Injury Epidemiology: Fourth Edition

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Foreword

This 4th edition of *Injury Epidemiology* is the culmination of my 50+ years of research, writing, and teaching about the topic. In early 1970, I received a call from William Haddon, Jr. (MD, MPH) who said that he had heard of my research work and wanted to meet with me in Boston where I was an Assistant Professor at Harvard Medical School. Haddon was President of the Insurance Institute for Highway Safety, having recently left the government as the first head of an agency now known as the National Highway Traffic Safety Administration. I told Dr. Haddon that I knew nothing about highway safety but he said that was no problem. He had been told that I knew how to design and implement research projects and was not reluctant to critique the work of others. He wanted to explore the possibility of my joining the Institute. I agreed to a meeting.

Before the appointment, I read major parts of Dr. Haddon's book, *Accident Research: Methods and Approaches* (1964), co-edited by Haddon with Ed Suchman and David Klein. That book contained reviews of many studies of "accidents" of all types, not just those that occur on roadways. In contrast to most literature reviews, the editors published excerpts from the studies and provided astute criticism of the research designs and methodology. I was intrigued by the possibility of doing pioneering research in collaboration with Dr. Haddon. After the meeting, he offered me a job which, after a subsequent meeting at the Institute in Washington D.C., I accepted. Some of my colleagues at Harvard thought I was nuts to leave a great university to work at an institute supported by the auto insurance industry. Haddon assured me that the industry would not interfere with decisions regarding needed research or its implementation and publication. He proved as good as his word.

During the subsequent 8 years, I learned a tremendous amount about injuries from Dr. Haddon. And in collaboration with Dr. Haddon and other researchers in and outside the Institute, I conducted numerous studies of various aspects of the driver, vehicle, and environmental factors that contribute to or prevent the incidence and severity of injuries related to motor vehicles. After leaving the Institute in 1978 to join the faculty of Yale University, I continued research on motor-vehicle and other types of injury, taught a class in injury epidemiology in the Department of Epidemiology and Public Health, and wrote a book entitled *Injuries: Causes, Control Strategies and Public Policy* (1983). Seeing the need for a textbook on injury research methods, in 1992 I persuaded Oxford University Press to publish the first of what became three editions of *Injury Epidemiology*.

When I proposed the 4th edition to Oxford in early 2015, I was told that a new edition was no longer feasible financially. Therefore, I decided to revise the book anyway and offer the digital edition free online as well as a soft cover edition from an on-demand publisher for sale at much less cost than previous editions (link to purchase at www.nanlee.net). Since this edition can be revised at will, I invite readers who find errors or who think that something not included should be covered to contact me at nanlee252000@yahoo.com. I do not promise to include all suggestions but I will give any reasonable suggestion serious consideration. The version you are reading now is a revision completed in late 2022. An advantage of a digital version is that referenced works can be accessed with the click of a mouse or touch of a pad if they have been posted on the Internet. The links are provided in the references where available.

As in previous editions, the purpose of the book is to aid students and researchers in understanding the scope of injuries as a public health problem, how epidemiologists think about and research such problems, and how to research the effectiveness of efforts at amelioration. The book does not contain an exhaustive literature review of the epidemiology of the various forms of injury. The referenced studies are used as illustrations of good as well as flawed conceptualization and research.

Science should be a self-correcting process but too many injury researchers, particularly those with economic and behavioral science backgrounds, seem more interested in promoting their disciplines than in reducing the injury burden. Researchers make mistakes and some are dishonest. We should be alert to those problems and not hesitate to be critical of one another's ideas and research. Scientists who are not prepared to be criticized should find another line of work.

In some respects, injury research has regressed to the pre-Haddon years. Every person who aspires to a career in injury research should read *Accident Research: Methods and Approaches* (1964). As a behavioral scientist, I am chagrined by many of my colleagues' poorly designed studies of behavior or attempts at behavior change related to injuries. Authors of meta-analyses of collections of studies of injuries have to throw out a majority (sometimes almost all) of published studies because of poor research methodology. For example, authors of a meta-analysis of the association between marijuana and the risk of motor-vehicle crashes found only 9 of 2975 studies worthy of inclusion in the analysis (Asbridge, et al., 2012).

The rise of journals that require authors to pay to publish has led to fake journals (Demir, 2018), and some editors of legitimate journals troll publications for author emails and invite them to submit to the journals. I get two or three a week, some focused on subjects far afield from anything I have published. These trends threaten to clutter the literature with increasingly shoddy or fake research (De Vrieze,2018).

