Overview of Injury Epidemiology

Charles DiMaggio, PhD[1,2]

March 5, 2011

[1] Department of Anesthesiology, Columbia University, College of Physicians and Surgeons, New York

[2] Department of Epidemiology, Columbia University, Mailman School of Public Health, New york

1 Introduction

Injury is the number one killer of 1 to 34-year olds in the United States. [1] As many Americans are killed every year in motor vehicle crashes as were killed during the Vietnam War, at a yearly economic cost of over $60 billion. [2] Injury exacts a greater toll in potential years of life lost than cancer and cardiovascular disease combined. [3] Yet, in 1985, the National Research Council of the Institute of Medicine reported that for every dollar spend on cancer research, the federal government spent about 11 cents for injury research. [4]

Injury is the immediate damage inflicted on human tissue by the transfer of energy. This definition presupposes several concepts. First, energy causes injury. In 1961, William Haddon and James Gibson separately and independently arrived at the conclusion that Injuries to a living organism can only be produced by some energy exchange. [5] This energy may be mechanical, thermal, or electrical. Second, the definition recognizes the existence of human tissue thresholds for the absorption of energy. Tissue thresholds for injury refer to levels above or below which human tissue suffers damage. Damage due to an excess of mechanical energy is evident in falls and blunt trauma. Insufficient energy is seen in the acute loss of oxygen due to tracheal injury, drowning or poisoning. [6] Human tissue can accommodate certain levels of energy exposure. Modification of the energy to which humans are exposed is a major means of injury control. John Stapp decelerated a rocket sled from 632 miles per hour to zero in 1.4 seconds without serious injury to the occupant. [7] The pertinent, modifiable, variables were a long stopping distance, the use of a harness system that distributed the energy over a large body area, and the inherent resistance of the human body to transient forces. This type of work led to interventions like seatbelts.

William Haddon felt it was important to accept injury as a disease. While the distinctions between injury and disease are in part semantic, he saw conceptual difficulties as well. 5 We are used to thinking of disease in terms of incubation periods. The effects of injury, though, are often thought of as being immediate. This may impose an intangible barrier to accepting injury as a disease. Yet, the incubation period of some infectious diseases can be measured in mere hours. [8] And, not all the effects of injury follow closely on the heels of the initial insult. Death due to injury-related sepsis and multiple organ system failure occur days to weeks after the incident. [9] Repetitive stress injuries such as carpal tunnel syndrome may require years to develop.

A further difficulty is the seemingly random nature of injury. We are taught, Accidents happen. In fact, injuries are far from random events. Events as disparate as falls from windows and horse kicks in the Prussian cavalry have been fitted to statistical models implying they may be predictable from independent variables. [5] The greatest barrier to successfully addressing the epidemic of injuries in our society may be in our minds. Accidents may happen, but injury is controllable.

This paper briefly reviews the major causes of injury in the United States, details approaches to the analytic epidemiology of injury, and describes injury control concepts.

2 Descriptive Epidemiology

In the International Classification of Diseases (ICD) the external causes of injury are broadly classified by intent. The broad categories include unintentional, self-inflicted, and injuries due to assault, injuries due to police intervention, injuries of unknown cause and warfare. But, classifying injuries by the mechanisms by which they occur, e.g. fire-arms, motor vehicles, and burns may be more amenable to prevention and control efforts than are classifications by intent. [10] Much of injury epidemiology describes mortality. But, we are learning more about the morbidity of injuries resulting in hospital admissions and emergency department visits. [11–13] There have been notable advances since Trunkey declared We simply to not know what the incidence of trauma is in this country, or where it occurs. [11] Even if many of the statistics are based on mortality, we can take accept the observation of William Farr who noted, The death rate is a fact; anything beyond this is an inference. [14]

2.1 Cars

Motor vehicles crashes (MVCs) are the number one cause of trauma deaths world wide, surpassing even the toll taken by the casualties of war. [3] There is a pronounced age-related pattern of death, with an increase after age 13 and a peak at age 18 for occupants; there is a peak at age 6 for pedestrian deaths. [15]

In the United States, yearly motor-vehicle-related deaths decreased from a high of about 55,000 in the 1960s to about 40,000 in the 1990s. Much of this decline has been attributed to federal and state regulations such as the 1966 National Traffic and Motor Vehicle Safety Act and the related Highway Safety Act. [16] Most motor-vehicle occupant deaths are due to deceleration injuries. Control measures have been aimed at decreasing highway speeds, improving the crash-worthiness of cars and distributing deceleration forces over a greater human body area with seatbelts and airbags. Large trucks pose a particular hazard. They account for only 1% of vehicles on the road, but 10% of fatalities. [16]

