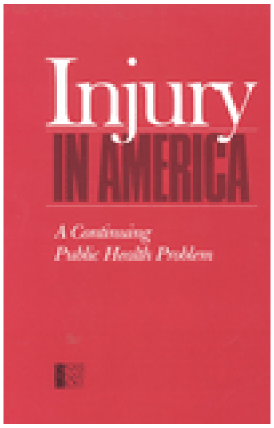

Injury in America: A Continuing Public Health Problem

Committee on Trauma Research, Institute of Medicine, National Research Council

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Injury In America

A Continuing Public Health Problem

Committee on Trauma Research
Commission on Life Sciences
National Research Council and the
Institute of Medicine

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NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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Preface

Throughout history, the two major causes of early death have been infectious disease and injury. For most of the world, they continue to be the major determinants of longevity. In the developed countries, inroads have been made in the battle against infectious disease, but injury, continues to take its toll—relentless, unexpected by those involved, and yet often avoidable and unnecessary.

Injury is the principal public health problem in America today; it affects primarily the young and will touch one of every three Americans this year. But injury is a problem that can be diminished considerably if adequate attention and support are directed to it. Exciting opportunities to understand and prevent injuries and to reduce their effects are at hand. The alternative is the continued loss of health and life to predictable, preventable, and modifiable injuries.

In 1966, a landmark National Research Council report, *Accidental Death and Disability: The Neglected Disease of Modern Society*, documented how little progress had been made in either explicating the scientific aspects of injury control or applying what was known. More than 2.5 million Americans have died from injuries since that report was issued.

In 1983, Congress enacted a law authorizing the secretary of the Department of Transportation to request a study on trauma (injury) by the National Academy of Sciences, to determine what is known about injury, what research should be done to learn more, and what arrangements the federal government could use to increase and improve the knowledge of injury. In response to that authorization, the Committee on Trauma Research, in the National Research Council's Commission on Life Sciences, was established in collaboration with the Institute of Medicine. This report, the result of the committee's deliberations, reviews the progress that has been made in injury control in recent years and identifies future research needs.

The committee believes that injury is a public health problem whose toll is unacceptable. The time has come for the nation to address this problem — a problem that affects all Americans and one on which an investment in research could yield an unprecedented public health return.

WILLIAM H. FOEGE

CHAIRMAN

Acknowledgments

The following colleagues in both the public and private sectors generously shared information, resource material, and expertise: Eula Bingham, Emilie Black, Gregory. Dahlberg, Erich Daub, Rolf Eppinger, James Fletcher, Michael Finkelstein, Charles Miller, Thomas Morris, Stephen Nelson, Gary Noble, Ayub Ommaya, David Rail, Lawrence Rose, Bernard Schriever, Gordon Smith, Michael Stoto, Stephen Teret, and Donald Trunkey.

The committee notes with regret the passing of William Haddon, a pioneer in the field of injury control with long-time interest in the subject of this report.

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Executive Summary

Injuries are the leading cause of death and disability in children and young adults. They destroy the health, lives, and livelihoods of millions of people, yet they receive scant attention, compared with diseases and other hazards.

- Each year, more than 140,000 Americans die from injuries, and one person in three suffers a nonfatal injury.
- Injury is the last major plague of the young. Injuries kill more Americans aged 1-34 than all diseases combined, and they are the leading cause of death up to the age of 44.
- Injuries cause the loss of more working years of life than all forms of cancer and heart disease 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.
- Injuries constitute one of our most expensive health problems, costing $75-$100 billion a year directly and indirectly, but research on injury receives less than 2 cents out of every federal dollar for research on health problems.

Injury is not an insoluble problem. Exciting opportunities to understand and prevent injuries and reduce their effects are available. By taking advantage of such opportunities, we can save or improve the lives of countless Americans who otherwise will die or become disabled because of injury.

The committee found serious, but remediable, inadequacies in the understanding of and approach to injury as a health problem.

- Injury has traditionally been regarded primarily as an unavoidable accident or a behavioral problem, rather than a health problem.
- No central agency has responsibility for reducing the incidence of injuries.
- Injury control, including research, has not been given high priority.
- Reducing injuries requires coordinated effort among specialists in epidemiology, prevention, biomechanics, treatment, and rehabilitation; trained manpower is inadequate.
- Funding for injury control is disproportionately low and discontinuous, in comparison with that for cancer, heart disease, and other major health problems. Without funding continuity, centers of excellence in injury research and care cannot survive and grow.
- Funding is not only inadequate, but widely and unevenly distributed; some crucial subjects, such as biomechanics, receive scant attention.

The result of those inadequacies is that research efforts in injury are unfocused, lack continuity, and are undersupported. Many gaps exist in efforts to prevent and treat injury and deal with its aftermath.

- Almost no current research deals with the mechanisms and prevention of injury from falls (the leading cause of nonfatal injury) and many other important injury-related causes of death, such as injuries associated with farm machinery and light aircraft.
- The causes and circumstances—and even the numbers—of assaultive injuries are not known.
- Injury-prevention measures have been poorly implemented, and the effectiveness of many such measures has not been evaluated.
- Knowledge of the tissue-injury thresholds of children, women, and middle-aged and elderly men is sparse.
- Little is known of the mechanism of functional damage to the brain and spinal cord.

The committee found one recurrent theme in its examination of the current research effort on injury—the lack of a single coordinated focus of activity that would give visibility to this important public health issue and permit an organized program of effective action to address the problems.

The committee recommends the establishment of a center for injury control within the federal government. The Centers for Disease Control of the Department of Health and Human Services is recommended as the location for that center.

