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Mary Ann Cooper · Ronald L. Holle

Reducing Lightning Injuries Worldwide

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Foreword

Lightning has intrigued mankind over the centuries, yet it is still one of the least understood natural phenomena commonly observed by the public. It strikes somewhat randomly, kills or injures many thousands of people worldwide each year, and causes billions of dollars in damages. Understanding this powerful and dangerous phenomenon and its impacts on people's lives is an important step in reducing deaths, injuries, and damages from lightning around the world.

Both Dr. Mary Ann Cooper and Ron Holle have been leaders in the effort to help people understand the dangers of lightning, its impacts, and what people can do to protect themselves and their property. Over the years, they have accumulated a wealth of knowledge and have shared their knowledge with the medical and scientific communities through their writings and presentations. Both have also been at the forefront in developing lightning safety guidelines.

Dr. Cooper has been a leader in the medical community in investigating, understanding, and documenting the short- and long-term effects of a lightning strike on the human body. She has worked with numerous lightning strike survivors and their families to not only understand the physical injuries that lightning causes, but also the mental, psychological, and financial effects on the victims and their families. She has been a resource for doctors around the world to help them understand the medical impacts of lightning injury and has shared her knowledge to help in the treatment of lightning strike survivors.

Ron Holle has been a leader in investigating and documenting lightning deaths and injuries worldwide. He has documented and analyzed US lightning deaths and injuries for more than 30 years. In addition, he has investigated historic US lightning fatality data to determine differences between recent fatalities and those that occurred more than 100 years ago when the United States would be considered a developing country by today's standards. This has allowed him to understand the demographics of victims and the situations that put people at risk, both now and when the population of the United States was more rural. In addition, his work with global lightning detection systems has allowed him to understand the distribution of lightning around the world and identify areas where large populations are most vulnerable.

I have personally known Mary Ann and Ron for almost two decades as part of the National Oceanic and Atmospheric Administration's (NOAA's) Lightning Safety Team and through our joint efforts to reduce lightning deaths and injuries. During this time, their knowledge and dedication to the lightning safety effort has been critical to the success of NOAA's lightning safety campaign. Both have contributed their professional expertise and personal time to help make the information on NOAA's lightning safety website the best in the world.

While NOAA's efforts have focused mainly on safety issues in the United States, Dr. Cooper and Ron Holle have expanded their personal efforts to other areas of the world, and, in particular, the unique challenges of the developing world. Most recently, they have been working together with leaders of developing countries to understand the specific challenges that those countries face and to develop ideas of what could be done to address those challenges. In some ways, the challenges that those countries face are similar to the challenges faced by the United States and other developed countries more than 100 years ago. Personally, I look back to the 1950s and 1960s when I was growing up in rural Pennsylvania. At the time, there were many small farms and people generally waited for it to start raining before going inside. As a result, the US lightning death toll was typically between 100 and 200 people per year. In fact, in the early 1940s, the United States typically saw between 300 and 400 lightning fatalities a year. While many things in the United States have changed since then, I truly believe that a better understanding of the dangers of lightning and improvements in the medical treatment of victims have both contributed greatly to the lower US lightning death toll.

With recent advances in technology, telecommunications, and reporting, governments of developing countries now have become more aware of the large numbers of people killed by lightning each year in their respective countries. This information has led to calls for greater efforts to minimize the threat to vulnerable populations. While education is a key component in reducing deaths in those countries, there are other critical issues such as the need for structures that provide safety.

In *Reducing Lightning Injuries Worldwide*, the authors have put together a comprehensive background on lightning and the medical effects on the human body; issues related to lightning safety and lightning protection; and documentation on worldwide lightning fatalities. The book also discusses the differences between developed and developing countries and the challenges that the developing countries face in trying to reduce lightning fatalities. Finally, and most importantly, this book offers suggestions and recommendations for reducing global lightning fatalities, based partially on the efforts that have worked in developed countries, but with consideration given to the limited resources available in developing countries and an understanding of cultural background differences.

For all those who are interested in protecting people from the potentially devastating impacts of lightning, *Reducing Lightning Injuries Worldwide* will provide valuable information and ideas to help reduce lightning deaths and injuries across the globe.

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Preface

Why Is This Book Needed?

Ideally, we should be able to prevent all lightning injuries, deaths, and property damage. Prevention is always better than burying the dead, taking care of those who survive, or trying to repair the damage to property and electronics. However, we have not reached the point where all injuries and property damage can be prevented.

Ideally, for the lightning injuries that we cannot prevent, physicians should know how to treat it based on known and certain pathophysiology using research based therapies. The pathophysiology of lightning injury may never be known because of the difficulty in doing research with lightning on living tissue – or even on nonliving tissue. To be brutally honest, papers on the pathophysiology of lightning injury have almost always been more educated speculation than fact supported by research.

