation. A large number of patients are afflicted with neurobehavioral symptoms that may last for months or years. Category III contains delayed neurologic syndromes. Category IV encompasses neurologic lesions that are not directly activated by the lightning strike but are the result of trauma secondary to falls or blasts effects. The sensible course for individuals at risk is to learn and follow lightning safety recommendations **(6)**.

Martin & al. (7) determined if lightning is associated with the frequency of headache in migraineurs. Participants fulfilling diagnostic criteria for International Headache Society-defined migraine were recruited from sites located in Ohio (n=23) and Missouri (n=67). They recorded headache activity in a daily diary for three to six months. A generalized estimating equations (GEE) logistic regression determined the odds ratio (OR) of headache on lightning days compared to non-lightning days. Other weather factors associated with thunderstorms were also added as covariates to the GEE model to see how they would attenuate the effect of lightning on headache. The mean age of the study population was 44 and 91% were female. The OR for headache was 1.31 (95% confidence limits [CL] 1.07-1.66) during lighting days as compared to non-lightning days. The addition of thunderstorm-associated weather variables as covariates were only able to reduce the OR for headache on lightning days to 1.18 (95% CL 1.02-1.37). The probability of having a headache on lightning days was also further increased when the average current of lightning strikes for the day was more negative. This study suggests that lightning represents a trigger for headache in migraineurs that cannot be completely explained by other meteorological factors. It is unknown if lightning directly triggers headaches through electromagnetic waves or indirectly through production of bioaerosols (e.g., ozone), induction of fungal spores or other mechanisms. These results should be interpreted cautiously until replicated in a second dataset **(7)**.

Cherington & al. (8) reported an extraordinary event of a lightning strike to the head of a helmeted bicyclist that occurred under fair weather conditions with a cloudless sky. The patient sustained a cardiac arrest and hypoxic encephalopathy with residual neurologic impairment. With the availability of highly developed meteorologic equipment, the lightning "bolt from the blue" probably originated in a thunderstorm that was about 16 km away and obscured by the mountains **(8)**.

Steinbaum & al. (9) presented a case is presented of a teen-aged athlete who sustained a direct lightning strike to the head while wearing a football helmet. The helmet, the presence of sweat, and aggressive resuscitation were instrumental in his survival and complete recovery. This appears to be the first documentation of a lightning strike to an individual wearing protective headgear **(9)**.

Carrera-Izquierdo & al. (10) reported that the damage caused to the central nervous system by lightning can be immediate or delayed. Cerebrovascular accidents are usually an infrequent complication of lightning strikes. The case of a patient is reported was hit by lightning and then developed an acute bilateral intraparenchymatous hemorrhage in the basal ganglia and the left internal capsule. Few cases of intracranial hemorrhages secondary to lightning strikes have been reported. A review and analysis of the literature currently available on the subject were carried out. A number of theories have been put forward that attempt to explain the mechanism behind these hemorrhages in patients who have been hit by lightning. The reason why there is a predilection for the basal ganglia is unknown, although it could be linked to the particular features of the vascularization of the area **(10)**.

References

1. Gruhn KM, Knossalla F, Schwenkreis P, et al. Neurological diseases after lightning strike: lightning strikes twice. Nervenarzt. 2016;87(6):623-8.

2. Cherington M. Hazards of bicycling: from handlebars to lightning. Semin Neurol. 2000;20(2):247-53.

3. Kleinschmidt-DeMasters BK. Neuropathology of lightning-strike injuries. Semin Neurol. 1995;15(4):323-8.

4. Cherington M, Yarnell PR, London SF. Neurologic complications of lightning injuries. West J Med. 1995;162(5):413-7.

5. Lakshminarayanan S, Chokroverty S, Eshkar N, Grewal R. The spinal cord in lightning injury: a report of two cases. J Neurol Sci. 2009;276(1-2):199-201.

6. Cherington M. Spectrum of neurologic complications of lightning injuries. NeuroRehabilitation. 2005;20(1):3-8.

7. Martin GV, Houle T, Nicholson R, et al. Lightning and its association with the frequency of headache in migraineurs: an observational cohort study. Cephalalgia. 2013;33(6):375-83.

8. Cherington M, Krider EP, Yarnell PR, Breed DW. A bolt from the blue: lightning strike to the head. Neurology. 1997;48(3):683-6.

9. Steinbaum S, Harviel JD, Jaffin JH, Jordan MH. Lightning strike to the head: case report. J Trauma. 1994;36(1):113-5.

10. Carrera-Izquierdo E, Morán-Sánchez JC, Carrera-Izquierdo M, et al. Intracranial haemorrhage secondary to a lightning strike: a case report. Rev Neurol. 2004;39(6):530-2.

NEUROREHABILITATION. **Yarnell (1)** described the most devastating casualties in lightning and electrical trauma patients as the result of lesions of the nervous system, and especially lesions of the brain. The brain injuries can be divided into three categories: global dysfunction; focal brain injuries; and behavioral-cognitive sequelae without gross physical signs. Lightning injuries are usually the result of outdoor sports and leisure activities. Most electrical trauma cases are the result of workplace accidents. Rehabilitation planning should begin early after the incident and often needs to be continued for a long time. The goal of the rehabilitation team is to maximize functional return in patients with deficits related to brain

lesions. The neurorehabilitation team includes the neurorehabilitation physician, physical therapists, occupational therapists, psychologists, speech therapists, and case managers **(1)**.