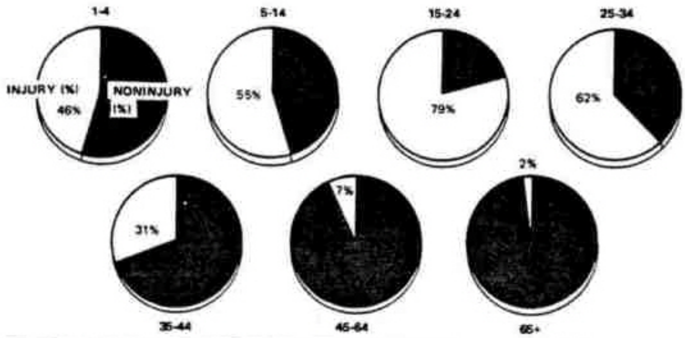
The second overriding problem the committee has identified is the lack of financial support for research on injury. The committee recognizes that competition for available dollars is already severe in this time of financial constraint, but contends that research on injury has been undersupported historically and that vast sums could be saved by a relatively small investment in this field.

The committee recommends that funding for research on injury be commensurate with the importance of injury as the largest cause of death and disability of children and young adults in the United States.

Chapter 1 of this report introduces the subject by defining and describing injury and the magnitude of the injury problem. Chapters 2 through 6 describe the state of knowledge of various facets of the injury problem and identify the kinds of research that are required. Chapters 7 and 8 deal with the research funding and organizational arrangements for research and training related to injury. Appendix A contains some examples of the general research problems associated with injury control and the committee's recommendations for addressing them, and Appendix B contains brief biographies on the committee members.

INJURY: MAGNITUDE AND CHARACTERISTICS OF THE PROBLEM

Injury is caused by acute exposure to energy, such as heat, electricity, or the kinetic energy of a crash, fall, or bullet. It may also be caused by the sudden absence of essentials, such as heat or oxygen, as in the case of drowning. Injury may be either unintentional (accidental) or deliberate (assaultive or suicidal).



Age	Injuries	Congenital Anomalies	Cancer	Pneumonia/ Influenza	Heart Disease	Liver Disease	Stroke	Other
1-4	46%	13%	7%	3%	4%	–	–	27%
5-14	55%	5%	14%	–	3%	–	–	23%
15-24	79%	–	5%	–	3%	–	–	13%
25-34	62%	–	10%	–	6%	3%	–	19%
35-44	31%	–	21%	–	20%	6%	4%	18%
45-64	7%	–	32%	–	36%	4%	5%	16%
65+	2%	–	19%	3%	48%	–	10%	18%

Figure 1
Percentages of deaths from injury and other causes in the United States in 1980, by age. Modified from Baker, S. P., B. O'Neill, and R. Karpf. The Injury Fact Book (Lexington, Mass.: Lexington Books, 1984).

Each year, more than 140,000 Americans die from injuries and 70 million sustain nonfatal injuries. Injury causes almost half the deaths of children aged 1-4, more than half the deaths of children aged 5-14, and nearly four-fifths of the deaths of persons aged 15-24 (Figure 1). Thus, injury is the leading cause of death among children.

As infectious diseases have come under control during the last century, the relative importance of injury has increased to the point where it is now the most prominent cause of death for more than half the human lifespan (ages 1-44). For more than three decades of life (ages 1-34), motor-vehicle crash injuries alone are the leading cause of death. For all ages *combined*, the injury death rate is surpassed only by the rates for heart disease, cancer, and stroke.

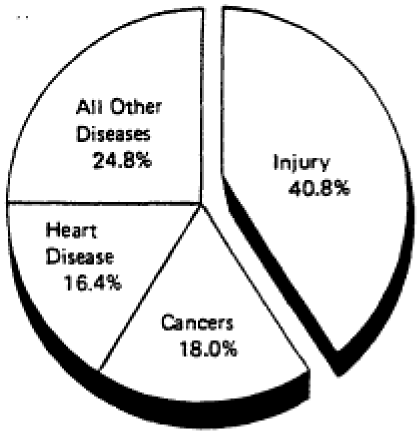


Figure 2
Percentages of years of potential life lost to injury, cancer, heart disease, and other diseases before age 65. Modified from Centers for Disease Control. Table V. Morb. Mort. Weekly Rep. 31:599, 1982.

Injury greatly surpasses all major disease groups as a cause of prematurely lost years of life, because it is the preeminent cause of death among children and young adults. More years of future worklife are lost to injury than to heart disease and cancer combined. Each year, over 4 million years of future worklife are lost to injury, compared with 2.1 million to heart disease and 1.7 million to cancer (Figure 2). The impact of nonfatal injury is of similar proportions.

Injury is the leading cause of physician contacts. It is the most common cause of hospitalization among people less than 45 years old. The personal, family, and societal costs of mental and physical disability and disfigurement are huge.

Although injury is the most costly of all major health problems (about $75-$100 billion per year), support for injury research has been minimal. The total annual expenditure for injury-related research by the National Institutes of Health (NIH), about $34 million, is less than 2 percent of the NIH research budget. The total expenditure by all nonmilitary federal agencies is about $112 million—less than $2 for every $1,000 of the cost of injuries themselves.

EPIDEMIOLOGY OF INJURY: THE NEED FOR MORE ADEQUATE DATA

A prerequisite for the scientific study of injury is the acquisition of data on which to base priorities and research. Despite the obvious importance of injury as a public health problem, information to permit the study of the epidemiology of most injuries is not available. Although there are basic data on time, place, and person for some injuries and deaths, even basic information is often lacking as to the numbers and characteristics of people injured and the factors that influence injury causation, especially in nonfatal events. Detailed information on the groups that are particularly susceptible to injuries and their effects is not adequate. Injuries from motor-vehicle crashes constitute the only exception to this limitation. The incidence, prevalence, and effects of motor-vehicle injuries, as well as measures to counter them, are moderately well understood, compared with the epidemiology of other injuries, although even here information about long-term effects is sparse. The acquisition of knowledge about motor-vehicle injuries is a direct result of the funding of research on injury epidemiology from two sources whose primary mandate is the study of automobile injuries—the National. Highway Traffic Safety Administration and the Insurance Institute for Highway Safety. Little funding has been available for research into the epidemiology of other injuries; consequently, our knowledge of these other injuries is slight.

Continuous, systematic data collection is essential for planning and evaluating preventive programs. The lack of appropriate data systems has led to the institution of some expensive but ineffective preventive programs.

