FOURTH EDITION

ESSENTIALS OF Epidemiology IN PUBLIC HEALTH

ACCESS CODE INSIDE

NAVIGATE 2 ADVANTAGE ACCESS

Ann Aschengrau
George R. Seage III

FOURTH EDITION

ESSENTIALS OF

Epidemiology

IN PUBLIC HEALTH

Ann Aschengrau, ScD
Professor, Department of Epidemiology
Boston University School of Public Health
Boston, Massachusetts

George R. Seage III, DSc
Professor of Epidemiology
Harvard T.H. Chan School of Public Health
Boston, Massachusetts

JONES & BARTLETT
LEARNING

World Headquarters
Jones & Bartlett Learning
5 Wall Street
Burlington, MA 01803
978-443-5000
info@jblearning.com
www.jblearning.com

Jones & Bartlett Learning books and products are available through most bookstores and online booksellers. To contact Jones & Bartlett Learning directly, call 800-832-0034, fax 978-443-8000, or visit our website, www.jblearning.com.

Substantial discounts on bulk quantities of Jones & Bartlett Learning publications are available to corporations, professional associations, and other qualified organizations. For details and specific discount information, contact the special sales department at Jones & Bartlett Learning via the above contact information or send an email to specialsales@jblearning.com.

12843-7

Production Credits

VP, Product Management: David D. Cella
Director of Product Management: Michael Brown
Product Specialist: Carter McAlister
Production Manager: Carolyn Rogers Pershouse
Associate Production Editor, Navigate: Jamie Reynolds
Senior Marketing Manager: Sophie Fleck Teague
Manufacturing and Inventory Control Supervisor: Amy Bacus
Composition: codeMantra U.S. LLC
Cover Design: Kristin E. Parker
Rights & Media Specialist: John Rusk
Media Development Editor: Shannon Sheehan
Cover Image (Title Page, Chapter Opener):
© Smartboy10/DigitalVision Vectors/Getty Images
Printing and Binding: Bang Printing
Cover Printing: Bang Printing

Library of Congress Cataloging-in-Publication Data

Names: Aschengrau, Ann, author. | Seage, George R., author.
Title: Essentials of epidemiology in public health / Ann Aschengrau, ScD, Professor of Epidemiology, Boston University School of Public Health, George R. Seage III, ScD, Professor of Epidemiology, Harvard T.H. Chan School of Public Health.
Description: Fourth edition. | Burlington, MA : Jones & Bartlett Learning, [2020] | Includes bibliographical references and index.
Identifiers: LCCN 2018023772 | ISBN 9781284128352 (paperback)
Subjects: LCSH: Epidemiology. | Public health. | Social medicine. | BISAC: EDUCATION / General.
Classification: LCC RA651 .A83 2020 | DDC 614.4–dc23
LC record available at https://lccn.loc.gov/2018023772

6048

Printed in the United States of America

22 21 20 19 18 10 9 8 7 6 5 4 3 2 1

Contents

Preface

What is epidemiology, and how does it contribute to the health of our society? Most people don't know the answer to this question. This is somewhat paradoxical because epidemiology, one of the basic sciences of public health, affects nearly everyone. It affects both the personal decisions we make about our lives and the ways in which governments, public health agencies, and medical organizations make policy decisions that affect how we live.

In recent years, the field of epidemiology has expanded tremendously in size, scope, and influence. The number of epidemiologists has grown rapidly along with the number of epidemiology training programs in schools of public health and medicine. Many subspecialties have arisen to study public health questions, from the molecular to the societal level.

Recent years have also witnessed an important evolution in the theory and methods of epidemiological research and analysis, causal inference, and the role of statistics (especially P values) in research.

Unfortunately, few of these changes have been taught in introductory epidemiology courses, particularly those for master's-level students. We believe this has occurred mainly because instructors have mistakenly assumed the new concepts were too difficult or arcane for beginning students. As a consequence, many generations of public health students have received a dated education.

Our desire to change this practice was the main impetus for writing this book. For nearly three decades we have successfully taught both traditional and new concepts to our graduate students at Boston University and Harvard University. Not only have our students successfully mastered the material, but they have also found that the new ideas enhanced their understanding of epidemiology and its application.