Haddon and others in the 1960s and 1970s pointed to the fact that major reductions in diseases in the past were accomplished by "passive" strategies, meaning that every person to be protected did not have to take action to implement the protection. Sanitation, water treatment, pasteurization of milk, and control of disease carriers such as rats and insects were accomplished without every individual having to act. Where behavioral change was necessary, such as obtaining immunizations, laws requiring the action were far more effective than attempts at voluntary behavior change.

In a summary of some of the literature on behavior change theories and attempts to use them to change injury-related behavior, behavior change advocates claimed that behavior change was neglected in favor of passive approaches (Gielen and Sleet, 2003). One of the coauthors (Sleet) once told me that, as a psychologist, he felt obligated to promote his discipline. Such a view is not conducive to objective analysis of problems and alternatives for their amelioration. My experience in the last half of the 20th Century does not support a claim of neglect of behavioral approaches. I and other behavioral scientists who pointed out the limits of behavioral research and behavior change approaches were repeatedly attacked by behavioral change advocates. My academic training was in sociology and psychology but my early research experience taught me that human behavior is difficult to change in the absence of laws or administrative rules requiring the change and too many people misrepresent their thoughts and behavior in self-reports, threatening the validity of behavioral research based on interviews and questionnaires (Robertson, 2006).

In a book containing reviews of the literature by several behavioral change researchers (Gielen, et al., 2006), behavioral change disasters such as driver education in public schools that increases teenagers on the roads and the accompanying increases in injury (e.g., Shaoul, 1975) were ignored. The authors cited studies of behavior change supposedly supporting their theories but several authors neglected to indicate the quantity of change achieved or whether the change was validated by actually observed behavior rather than dubious self-reports.

In his Foreword to the Gielen, et al. book David Grossman (2006) writes, "Few purely passive solutions to injury control problems remain untapped". In the following year, I published a study finding that 70-80 percent of fatalities related to cars, vans, and SUVs could be prevented if four passive approaches were fully adopted (Robertson, 2007). More technology that reduces driver error in motor vehicles (e.g, lane retention warning) is being adopted and driverless personal transportation is being tested. In early 2018, General Motors Corporation announced that its driverless car could be in mass production in 2019. That was premature but several companies are testing technology toward that end. Grossman's statement will rank alongside statements such as one attributed in 1977 to Ken Olson, founder of Digital Equipment Corp. "There is no reason anyone would want a computer in their home" (Strohmeyer, 2008).

It is time to get back to the future and focus on controlling the forms of energy that kill and maim. In many instances, behavior change will be a necessary part of the mix of strategies to reduce severe and fatal injuries, but that contribution will depend on more rigorous research than many behavioral scientists have produced so far.

References -- Foreword

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Chapter 1. Injury and the Role of Epidemiology

For almost two-thirds of the 20th Century, injury deaths from motor vehicles, falls, poisoning, drowning, fires, homicides, and suicides were listed in mortality statistics and largely ignored by researchers in epidemiology and public health. Near the end of the century, despite a growing body of research reported in the public health literature during the second half of the century, influential and important discussions of the future direction of epidemiological and public health research made no mention of injury (Susser and Susser, 1996; Pearce, 1996). A conference held in 2005 on the future of Public Health included one brief mention of injury but more was said about Elvis impersonators than injury prevention (University of the Sciences in Philadelphia, 2005). The World Health Organization publication "A Safer Future" emphasized safety from diseases. It had no section on the major categories of injury that kills millions worldwide annually (World Health Organization, 2007).

Occasionally the importance of injury control gains some prominence in public health circles. Regarding deaths to the young and a significant proportion of health care costs, the Executive Director of the American Public Health Association wrote, "The Solution is Injury Prevention" (Benjamin, 2004). A lecture by a former Director of the Centers for Disease Control and Prevention mentioned motor vehicle injuries worldwide but failed to include vehicles and environments in his policy prescriptions in contrast to his remarks on infectious diseases (Frieden, 2015). Injury remains a relatively neglected public health problem.

Injury control efforts should not be left exclusively to public health agencies that ignore or misunderstand the problem. Epidemiology and public health bring a perspective on prevention honed from major victories in the control of many infectious diseases. As was the case in those triumphs, the implementation of injury control strategies requires the involvement of a wide variety of government agencies, businesses, healthcare providers, private voluntary organizations, and the research community. To implement an injury control agenda effectively and efficiently, the leadership and implementers in these entities should understand the epidemiological and public health perspective (Bonnie and Guyer, 2002) and research specifying what works and what does not.