Recommendations

- The United States requires effective injury surveillance systems for gathering and integrating information from a variety of sources on which to base the planning and evaluation of control efforts. This would include long-term longitudinal studies of injuries and the collection of more refined data on specific types and causes of injuries and exposures to injurious environments.

- A national capacity should be developed for the quick identification and control of outbreaks of specific injuries.
- A consistent and accurate system for coding the causes of injuries needs to be used by hospitals.
- More refined data on the specific types and causes of injuries are needed to develop effective interventions
- Research is needed to determine the short- and long-term costs of injuries.

PREVENTION OF INJURY

Injuries can be prevented with a variety of strategies. The effectiveness of these strategies varies inversely with the extra effort required to keep people from being harmed and the degree to which people must change their usual behavior patterns.

Three general strategies are available to prevent injuries:

- Persuade persons at risk of injury to alter their behavior for increased self-protection—for example, to use seatbelts or install smoke detectors.
- Require individual behavior change by law or administrative rule—for example, by laws requiring seatbelt use or requiring the installation of smoke detectors in all new buildings.
- Provide automatic protection by product and environmental design—for example, by the installation of seatbelts that automatically encompass occupants of motor vehicles or built-in sprinkler systems that automatically extinguish fires.

Each of these general strategies has a role in any comprehensive injury-control program; however, a basic finding from research is that the second strategy— requiring behavior change—will generally be more effective than the first, and that the third—providing automatic protection—will be the most effective. A fundamental reason for this is that members of high-risk groups tend to be the hardest to influence with approaches that involve either voluntary or mandated changes in individual behavior. Teenagers, for example, are much less likely than adults to wear seatbelts, whether or not a law requires them to do so. Programs intended to change alcohol-related behavior voluntarily have not produced sustained reductions in death rates. Elderly pedestrians admonished by police for jaywalking were no less likely to do it again. Scofflaw drivers whose licenses had been revoked were more likely than the average licensed driver to be involved in fatal crashes. And not only are young children hard to influence, but intensive efforts at a well-baby clinic, for example, had no effect on dangerous maternal behavior, such as leaving knives and matches within the reach of small children.

The shortage of health professionals and scientists with relevant training is a major impediment to injury control. Without knowledgeable and interested persons trained in the relevant sciences, the injury toll will continue ·

Recommendations

- Education, training, and information programs intended to control injuries should be evaluated experimentally.
- Laws and regulations aimed at controlling injuries should be scientifically evaluated. The separate influences of degree of enforcement, severity of punishment, and speed of administration of punishment should also be researched.
- Continuing research is needed on efficacy of product designs and environmental modifications in protecting people effectively and automatically.
- Research is needed to understand the barriers to implementing existing effective injury-control measures that are not widely applied.
- Research is needed in the prevention of injuries in the recreational, occupational, and home environments.
- Training health professionals and other scientists in injury research and the basic concepts of injury control is crucial, if we are to develop and apply new knowledge about the prevention of injury.

INJURY BIOMECHANICS RESEARCH AND THE PREVENTION OF IMPACT INJURY

Impact injury of the human body occurs by deformation of tissues beyond their failure limits, which results in damage of anatomic structures or alteration in normal function. Injury biomechanics research uses the principles of mechanics to explore the mechanisms of physical and physiologic responses to impact, including both penetrating and nonpenetrating blows to the body. Although injury can occur by slow deformation, in crushing, the predominant feature of impact injury is the fast, violent nature of the event, whether it is the rapid impact of a person's chest on the instrument panel of an automobile or a bullet's penetration of the chest cavity.

Improved protection could be realized with a better understanding of the biomechanics of injury and disability. Design of less injurious environments depends partly on knowledge of the effects of specific kinds and amounts of energy on specific human tissues. Although we know the approximate limits of forces that can be tolerated by young healthy males in rapid deceleration, we do not have refined data on other elements of the population, on the extent of reversibility of damage, or on effects on nervous tissues or tissues outside particular size and structural ranges.

Recommendations

- High priority should be given to research that can provide a clearer understanding of injury mechanisms. Crucial subjects are the relative contributions of linear and angular acceleration of the head to deformation and injury of the brain and the body deformations that cause injury of the spinal cord, thoracic and abdominal viscera, and the joints.
- Quantification of the injury-related responses of critical body areas—nervous system, thoracic and abdominal viscera, joints, and muscles—to mechanical forces is needed.
- High priority should be given to obtaining and defining limits of human tolerance to injury, particularly with regard to segments of the population on which data are extremely limited, including children, women, and the aged; both whole-body and regional tolerances; the effect of human and environmental variables on tolerance; long-term effects of impact deceleration on the body; and survival of extreme impact.
- Improvement in injury assessment technology is needed, including development of means for assessing the important debilitating injuries and causes of fatality,

improvement of anthropomorphic dummies, and development of computer models to predict injury in complex crash conditions.

- There is a need for an organization to administer research on injury mechanisms and injury biomechanics and ensure a supply of scientists trained in injury biomechanics.

TREATMENT

Except when death occurs immediately, the outcome of an injury depends not only on its severity, but also on the speed and appropriateness of treatment. Communication systems are needed to facilitate decision making, injury management at the site, and the rapid delivery of the patient to a hospital *that* can provide the needed care.

Once a severely injured person arrives at a hospital, treatment requires the effort of a team *that* includes specialists in various aspects of injury management. Designated trauma centers with experienced teams available and necessary backup facilities, such as well-stocked blood banks, are essential. In addition to the develop*ment* and evaluation of such systems, there is a need to ensure that patients treated in hospitals other than trauma centers receive the most up-to-date care, so that unnecessary morbidity, mortality, and residual disability are avoided.

The most important topic to be addressed with regard to treatment is control of swelling of the brain; improvements could substantially reduce injury mortality. Understanding of the immune system and prevention and control of infection also warrant high priority as does control of spinal cord swelling and research in spinal cord regeneration.

Recommendations

- Long-term collaborative studies should be instituted by epidemiologists, statisticians, biomedical engineers, trauma physicians, rehabilitation physicians, behavioral scientists, and health economists, to identify and evaluate factors that produce optimal results, to identify factors that result in less than optimal results, and to institute programs for promulgating optimal management techniques.