According to **Lammertse (2)**, while spinal cord injuries caused by lightning strike or electrical shock are rare, their clinical manifestations pose unique challenges to the clinician who must anticipate the interaction of multiple system involvement with the altered physiology of spinal cord injury. Spinal cord damage may be secondary to the direct effects of electrical current passing through neural tissue producing immediate or delayed impairment. Alternatively, lightning strike and electrical shock may lead to spinal cord damage due to the secondary consequences of injury such as spinal fractures sustained after a fall. In addition to effects on the spinal cord, electrical trauma may result in injury to the brain, peripheral nervous system, musculoskeletal system, skin, and cardiovascular system. This article will review the neurorehabilitation approach to this rare and challenging group of patients **(2)**.

Yarnell &, Lammertse (3) noticed that lightning and electrical (L/E) injuries can be among the most dramatic of all events that damage the nervous system. The three major classes of neurologic sequelae that require the expertise of the neurorehabilitationist are: [1] cerebral disorders, either global or focal; [2] neuropsychologic sequelae; and [3] spinal cord injury. Neurorehabilitation management necessary for each of these three areas will be discussed. From the viewpoint of the neurorehabilitationist, therapy principles are the same for L/E trauma as for other more common forms of injury. The goal is to maximize the functional return given the specific impairment **(3)**.

Anketell & al. (4) mentioned that there is a limited evidence base to inform patient management following lightning-induced injuries. A 36-year-old right-handed Caucasian male was struck by lightning while outdoors suffered an out-of-hospital cardiac arrest with a recorded 50-min interval before the restoration of spontaneous circulation. Multiple life-threatening injuries were sustained, and a profound peripheral neuropathy developed. Cognitively, he was remarkably intact. His acute admission and his recovery was documented during an inpatient stay in a UK-based Neurorehabilitation Unit. Intensive neurorehabilitation in this case improved functional independence and facilitated neuropsychological recovery, to the point that the patient was discharged to independent living. This case offers some support to the hypothesis that the electrical activity of a lightning strike can be both cardioprotective and neuroprotective, and that prolonged cardiopulmonary resuscitation is warranted in such cases **(4)**.

References

1. Yarnell PR. Neurorehabilitation of cerebral disorders following lightning and electrical trauma. NeuroRehabilitation. 2005;20(1):15-8.

2. Lammertse DP. Neurorehabilitation of spinal cord injuries following lightning and electrical trauma. NeuroRehabilitation. 2005;20(1):9-14.

3. Yarnell PR, Lammertse DR. Neurorehabilitation of lightning and electrical injuries. Semin Neurol. 1995;15(4):391-6.

4. Anketell J, Wilson FC, McCann J. 'Thunder bolts and lightning': survival and neurorehabilitation following out of hospital cardiac arrest secondary to lightning strike. Brain Inj. 2018; 32(12):1585-7.

OPHTALMIC MANIFESTATIONS

Pradhan & al. (1) reported that in ophthalmology, injuries due to lightning strikes have been documented as various entities ranging from keratitis, cataracts, uveitis in the anterior segments to retinal detachments, papillitis, and macular hole formation in the posterior segment. The Authors report the largest case series so far with a total of seven cases of lightning injuries with ocular involvement and its management and a brief review of the literature on this topic. All of the patients were evaluated for ocular injuries due to a lightning strike and each of the cases has been individually described as case series with their findings and management in this report. Ocular injuries caused by lightning are very rare, but when they occur, they can present with various ocular tissue pathology-ranging from anterior to the posterior segment structures. Most of the cases presented with maculopathy and foveschitic lesions, which resolved over time with the use of steroids. The data show that lightning injuries to the eyes, if detected early and managed appropriately, have a very good prognosis. The recovery is usually good with minimal functional loss if there is a quick referral. The macular region seems to be particularly involved in most cases and OCT can be a valuable diagnostic tool to detect and monitor the pathology **(1)**.

Dhillon & Gupta (2) reported that various ophthalmic complications affecting the anterior and posterior segments have been identified due to lightning strike. The Authors report the first case of an indirect lightning-induced full thickness macular hole formation in the UK as evidenced by slit lamp examination and optical coherence tomography (OCT) scan in a 77-year-old woman presenting with sudden visual loss in her right eye and thermal skin injury affecting her scalp. Her best corrected visual acuities were LogMAR 0.46 and 0.12 in the right and left eyes, respectively. There were no other ocular manifestations observed in either eye. She was initially managed conservatively with non-steroidal anti-inflammatory drug eye drops but surgery was later advised due to minimal changes in the visual acuity and macular hole on follow-up. OCT scanning is important in diagnosing macular holes, which usually warrant surgical intervention **(2)**.

Norman & al. (3) mentioned that every year in the USA, 100-150 people die and 1000-1500 others are injured by lightning strikes. Ophthalmic and neurologic injuries from lightning strike are common. The most common permanent ocular sequela is cataract, but many areas of the eye can be affected. Prompt evaluation by an ophthalmologist is imperative for maximizing outcomes. Incidence and mechanisms of lightning strike injury are summarized, with special emphasis on the treatment of ocular injuries **(3)**.