Nationally, occupants account for 84% and pedestrians 16% of motor-vehicle-related death in the U.S. [1] Pedestrian injuries primarily afflict the youngest and the oldest segments of the population. For children, these injuries peak between the ages of 5 and 9, and are associated with male gender, low socio-economic status, and urban areas. Due to the massive transference of energy from the vehicle to the human, it would appear that the most effective public health measures would involve prevention. But, there may be some vehicle characteristics amenable to change that might result in injury control. Vehicle size and weight contribute to the severity of pedestrian injuries. As might be expected, the bigger the vehicle, the deadlier. Also contributing are vehicle shape, bumper height relative to pedestrian height, speed at impact and braking action. [17] Many of these variables are amenable to change.

2.2 Guns

Firearms are the second-leading cause of injury death in the U.S.; the U.S. rate is 90 times that of any other country in the world. [2] Handguns account for 25% of the estimated 100 million firearms in the U.S., but are involved in 80% of injuries. [2] They are a particularly lethal mechanism of injury. Case-fatality rates for assaults involving firearms are 5 times greater than for those involving sharp instruments, such as knives. Firearms are frequently involved in suicides and homicides. Homicide is the leading cause of death among blacks aged 15-34, and the leading cause of fatal occupational trauma in women. [17] Political and legislative approaches to controlling gun-related injuries have proved controversial. Effective control measures remain to be implemented.

2.3 Falls

Falls are the third-leading cause of injury death, but the leading cause of hospitalization due to injury. [16] Falls most frequently affect the elderly, with hip fracture the most common serious injury suffered. A 50-year-old white female with osteoporosis has as high as a 40% lifetime probability of suffering a hip fracture. [19] Such fractures have been described as uncommon among women with normal bone densities (greater than or equal to $1.0 g/cm^2$). [20] Epidemiologic surveillance to identify fall-prone individuals, locations in the community associated with falls, and the implementation of counseling, and exercise programs to increase the injury threshold of those most at risk are possible means of control.

2.4 Poison

Poisonings account for up to 15,000 deaths per year, most often involving adults, and account for half of all suicides. [21] Carbon monoxide is the most common cause of poisoning death, but opium and cocaine overdoses increased dramatically during the 1980s.21 An injury-control success story is the Poison Prevention Packaging Act of 1970 which was attributed with more than halving the rate of salicylate poisoning in children. [19]

2.5 Fire, Water and Air

Among whites in the United States, drowning, fires and aircraft ranked 5th, 6th, and 10th among leading causes of death by injury. Drowning and fire ranked either 4th or 5th among blacks and Native Americans; in these groups aircrafts did not figure in the top ten causes of traumatic injury. [22]

Smoke detectors have decreased fire-related mortality by 70%; additional lives could be saved by the introduction of fire-safe cigarettes, which are available, but not marketed. [19] A simple means of preventing scald injury is to lower the temperature on home water heaters. For example, at 60 degrees Celsius it takes 2 seconds for a 3rd degree burn to occur; at 50 degrees, it takes 10 minutes. [19] The Flammable Fabrics Act of 1953 has also contributed to a decline in fire-related deaths. [16]

The relative importance of drowning varies by location. In 10 states it is the leading cause of unintentional- injury fatality. In many areas drowning deaths are associated with rivers and lakes, while in others, such as Los Angeles, most drowning deaths occur in pools. [23] Only 2% of drownings involve surfers and divers. Describing the proportion of drowning deaths due to different activities, however, does not convey the risk associated with that activity because such proportions do not take into account person-time of exposure.