- Programs in basic research should be instituted and supported, in collaboration with morphologists, biochemists, membrane physiologists, pharmacologists, neurobiologists, bacteriologists, virologists, and others, to study shock, infection, tissue responses and healing, and brain and spinal cord swelling.
- Biomedical and biomechanical programs should be instituted and supported in relation to injury mechanism and prevention and the development and evaluation of biomedical materials, including prostheses and artificial organs.
- Clinical studies should be instituted and supported in development and evaluation of pharmacologic options, of surgical techniques, and of management options.
- Programs designed to train professionals in the research and care of injury should be instituted and supported.

REHABILITATION

Rehabilitation is the process by which physical, sensory, and mental functional capacities are restored or developed after damage. In the context of injury control, rehabilitation is the process by which biologic, psychologic, and social functions are restored or developed to permit an injured person to achieve maximal personal autonomy and an independent noninstitutional lifestyle. Rehabilitation is achieved not only through functional change in the person (e.g., development of compensatory muscular strength, use of prosthetic limbs, and treatment of postinjury behavioral disturbances), but also through changes in the physical and social environment, such as reductions in architectural and attitudinal barriers that hamper those requiring use of a wheelchair.

In the last decade, improvements in emergency medical systems, in immediate management by trauma centers, and in care of the injured en route to hospitals have increased the survival of persons with nervous system injuries, multiple injuries of the musculoskeletal system and viscera, or extensive burns. Trauma units have increased the need for defined referral to special rehabilitation programs and follow-up services. More persons survive major injuries, and survivors often have severely disabling effects from the injuries themselves and from uncreated complications. Many need functional restoration of cognition, sensation, movement control, and mobility after brain, spinal cord, and musculoskeletal injury. Further negative effects on health and performance in daily life that result from the loss of body parts and from inactivity and immobility must be prevented.

Preventable disability is not an uncommon consequence of inadequate management of the injury patient—for example, limitation of motion due to contracture in burned patients or paralysis in patients with unrecognized injury of cervical vertebrae. Pressure sores, or "bedsores," are an entirely preventable complication that occurs in 35-40 percent of persons with spinal cord injury, at an average cost of $25,000-$28,000 per pressure sore, inestimable misery, and increased debilitation.

With comprehensive care, the profound biologic, psychologic, and social responses to paralysis and movement disorders, disfigurement, and loss of body parts are controllable to a remarkable extent. Although limited resources for clinical programs have been provided through private and publicly supported efforts, parallel research and educational resources for the development and dissemination of knowledge and technology have been seriously inadequate. The development of expanded special regional centers and programs has been lacking for the large number of unserved persons who could benefit.

Recommendations

- Major research centers should be developed for clinical neurophysiology programs on evaluation and management of neural injury residua, neural system function, and technologic replacement of lost function.
- Funding priority should be given to research on the identification and preservation of residual functions, development of substitute functions, psychosocial management of the patient and family, and deinstitutionalization.
- Research programs aimed at minimizing the effects of injury to the musculoskeletal system, including both bone and soft tissue, that result from physical, chemical, and thermal causes should be promoted.
- Research programs should be established in the behavioral and social sciences for cross-disciplinary

studies of adaptive behavior and its relationship to brain function in environmental adjustment and learning.

- Wider application of existing knowledge related to rehabilitation and prevention of second injury is needed.
- Development and evaluation of model systems of rehabilitation should be promoted.
- Research should be greatly expanded on behavioral and social factors related to stigmatization of and discrimination against the disabled.
- A system is needed that can identify disabled persons and persons with injuries that are likely to produce severe disability, so that services for those who might benefit can be planned. Linked local, regional, and national reporting systems for the disabled are necessary to go beyond social security studies limited to work disability; these systems could be built into the surveillance systems recommended in Chapter 2.

CURRENT FEDERAL EXPENDITURES FOR INJURY-RELATED RESEARCH

To assess federal support for injury-related research, the committee reviewed federal research expenditures for fiscal 1983.

The total federal expenditures for nonmilitary research on injury were approximately $112 million in fiscal 1983. Expenditures in 1 year are more relevant when compared with other expenditures in the same year. For example, although injury research in fiscal 1983 accounted for approximately $34.4 million of expenditures at the National Institutes of Health (NIH), that was less than 2 percent of the total NIH research budget. Although injuries are responsible for the loss of more economically productive years of life than heart disease and cancer combined, the federal expenditure for research in injury control is relatively small—approximately one-tenth of that for cancer and less than one-fifth of that for heart disease and stroke (Figure 3). Thus, when one compares the relative research expenditures and the years of life lost to these causes of death before age 65, it is apparent that the smallest portion of the funds is being allocated to the largest problem—injury.

The committee believes that substantial decreases in current injury rates would result from research requiring substantially less support than is now expended on cancer