In addition to providing an up-to-date education, we have taught our students the necessary skills to become knowledgeable consumers of epidemiological literature. Gaining competence in the critical evaluation of this literature is particularly important for public health practitioners because they often need to reconcile confusing and contradictory results.

This textbook reflects our educational philosophy of combining theory and practice in our teaching. It is intended for public health students who will be consumers of epidemiological literature and those who will be practicing epidemiologists. The first five chapters cover basic epidemiological concepts and data sources. Chapter 1 describes the approach and evolution of epidemiology, including the definition, goals, and historical development of epidemiology and public health. Chapters 2 and 3 describe how epidemiologists measure and compare disease occurrence in populations. Chapter 4 characterizes the major sources of health data on the U.S. population and describes how to interpret these data appropriately. Chapter 5 describes how epidemiologists analyze disease patterns to understand the health status of a population, formulate and test hypotheses of disease causation, and carry out and evaluate health programs.

The next four chapters of the textbook focus on epidemiological study design.

Chapter 6 provides an overview of study designs—including experimental, cohort, case–control, cross-sectional, and ecological studies—and describes the factors that determine when a particular design is indicated. Each of the three following chapters provides a detailed description of the three main analytic designs: experimental, cohort, and case–control studies.

The next five chapters cover the tools students need to interpret the results of epidemiological studies. Chapter 10 describes bias, including how it influences study results and the ways in which it can be avoided. Chapter 11 explains the concept of confounding, methods for assessing its presence, and methods for controlling its effects. Chapter 12 covers random error, including hypothesis testing, P-value and confidence interval estimation and interpretation, and sample size and power calculations. We believe this chapter provides a balanced view of the appropriate role of statistics in epidemiology. Chapter 13 covers the concept of effect measure modification, an often neglected topic in introductory texts. It explains the difference between confounding and effect measure modification and describes the methods for evaluating effect measure modification. Chapter 14 pulls together the information from Chapters 10 through 13 by providing a framework for evaluating the literature as well as three examples of epidemiological study critiques.

Chapter 15 covers the epidemiological approach to causation, including the historical development of causation theories, Hill's guidelines for assessing causation, and the sufficient-component cause model of causation. Chapter 16 explains screening in public health practice, including the natural history of disease, characteristics of diseases appropriate for screening, important features of a screening test, and methods for evaluating a screening program. Finally, Chapter 17 describes the development and application of guidelines to ensure the ethical conduct of studies involving humans. Up-to-date examples and data from the epidemiological literature on diseases of public health importance are used throughout the book. In addition, nearly 50 new study questions were added to the fourth edition.

Our educational background and research interests are also reflected in the textbook's outlook and examples. Ann Aschengrau received her doctorate in epidemiology from the Harvard School of Public Health in 1987 and joined the Department of Epidemiology at the Boston University School of Public Health shortly thereafter. She is currently Professor, Associate Chair for Education, and Co-Director of the Master of Science Degree Program in Epidemiology. For the past 30 years, she has taught introductory epidemiology to master's-level students. Her research has focused on the environmental determinants of disease, including cancer, disorders of reproduction and child development, and substance use.

George R. Seage III received his doctorate in epidemiology from the Boston University School of Public Health in 1992. For more than a decade, he served as the AIDS epidemiologist for the city of Boston and as a faculty member at the Boston University School of Public Health. He is currently Professor of Epidemiology at the Harvard T.H. Chan School of Public Health and Director of the Harvard Chan Program in the Epidemiology of Infectious Diseases. For over 30 years, he has taught courses in HIV epidemiology to master's and doctoral students. His research focuses on the biological and behavioral determinants of adult and pediatric HIV transmission, natural history, and treatment.

Drs. Aschengrau and Seage are happy to connect with instructors and students via email (aaschen@bu.edu and gseage@hsph.harvard.edu). Also check out Dr. Aschengrau's Twitter feed @AnnfromBoston.