Lists of the numbers of deaths by type can be misleading regarding their relative importance for individual or societal well-being. Neither preventive measures nor medical treatment "saves lives" as is often claimed. If prevention or treatment is effective, it may delay death for some time, but everyone eventually dies. An accurate assessment of deaths, and the effects of prevention or treatment to extend years of life, would indicate potential years of life lost or preserved, and years of disability avoided. Such statistics are too rarely seen in medical and public health literature.

In 1985, a committee appointed by the National Research Council/Institute of Medicine (NRC/IOM) published a report -- *Injury in America: A Continuing Public Health Problem*. The report concluded:

"*Each year, more than 140,000 Americans die from injuries, and one person in three suffers a nonfatal injury. ... Injuries kill more Americans aged 1-34 than all diseases combined, and they are the leading cause of deaths up to the age of 44. Injuries cause the loss of more working years of life than all forms of heart disease and cancer combined. One of every eight hospital beds is occupied by an injured patient. Every year, more than 80,000 people in the United States join the ranks of those with unnecessary, but permanently disabling,* *injury of the brain or spinal cord." (Committee on Trauma Research, 1985).*

The rank of major causes of death by age did not change much in the ensuing 30+ years. Figure 1-1 is a depiction of the top ten causes of death by age group in 2020. Despite reductions in the rates of fatalities and hospitalizations per population, particularly homicides and those related to motor vehicle use, the absolute numbers increased related to population growth and other factors. In 2020, about 200,955 U.S. residents died from an injury. Despite a deadly coronavirus pandemic beginning in 2020, injury remains the leading cause of death among those 1 to 45 years of age.

	Age Groups										
Rank	≤1	1-4	5-9	10-14	15-24	25-34	35-44	45-54	55-64	65+	All Ages
1	Congenital Anomalies 4,043	Unintentional Injury 1,153	Unintentional Injury 685	Unintentional Injury 881	Unintentional Injury 15,117	Unintentional Injury 31,315	Unintentional Injury 31,057	Malignant Neoplasms 34,589	Malignant Neoplasms 110,243	Heart Disease 556,665	Heart Disease 696,962
2	Short Gestation 3,141	Congenital Anomalies 382	Malignant Neoplasms 382	Suicide 581	Homicide 6,466	Suicide 8,454	Heart Disease 12,177	Heart Disease 34,169	Heart Disease 88,551	Malignant Neoplasms 440,753	Malignant Neoplasms 602,350
3	SIDS 1,389	Homicide 311	Congenital Anomalies 171	Malignant Neoplasms 410	Suicide 6,062	Homicide 7,125	Malignant Neoplasms 10,730	Unintentional Injury 27,819	COVID-19 42,090	COVID-19 282,836	COVID-19 350,831
4	Unintentional Injury 1,194	Malignant Neoplasms 307	Homicide 169	Homicide 285	Malignant Neoplasms 1,306	Heart Disease 3,984	Suicide 7,314	COVID-19 16,964	Unintentional Injury 28,915	Cerebro-vascular 137,392	Unintentional Injury 200,955
5	Maternal Pregnancy Comp. 1,116	Heart Disease 112	Heart Disease 56	Congenital Anomalies 150	Heart Disease 870	Malignant Neoplasms 3,573	COVID-19 6,079	Liver Disease 9,503	Chronic Low. Respiratory Disease 18,816	Alzheimer's Disease 132,741	Cerebro-vascular 160,264
6	Placenta Cord Membranes 700	Influenza & Pneumonia 84	Influenza & Pneumonia 55	Heart Disease 111	COVID-19 501	COVID-19 2,254	Liver Disease 4,938	Diabetes Mellitus 7,546	Diabetes Mellitus 18,002	Chronic Low. Respiratory Disease 128,712	Chronic Low. Respiratory Disease 152,657
7	Bacterial Sepsis 542	Cerebro-vascular 55	Chronic Low. Respiratory Disease 54	Chronic Low. Respiratory Disease 93	Congenital Anomalies 384	Liver Disease 1,631	Homicide 4,482	Suicide 7,249	Liver Disease 16,151	Diabetes Mellitus 72,194	Alzheimer's Disease 134,242
8	Respiratory Distress 388	Perinatal Period 54	Cerebro-vascular 32	Diabetes Mellitus 50	Diabetes Mellitus 312	Diabetes Mellitus 1,168	Diabetes Mellitus 2,904	Cerebro-vascular 5,686	Cerebro-vascular 14,153	Unintentional Injury 62,796	Diabetes Mellitus 102,188
9	Circulatory System Disease 386	Septicemia 43	Benign Neoplasms 28	Influenza & Pneumonia 50	Chronic Low. Respiratory Disease 220	Cerebro-vascular 600	Cerebro-vascular 2,008	Chronic Low. Respiratory Disease 3,538	Suicide 7,160	Nephritis 42,675	Influenza & Pneumonia 53,544
10	Neonatal Hemorrhage 317	Benign Neoplasms 35	Suicide 20	Cerebro-vascular 44	Complicated Pregnancy 191	Complicated Pregnancy 594	Influenza & Pneumonia 1,148	Homicide 2,542	Influenza & Pneumonia 6,295	Influenza & Pneumonia 42,511	Nephritis 52,547