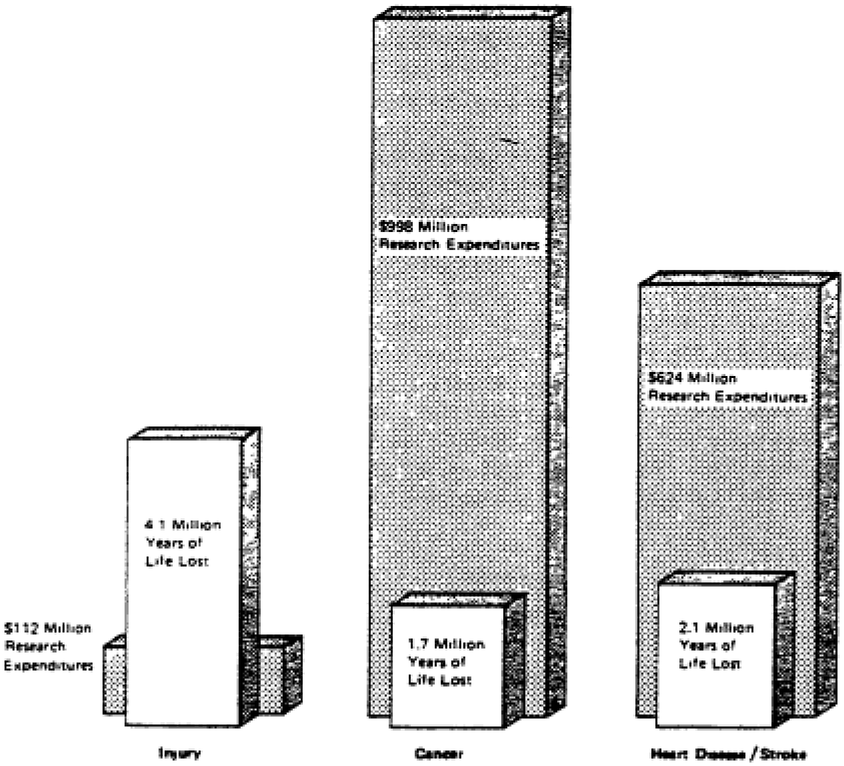


Figure 3
Preretirement years of life lost annually and federal research expenditures for major causes of death in the United States. Years of life lost derived from age-at-death distributions in the National Center for Health Statistics Vital Statistics of the United States, 1978, Volume II. Mortality (Hyattsville, Md.: U.S. Department of Health and Human Services, 1981). The total federal expenditure for injury research is the sum of the amounts discussed in Chapter 7 plus a 5 percent increment for administration, the latter in line with NIH administration costs. Expenditures for research on neoplasms and cardiovascular diseases are the 1983 fiscal year budgets of the National Cancer Institute and the National Heart, Lung, and Blood Institute from the Institute of Medicine's Response to Health Needs and Scientific Opportunity: The Organizational Structure of the National Institutes of Health (Washington, D.C.: National Academy Press, 1984).

and cardiovascular disease. An increment in current funding with close monitoring of the application of the research results could illustrate the investment value of such expenditures for the entire population.

The committee does not advocate a reduction in federal expenditures for health research in cancer or heart disease and stroke. It does feel, however, that federal expenditures for injury research and injury control are seriously inadequate. The committee believes that substantial progress could be made in the reduction of the incidence of injury and its associated morbidity and mortality if adequate funding, direction, and support were given to a coordinated federal program of injury research.

ADMINISTRATION OF INJURY RESEARCH

The committee discussed the advantages and disadvantages of various models for managing injury research in the federal government. Criteria were established for a unit that could effectively manage a large-scale federal program in injury research, and the selected models were compared for suitability. After consideration of the various alternatives, the committee recommended the establishment of a new "Center for Injury Control" (CIC) in the Centers for Disease Control (CDC). The function of the Center for Injury Control would be to carry out a national injury research program in the following manner:

- Support research in biomechanics, injury epidemiology and prevention, acute care, and rehabilitation.
- Establish injury surveillance systems and conduct injury prevention projects.
- Improve and expand professional education and training.
- Establish centers of excellence in injury biomechanics, prevention, and care.
- Collect and analyze data on injury.
- Serve as a clearinghouse and lead agency among federal agencies and private organizations interested in injury research and prevention.

The structure of CIC is visualized along the lines of the diagram in Figure 4. Divisions dedicated to the major sectors of needed research—epidemiology, prevention, biomechanics, acute care, and rehabilitation—would be coordinated by a director. The CIC director would report administratively to CDC and would convene an advisory council consisting of representatives of federal agencies and other organizations engaged in injury research.

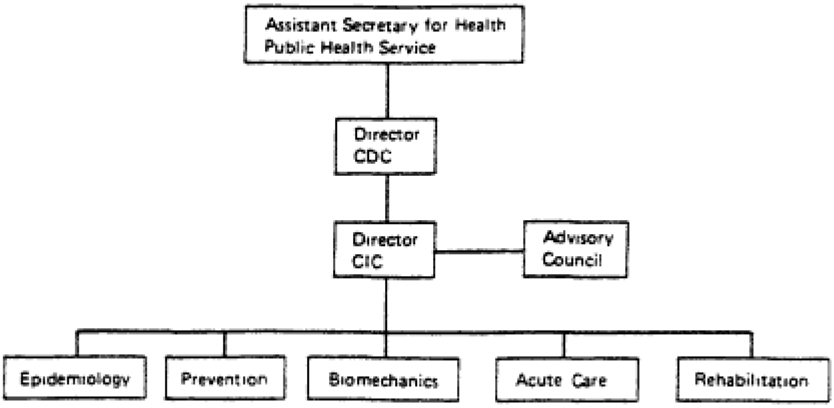


Figure 4
Suggested location and organizational structure of proposed center for injury control.

The CIC director and staff would review priorities, establish specific research goals, identify scientists capable of implementing the research, and coordinate peer review. It is imperative that all appropriate disciplines be represented and that the CIC director be a scientist with recognized research accomplishments and successful experience in interdisciplinary investigations of injury. No single discipline or disciplinary orientation can produce the broad spectrum of research needed for injury control.

Clearinghouse and coordinating functions in CIC are essential, although the injury research problem is much more than a matter of insufficient coordination.

CIC should foster and support research directed to filling the knowledge gaps that inhibit the control of injury. To do this, it should contain special study sections and a granting mechanism in each that would provide for continued, rather than year-by-year, funding of research projects. Funding should cover demonstration programs, multiple centers of excellence, and training of researchers in appropriate fields. CIC funds should supplement, rather than replace, funds currently allocated to other agencies, such as the Department of Transporta tion (DOT), the Department of Defense (DOD), and NIH; and their funding related to injury research should not be channeled through CIC.

The director and the advisory council should be charged with the development of an annual plan and report to Congress—an approach similar to that followed by the National Toxicology Program. This administrative mechanism would encourage the CIC director and representatives of other agencies to consider the scope of what is being done, in view of the various agency mandates, and to avoid inappropriate duplication of effort.

An independent review of CIC should be conducted within 5 years of its establishment to assess its progress in accomplishing the objectives recommended in this report. At that time, consideration should also be given to the elevation of this center to independent agency status.