New to This Edition

- Completely updated with new examples and the latest references and public health statistics
- New section on process of investigating infectious disease outbreaks
- New section on the Ebola outbreaks and their investigation in Africa
- Introduction of the latest epidemiological terms and methods
- New figures depicting epidemiological concepts
- Expanded ancillary materials, including improved PowerPoint slides, an enlarged glossary, and new in-class exercises and test questions
- Over 50 new review questions

Acknowledgments

Our ideas about the principles and practice of epidemiology have been greatly influenced by teachers, colleagues, and students. We feel privileged to have been inspired and nurtured by many outstanding teachers and mentors, including Richard Monson, George (Sandy) Lamb, Steve Schoenbaum, Arnold Epstein, Ken Rothman, the late Brian MacMahon, Julie Buring, Fran Cook, Ted Colton, Bob Glynn, Adrienne Cupples, George Hutchison, and the late Alan Morrison. We are pleased to help spread the knowledge they have given us to the next generation of epidemiologists.

We are also indebted to the many colleagues who contributed to the numerous editions of this book in various ways, including clarifying our thinking about epidemiology and biostatistics, providing ideas about how to teach epidemiology, reviewing and commenting on drafts and revisions of the text, pilot testing drafts in their classes, and dispensing many doses of encouragement during the time it took to write all four editions of this book. Among these individuals are Bob Horsburgh, Herb Kayne, Dan Brooks, Wayne LaMorte, Michael Shwartz, Dave Ozonoff, Tricia Coogan, Meir Stampfer, Lorelei Mucci, Murray Mittleman, Fran Cook, Charlie Poole, Tom Fleming, Megan Murray, Marc Lipsitch, Sam Bozeman, Anne Coletti, Michael Gross, Sarah Putney, Sarah Rogers, Kimberly Shea, Kunjal Patel, and Kelly Diringer Getz. We are particularly grateful to Krystal Cantos for her many contributions to this edition, particularly the new sections on disease outbreaks, and Molly Pretorius Holme for contributing the chapter on ethics in human research. Ted Colton also deserves a special acknowledgment for originally recommending us to the publisher.

We thank our students for graciously reading drafts and earlier editions of this text in their epidemiology courses and for contributing many valuable suggestions for improvement. We hope that this book will serve as a useful reference as they embark on productive careers in public health. We also recognize Abt Associates, Inc., for providing George Seage with a development and dissemination grant to write the chapter on screening in public health practice. We are very grateful to the staff of Jones & Bartlett Learning for guiding the publication process so competently and quickly. Finally, we thank our son Gregory, an actor, for his patience and for providing many interesting and fun diversions along the way. Break a leg!

CHAPTER 1

The Approach and Evolution of Epidemiology

LEARNING OBJECTIVES

By the end of this chapter the reader will be able to:

- Define and discuss the goals of public health.
- Distinguish between basic, clinical, and public health research.
- Define epidemiology and explain its objectives.
- Discuss the key components of epidemiology (population and frequency, distribution, determinants, and control of disease).
- Discuss important figures in the history of epidemiology, including John Graunt, James Lind, William Farr, and John Snow.
- Discuss important modern studies, including the Streptomycin Tuberculosis Trial, Doll and Hill's studies on smoking and lung cancer, and the Framingham Study.
- Discuss the current activities and challenges of modern epidemiologists.

Introduction

Most people do not know what epidemiology is or how it contributes to the health of our society. This fact is somewhat paradoxical given that epidemiology pervades our lives. Consider, for example, the following statements involving epidemiological research that have made headline news:

- Ten years of hormone drugs benefits some women with breast cancer.
- Cellular telephone users who talk or text on the phone while driving cause one in four car accidents.
- Omega-3 pills, a popular alternative medicine, may not help with depression.
- Fire retardants in consumer products may pose health risks.
- Brazil reacts to an epidemic of Zika virus infections.

The breadth and importance of these topics indicate that epidemiology directly affects the daily lives of most people. It affects the way that individuals make personal decisions about their lives and the way that the government, public health agencies, and medical organizations make policy decisions that affect how we live. For example, the results of epidemiological studies described by the headlines might prompt a person to use a traditional medication for her depression or to replace old furniture likely to contain harmful fire retardants. It might prompt an oncologist to determine which of his breast cancer patients would reap the benefits of hormone therapy, a manufacturer to adopt safer alternatives to fire retardants, public health agencies to monitor and prevent the spread of Zika virus infection, or a state legislature to ban cell phone use by drivers.