Figure 1-1. Leading Causes of Death by Age Group in 2020 According to the Centers for Disease Control and Prevention. https://wisqars.cdc.gov/cgi-bin/broker.exe

In 2010 more than 2.5 million persons were hospitalized at an estimated lifetime cost of $80.2 billion in medical care costs and $150.2 billion in lost productivity (CDC, 2015).

There have been substantial changes in the ranking of deaths by type of injury. Changes in U.S. population death rates during 1980-2020 for the leading causes of injury deaths, adjusted for changes in age distribution, are shown in Figure 1-2. Motor vehicle fatality and homicide rates declined by about half but were substantially offset by huge increases in poison deaths. Deaths from falls declined until the turn of the century and then increased as did those from suicides. Evidence regarding the reasons for some of these changes will be examined in subsequent chapters.

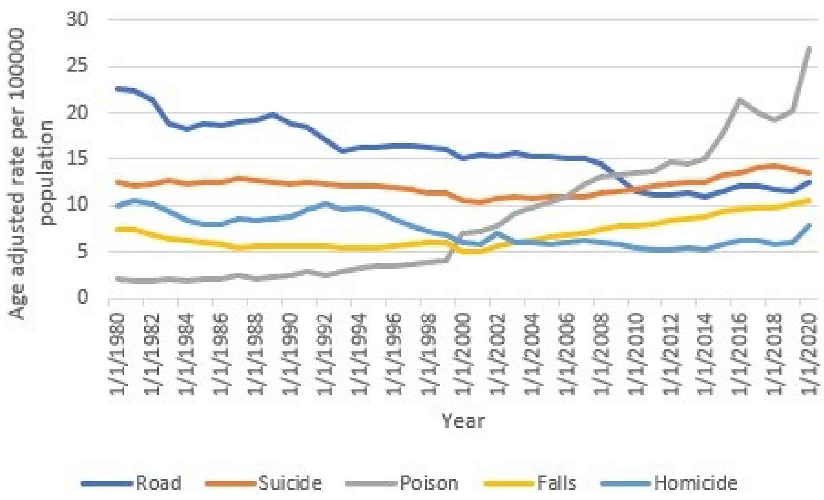

Figure 1-2. Age-adjusted Deaths Per 100,000 Population
Sources:
http://www.cdc.gov/nchs/data/mortab/aadr7998s.pdf,
http://webappa.cdc.gov/sasweb/ncipc/mortrate10_us.html,
http://www.cdc.gov/nchs/data/mortab/aadr7998i.pdf

Although major new concerns about diseases such as COVID-19, HIV/AIDS, and diabetes grab attention, injury takes more than ten times the potential years of life as each of these diseases because of the differences in age at death. Internationally, injury is a large proportion of the loss of life and disability in low-income countries but is seldom considered in international aid programs (Mock, et al., 2004).

The 1985 NRC/IOM report also pointed to the fact that injuries are highly patterned -- subject to study and targeting of interventions, that many interventions are known to be effective but are unused, and that modest increases in funding would have large payoffs in cost savings. Eight years after the report recommended that a Center for Injury Control be established at the Centers for Disease Control and Prevention (CDC), it was established in 1993. The Center supported academic injury prevention research centers in subsequent years and other governmental agencies and private foundations supported research as well. Although the number of professionals doing studies, teaching, and implementing injury control projects has grown modestly, the needs both in quantity and quality remain large. A study of 82 medical schools in 31 countries found large gaps in the injury topics addressed (Villaveces, et al., 2005). A 2021 survey of accredited schools of public health and other public health training programs found that 32 percent of the schools and 60 percent of the other programs did not have a single course for credit focused on injuries (Runyan, et al., 2022). Students who wish to study injury epidemiology and injury control should check on the faculty interest and course offerings of a given school before deciding where to apply for admission.