Khadka & al. (4) reported that lightning is a naturally occurring atmospheric phenomenon. Though uncommon, it is a potentially devastating and underreported natural calamity. Lightning accounts for the second leading cause of weather-related death in most parts of the world. Among the survivors of lightning injury, more than half of the victims may suffer from some form of ophthalmic injury. The lightning-associated ocular injury varies from a range of anterior segment to posterior segment pathologies. Two clinical cases of ocular injuries are reported among the survivors of lightning injury. Anatomical involvement is seen at different levels with presentation as uveitis, pupillary abnormality, maculopathy, and later development of lenticular opacification. OCT, a noninvasive diagnostic tool, is particularly useful in the evaluation of lighting maculopathy as well as to monitor its progression through the course of time. Visual prognosis depends upon the structures of the eyes affected in the injury. The presence of irreversible retinal damage as well as optic nerve damage often result in poor visual outcome in the absence of significant anterior segment pathology. This report highlights the evolution of maculopathy through the course of time and signifies the importance of long-term follow-up postlightning injury **(4)**.

Rao & al. (5) reported a case of a 16-year-old girl, who was struck by lightning, and experienced blurred vision in the right eye (RE) immediately following the episode. She reported for ophthalmic evaluation two months later. Examination revealed relative afferent pupillary defect in the RE. Posterior subcapsular cataract was noted in both eyes. Fundus examination revealed macular holes and multiple areas of RPE hyperpigmentation in the periphery in both eyes. Fundus fluorescein angiography showed increased choroidal transmission with early fluorescence and late fading in the foveal region and retinal pigment epithelium (RPE) stippling in the periphery in both eyes. This is the first case report of such nature in India to the best of the Authors' knowledge **(5)**.

Handa & Jaffe (6) mentioned that lightning can cause a number of ocular complications. A case involving a patient who developed a cataract and reversible maculopathy in both eyes after being struck by lightning is reported. The patient was evaluated for cataract and macular edema by ophthalmoscopic examination, fluorescein angiography, and potential acuity meter. Maculopathy developed that was characterized initially by a retinal cyst with surrounding edema. Later, the lesions evolved to simulate a full-thickness hole. These lesions subsequently resolved, and the patient's visual acuity improved to 20/20 in each eye after cataract extraction. The data indicate that because the visual prognosis for lightning-induced maculopathy is potentially different than that for full-thickness macular holes, careful retinal examination is essential in the preoperative workup **(6)**.

Augustin & al. (7) reported two men with recent history of lightning strike were referred to the hospital. Both patients complained of metamorphosia in one eye and reduced visual acuity. Funduscopy revealed target-like alterations at the fovea. Fluorescein

angiography showed window defects of the central retinal pigment epithelium in both patients. One patient developed an anterior subcapsular cataract. If the eye is part of the current circuit, the melanin granules of the iris, pigment epithelium, and choroid might act as a resistor. The resulting accumulation of heat may lead to damage of the surrounding tissues **(7)**.

Gupta & al. (8) reported a case of bilateral cataract with posterior vitreous detachment induced by lightning injury. A case report is presented of 30-year-old man injured by lightning. The patient developed visually significant bilateral cataract after four years of the initial insult on the scalp. The exit wound was noted on the right foot. Fundus evaluation after cataract extraction revealed posterior vitreous detachment. The data demonstrate that lightning can induce various ocular complications. Decrease in vision due to cataract is usually seen years after the initial lightning injury as the initial changes are in the mid-periphery and often missed in the acute setting. Posterior vitreous detachment induced by lightning can rarely lead to retinal tear formation and subsequently retinal detachment. The severity of entry and exit may not give a true picture of the internal organ damage **(8)**.

Alexík & al. (9) mentioned that lightning injuries are dangerous and often deadly trauma. A case is presented of 41-year-old woman who suffered an indirect lightning injury, dropping into unconsciousness followed by amnesia. Initial irritation of her left eyeball was followed by subtle changes in retinal pigment epithelium without any drop in visual acuity for a period of three months. Subsequently there began a slow deterioration of visual acuity and progression of cataract causing BCVA to drop to 5/50. Patient underwent uncomplicated cataract phacoemulsification with IOL implantation which resulted in restoring BCVA to 5/5 postoperatively. Such cases are scarce in literature **(9)**.

Espaillat & al. (10) reported ocular injuries, including a unilateral rhegmatogenous retinal detachment, induced by lightning. In this case report, a 30-year-old man was injured by lightning. The patient developed a severe decrease in visual acuity in both eyes, an afferent pupillary defect in his left eye, bilateral cataracts, posterior vitreous detachments, macular holes, and an inferotemporal retinal detachment with an associated flap retinal tear in his left eye. This is a case of bilateral cataracts, posterior vitreous detachments, macular holes, and a unilateral retinal detachment associated with lightning. It was postulated that the heating of the retinal surface, the concussive forces on the eye, and a sudden lateral contraction of the attached vitreous resulted in bilateral posterior vitreous detachments and a unilateral peripheral retinal break **(10)**.

References

1. Pradhan E, Khatri A, Ahmed AA, et al. Lightning injury to eye: brief review of the literature and case series. Clin Ophthalmol. 2020;14:597-607.