Most of the approximately 1,300 yearly aviation-related deaths involve general, non-commuter, aviation, which accounts for 250 times more deaths than scheduled, non-commuter flights. It is notable that 60% of all active-duty naval officer deaths during World War II were the result of plane crashes in the continental United States. [24]

2.6 Alcohol

Alcohol plays a role in many injuries. Most serious injuries occur on weekends and at night, when alcohol consumption is at its highest. [25] Its role is not completely understood. Even controlling for level of damage, there is increased death and disability in MVCs that involve alcohol. [3] A case-control study found alcohol intoxication among pedestrians, particularly the elderly, to be a strong risk factor for death. [26] There is a correlation between motor-vehicle death rates and rates of other unintentional injuries, which may reflect common factors such as alcohol use. [16] An increased blood alcohol concentration (BAC) is seen in 40-50% of adult drownings. [23] In 1980, 53% of fatally injured passenger car drivers had BAC of 0.10% or greater; each 0.02% increase in BAC doubles the risk of a fatal crash. [27]

Preventive measures have relied on punishment. Yet, four fifths of intoxicated driver fatalities had no prior convictions for driving while intoxicated. Price increases, though, have been shown to be effective. [16]

3 Analytic Epidemiology

3.1 Data Sources

Data for epidemiologic studies of injury may be either original (primarily collected), or existing (secondary) sources. Original data collection entails the time and expense associated with any such epidemiologic study, but has the advantage of tailoring the variables to those necessary to answer the study question.

Existing data sources expedite the study process, but involve other difficulties. Some data sources are pre-existing compilations. For example, the National Safety Council publishes Accident Facts yearly. It is a compilation based on data obtained from state, federal and international sources. Some databases are available for query. The Statewide Planning and Research Cooperative System (SPARCS) maintained by the New York State Department of Health, make available demographic data as well as discharge diagnoses (ICD N codes) and external cause (ICD E) codes. [28] Information on motor-vehicle-related mortality is available from the National Highway Traffic Safety Administrations Fatality Analysis Reporting System (FARS). The database can be queried on line, or down loaded directly in either ASCII or SAS format. Data on traumatic fatalities can also be ascertained from the National Center for Health Statisticss (NCHS) Multiple Cause of Death databank that identifies anatomic injuries listed on death certificates. There has also been some movement toward creating comprehensive trauma registries. One such registry is the National Trauma Data Bank maintained by the American College of Surgeons.

Different data sources have different strengths. The FARS system has detailed information on vehicles and the environment at the time of the crash, but little clinical information on the cause of death. The NCHS system has detailed clinical information but scant causal information. One attempt to link these two data sources had 85% success in matching FARS cases with a case in the NCHS. [29] Linking unassociated data bases presents difficulties. Possible problems include differences in definitions of injuries, mis-specification of dates, locations or other personal identifiers, differing inclusion criteria and completeness of data collection.

3.2 Study Types

As the basic science of public health, epidemiology has an important role to play in the control of injury death and disability. There is a need for descriptive epidemiology. Sewell has written that, factors involving the agent, environment and host must be identified by epidemiologic techniques so effective intervention strategies can be designed.

There is a need for analytic studies. A cohort study is a difficult undertaking under any circumstances. In the area of injury, it is particularly challenging. For example, a prospective cohort study of 100,000 people would yield just 1000 motor-vehicle injuries in 4 years. [30] This figure ignores the need for additional cases to control for various confounders. The lack of readily available data sources would hamper the conduct of a retrospective cohort.

Much of injury epidemiology has been cross sectional or case control. The unit of analysis may be an injured person, a vehicle, or a stretch of road. The major difficulty in case-control studies is the selection of appropriate controls. Controls should represent the same base experience as the cases. [31] They should be chosen such that if they had the disease under consideration, they would have been included as cases

This principle can be violated in numerous ways. Does an individual with no history of injury satisfy this principle? Are motor-vehicle occupants suitable controls for pedestrians? Consider a case-control study of alcohol as a risk factor for injuries seen in emergency departments. Non-injured, medical cases are chosen as controls. One must expect that alcohol has some association with other conditions seen in the emergency department. The odds ratio in such a study may be biased toward the null (i.e. Berksons Bias). This is a problem in other areas of epidemiology as well, and one must consider the underlying cohort that gives rise to the case-control study [32] and guard against such phenomena as Berksons Bias.

The case-crossover design has been advocated as a possible solution to the problem of control selection in injury epidemiology. [33] Exposure is measured during a predefined risk period prior to the outcome and compared to a control period in the same individual. [34] A case essentially acts as his or her own control. This approach was used successfully in studying the risk of cell phone use for motor-vehicle crashes. [35]

3.3 Measurement

It has been said that every epidemiologic study is an exercise in measurement. [36] Injury epidemiology shares a difficulty with psychiatric epidemiology in that many of the risk factors are behavioral and difficult to objectively define and operationalize. But, there is a marked lack of the measurement studies that have characterized psychiatric epidemiology. Poor measurement can bias results, and inhibit the ability to control for confounders.