Therefore, the REASON THIS BOOK IS NEEDED is because PREVENTION is better than caring for the survivors of lightning injury.

Reason for This Book (and How to Use It)

The authors were solicited to write a book about the current state of lightning studies. We proposed to write a book that gives an overview of the current state of knowledge of many aspects of lightning, some of which are more within our particular areas of expertise than other areas. We see each chapter standing independently but with references to other chapters that may be pertinent to questions that are more specific. We have been privileged to work together for nearly three decades on lightning injury prevention, the ultimate goal for this book, and to have known and often worked with the giants in lightning over that time.

The book is intended to provide a resource to understand the current situation in the developed and lesser-developed areas of the world and how to address reducing lightning casualties in vulnerable areas of the world. How, when, where, and during what types of activities people become lightning casualties will be addressed, as well as a description of the distribution of lightning around the world and the factors responsible for its occurrence.

Information on lightning fatalities and injuries cuts across many disciplines: public health, medicine, trauma studies, pain management, injury prevention, electrical engineering, physics, architecture and structural protection, geography, commerce, business, education, communications and media, psychology, neuropsychology, as well as social science including what individuals and populations believe and how they respond to the threat, mining, utility management, aviation, and many, many more (Andrews 1995).

Depending on the discipline of the researcher, lightning fatality reduction is often considered in isolated efforts that do not provide complete solutions; nevertheless, the possibility exists to reduce the large loss of life due to lightning in the developing world. To address these issues, we intend the audience for the book to be those in public health, public policy programs, government and private organizations involved in improving public safety in the developing world, and others who want to address the threat of lightning and decrease injuries and deaths.

This book is also meant to serve as a resource and sometimes a starting point for students and faculty who may be interested in initiating local studies and projects related to reducing global lightning casualties or in pursuing more in-depth studies, whether an undergraduate project, master's thesis, or doctoral dissertation. Each chapter serves as an introduction, not an exhaustive discussion – much more exhaustive books are available for many of the topics. Each chapter will include questions that naturally arise from curiosity about lightning and the different areas each chapter covers. Many of these have not been answered and could serve as a basis for forming more specific research questions. Some of the questions will be for the reader's particular situation and encourage critical thinking.

Each chapter ends with a list of some key references that can serve as a beginning reading list for the student. We have also cataloged lightning injury prevention program activists and researchers so that students, public health policy makers, and others may access their work or contact them for more information, collaboration, or mentoring for programs they wish to start.

With very few exceptions, we have found the lightning injury prevention community worldwide to be warm, sharing, concerned people who do most of their work on their own time and often on their own money, hoping to prevent injuries and save lives. For those of you who wish to join us, we welcome you and will do what we can to help you!

Reference

Andrews CJ (1995) Keraunomedicine – a discipline come of age. Ann Emerg Med 25(4):543–545

River Forest, IL, USA — Mary Ann Cooper
Oro Valley, AZ, USA — Ronald L. Holle

List of Abbreviations and Definitions

Lightning

CG flash	Cloud-to-ground flash. A cloud-to-ground lightning flash has one or more return strokes.
CG return stroke	Cloud-to-ground stroke. One of the components of a cloud-to-ground flash. A flash has one or more return strokes, averaging four to five strokes per flash.
Flash	The entire sequence of a lightning event, starting with its initiation in the cloud through the last portion of its visible light.
GLD360	Global Lightning Dataset lightning detection network.
IC	In-cloud lightning. About three times as many lightning events occur in cloud without reaching the ground as those that contact the surface of the earth.
Hardening	Making equipment or infrastructure lightning resistant.
NLDN	National Lightning Detection Network.
LCC	Long continuing (continuous) current occurs when current continues to flow between the individual cloud-to-ground strokes of a cloud-to-ground flash.
Lightning density	The number of lightning events per area per time, such as CG flashes per square kilometer per year.
"Lightning safe" areas	Only two areas are identified as "lightning safe": substantial buildings, defined as those having plumbing, wiring, and metal structural elements in the walls, and fully enclosed all metal vehicles.
Substantial building	A structure that is safe from lightning with paths for lightning to follow through grounded wiring and plumbing in the walls, and may have metal structural members (Chap. 16).
Total lightning	Sum of CG and IC data.