2. Dhillon PS, Gupta M. Ophthalmic manifestations postlightning strike. BMJ Case Rep. 2015 Mar 31;2015:bcr2014207594.

3. Norman ME, Albertson S, Younge BR. Ophthalmic manifestations of lightning strike. Surv Ophthalmol. 2001;46(1):19-24.

4. Khadka S, Byanju R, Pradhan S, et al. Evolution of lightning maculopathy: presentation of two clinical cases and brief review of the literature. Case Rep Ophthalmol Med. 2021 Jan 22;2021: 8831987.

5. Rao KA, Rao LG, Kamath AN, Jain V. Bilateral macular hole secondary to remote lightning strike. Indian J Ophthalmol. 2009; 57(6):470-2.

6. Handa JT, Jaffe GJ. Lightning maculopathy. A case report. Retina. 1994;14(2):169-72.

7. Augustin AJ, Koch F, Böker T. Macular damage following lightning strikes. Ger J Ophthalmol. 1995;4(4):214-6.

8. Gupta A, Kaliaperumal S, Sengupta S, Babu R. Bilateral cataract following lightning injury. Eur J Ophthalmol. 2006;16(4):624-6.

9. Alexík M, Stubna M, Kácerik M. Cataract after lightning injury -case report. Cesk Slov Oftalmol. 2011;67(1):27-9.

10. Espaillat A, Janigian Jr R, To K. Cataracts, bilateral macular holes, and rhegmatogenous retinal detachment induced by lightning. Am J Ophthalmol. 1999;127(2):216-7.

CUTANEOUS MANIFESTATIONS

Asuquo & al. (1) emphasized that lightning injuries are relatively uncommon and have been a subject of awe since primitive times. It most significantly affects the cardiorespiratory, nervous, and integumentary systems. Surprisingly, cutaneous burn injuries caused by lightning are usually superficial. The objective was to present the cutaneous manifestations of lightning injuries and the sequelae of improper management. A 22-year-old woman presented with cutaneous manifestations of lightning-induced burns and bilateral upper limb gangrene after 2 months of improper treatment. She refused amputation after counseling and left the hospital. This is a rare case of burns with cutaneous manifestations peculiar to lightning injury. These features serve as evidence of lightning injury, when in doubt, especially in societies where superstition is rife. Education concerning the nature of lightning and proper management would improve outcome **(1)**.

Reference

1. Asuquo ME, Ikpeme IA, Abang I. Cutaneous manifestations of lightning injury: a case report. Eplasty. 2008;8:e46.

LICHTENBERG FIGURES

Cherington & al. (1) emphasized that the Lichtenberg figure (LF) is a recognizable skin pattern that is only seen in individuals struck by lightning. LF, also known as a ferning pattern, is a transient finding. It is not a burn, and biopsies of the skin reveal no pathologic changes. Three case reports of patients were presented with LF after being struck by lightning. The explanation of what LF represents remains unknown. Many researchers believe that LFs are fractal patterns and do not correspond to known vascular or neuroanatomic patterns.

The ideas are presented on possible mechanisms of the pathophysiology of LFs **(1)**.

Reference

1. Cherington M, McDonough G, Olson S, et al. Lichtenberg figures and lightning: case reports and review of the literature. Cutis. 2007; 80(2):141-3.

BURNS

Ikpeme & al. **(1)** reported that lightning strikes are relatively uncommon. In our culture where superstitions are strong and natural events often linked to evil forces, the traditional bonesetter/healer is often consulted first. Patients then seek orthodox care when complications develop. Patients also have difficulty accepting ablative treatment when indicated. The objective was to present a usual case of bilateral upper limb burns caused by lightning and complicated by refusal to receive orthodox treatment. A 22-year-old woman was struck by lightning while asleep. Instead of going to hospital, she was taken to a traditional healer where she spent two months before presenting with gangrenous upper limbs to hospital. Patient refused amputation and abandoned hospital against medical advice. This case report of bilateral upper limb burns resulting from lightning is rare. Importantly, the case highlights the role of ignorance, superstition, and the disastrous results of traditional medical practice in the healthcare delivery **(1)**.

Apanga & al. (2) emphasized that lightning is a natural phenomenon that mostly affects countries in the tropical and subtropical regions of the globe, including Ghana. Lightning strikes pose a global public health issue. Although strikes to humans are uncommon, it is associated with high morbidity and mortality. The Authors presented a case of a 10-year-old Ghanaian girl who got second-degree burns after being struck by lightning. She was put on an intravenous broad-spectrum antibiotic (ceftriaxone), Ringer's lactate, and her burns were dressed with sterile gauze impregnated with Vaseline (petroleum jelly) and silver sulfadiazine ointment. There was marked improvement on the 16th day of treatment despite the lack in capacity of the hospital to carry out some laboratory diagnostic tests. On the 21st day of treatment, the burns were completely healed without scars and contractures. This is evidence of burns due to lightning strike, despite its rare occurrence. This report will help inform those in doubt, particularly in communities where lightning injuries are associated with widespread superstition. The case report also revealed how rural healthcare can be challenging amid a lack of basic diagnostic equipment and logistics. However, in resource-limited settings, Vaseline (petroleum jelly) and silver sulfadiazine could be used in the treatment of burns **(2)**.