This chapter helps the reader understand what epidemiology is and how it contributes to important issues affecting the public's health. In particular, it describes the definition, approach, and goals of epidemiology as well as key aspects of its historical development, current state, and future challenges.

Definition and Goals of Public Health

Public health is a multidisciplinary field whose goal is to promote the health of the population through organized community efforts.[1(pp3-14)] In contrast to medicine, which focuses mainly on treating illness in separate individuals, public health focuses on preventing illness in the community. Key public health activities include assessing the health status of the population, diagnosing its problems, searching for the causes of those problems, and designing solutions for them. The solutions usually involve community-level interventions that control or prevent the cause of the problem. For example, public health interventions include establishing educational programs to discourage teenagers from smoking, implementing screening programs for the early detection of cancer, and passing laws that require automobile drivers and passengers to wear seat belts.

Unfortunately, public health achievements are difficult to recognize because it is hard to identify people who have been spared illness.[1(pp6-7)] For this reason, the field of public health has received less attention and fewer resources than the field of medicine has received. Nevertheless, public health has had a greater effect on the health of populations than medicine has had. For example, since the turn of the 20th century, the average life expectancy of Americans has increased by about 30 years, from 47.3 to 78.8 years.[2] Of this increase, 25 years can be attributed to improvements in public health, and only 5 years can be attributed to improvements in the medical care system.[3] Public health achievements that account for improvements in health and life expectancy include the routine use of vaccinations for infectious diseases, improvements in motor vehicle and workplace safety, control of infectious diseases through improved sanitation and clean water, modification of risk factors

for coronary heart disease and stroke (such as smoking cessation and blood pressure control), safer foods from decreased microbial contamination, improved access to family planning and contraceptive services, and the acknowledgment of tobacco as a health hazard and the ensuing antismoking campaigns.[4]

The public health system's activities in research, education, and program implementation have made these accomplishments possible. In the United States, this system includes federal agencies, such as the Centers for Disease Control and Prevention; state and local government agencies; nongovernmental organizations, such as Mothers Against Drunk Driving; and academic institutions, such as schools of public health. This complex array of institutions has achieved success through political action and gains in scientific knowledge.[1(pp5-7)] Politics enters the public health process when agencies advocate for resources, develop policies and plans to improve a community's health, and work to ensure that services needed for the protection of public health are available to all. Political action is necessary because the government usually has the responsibility for developing the activities required to protect public health.

Sources of Scientific Knowledge in Public Health

The scientific basis of public health activities mainly comes from (1) the basic sciences, such as pathology and toxicology; (2) the clinical or medical sciences, such as internal medicine and pediatrics; and (3) the public health sciences, such as epidemiology, environmental health science, health education, and behavioral science. Research in these three areas provides complementary pieces of a puzzle that, when properly assembled, provide the scientific foundation for public health action. Other fields such as engineering and economics also contribute to public health. The three main areas approach research questions from different yet complementary viewpoints, and each field has its own particular strengths and weaknesses.

Basic scientists, such as toxicologists, study disease in a laboratory setting by conducting experiments on cells, tissues, and animals. The focus of this research is often on the disease mechanism or process. Because basic scientists conduct their studies in a controlled laboratory environment, they can regulate all important aspects of the experimental conditions. For example, a laboratory experiment testing the toxicity of a chemical is conducted on genetically similar animals that live in the same physical environment, eat the same diet, and follow the same daily schedule.[5(pp157-237)] Animals are assigned (usually by chance) to either the test group or the control group. Using identical routes of administration, researchers give the chemical under investigation to the test group and an inert chemical to the control group. Thus, the only difference between the two groups is the dissimilar chemical deliberately introduced by

the investigator. This type of research provides valuable information on the disease process that cannot be obtained in any other way. However, the results are often difficult to extrapolate to real-life situations involving humans because of differences in susceptibility between species and differences in the exposure level between laboratory experiments and real-life settings. In general, humans are exposed to much lower doses than those used in laboratory experiments.