The lack of measurement instruments in injury epidemiology has been commented on, [33] and affects areas of assessment other than behavioral. The reliability and validity of data sources, such as police reports, have been questioned. [11] There has been some progress. Scales have been developed to measure the severity of injury. One such scale, the Injury Severity Score, is based on the sum of the square of the three most injured body parts as measured by a 1-5 scale. [37] It is linearly correlated with mortality. The use of novel measurement scales, such as quality-adjusted years of life has been proposed, but remain to be validated. [38]

Data sources are also problematic. While large amounts of information are available describing injuries and their related mortality patterns, few are in a form amenable to epidemiologic analysis. [39] For example, the National Highway Traffic and Safety Administration compiles considerably detailed nation-wide data on traffic fatalities as part of the Fatality Analysis Reporting System (FARS). The information, though, is listed in three separate data bases, one each for vehicle information, person-related variables, and environmental variables. An investigator interested in examining the relationship between vehicles and individual characteristics must find ways of reliably and validly linking the separate data bases. Another data base, the National Center for Health Statistics Multiple Cause of Death, (NCHS) identifies the anatomic injuries listed on the death certificate. In an encouraging development, an investigator was able to link FARS data with NCHS data for 85% of the cases. [40]

In addition to innovative approaches to identifying and linking existing data sources, injury epidemiology would benefit from the novel use of disease association measures such as standardized mortality ratios (SMR) [41] , common in occupational and environmental epidemiology but less commonly seen in injury epidemiology.

3.4 Causation

Robertson has called the analysis of injury causation a long cut to prevention because of inevitable industry defensiveness about the legal implications of causal attributions. [42] This can interfere with public health interventions to prevent injury.

Many injuries are the result of use (or misuse) of technology. To avoid legal liability manufacturers often cannot readily admit design flaws as the cause of injuries. They may, instead, point to individual behavior and demand that all user-related variables be accounted for before a firm causal inference can be made. But, no single study cannot control for every possible behavioral or other non-product related variable. Focus on the physics of energy exchange to guide engineering and legislation has been proposed as a way to prevent concerns about liability from interfering with prevention. [42] For example, requiring childproof caps may reduce poisonings, regardless of who is at fault.

Despite such difficulties, causal criteria, such as those described by AB Hill [43] may still be effectively applied to injury epidemiology. How strongly is the factor associated with the injury? How specific and consistent is this association? Can a dose-response gradient be demonstrated? Is it plausible? Questions such as these can help inform the debate and lead to interventions. The work of Rothman, as well as MacMahon and Pugh can lend some clarity to the confusion of multiple behavioral and technological causes. [44, 45]

It is telling that MacMahon and Pugh chose an injury as an example of the nature of causality:

The pedestrian struck by an automobile and dying with a ruptured spleen shortly after admission to hospital, is an example. The pathologist may ascribe the death to splenic rupture, the internist to shock, the surgeon to delay in diagnosis in the admitting room. The Registrar of Vital Statistics may be content to assign the death to Motor vehicle accident involving pedestrian. The highway engineer, in defending his next annual budget, may attribute the death to lack of adequate separation of pedestrian and vehicular traffic, while the engineer responsible for automobile design may count the case among those due to brake failure. [45]

One could add that the epidemiologist must play the role of pathologist, surgeon, internist, statistician and engineer to fully describe the cause of the injury. This view of multiple causes leads easily into Rothmans sufficient/component causal pies. Extending the example of a pedestrian injury, the automobile is a necessary cause and must be part of every sufficient cause. Splenic injury is a component cause of one sufficient cause. Automobile design is a component cause of a subset of sufficient causes. It is the task of the epidemiologist to describe as many sufficient causes as possible and calculate their attributable fractions.

While the role of inductive reasoning in epidemiology continues to be debated, injury epidemiology could also benefit from an appreciation of hypothesis-driven research and the value of refutation.