Celiköz (3) noticed that an unusual full-thickness burn of the scalp and cranial bones due to a lightning strike is reported. A thick nylon cover protected the head from the direct effects of the lightning injury, but heated water over the thick nylon cover caused full-

thickness burn of the scalp and cranial bones. The relevant literature has been reviewed **(3)**.

Murty (4) reported that this is a case report of an environmental accident due to lightning where one school boy sustained current, blast, and flame effects of it. A bolt of lightning directly struck the pole of a football ground, and the scatter struck the child. In addition to burn injuries, he showed an exit wound of lightning in left foot. The exit wound of lightning current is a very rare finding. The body of victim had flame and heat effect of atmospheric electricity on head and neck, face, and trunk. In this incidence of lightning other team mates of the victim were safe. The patient survived the attack **(4)**.

Moollaor & Annoppetch (5) reported a 40-year-old Thai male who was struck by lightning while he was riding his motorcycle during a day of gathering clouds and threatening rain. There were third degree burns around the mastoid areas corresponding to the metal arms of the spectacles, also around the neck where a silver chain with pendant (Buddha image) hung, as well as a full thickness vertical lesion down the center of the chest and abdomen where the zip of the jacket made its mark. Fern-like skin erythema was also seen around the later wound. These are stigmas of lightning skin injuries and the patient survived with no memory of the event **(5)**.

Sorando et. al. (6) presented a case of a golfer who was struck by lightning while playing golf during a thunderstorm. The patient was found lying unconscious on wet grass with his clothes scorched and his spiked golf shoes torn. He had suffered dermal burns affecting the neck, thorax, abdomen, and upper and lower limbs (10% total body surface area), without any cardiovascular or respiratory disturbances. It may be hypothesized that the lightning current went over the outside of the patient, causing ignition of his clothes. Treatment included monitoring, adequate fluid management, debridement, and topical treatment (silver sulphadiazine). Complete healing of the wounds was achieved in two weeks. After three years' follow-up, the patient had no sequelae **(6)**.

References

1. Ikpeme IA, Udosen AM, Asuquo ME, Ngim NE. Lightning burns and traditional medical treatment: a case report. West Afr J Med. 2007;26(1):53-4.

2. Apanga PA, Azumah JA, Yiranbon JB. A rare manifestation of burns after lightning strike in rural Ghana: a case report. J Med Case Rep. 2017 Jul 25;11(1):200.

3. Celiköz B, Işik S, Türegün M, Selmanpakoğlu N. An unusual case of lightning strike: full-thickness burns of the cranial bones. Burns. 1996;22(5):417-9.

4. Murty OP. Dramatic lightning injury with exit wound. J Forensic Leg Med. 2007;14(4):225-7.

5. Moollaor P, Annoppetch C. Lightning injury: a case report. J Med Assoc Thai. 1993;76(7):410-4.

6. Sorando E, Galeano-Ricaño N, Agulló-Domingo A, et al. Lightning strike in golf practice. Ann Burns Fire Disasters. 2006; 19(1):44-6.

ACUTE LUNG INJURY

Şener & al. (1) reported that lightning strike is an environmental electrical injury with high rates of morbidity and mortality. Lightning strike injuries are also considered to be high-voltage injuries. Respiratory injuries associated with lightning strikes include pulmonary edema, pulmonary contusion, acute respiratory distress syndrome, and pulmonary hemorrhage. In addition to direct damage, the affected patients are also exposed to secondary trauma; similarly, many other mechanisms associated with lightning injury have the same risk. It will therefore always be a rational approach to evaluate patients as multiple trauma patients. In this case report, a 19-year-old patient was admitted to the emergency department with amnesia, disorientation, shortness of breath, abdominal pain complaints and lung contusion, and myopathy signs as a result of a lightning strike in open terrain. The patient had a blood pressure of 80/50 mmHg, a heart rate of 110/min, and oxygen saturation of 85%. Bilateral lung contusion and pleural effusion were detected on the computerized tomography of the thorax. In addition, global cardiac hypokinesia and the 20%-25% ejection fraction were detected on echocardiography. The central nervous system and abdominal scans were normal. The patient was admitted to the intensive care unit and treated with supportive oxygen, intravenous hydration, antibiotics, systemic steroids, and invasive cardiac monitoring. On the 10th day of admission to the hospital, the patient was discharged with clinical and radiological improvement. On the 20th day after discharge, tomography scans showed no thoracic pathologic findings **(1)**.

Reference

1. Şener MU, Demir A, Şener A. Lightning-strike-induced acute lung injury: a case report. Ulus Travma Acil Cerrahi Derg. 2019;25(2):198-201.

ACUTE RENAL FAILURE

Okafor (1) emphasized that lightning strikes cause multimodal injuries in victims, and although the number of deaths due to lightning is reportedly in the area of 1,000 deaths per year, they cause significant morbidity in many others. A major complication of a lightning strike is acute renal failure (ARF). The true incidence of ARF due to lightning injuries worldwide is difficult to ascertain because of significant underreporting, due in large measure to cultural and sociodemographic factors. Its incidence is reportedly rare in some literature and significant in others. However, lightning's potential to cause ARF due to myoglobinuria has been noted by many authors. Prompt treatment of myoglobinuric patients prevents the development of ARF. ARF due to direct organ damage by lightning is virtually unheard of. In this article, the current mechanisms of lightning injuries leading to muscle damage, myoglobinuria, and subsequent ARF are discussed, as well as signs and symptoms, laboratory investigations, and patient management **(1)**.