Clinical scientists focus their research questions mainly on disease diagnosis, treatment, and prognosis in individual patients. For example, they try to determine whether a diagnostic method is accurate or a treatment is effective. Although clinicians are also involved in disease prevention, this activity has historically taken a backseat to disease diagnosis and treatment. As a consequence, clinical research studies are usually based on people who come to a medical care facility, such as a hospital or clinic. Unfortunately, these people are often unrepresentative of the full spectrum of disease in the population at large because many sick people never come to the attention of healthcare providers.

Clinical scientists contribute to scientific knowledge in several important ways. First, they are usually the first to identify new diseases, the adverse effects of new exposures, and new links between an exposure and a disease. This information is typically published in case reports. For example, the epidemic of acquired immune deficiency syndrome (AIDS) (now called HIV for human immunodeficiency virus infection) officially began in the United States in 1981 when clinicians reported several cases of *Pneumocystis carinii* pneumonia and Kaposi's sarcoma (a rare cancer of the blood vessels) among previously healthy, young gay men living in New York and California.[6,7] These cases were notable because *Pneumocystis carinii* pneumonia had previously occurred only among individuals with compromised immune systems, and Kaposi's sarcoma had occurred mainly among elderly men. We now know that these case reports described symptoms of a new disease that would eventually be called HIV/AIDS. Despite their simplicity, case reports provide important clues regarding the causes, prevention, and cures for a disease. In addition, they are often used to justify conducting more sophisticated and expensive studies.

Clinical scientists also contribute to scientific knowledge by recording treatment and response information in their patients' medical records. This information often becomes an indispensable source of research data for clinical and epidemiological studies. For example, it would have been impossible to determine the risk of breast cancer following fluoroscopic X-ray exposure without patient treatment records from the 1930s through the 1950s.[8] Investigators used these records to identify the subjects for the study and gather detailed information about subjects' radiation doses.

Public health scientists study ways to prevent disease and promote health in the population at large. Public health research differs from clinical research in two important ways. First, it focuses mainly on disease prevention rather than disease treatment. Second, the units of concern

TABLE 1-1 Main Differences Among Basic, Clinical, and Public Health Science Research

Characteristic	Basic	Clinical	Public health
What/who is studied	Cells, tissues, animals in laboratory settings	Sick patients who come to healthcare facilities	Populations or communities at large
Research goals	Understanding disease mechanisms and the effects of toxic substances	Improving diagnosis and treatment of disease	Prevention of disease, promotion of health
Examples	Toxicology, immunology	Internal medicine, pediatrics	Epidemiology, environmental health science

are groups of people living in the community rather than separate individuals visiting a healthcare facility. For example, a public health research project called the Home Observation and Measures of the Environment (HOME) injury study determined the effect of installing safety devices, such as stair gates and cabinet locks, on the rate of injuries among young children.[9] About 350 community-dwelling mothers and their children were enrolled in this home-based project.

The main differences between the three branches of scientific inquiry are summarized in **TABLE 1-1**. Although this is a useful way to classify the branches of scientific research, the distinctions between these areas have become blurred. For example, epidemiological methods are currently being applied to clinical medicine in a field called "clinical epidemiology." In addition, newly developed areas of epidemiological research, such as molecular and genetic epidemiology, include the basic sciences.

Definition and Objectives of Epidemiology

The term *epidemiology* is derived from the Greek words *epi*, which means "on or upon"; *demos*, which means "the common people"; and *logy*, which means "study."[10(pp484,599,1029)] Putting these pieces together yields the following definition of epidemiology: "the study of that which falls upon the common people." Epidemiology can also be defined as the "branch of medical science which treats epidemics."[11] The latter definition was developed by the London Epidemiological Society, which was formed in 1850 to determine the causes of cholera and other epidemic diseases and methods of preventing them.[12] Over the past century, many definitions

of epidemiology have been set forth. Some early definitions reflect the field's initial focus on infectious diseases, and later ones reflect a broader scope encompassing all diseases.[12]

We define **epidemiology** as follows: The study of the distribution and determinants of disease frequency in human populations and the application of this study to control health problems.[13(p1),14(p95)] Our definition is a combination of a popular one coined by MacMahon and Pugh in 1970 and another described by Porta in the sixth edition of *A Dictionary of Epidemiology*.[14(p95),15(p1)] Note that the term ***disease*** refers to a broad array of health-related states and events, including diseases, injuries, disabilities, and death.