Should injuries have a higher priority? Reduction of injuries is justifiable on humane grounds, particularly since they disproportionately affect the health of the young. In a time of concern for health care costs, injury reduction is also an economic necessity. Injury control is one of the most promising ways to reduce healthcare costs in the immediate future. While attention to diet, increased exercise, and prevention of smoking among the young are worthwhile, the health benefits are often not realized for decades. An injury prevented or reduced in severity has immediate benefits in reduced costs as well as grief, pain, and suffering.

This chapter lays out some of the important concepts in injury epidemiology and prevention: the distinction between accident and injury, the application of the epidemiologic model for infectious diseases to injuries, and the phases of injury related to the factors that contribute to incidence and severity.

ACCIDENTS AND INJURIES. One aspect of injury to be addressed in this book is the importance of measuring severity when investigating injuries or considering injury control efforts. In the United States, poisoning, motor vehicles, firearms, falls, fire/burns and drowning accounted for about 77 percent of deaths at the turn of the century, but only 36 percent of non-hospitalized injuries are severe enough that their sufferers seek medical treatment (Finkelstein, et al., 2006). Emphasis on the prevention of all "accidents" will lead to misdirection of effort from the more serious and costly cases.

The evolution in thought about injuries is reflected in how they have been classified. Injuries often are characterized as either accidental or intentional. Before the 1960s, injury control was primarily focused on "accident prevention" and interpersonal or self-directed violence was largely left to law enforcement, psychiatry, social workers, and the clergy. That is not to say that these professions have not contributed to injury control, or that all attempts to prevent "accidents" have been unsuccessful, but the extent of scientific investigation of the effectiveness of these approaches was very limited (Haddon, Suchman, and Klein, 1964).

"Accidents" refer to a very large and fuzzily defined set of events, only a small proportion of which are injurious. Any unintended, incidental event that interferes with one's daily pursuits is an accident. In writing these few paragraphs, I had several accidents in typing, but hopefully, they will be corrected enough so as not to irritate the reader, and thus become irrelevant to my exposure to the risk of injury.

The word "accident" is also intertwined with the notion that some human error or behavior is responsible for most injuries. Exclusive focus on the human actors involved tends to detract from an examination of the full range of factors that contribute to injuries and, particularly, their severity (Haddon, et al, 1964; Robertson, 2014).

Although the word "accident" had various meanings historically (Loimer, et al., 1996), it is now primarily a euphemism for lack of intent, as though intent were a primary consideration in injury control. If two people have an argument that results in a brief exchange of fisticuffs, the incident usually goes unrecorded as an injury. In a similar situation, if one of the persons has a gun and kills the other with it, the case is classified as homicide as though the person intended to kill, which is often not true. While criminal law has various categories of homicide based on degree and type of intent, aggregated statistics of the broad category "homicide" are included in "intentional injuries" without any data on the intent of the persons who used the weapon.

Even in the case of suicide, intent can be questioned. Some supposedly suicidal acts are attempts to get attention rather than serious attempts at self-destruction. But if the attentiongetter makes a mistake and dies, he or she will be classified as a suicide (Maris, et al., 2000).

In this book, the term injury or specific types of injury -- amputations, burns, and lacerations -- will be used to indicate the phenomena of interest. Also, when referring to attempts to reduce injury, the term injury control will be used. While "injury prevention" has been used by respectable scientists, and on occasion even by the author, the term is less precise than "injury control" when the severity of an injury can be reduced without reducing incidence.

EPIDEMIOLOGY. The word epidemiology is a derivation of the classical Greek word *epidemion*, a verb meaning "to visit", used in connection with human maladies by Hippocrates circa 2400 B.C. The first known published use of the word in modern languages was in 1598, the Spanish word *epidemiologia*, in a study of bubonic plague in Spain (Najera, 1988).

There are all sorts of definitions of epidemiology. The scientific study of the visitations of disease and injury on a population is as good as any. Scientific research on the distributions of diseases and injuries in populations, and factors that increase or decrease risk, is somewhat more descriptive of what epidemiologists do.

Historically, early epidemiologists concentrated their attention on what was later called "infectious diseases". Although the specific organisms that often infected populations were microscopic and unknown, quantification of the numbers of illnesses and deaths by location or exposure to certain environmental conditions led to actions that reduced disease and death in some instances. In mid-19th Century London, John Snow found that cholera occurred largely in people who used one water supply but not in people who used another. He didn't know what was in the water that caused the disease, but he knew enough to recommend that the flow from that water supply be halted (Evans, 1993).