Reference

1. Okafor UV. Lightning injuries and acute renal failure: a review. Ren Fail. 2005;27(2):129-34.

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GASTRIC PERFORATION

Kilbas & al. (1) mentioned lightning strike is an unusual form of trauma in terms of being one of the leading causes of death from natural phenomenon. Lightning strike can cause severe damage to many systems and results in a high mortality. The most common cause of death in the lightning strike victim is cardiopulmonary arrest. The most vulnerable subjects for lightning strike are individuals who work in open fields, farmers, and swimmers. The cardiac and neurological injuries are the most serious injuries. Burns, tinnitus, blindness, and secondary blunt trauma have also been reported. Gastrointestinal complications have been documented very rarely. In this study, a case of gastric perforation after lightning strike is presented. No report related to gastric perforation caused by lightning strike has been identified in the literature **(1)**.

Reference

1. Kilbas Z, Akin M, Gorgulu S, et al. Lightning strike: an unusual etiology of gastric perforation. Am J Emerg Med. 2008; 26(8):966.e5-7.

AURICULAR DAMAGE

Leveillé-Nizeroll (1) mentioned that auricular accidents provoked by lightning and induced by telephone are extremely rare. The authors of this paper relate the case of a young lady suffering from an inflammation of the external auditive canal and of an irritation of the tympanic membrane with a perception's hypacusis of 30 db. A physiological explanation is proposed, and two factors come into account: the acoustic traumatism induced by the thunder; the burn produced by the electrical current **(1)**.

Reference

1. Leveillé-Nizerolle M, Lintzer JP, Bérézin A. Auricular consequences of lightning (author's transl). Ann Otolaryngol Chir Cervicofac. 1978; 95(10-11):695-702.

MANAGEMENT

Lederer & al. (1) emphasized that the pattern of injuries following electrical accidents and the treatment by emergency teams differ depending on whether exposure was to a low-voltage or high-voltage power source or to a lightning bolt. Tissue damage results from the direct effect of current on cell membranes and from conversion of electrical energy into heat. Depending on the magnitude of electrical energy and the duration of exposure, cardiac dysrhythmia, damage to nerve tissue, extensive burns and shock may occur. Multi-system injury is frequently observed, either directly related to electrical shock or secondary to concurrent trauma. Extrication of victims from the0 energy field must be performed under strict observance of self-protection measures for the rescuers. In high-voltage incidents the rescuers must wait at a distance until the power supply has been turned off and demonstrably grounded. Analgesia, anxiolysis and administration of crystalloid fluids are needed, especially for injuries from high-voltage power sources. Severe burns of the face and neck call for early intubation and ventilation. Monitoring is performed with pulsoximetry, blood pressure measurement and ECG, giving highest priority to the unconscious patient with cardiac and respiratory arrest. Cardio-pulmonary resuscitation (CPR) follows the international guidelines for resuscitation and may be effective after delayed onset and even after prolonged resuscitation attempts **(1)**.

Walsh (2) mentioned that there are a few national position stands/guidelines that address environmental conditions in athletics, yet they do not govern all outdoor sports. Extreme heat and cold, lightning, and severe wind can all be fatal, yet the majority of outdoor sports have no published guidelines addressing these conditions in relation to activity. Available research on extreme heat and cold conditions in athletics provides prevention strategies, to include acclimatization. Lightning and severe wind are two environmental conditions to which humans cannot accommodate, and they both can be deadly. There are strong positions on extreme heat/cold and lightning safety in athletics, but none affiliated with severe winds. Medical personnel involved in planning large outdoor sporting events must know of the presence of nationally published weather-related documents and apply them to their event. In addition, research needs to be expanded in the realm of establishing guidelines for safety to participants and spectators in severe wind conditions **(2)**.

Cooper (3) mentioned that high-voltage electrical injuries may be devastating, with extensive burns, cardiac arrest, amputations, and long, complicated hospitalizations. Low-voltage injuries, after other pathologic and high-voltage sources are ruled out, tend to be rather benign acutely although they may have significant long-term

morbidity, including chronic pain syndromes. Lightning injuries affect 800 to 1,000 persons per year. In lightning injury, cardiac arrest is the main cause of death, burns tend to be superficial, ad injuries often are what one would expect of short-circuiting or overloading the body's electrical systems (tinnitus, blindness, confusion, amnesia, cardiac arrhythmias, and vascular instability). Although high-voltage injuries may require the services of trauma surgeons, in general, therapy for low-voltage and lightning injury is supportive and involves cardiac resuscitation for the more seriously injured and supportive care for the less severely injured. Long-term problems from sleep disturbances, anxiety attacks, pain syndromes, peripheral nerve damage, fear of storms (for lightning patients), and diffuse neurologic and neuropsychologic damage may occur in both electrical and lightning patients. Other sequelae - such as seizures or severe brain damage from hypoxia during cardiac arrest and spinal artery syndrome from vascular spasm - are indirect results of electrical and lightning injury **(3).**

O'Keefe Gatewood & Zane (4) mentioned that lightning is persistently one of the leading causes of death caused by environmental or natural disaster. To understand the pathophysiology and treatment of lightning injuries one must first discount the innumerable myths, superstitions, and misconceptions surrounding lightning. The fundamental difference between high voltage electrical injury and lightning is the duration of exposure to current. Reverse triage should be instituted in lightning strike victims because victims in cardiopulmonary arrest might gain the greatest benefit from resuscitation efforts, although there is no good evidence suggesting that lightning strike victims might benefit from longer than usual resuscitation times. Many of the injuries suffered by lightning strike victims are unique to lightning, and long-term sequelae should be anticipated and addressed in the lightning victim **(4)**.