We prefer this hybrid definition because it describes both the scope and ultimate goal of epidemiology. In particular, the objectives of epidemiology are to (1) study the natural course of disease from onset to resolution, (2) determine the extent of disease in a population, (3) identify patterns and trends in disease occurrence, (4) identify the causes of disease, and (5) evaluate the effectiveness of measures that prevent and treat disease. All of these activities contribute scientific knowledge for making sound policy decisions that protect public health.

Our definition of epidemiology has five key words or phrases: (1) population, (2) disease frequency, (3) disease distribution, (4) disease determinants, and (5) disease control. Each term is described in more detail in the following sections.

Population

Populations are at the heart of all epidemiological activities because epidemiologists are concerned with disease occurrence in groups of people rather than in individuals. The term ***population*** refers to a group of people with a common characteristic, such as place of residence, gender, age, or use of certain medical services. For example, people who reside in the city of Boston are members of a geographically defined population. Determining the size of the population in which disease occurs is as important as counting the cases of the disease because it is only when the number of cases is related to the size of the population that we know the true frequency of disease. The size of the population is often determined by a census—that is, a complete count—of the population. Sources of these data range from the decennial census, in which the federal government attempts to count every person in the United States every 10 years, to computerized records from medical facilities that provide counts of patients who use the facilities.

Disease Frequency

Disease frequency refers to quantifying how often a disease arises in a population. Counting, which is a key activity of epidemiologists, includes three steps: (1) developing a definition of disease, (2) instituting

a mechanism for counting cases of disease within a specified population, and (3) determining the size of that population.

Diseases must be clearly defined to determine accurately who should be counted. Usually, disease definitions are based on a combination of physical and pathological examinations, diagnostic test results, and signs and symptoms. For example, a case definition of breast cancer might include findings of a palpable lump during a physical exam and mammographic and pathological evidence of malignant disease.

Currently available sources for identifying and counting cases of disease include hospital patient rosters; death certificates; special reporting systems, such as registries of cancer and birth defects; and special surveys. For example, the National Health Interview Survey is a federally funded study that has collected data on the health status of the U.S. population since the 1950s. Its purpose is to "monitor the health of the United States population" by collecting information on a broad range of topics, including health indicators, healthcare utilization and access, and health-related behaviors.[16]

Disease Distribution

Disease distribution refers to the analysis of disease patterns according to the characteristics of person, place, and time, in other words, who is getting the disease, where it is occurring, and how it is changing over time. Variations in disease frequency by these three characteristics provide useful information that helps epidemiologists understand the health status of a population; formulate hypotheses about the determinants of a disease; and plan, implement, and evaluate public health programs to control and prevent adverse health events.

Disease Determinants

Disease determinants are factors that bring about a change in a person's health or make a difference in a person's health.[14(p73)] Thus, determinants consist of both causal and preventive factors. Determinants also include individual, environmental, and societal characteristics. Individual determinants consist of a person's genetic makeup, gender, age, immunity level, diet, behaviors, and existing diseases. For example, the risk of breast cancer is increased among women who carry genetic alterations, such as BRCA1 and BRCA2; are elderly; give birth at a late age; have a history of certain benign breast conditions; or have a history of radiation exposure to the chest.[17]

Environmental and societal determinants are external to the individual and thereby encompass a wide range of natural, social, and economic events and conditions. For example, the presence of infectious agents, reservoirs in which the organism multiplies, vectors that transport the agent, poor and crowded housing conditions, and political instability are environmental and social factors that cause many communicable diseases around the world.