Similarly, when there are known effective means of reducing injury or severity, relatively simple studies of when, where, and how people are injured can lead to large reductions by targeting the relevant injury control measures to the circumstances to which they apply (Chapter 7). This approach avoids the question of causation which is both a point of fascination and contention among epidemiologists as well as other scientists.

Some epidemiologists avoid the word "cause" and use euphemisms such as "risk factor" and "etiology". Often the incidence and severity of disease and injury occur coincident with several factors, some of which may contribute to an increased probability of incidence or severity and some of which may be correlates of the real causes, but play no meaningful role in incidence or severity. For example, if a disease or injury is seasonal, as many are, an increase in incidence may be correlated with other seasonal happenings. In northern areas of the United States, the vast majority of injuries to people while riding motorcycles occur during the season that robins are in the environment, but the correlation is known to be spurious. Few, if any, motorcyclists crash when impacting robins. The correlation occurs because both robins and motorcyclists prefer warm weather for their activities.

Since correlations thought to represent causal connections occasionally turn out to be false inferences, the embarrassment to the scientists proved wrong leads other scientists to great caution in causal inference. When dealing with maladies that kill or maim, however, one must sometimes risk embarrassment to contribute to the welfare of fellow human beings. At some point, as evidence accumulates, an attempt to change conditions coincident with the disease or injury that would likely reduce it is appropriate. The amount, type, and quality of the evidence necessary to reach that point is a matter of controversy to be addressed, especially in Chapter 8, of this book.

A few epidemiologists and other scientists believe that objective scientific investigation is incompatible with recommendations for changes in policies or practices that epidemiological research suggests would reduce harm. Some journal editors do not even allow discussions of policy implications of research results in articles reporting the results, much less recommendations for policy changes. Two important points are ignored by those stances: 1. The work of the scientist who proposes change based on research is likely to have that research scrutinized more carefully for bias and error. To the extent that such scrutiny weeds out invalid results, the science is improved. 2. Self-imposed or institutional bars from the policy debate of the scientists closest to the data increase the probability of misinterpretation or misuse of the data. Therefore, this book is devoted not just to the application of the theory and methods of epidemiology in injury research, but also the uses and misuse of epidemiological data relevant to injury control.

Epidemiological methods are also applied to the study of the effectiveness of policies and practices aimed at the reduction of injury incidence and severity. Although this is called "applied" research and somehow has less prestige than "basic" research, the distinction is false. The study of human activities and other phenomena that increase the risk of injury is no more "basic" than the study of human activities that seek to intervene in the causal process to reduce injury. Indeed, the reduction of injury (or disease) by deliberately changing a factor inferred as a condition necessary for, or contributing to, specific injuries is additional evidence of causation, particularly if the change is introduced in such a way as to rule out the contribution of other factors to the reduction. Chapters 11-14 of the book discuss the use of scientific methods to measure the effects of programs, laws, environmental modifications, medical care, and rehabilitation to reduce injuries, their severity, and longer-term consequences.

Of course, disciplines other than epidemiology also study injury. Clinicians often describe a case or series of cases and scientists ranging from physics to biomechanics contribute to our understanding of the mechanisms of injury. The research methods used by epidemiologists are shared by many disciplines. Statisticians, sociologists, psychologists, physicists, chemists, and biological scientists use more or less the same methods. Many epidemiologists were originally trained in those disciplines as well as medicine. Nevertheless, the concepts of epidemiology provide a valuable perspective, particularly concerning the reduction of disease and injury in the population as a whole or subsets of the population.

THE EPIDEMIOLOGICAL MODEL. Based on the experience of their predecessors in the scientific investigation of infectious diseases, many injury epidemiologists conduct their investigations mindful of a theoretical model developed by infectious disease epidemiologists. The core concepts of this model include the host (the person injured), the agent that injures the host, conveyances that bring the agent to the host, as well as environmental factors that increase or decrease the probability of agent-host interaction.

Early epidemiological investigations of what came to be known as infectious diseases showed correlations of the diseases to seasons, water sources, economic status of the populations primarily affected, and the like (Buck, et al., 1988). We now know that in some cases these correlates of the diseases were carriers (vehicles or vectors) of infectious agents. In others, they were factors that increased or decreased host exposure or susceptibility to the agents, and some were spurious.

Microbiologists subsequently identified tiny biological structures (bacteria, parasites, viruses) that secreted toxins in an invaded host, removed elements from the host, or caused other changes at the cellular or organ levels, that resulted in sickness and death. Then epidemiologists knew to look for these agents in the seasons, water, living conditions, etc. associated with a given disease (Lilienfeld and Lilienfeld, 1980).