4 Injury Control

4.1 Control vs. Prevention

Primary prevention may not be the only means of addressing injuries. In a mechanized, technology-driven society mishaps and misadventures are endemic. Accidents do happen. The goal, as Haddon so clearly emphasized, should be to reduce the endpoint, not just prevent the event. [46] Even the most conscientious postal employee will occasionally drop a box; we are prescient in packaging it well. The severity of injury can be reduced without eliminating the incidence of injury. [47]

To guide control efforts, William Haddon developed a matrix categorizing the factors and phases involved in an injury occuring. [46] The factors are based on the well-known epidemiologic triangle of host, agent, and environment. [48] In cases of injury these factors are most often human, vehicle and environment. The phases refer to the time during which the injurious forces are marshaled: Pre-Event, Event, and Post-Event. A simple illustration of the Haddon Matrix for a motor-vehicle crash is presented in table 1 below.

Much useful insight into research and injury control can be gained from such a logical classification of injurious events. Most preventive efforts are limited to Pre-Event factors, ignoring the possible interventions at the Event and Post-Event phases. If one accepts, as Haddon did, that there is no reason to believe that crashes, fires, and drownings can be eliminated, then attention to control of the results of these events, must be guided by the holistic approach seen in this matrix.

A logical consequence of Haddons approach to classifying injury, was his prescription for 10 strategies to control injuries: [**?**]

These strategies can be fruitfully applied to almost any injury.

4.2 Behavior vs. Engineering

In the U.S. we live in a pluralistic society that emphasizes the rights and responsibilities of the individual. Our system of government sets up a tension between

Table 1: Approaches to Injury Prevention

Approach	**Example**
Prevent Creation of the Energy	do not manufacture dangerous vehicles
Reduce the Amount of Energy Created	allow sale of handguns only to police
Prevent the Release of the Energy	improve braking capacity of cars
Modify the Rate of Release of the Energy	reduce slope of ski trails
Separate in Time or Space the Energy from the Victim	use of sidewalks
Separate by Barrier the Energy from the Victim	use motorcycle helmets
Modify the Contact Surface	round sharp interior car surfaces
Strengthen the Structure or the Victim	reduce osteoporosis in elderly
Rapid Detection and Evaluation of Damage	improve EMS response time
Rehabilitation	occupational therapy

the individual and society. One controversy in the field of injury epidemiology is the role of education and behavior modification in preventing injuries (individual approaches) versus engineering and political (societal) solutions.

Some experts see little or no utility in behavioral approaches. Rivara writes that there is no evidence that programs focused on drivers have any benefit in controlling motor vehicle crashes, and that of recent declines in child pedestrian injuries littlecan be attributed to preventive efforts. [1] Robertson believes injury control measures should be simple, specific, and require little or no participation of the user. [16] Haddon felt that an emphasis on the individual results in blame being placed on the victim, and that the same approach to polio would still have us trying to change a childs behavior by keeping them out of pools. [5]

The role of safety education should not be quickly dismissed, though. One such program in Northern Manhattan documented a 35% reduction in severe traffic injuries, and a nearly 50% decline in severe assault injuries, in a community participating in multiple safety-education initiatives. [50, 51]

A more balanced approach is based on the idea of a hierarchy of control measures, the so-called 3 Es: Engineering, Enforcement and Education. Engineering approaches refer to simple, non-participatory measures such as reducing the carbon monoxide content of natural gas. Enforcement includes legislative and police actions aimed at changing behavior, such as helmet requirements for motorcyclists. Education is an attempt to persuade individuals to change their behavior through communication.

As in many public health interventions, the most successful approach may be the most balanced. William Haddon felt that any single measure is guaranteed to fail. [46] The so-called New York Model, which introduced the idea of the 3 Es, described the integration of engineering, enforcement and education. Engineering approaches are clearly effective, but may not be sufficient to prevent or reduce all or even most injuries. There must be role for education and enforcement in any comprehensive injury control effort. There is some consensus that educational efforts should concentrate on a single behavior or actions, rather than more diffuse approaches. [16] All efforts, though, should be guided by sound epidemiologic research.

5 Conclusion

Injury is an important cause of death and disability, and injury epidemiology deserves greater attention from public health and epidemiology. The descriptive epidemiology of injuries is largely based on mortality statistics and is well documented. Non-fatal injuries have not been as well documented because of difficulties in obtaining data. Motor-vehicles injuries predominate as a cause of injury with other leading causes such as fire-arm related injuries and falls contributing to the toll. There is a need for analytic studies of injury, with particular attention paid to measurement. Identification, evaluation and possible linkage of existing databases are viable options in study design. A focus on energy exchange can help guide research and identify controllable factors. Assessing causality, while important, should not stand in the way of a balanced approach to control that includes both education and engineering measures.

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