Epidemiological research involves generating and testing specific hypotheses about disease determinants. A hypothesis is defined as "a tentative explanation for an observation, phenomenon, or scientific problem that can be tested by further investigation."[10(p866)] Generating hypotheses is a process that involves creativity and imagination and usually includes observations on the frequency and distribution of disease in a population. Epidemiologists test hypotheses by making comparisons, usually within the context of a formal epidemiological study. The goal of a study is to harvest valid and precise information about the determinants of disease in a particular population. Epidemiological research encompasses several types of study designs; each type of study merely represents a different way of harvesting the information.

Disease Control

Epidemiologists accomplish **disease control** through epidemiological research, as described previously, and through surveillance. The purpose of surveillance is to monitor aspects of disease occurrence that are pertinent to effective control.[18(p704)] For example, the Centers for Disease Control and Prevention collects information on the occurrence of HIV infection across the United States.[19] For every case of HIV infection, the surveillance system gathers data on the individual's demographic characteristics, transmission category (such as injection drug use or male-to-male sexual contact), and diagnosis date. These surveillance data are essential for formulating and evaluating programs to reduce the spread of HIV.

Historical Development of Epidemiology

The historical development of epidemiology spans almost 400 years and is best described as slow and unsteady. Only since World War II has the field experienced a rapid expansion. The following sections, which are not meant to be a comprehensive history, highlight several historic figures and studies that made significant contributions to the evolution of epidemiological thinking. These people include John Graunt, who summarized the pattern of mortality in 17th-century London; James Lind, who used an experimental study to discover the cause and prevention of scurvy; William Farr, who pioneered a wide range of activities during the mid-19th century that are still used by modern epidemiologists; John Snow, who showed that cholera was transmitted by fecal contamination of drinking water; members of the Streptomycin in Tuberculosis Trials Committee, who conducted one of the first modern controlled clinical trials; Richard Doll and A. Bradford Hill, who conducted early research on smoking and lung cancer; and Thomas Dawber and William Kannel, who began the Framingham Study, one of the most influential and longest-running studies of heart disease in the

world. It is clear that epidemiology has played an important role in the achievements of public health throughout its history.

John Graunt

The logical underpinnings for modern epidemiological thinking evolved from the scientific revolution of the 17th century.[20(p23)] During this period, scientists believed that the behavior of the physical universe was orderly and could therefore be expressed in terms of mathematical relationships called "laws." These laws are generalized statements based on observations of the physical universe, such as the time of day that the sun rises and sets. Some scientists believed that this line of thinking could be extended to the biological universe and reasoned that there must be "laws of mortality" that describe the patterns of disease and death. These scientists believed that the "laws of mortality" could be inferred by observing the patterns of disease and death among humans.

John Graunt, a London tradesman and founding member of the Royal Society of London, was a pioneer in this regard. He became the first epidemiologist, statistician, and demographer when he summarized the Bills of Mortality for his 1662 publication *Natural and Political Observations Mentioned in a Following Index, and Made Upon the Bills of Mortality*.[21] The Bills of Mortality were a weekly count of people who died that had been conducted by the parish clerks of London since 1592 because of concern about the plague. According to Graunt, the Bills were collected in the following manner:

> When any one dies, then, either by tolling, or ringing a Bell, or by bespeaking of a Grave of the Sexton, the same is known to the Searchers, corresponding with the said Sexton. The Searchers hereupon (who are ancient matrons, sworn to their office) repair to the place, where the dead Corps lies, and by view of the same, and by other enquiries, they examine by what Disease, or Casualty the Corps died. Hereupon they make their Report to the Parish-Clerk, and he, every Tuesday night, carries in an Accompt of all the Burials, and Christnings, happening that Week, to the Clerk of the Hall. On Wednesday the general Accompt is made up, and Printed, and on Thursdays published and dispersed to the several Families, who will pay four shillings per Annum for them.[21(pp25-26)]

This method of reporting deaths is not very different from the system used today in the United States. Like the "searchers" of John Graunt's time, modern physicians and medical examiners inspect the body and other evidence, such as medical records, to determine the official cause of death, which is recorded on the death certificate. The physician typically submits the certificate to the funeral director, who files it with the local