In some cases, the microorganism was conveyed to the host by inanimate media, such as water and milk, which came to be called vehicles. Others were carried to human hosts by insects, by animals, or were directly transmitted from human beings to human beings. These animate carriers came to be called vectors. Living conditions, often related to economic status, increased or decreased exposure to the carriers of the agents, or increased susceptibility to infection due to nutritional or other factors.

All of these discoveries had implications for the control of infectious diseases. The agents could be eliminated from the media in which they reached hosts such as water and milk. In some cases, susceptibility could be reduced by modification of the immune mechanisms of the potential hosts. In others, antibiotic agents could be introduced into the infected hosts to reduce the severity of the illness. Elimination or control of certain carriers, such as rodents and insects, could be tried and, in some cases, accomplished. While diseases sometimes declined as people improved their living conditions, removing harmful agents or carriers in the process, epidemiological evidence on vehicles or vectors, as well as times, places, and populations involved were crucial in the deliberate attempts to reduce many infectious diseases.

Although injuries can be characterized using the concepts of infectious disease epidemiology, injury epidemiology lagged in development by decades. The twentieth century was almost two-thirds past before the agents of injury were accurately identified as the various forms of energy -- mechanical, thermal, chemical, electrical, ionizing radiation -- or too little energy in the case of asphyxiation (Gibson, 1961). And that identification came from a psychologist, not an epidemiologist. Before and since that date, certain authors referred to motor vehicles, guns, and alcohol as agents of injury, but except for alcohol poisoning, that is inaccurate in the epidemiological use of the concept of an agent. Motor vehicles and guns are vehicles of mechanical energy in epidemiological parlance, and alcohol contributes to injury by sometimes affecting a behavior that places people at greater risk of injurious energy exposure as well as perhaps increasing the vulnerability of tissues to energy insults.

Before these insights, injury research was primarily focused on human characteristics and human behavior correlated with injury incidence and, more rarely, severity -- with occasional studies of seasonal and geographical variations and the like. A few isolated researchers looked at human tolerance of mechanical energy as important (DeHaven, 1941; Haddon, Suchman, and Klein, 1964; Stapp, 1957).

It is not that the characteristics of the energy were unknown. The leading source of injury by far is mechanical energy, the characteristics of which were known since Sir Isaac Newton's work on the laws of motion in the 17th Century. Although Newton's laws of motion do not apply near the speed of light, they apply to moving motor vehicles and bullets or falling human beings.

Why did it take so long to recognize energy as the agent of injury? It is more difficult to prove why something does not happen than why it does. After the great decline in death due to infectious diseases in the first half of the Twentieth Century, many epidemiologists turned their attention to cardiovascular diseases and cancers, at least partly due to the increases in government support of research on those diseases. The popular folklore focused on human behavior or human error as the cause of "accidents" and the small amounts of research funds available were devoted to a reinforcement of that view.

Manufacturers of motor vehicles –the leading source of mechanical energy leading to death from the 1920s until recently -- deliberately supported the behavioral approach to divert attention from their vehicles (Eastman, 1984; Lemov, 2015). The National Rifle Association, the leading opponent of the regulation of guns, coined the slogan, "Guns don't kill people. People kill people." Mosquitoes don't have political lobbyists, but motor vehicles and guns do.

FACTORS AND PHASES OF INJURY. The transfer of energy to human beings at rates and in amounts above or below the tolerance of human tissue is the necessary and specific cause of injury. The amount of energy concentration outside the bands of tolerance of tissue determines the severity of the injury.

The word injury usually refers to the damage to cells and organs from energy exposures that have relatively sudden, discernible effects, although some researchers have included damage from chronic low-energy exposures, such as back strain or carpel tunnel syndrome, as injury (Waller, 1985). Chemical and radiation exposures that produce cellular changes resulting in neoplasm are called cancers rather than injury. A debate regarding the appropriateness of inclusion or exclusion of any harmful condition as an injury or a disease would be pointless, but at the fuzzy edges of a set of harmful consequences from energy exchanges, a given researcher should make clear the cases that are considered injuries.

Most of the concentrations of energy involved in severe and fatal injuries are the result of modification by human organizations of the energy inherent in physical matter (Robertson, 1983). Some falls occur from heights unmodified by human construction. Lightening, tornadoes, and hurricanes kill a few hundred people annually. But opioid drugs, motor vehicles, and guns, as well as cigarettes that cause more house fires than any other ignition source and home swimming pools that drown more children than other bodies of water, are human inventions that are the major sources of serious injuries.