Craig (5) mentioned that lightning accidents are responsible for several hundred deaths and thousands of injuries each year in this country. Survivors sustain a variety of cardiac, neurologic, musculoskeletal, and dermatologic injuries. Eye and ear injuries are also occasionally noted. Education on how to minimize the possibility of such an accident is the best method of dealing with the problem. When prevention fails, prompt cardiopulmonary resuscitation and supportive treatment for the patient's particular injury are indicated **(5)**.

Holle & al. (6) emphasized that not enough emphasis is usually placed on the proactive ability to recognize the lightning hazard. Instead, most literature and training materials treat the reactive mode. The latter approach emphasizes the posture to take when a person is caught by surprise in the open by a thunderstorm when the lightning threat is at its greatest; in other words, it is too late for precautions. The same reactive approach concentrates on what a person is wearing or holding when lightning is overhead instead of how the person came to be in this situation in the first place. Rather than focusing on these last-minute factors, the primary issue must be

on the ability of a person, whether in a baseball game, riding a bike, or on a golf course, to recognize in advance the existence of a major lightning threat. This proactive approach emphasizes advance planning and recognition of a potential threat from lightning. A complete plan involves a sequence of decisions on a time scale from days to seconds. Although most of the available information in pamphlets and safety guidelines is correct concerning the reactive phase of lightning safety, the hazard remains important because of the lack of emphasis on planning and awareness **(6)**.

Zimmermann & al. (**7**) mentioned that on average, lightning causes more casualties annually in the United States than any other storm-related phenomenon except floods. Although 90% of those injured survive, they may have permanent sequelae and disability. Many of these people incur injuries or are killed by lightning because of misinformation and inappropriate behavior during thunderstorms. A few simple precautions can reduce lightning injury risk. To standardize recommended actions during thunderstorms, the Lightning Safety Group (LSG), composed of lightning experts from many lightning-related backgrounds, met at the American Meteorological Society Meeting Phoenix, AZ, in January 1998 to collectively address personal lightning safety. This paper is a summary of the recommendations developed by the LSG **(7)**.

Scarneo-Miller & al. (8) reported that lightning-related injuries are among the top 10 causes of sport-related death at all levels of sport, including the nearly 8 million athletes participating in US secondary school sports. The objective was to investigate the adoption of lightning safety policies and the factors that influence the development of comprehensive lightning safety policies in United States secondary schools. This was a cross-sectional study conducted at a secondary school. Patients or other participants were Athletic trainers (ATs). An online questionnaire was developed based on the "National Athletic Trainers' Association Position Statement: Lightning Safety for Athletics and Recreation" using a health behavior model, the precaution adoption process model, along with facilitators of and barriers to the current adoption of lightning-related policies and factors that influence the adoption of lightning policies. Precaution adoption process model stage (unaware for need, unaware if have, unengaged, undecided, decided not to act, decided to act, acting, maintaining) responses are presented as frequencies. Chi-square tests of associations and prevalence ratios with 95% CIs were calculated to compare respondents in higher and lower vulnerability states, based on data regarding lightning-related deaths. The response rate for this questionnaire was 13.43% (n=365), with additional questionnaires completed via social media (n=56). A majority of ATs reported maintaining (69%, n=287) and acting (6.5%, n=27) a comprehensive lightning safety policy. Approximately 1 in 4 ATs (25.1%, n=106) described using flash to bang as an evacuation criterion. Athletic trainers practicing in more vulnerable states were more likely to adopt a lightning policy than those in less vulnerable states (57.4% versus 42.6%, prevalence ratio [95% CI] 1.16 [1.03-1.30]; p=0.009). The most commonly cited facilitator and barrier

were a requirement from a state high school athletics association and financial limitations, respectively. The data show that a majority of ATs related adopting (e.g., maintaining and acting) the best practices for lightning safety. However, many ATs also indicated continued use of outdated methods (e.g., flash to bang) **(8)**.

Walsh & al. (9) investigated the hazards of lightning for participants in outdoor athletics and to determine the existence of, and assess the nature of, lightning safety policy at the collegiate level. Data were used from the National Severe Storms Laboratory in Norman, Oklahoma, and from a survey of Division I institutions. Subjects included the 48 National Collegiate Athletic Association Division I (football) universities in Florida, Michigan, Pennsylvania, North Carolina, and New York. Athletic trainers at all of the selected 48 Division I institutions responded to the telephone survey. Florida, Michigan, Pennsylvania, North Carolina, and New York led the country in lightning deaths and injuries from 1959-1994. Only 8% (n = 4) of the institutions surveyed in these states have a written policy regarding lightning safety. This study demonstrated the lack of lightning safety policy in the surveyed universities and the need for a systematic plan of action to make fields safer for all who are involved in outdoor sport activities **(9)**.