Injury is the major health problem facing young Americans today. The opportunity exists to create a focused, coordinated research effort with the potential to save lives, improve productivity, and reduce costs and long-term losses to the injured, their families, and society. The alternative is the continued loss of health and life to predictable, preventable, or modifiable injuries. The committee firmly believes that it is time to plan and undertake a national program to address this problem.

1

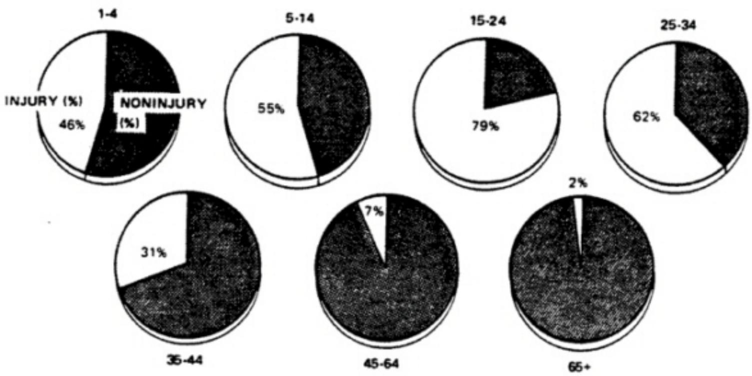
Injury: Magnitude and Characteristics of the Problem

Two types of health problems—infectious disease and injury—have been the most important causes of lost years of productive life for Americans. Improvements in sanitation and housing and other public health measures in the nineteenth century made it possible to reduce the prevalence of infectious disease. In the early twentieth century, infectious disease ceased to be a major cause of lost years of life before age 65, leaving injury alone in that position in the United States, exceeding cancer and heart disease combined. This report deals with injury that is severe enough to cause one to seek medical care or to be unable to perform usual activity for a day or longer. Such injury strikes almost one-third of Americans in a given year.[123]

Consider some of the primary facts concerning injury in the United States:

- Injury caused 143,000 deaths in 1983.[124]
- Injury is the fourth leading cause of death among all Americans, accounting for 61 deaths per 100,000 population in 1983, compared with 328 for heart disease, 188 for cancer, and 67 for stroke.[124]
- Injury causes almost half the deaths of children aged 1-4, more than half the deaths of children aged 5-14, and nearly four-fifths of the deaths of persons aged 15-24. Thus, injury is the leading cause of death among children and young adults (Figure 1-1).

Among young children, the largest numbers of injury deaths are caused by motor-vehicle crashes, drowning, and fire; pedestrian deaths constitute a major problem in urban areas.[12] Especially high death rates among teen agers and young adults ate associated with motor-vehicle crashes, firearms, and drowning.



Age	Injuries	Congenital Anomalies	Cancer	Pneumonia/ Influenza	Heart Disease	Liver Disease	Stroke	Other
1-4	46%	13%	7%	3%	4%	–	–	27%
5-14	55%	5%	14%	–	3%	–	–	23%
15-24	79%	–	5%	–	3%	–	–	13%
25-34	62%	–	10%	–	6%	3%	–	19%
35-44	31%	–	21%	–	20%	6%	4%	18%
45-64	7%	–	32%	–	36%	4%	5%	16%
65+	2%	–	19%	3%	48%	–	10%	18%

Figure 1-1
Percentages of deaths from injury and other causes in the United States in 1980, by age. Modified from Baker et al.[14]

Up to age 44, injury deaths continue to outnumber deaths from any other cause. Only after age 45 do other health problems—notably heart disease and cancer—cause more deaths than injuries. Even among the elderly, however, injury is an important cause of death; in fact, the death rate from injury (the number of injury deaths per 100,000 of population) is higher among the elderly than among younger people.

Injury is the leading cause of physician contacts—in 1980, there were 99 million such contacts, compared with 72 million for heart disease, the second leading cause of such visits, and 64 million for respiratory disease, the third leading cause.[125] And more than 25 percent of hospital emergency-room visits are for the treatment of injuries.[125]

Injury is also a leading cause of short- and long-term disability. In 1981, people spent 144 million days in bed because of injuries.[1] [2] [3] With respect to long-term disability, more than 75,000 Americans each year sustain brain injuries that result in long-term disability, including 2,000 who remain in persistent vegetative states.[98] [99] In addition, over 6,000 persons who were injured are discharged from hospitals with paraplegia or quadriplegia.[100] Each year, over 4 million years of future worklife are lost to injury, compared with 2.1 million to heart disease and 1.7 million to cancer[32] (Figure 1-2).

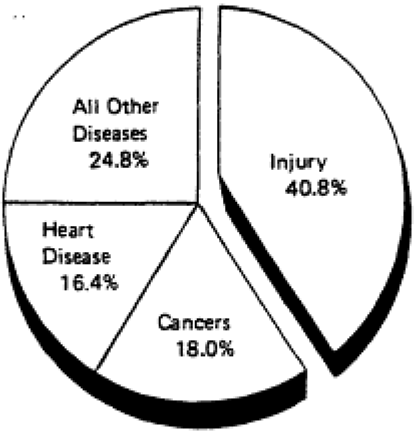


Figure 1-2
Percentages of years of potential life lost to injury, cancer, heart disease, and other diseases before age 65. Modified from Centers for Disease Control.[32]

The importance of health problems to society can be seen by measuring the dollar costs of their effects, such as lost productivity (indirect costs to society) and the use of medical and other resources (direct costs to society). The societal costs of <u>all</u> injuries occurring in a given year have not been computed, but the costs of the largest class of severe injuries—those resulting from motor-vehicle crashes—have been estimated:

- Motor-vehicle crash injuries in 1980 were estimated to cost society over $36 billion.[110]
- Injuries resulting from motor-vehicle crashes cost the federal government about $7.5 billion and state governments about $3.5 billion in direct payments and revenue loss in 1980.[130]

- The societal costs of motor-vehicle crash injuries are second only to those of cancer, among the other leading causes of death.[79]
- The direct costs resulting from motor-vehicle crash injuries are approximately twice those resulting from heart disease.[79]
- The indirect costs of motor-vehicle crash injuries are especially high, because the average age at which injuries occur is much lower than the average ages at initial onset of the other leading causes of death.[79]