Meteorology (American Meteorological Society, 2015)

30–30 rule	The first 30 refers to the number of seconds between seeing lightning and hearing its associated thunder; a 30-second interval refers to six miles (10 km). The second 30 refers to the number of minutes to wait until resuming outdoor activity after the last lightning or thunder within a specific range.
Convection	Primarily vertical cloud development.
Tropical cyclone	An organized low-pressure system over warm oceans. A tropical depression has winds up to 17 m s^{-1} (34 knots), a tropical storm has winds of 18–32 m s^{-1} (35–64 knots), and a severe tropical cyclone (also called hurricane or typhoon) has winds of 33 m s^{-1} (65 knots) or more.
Derecho	An organized area of convection with widespread strong winds in the evening and nighttime, primarily during the middle-latitude summer.
Diurnal	Daily variations that occur within a 24-h cycle.
Equatorial trough	Nearly continuous belt of low pressure between the subtropical high-pressure belts of the Northern and Southern hemispheres. It moves into or toward the summer hemisphere. Also called the ITCZ.
Flash-to-bang	The time interval in seconds between seeing lightning and hearing its associated thunder.
Inter-tropical Convergence Zone (ITCZ)	A shallow low-pressure zone around the *equator*, where winds tend to converge from both hemispheres. Also called the equatorial trough.
Large-scale systems	Meteorological systems with horizontal scales of thousands of kilometers.
Mesoscale	Atmospheric phenomena with horizontal scales ranging from a few to

	several hundred kilometers, such as thunderstorms.
Mesoscale convective systems (MCS)	Prolific lightning producers that cover very large areas, usually over land, are strongest at night, and last up to 18 h (Sect. 13.2).
Middle latitudes	Between 23.5 and 66.5 North and South latitudes where there are often four distinct seasons and weather systems frequently travel from west to east.
Monsoon	A seasonally reversing wind accompanied by corresponding changes in precipitation.
Small-scale systems	Meteorological systems that are tens of kilometers across.
Subsidence	Descending motion of air in the atmosphere.
Tropical	Between 23.5 North and South latitudes.
Turbulence	Random, continuously varying air motions in addition to the broader-scale air motions.
Updraft	Upward motion within cumulus convection.
Westerlies	Prevailing direction of motion of weather systems in the middle latitudes between 23.5 and 66.5 North and South latitudes.

Human Impacts

Cardiac	Having to do with the heart.
Casualty	The sum of deaths and injuries.
Cognitive	Having to do with thought or thought processing including memory, perception, executive function, and other brain functions. Usually does not include motor function.
Cranial	Having to do with the head (cranium).
Death, fatality	A person killed by lightning.
Dysesthesia	Abnormal (dys), usually unpleasant, sensory perception (esthesia), which may be called numbness, burning, tingling, shooting, itching, painful, or other adjectives the person chooses to use.

Hyperacusis	Sensitivity to noise.
Hypertension	High blood pressure.
Injury	A person injured by lightning, including both those killed and those who survive.
Injury cascade	The order of normally expected bodily responses after an injury.
Keraunoparalysis	Usually temporary paralysis of legs and/or arms that lasts for several minutes caused by lightning (kerauno).
Neurologic	Having to do with the brain, spinal cord, autonomic nervous system, or nerves.
Neuropathy	Pathologic (abnormal) signaling from injured/healed nerves: most commonly characterized by the person as painful.
Orifice	Normal opening on a body such as the mouth, nostrils, or anus.
Paresthesia	Abnormal sensory perception, most commonly numbness, but may also be called shooting, burning, tingling, itching, painful, or other adjectives that the person chooses to use.
Physiology	The branch of biology that deals with the normal functions of living organisms and their parts.
Pathophysiology	Physiology of an abnormal state, usually caused by an injury, illness, or toxin.
Photophobia	Sensitivity to light
Post-concussion syndrome	Set of signs and symptoms of brain injury caused by a fall, explosion, or other concussive injury. Common symptoms include headache, dizziness, fatigue, irritability, anxiety, insomnia, loss of concentration and memory, ringing in the ears, blurry vision, and noise and light sensitivity.
Pulmonary	Having to do with the lungs.
Sequela (plural sequelae)	After-effect or complication after the initial (acute) phase of an injury or illness.
Thrombosis	Blockage of a blood vessel by a clot.
Trauma	The exposure to some source of energy (mechanical, electrical, thermal, radiation, or chemical) in an intensity exceeding the tolerance level of the host (Chap. 2) (Navarrete-Aldana 2016).
Tympanic membrane (TM)	Ear drum.

Organizations

ACLENet African Centres for Lightning and Electromagnetics. A pan-African network of national and regional centers dedicated to decreasing deaths, injuries, and property damage from lightning (Chap. 18) (ACLENet.org/).

LSESSI Lightning Strike and Electric Survivors, International. A nonprofit organization in the United States dedicated to survivors, their families, and other interested parties (Cooper and Marshburn 2005; Chap. 3) (www.lightning-strike.org/).

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The authors of this book have been inspired by a host of collaborators and colleagues in studies of the impacts of lightning on people in the last three decades. No list is complete, and we emphasize that those not included should realize it was an oversight.