Walsh & al. (10) presented recommendations for the education, prevention, and management of lightning injuries for those involved in athletics or recreation. Lightning is the most common severe-storm activity encountered annually in the United States. The majority of lightning injuries can be prevented through an aggressive educational campaign, vacating outdoor activities before the lightning threat, and an understanding of the attributes of a safe place from the hazard. This position statement is focused on supplying information specific to lightning safety and prevention and treatment of lightning injury and providing lightning-safety recommendations for the certified athletic trainer and those who are involved in athletics and recreation **(10)**.

Walsh & al. (11) educated athletic trainers and others about the dangers of lightning, provide lightning-safety guidelines, define safe structures and locations, and advocate prehospital care for lightning-strike victims. Lightning may be the most frequently encountered severe-storm hazard endangering physically active people each year. Millions of lightning flashes strike the ground annually in the United States, causing nearly 100 deaths and 400 injuries. Three quarters of all lightning casualties occur between May and September, and nearly four fifths occur between 10:00 AM and 7:00 PM, which coincides with the hours for most athletic or recreational activities. Additionally, lightning casualties from sports and recreational activities have risen alarmingly in recent decades. The National Athletic Trainers' Association recommends a proactive approach to lightning safety, including the implementation of a lightning-safety policy that identifies safe locations for shelter from the lightning hazard. Further components of this policy are monitoring local weather forecasts, designating a weather watcher, and establishing a chain of command. Additionally, a flash-to-bang count of 30 seconds

or more should be used as a minimal determinant of when to suspend activities. Waiting 30 minutes or longer after the last flash of lightning or sound of thunder is recommended before athletic or recreational activities are resumed. Lightning- safety strategies include avoiding shelter under trees, avoiding open fields and spaces, and suspending the use of land-line telephones during thunderstorms. Also outlined in this document are the prehospital care guidelines for triaging and treating lightning-strike victims. It is important to evaluate victims quickly for apnea, asystole, hypothermia, shock, fractures, and burns. Cardiopulmonary resuscitation is effective in resuscitating pulseless victims of lightning strike. Maintenance of cardiopulmonary resuscitation and first-aid certification should be required of all persons involved in sports and recreational activities **(11)**.

References

1. Lederer W, Kroesen G. Emergency treatment of injuries following lightning and electrical accidents. Anaesthesist. 2005; 54(11):1120-9.

2. Walsh KM. Lightning and severe thunderstorms in event management. Curr Sports Med Rep. 2012;11(3):131-4.

3. Cooper MA. Emergent care of lightning and electrical injuries. Semin Neurol. 1995;15(3):268-78.

4. O'Keefe Gatewood M, Zane RD. Lightning injuries. Emerg Med Clin North Am. 2004;22(2):369-403.

5. Craig SR. When lightning strikes. Pathophysiology and treatment of lightning injuries. Postgrad Med. 1986;79(4):109-12, 121-4.

6. Holle RL, López RE, Howard KW, et al. Safety in the presence of lightning. Semin Neurol. 1995;15(4):375-80.

7. Zimmermann C, Cooper MA, Holle RL. Lightning safety guidelines. Ann Emerg Med. 2002;39(6):660-4.

8. Scarneo-Miller SE, Walsh Flanagan KW, Belval LN, et al. Adoption of lightning safety best-practices policies in the secondary school setting. J Athl Train. 2021;56(5):491-8.

9. Walsh KM, Hanley MJ, Graner SJ, et al. A survey of lightning policy in selected division I colleges. J Athl Train. 1997;32(3):206-10.

10. Walsh KM, Cooper MA, Holle R, et al. National Athletic Trainers' Association position statement: lightning safety for athletics and recreation. J Athl Train. 2013;48(2):258-70.

11. Walsh KM, Bennett B, Cooper MA, et al. National athletic trainers' association position statement: lightning safety for athletics and recreation. J Athl Train. 2000;35(4):471-7.

SUMMARY

Severe weather, including tornadoes, thunderstorms, wind, and hail annually cause significant loss of life and property.

In this Research, the Biblical verses dealing with the thunderstorms are described. Therefore, the research deals with the characteristics of thunder, the lightening effect, health effects of thunder and lightning, evaluating emergency medical services, hospital admissions, epidemiology, etiology, community responses, general practice perspective, asthma and leukemia risk, spontaneous

pneumothorax, subarachnoid hemorrhage, and suicide attempts, and coping strategies with the negative nature of the effects.

The research also evaluates various mechanisms involved in the development of lightning, the prevalence rates, the effects on humans, investigating mortality, various injuries, cardiovascular complications, autonomic nervous system dysfunction, neurological diseases, neurorehabilitation of cerebral disorders, ophthalmic manifestations, cutaneous manifestations, burns, Lichtenberg figures, acute lung injury, acute renal failure, gastric perforation, and auricular accidents.

This research indicates that the thunderstorms, including the lightening manifestations, have accompanied humans during the long years of our existence. With years, the scientific study validated the numerous negative effects associated with the thunderstorm that can help to cope with this nature disaster in human life.