To alert researchers to the factors contributing to injury incidence and severity, and the timing of involvement of those factors, William Haddon, Jr. (1972, 1980) devised a matrix of broad categories of factors and phases of injury. This matrix, along with some examples of factors known to be important in each cell, is shown in Table 1-1.

Before an injury, human, vehicle, and environmental factors contribute to the increase or decrease in exposure to potentially damaging energy. For example, alcohol impairs human perceptions, reactions, and judgments, and may increase aggressive behavior in some people. The weights of heavier vehicles extend stopping distances. Hedges and built structures at intersections reduce the visibility of oncoming traffic.

Table 1-1. The Haddon Matrix, With Examples

	Factors		
Phases	Human	Vehicle	Environment
Preinjury	1. Alcohol intoxication	4. Braking capacity of motor vehicles	7. Visibility of hazards
Injury	2. Resistance to energy insults	5. Sharp or pointed edges and surfaces	8. Flammable building materials
Postinjury	3. Hemorrhage	6. Rapidity of energy reduction response	9. Emergency medical

Although a pre-injury condition, the susceptibility of the host's tissue to damage influences the severity during the energy exchange that injures. For example, an older person with a brittle bone condition (osteoporosis) may be disabled by a fall that would hardly bruise a teenager. Sharp points and edges concentrate energy on the host. Flammable building materials and furnishings increase the intensity of heat and smoke in fires and may result in the release of toxic chemicals.

After the initial energy exchange, the condition of the host, the potential for more energy exposure, and the responses from the environment substantially affect survival and the time and extent of return to pre-injury functioning of those who survive. For example, if hemorrhaging is not stopped, the host may die from loss of blood. If a gas tank is ruptured by the initial energy exchange, a spark can result in thermal energy beyond host tolerance. If emergency response is delayed, the remainder of a life that could be preserved by surgery or other intensive treatment may be lost.

Carol Runyan (1998) added a third dimension to the matrix -- implementation issues such as the effectiveness of attempts to change the identified elements of the matrix and the cost of doing so. Research on these issues is considered in chapters 14 and 15 of this text. Every epidemiological investigation does not have to measure all of the human, vehicle, and environmental factors at various phases to be useful, but in those cases where there is a synergistic effect of particular factors on the outcome being studied; failure to consider them can be misleading. One crucial consideration in the relevance of epidemiology for injury control is the modifiability of the factors measured.

For example, historically a large number of early injury investigations were limited to the distributions of rates of a particular type of injury by age and gender. It is important to know how many potential years of life are affected by injury and whether disproportionate subsets of the population are involved, but other than those considerations, age and gender distributions are uninteresting. We are not going to change the age and gender of individuals in the population.

The major modifiable factors that contribute to injury are concentrations of energy and the characteristics of vehicles of energy. Human behavior that increases exposure or concentrates energy can be modified under certain conditions, but not by changing immutable factors such as age and gender (Robertson, 1983). Human tolerance to energy exposures varies among individuals by age, gender, and other factors that affect the condition of human tissue, such as the decalcification of bones and hemophilia. To the extent that diseases that increase susceptibility can be treated, the severity of an injury can be reduced by that method, but there are substantial limits to increasing tolerance to energy.

The importance of focusing on the degree and type of energy exposures was most dramatically illustrated to me during the conduct of a study of worker injuries. In two adjacent buildings of the same company, the injuries to the workers were remarkably different. In Building A, there were virtually no injuries to the workers that were severe enough to be reported on the log required by the Occupational Safety and Health Administration (OSHA) during the eight years of records studied. In Building B, about one in five workers had an OSHA-reportable injury annually. There were some age, gender, and other differences between the workforces in the two buildings, but these accounted for only a small amount of the variation in injuries among the workers in Building B (Robertson and Keeve, 1983), and there was essentially no variation in injuries while at work among people in Building A to investigate.

The major difference between the two buildings was the exposure to energy. In Building B, some of the workers poured molten metal, heated thousands of degrees, from large vats. Others worked adjacent to machines that rolled, shaped, and stamped the metal -- forming it into wire, rods, and keys. A fall or a movement of any sort in the wrong direction would place one or another part of a worker's anatomy in contact with thermal or mechanical energy beyond the tolerance of human tissue. The people in Building A also worked with machines -- typewriters, photocopying machines, and computers -- that contained potentially injurious electrical energy. But the manufacturers of those machines had the foresight to shield the energy from the workers so that the potential for contact with the energy was minimal.

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