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From the United States meteorological community, Dr. Raul López of the National Oceanic and Atmospheric Administration (NOAA) research laboratories participated in many studies. Within the National Weather Service of the National Oceanic and Atmospheric Administration, Mr. John Jensenius, Ms. Donna Franklin, Mr. Steve Hodanish, and Mr. Charles Woodrum continue to be active. Mr. William Roeder in Florida and Mr. Ken Langford in Colorado are also frequent collaborators.

From the lightning physics and protection community, Dr. Vladimir Rakov in Florida (United States) and Dr. E. Philip Krider, Dr. Kenneth Cummins, Dr. Amitabh Nag, and Ms. Daile Zhang in Arizona (United States) have often been sources of support and advice.

Additional champions of lightning safety include Dr. Katie Walsh Flanagan in North Carolina (United States), Dr. Chandima Gomes and Dr. Mohd. Zainal ab Kadir in Malaysia, Dr. John Gookin in Wyoming (United States), Mr. Richard Tushemereirwe in Uganda, Mrs. Foster Chileshe Lubasi in Zambia, Mr. Daniel Esteban Villamil Sierra in Colombia, Mr. Munir Ahmad in Bangladesh, and Dr. Shri Ram Sharma in Nepal.

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Part I
How Lightning Kills, Injures, and Causes Damage

Chapter 1
Introduction

Abstract Lightning causes injuries and deaths in nearly all parts of the world, more commonly in tropical and subtropical areas than in middle latitudes and rarely in the arctic areas. The distribution of injuries is partly due to lightning density, the number of times lightning hits a particular area over a particular time space, but also to population density and risk of exposure. This book will explore those features.

1.1 Problem Statement

Lightning causes injuries and deaths in nearly all parts of the world, more commonly in tropical and subtropical areas than in middle latitudes and rarely in the arctic areas. The distribution of injuries is partly due to lightning density, the number of times lightning hits a particular area over a particular time space, but also to population density and risk of exposure. This book will explore those features.

While lightning injuries occur all over the world, they have generally been poorly documented except in a few countries. Natural hazards such as hurricanes, tornadoes, floods, and extreme cold or heat tend to kill more people in a particular incident and are more likely to involve government response, an outpouring of aid to the victims, data collection, and attempts at prevention. They are also more likely to be published in the media, making the public more cognizant of these risks.

Thunderstorms tend to be small, often only a few kilometers in size, and form and disperse rapidly compared to hurricanes and floods. They are everyday, commonplace events and seldom newsworthy by themselves. Similarly, lightning injuries, with some exceptions, tend to injure only one or two individuals at a time, also making them less likely to come to the attention of the media or government, especially in rural or less developed areas where communication systems may be poor or nonexistent. Survivors may not seek medical care to be entered into a data system. Nevertheless, lightning kills and injures a significant number of people ever year as well as livestock, often the measure of wealth in developing nations, and damages property including infrastructure in industries such as utilities, communications systems, electronics, and many others, adversely affecting not only the company but also communities and nations struggling to develop stable economies.

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The number of lightning fatalities and injuries in the developed world has been steadily declining over the last century. However, the number of lightning casualties in the lesser developed regions is not decreasing due to billions of people living in lightning-vulnerable housing, working outdoors in labor-intensive manual agriculture, and other identifiable socioeconomic factors. The global lightning impacts to people may be as high as 24,000 deaths and 240,000 injuries per year.

Chapter 2
Mechanisms of Lightning Injury

Abstract The only mechanism of lightning injury that most people consider is the direct strike, from cloud to ground. In actuality, there are five mechanisms of injury by which a person can be impacted by the electrical nature of lightning. In addition, there are several possible secondary mechanisms of traumatic injury. This chapter will describe all of these mechanisms and discuss the differences in developed versus developing countries.

2.1 Introduction

Lightning can cause devastating injuries, but generally not in the way that most people would imagine nor conclude from their knowledge of electricity and lightning. Initially, if one asked a person on the street what types of injuries lightning would cause, they would probably say that it would be a serious burn injury. Some might add that it could cause the heart or other "electrical" organs to fail. A very few might think of thunder and explain it as a concussive or explosive injury. Nearly everyone speaks of lightning as if all injuries are from direct hits, mostly because most people don't know about the other mechanisms of injury (Cooper and Holle 2010).

Lightning injury is a traumatic injury. One does not have to be a physician to appreciate the injury, disability, and death caused by lightning nor to recognize the need for lightning injury prevention.

Definition of Trauma
The exposure to some source of energy (mechanical, electrical, thermal, radiation, or chemical) in an intensity exceeding the tolerance level of the host (Navarrete-Aldana 2016).

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