Motor-vehicle crashes are the leading cause of severe injury and death and have been studied in more detail than most other injury causes. Although police reports generally understate the magnitude of the problem,[15] consider the following statistics on motor-vehicle crashes: Approximately 3.2 million people were injured in motor-vehicle crashes in 1982.[132] Of these, approximately 1.4 million were treated in emergency rooms and 350,000 were hospitalized.[132] In 1982, over 50,000 person-years of work (not counting housewives, students, and others who are not classified as part of the work force) were lost by injured persons.[132]

Given that the total number of injury-related deaths per year is about 3 times the number resulting from motor-vehicle crashes, and that the total number of nonfatal injuries is more than 10 times the number resulting from motor-vehicle crashes, a conservative estimate of the societal costs of all injuries in 1980 is approximately $75-$100 billion (in 1980 dollars).

The dollar costs of injury, as large as they are, account for only a portion of the total costs. Additional, less easily measured costs include pain, grief, family and social disruption, and the social and psychologic effects of disfigurement and long-term disability, such as those caused by severe burns, epilepsy from head injury, limitations of mobility from spinal cord injury, amputations, traumatic arthritis, and severe reduction in mental function from head injury.

Injury and death result not only from unintentional events, such as motor-vehicle crashes and falls, but also from deliberate events, such as assault and suicide. It is Common to think of injuries as different from disease because they occur suddenly—in a few milliseconds or a few minutes—but that is not always the case. The cause of injury to the human body is excessive exposure to energy (kinetic, thermal, and chemical energy, electricity, and radiation) or the absence of essentials, such as oxygen and heat. The five forms of energy that cause injuries are termed agents of injury. Typically, injuries result from short-term exposure to large amounts of energy (e.g., involvement in a car crash, contact with a hot stove, or ingestion of an overdose of aspirin). However, injuries can also result from repeated exposure to smaller amounts of energy (e.g., deafness resulting from prolonged exposure to excessive noise or back pain or arthritis in a worker exposed to repeated vibration) or from a combination of acute and chronic exposure (as in the greater sensitivity to head injury in a football player or boxer who has previously had head injury or to acute back injury in a worker who has had back trouble).

Kinetic or mechanical energy (e.g., from motor vehicles and firearms and in falls, jumps, and cutting) is by far the leading cause of injury-related death in the United States and accounts for more than 95,000 deaths a year (Table 1-1). Asphyxiation (drowning, suffocation, hanging, and strangulation) causes over 13,000 deaths, chemical energy (poisoning by solids, liquids, and motor-vehicle carbon monoxide) approximately 10,000, and fires and burns about 6,000. Deaths from electricity make up only a small percentage of all injury deaths (about 1,000 a year). Deaths from radiation are extremely rare. Mechanical energy is also the leading cause of nonfatal injuries, although the relative importance of specific causes differs somewhat from the relative importance of causes of fatal injuries. For example, falls are the second leading cause of death from unintentional injury, but the leading cause of injuries treated in hospital emergency rooms.

Even though they are important, with many of the characteristics of injuries, health problems resulting from chronic exposure to injury agents will not be addressed in this report. Rather, it focuses on acute injuries and death associated with transportation, the workplace, the home, and recreational and public environments and on assaultive and self-inflicted injuries.

There are many misconceptions about the causes and control of injury. An event that produces injury is often thought of as an isolated occurrence with a single cause, and prevention of that single cause as the only, or best, solution to the problem. Note, for example, the common oversimplification in a report that someone died in a highway crash because the driver was drunk. The associated perception often is of a fatal injury attributable to a single cause—in this case, the misuse of

TABLE 1-1 Major Categories of Injury Deaths in 1982 in the United States[a]

Injury Category	Unintentional	Suicide	Homicide	Undetermined	Total
Motor vehicles (traffic)	44,713	57	[b]	16	44,786
Firearms	1,756	16,575	14,117[c]	540	32,988
Falls and Jumps	12,077	797	12	127	13,013
Drowning	6,351	530	85	387	7,353
Poisoning by solids or liquids	3,474	2,943	22	787	7,226
Fires and burns	5,354[d]	147	242	151	5,904
Suffocation, hanging, and strangulation	881	4,061	977	81	6,000
Cutting	118	409	4,365	36	4,928
Poisoning by motor-vehicle carbon monoxide	596	2,032	[b]	163	2,791
Other	18,752	691	2,528	924	22,895
TOTAL	94,082	28,242	22,348	3,212	147,884

[a] Data from National Center for Health Statistics (personal communication).
[b] Not separately identified in mortality statistics.
[c] Includes 276 firearm deaths termed "legal intervention."
[d] Includes 4,200 deaths from housefires, primarily attributable to carbon monoxide poisoning, rather than burns.
[e] Includes about 2,600 deaths from surgical and medical complications and misadventures, 1,700 from airplane crashes, 1,400 deaths from machinery, 1,100 deaths from nontraffic motor-vehicle crashes, 1,000 electrocutions, and 1,000 deaths caused by failing objects.

alcoholic beverages. That leads to the misperception that such deaths could be prevented by eliminating excessive alcoholic beverage consumption by drivers or by separating such drinkers from their vehicles. In fact, many ways of preventing or limiting such deaths are possible.

Over the last 2 decades, useful ways have been developed for systematically considering the potential to produce injury, and those ways lead to options for preventing or reducing injuries. In one such approach, presented by Haddon,[73] an event that could result in injury is considered to have three phases—the pre-event, event, and post-event phases. The pre-event phase covers the period during which people use or are otherwise exposed to a source of energy before a potentially injurious event occurs. The event phase begins once the energy source is out of control. The post-event phase begins after acute exposure to the energy. Each phase presents opportunities for intervention to reduce the likelihood or severity of injury, if one systematically considers interactions of each of the three phases with various entities, such as vehicles, humans, and the environment. This report examines the status of and needs for research in all three phases of injury-producing events that will permit development of effective injury-control measures.

The medical treatment of injury has a long history. Descriptions of treatments of 48 cases of head and foot injuries appear on papyrus dating to approximately 1600 B.C. In approximately 500 B.C., Hippocrates studied wounds and fractures and suggested mechanisms of injury and methods of treatment. Most early physicians spent much time managing wounds that occurred in civilian life and in warfare. Although treating injuries and wounds has occupied the primary attention of physicians since the beginnings of scientific medicine, coordinated research in the treatment of injury has been generally lacking.

Injury control, encompassing activities from prevention through treatment and rehabilitation, is relatively young—in many ways still in its infancy. Newtonian laws of motion have been known for some 300 years, but biomechanical concepts of injury were not developed until this century, and it was not until World War II that biomechanics research was systematized. There is now a growing body of scientific literature and research on injury control, but substantially more needed research can be identified than can be supported by the limited resources available today.

2

Epidemiology of Injuries: the Need for More Adequate Data

Epidemiology is the fundamental science for studying the occurrence, causes, and prevention of disease. Injury epidemiology is a young scientific field with a theoretical basis within the wider framework of epidemiology.[72 76 77 163] This new discipline has focused on the development of epidemiologic tools to identify problems, define their extent, and determine causative factors that are amenable to intervention. An equally important objective has been to develop evaluation methods to determine the effectiveness of countermeasures.[27 77 207]

Epidemiologic studies of injury should not exist in isolation, but must be able to draw ideas and methods from clinical, laboratory, and biomechanical research, just as these other forms of research need to draw from epidemiology. Furthermore, research methods applied to one segment of injury analysis may be relevant to others. For example, methods used for air-crash investigation have been applied to analysis of train crashes.[23] Such exchange of ideas and methods is common in disease research, but unfortunately not in injury research.

A prerequisite for the scientific study of injury is the acquisition of data on which to base priorities and research. Despite the obvious importance of injury as a public health problem, information to permit the study of the epidemiology of most injuries is not available.[209] Although there are basic data on time, place, and person for some injuries and deaths, even basic information is often lacking as to the numbers and characteristics of people injured and the factors that influence injury causation, especially in nonfatal events. Detailed information on the groups that are particularly susceptible to injuries and their effects is not adequate.

Injuries from motor-vehicle crashes constitute the only exception to this limitation. The incidence, prevalence, and effects of motor-vehicle injuries, as well as measures to counter them, are moderately well understood, compared with the epidemiology of other injuries, although even here information about long-term effects is sparse. The acquisition of knowledge about motor-vehicle injuries is a direct result of the funding of research on injury epidemiology from two sources whose primary mandate is the study of automobile injuries—the National Highway Traffic Safety Administration and the Insurance Institute for Highway Safety. Little funding has been available for research into the epidemiology of other injuries; consequently, our knowledge of these other injuries is slight.

HUMAN FACTORS IN INJURY CAUSATION

Injuries, like diseases, do not occur at random. Some population groups are at increased risk of injury because of greater exposure to hazards, decreased ability to avoid hazards, or decreased resistance to injury, and some groups have a lower likelihood of complete recovery or survival once injured.[11]

Age differences between injured and uninjured persons are substantial—injury rates are higher among persons under age 45, but the elderly and persons aged 15-24 have the highest injury fatality rates. Other demographic and social factors also influence the risk of injury. The risk of fatal injury is 2.5 times as great for males as for females; males are also at greater risk of nonfatal injury, although by a smaller factor.[14] Fracture rates are higher in older women, because of the greater prevalence of osteoporosis or bone decalcification in this group. The increased likelihood of fracture of the hip among the elderly is much greater for women than for men.

Death rates for many injury categories vary by a factor of 10 or more among the states. Except for homicide and suicide, death rates are highest in rural areas, perhaps because of differences in socioeconomic status, types of occupational and other exposures, and lower availability of prompt emergency care.[14]

Socioeconomic status can influence the likelihood of injury. For example, the incidences of homicide, assaultive injury, pedestrian fatality, and housefire fatality are high among the poor. Although wealth can place people in high-risk categories for some injury causes, such as crashes of private planes and incidents associated with home pools, the burden of injury rests disproportionately on the poor. High-risk jobs, low-quality housing, older cars, and such hazardous products as space heaters tend to be concentrated among poorer people.[13, 210] The death rate from unintentional injury as a whole is twice as high in low-income areas as in high-income areas.[14]

The use and abuse of alcoholic beverages influence the likelihood of virtually all types of injury, even among young teenagers. Almost half of fatally injured drivers and substantial proportions of adult passengers and pedestrians killed in motor-vehicle crashes—as well as in falls, drownings, fires, assaults, and suicides—have blood alcohol concentrations of 0.10 percent or higher.[206]

In a study of emergency-room patients, alcohol was detected in 30 percent of the patients injured on the road, 22 percent injured at home, 16 percent injured on the job, and 56 percent injured in fights or assaults.[197] Contrary to popular perception, alcohol can reduce the human tolerance to impact and increase the risk of permanent paralysis and other serious injuries. This reduced tolerance is receiving only scant attention and study. Understanding this might provide clues to methods of preventing injury.

In both highway and nonhighway events, the more severe the event, the higher the percentage in which alcohol plays a role. Alcoholic-beverage use is involved, for example, in about 10 percent of property-damage crashes, about 20 percent of crashes with a serious injury to an occupant, about 50 percent of all fatal crashes, and about 60 percent of all single-vehicle fatal crashes.[21, 206]

Other chemicals and drugs have not been shown to play a causal role in a substantial proportion of injuries, but some evidence suggests that abuse of amphetamines, marijuana, or other drugs can seriously impair driving performance, and individual cases of drug contributions to crashes have been documented.[92, 203] Use of multiple drugs, especially the combination of an alcoholic beverage with one or more other drugs, can create additional problems. Laboratory studies indicate that many drugs in common use—such as benzodiazepines, barbiturates, and phenothiazines—have a harmful additive or synergistic effect when used in combination with alcoholic beverages.[92] [208] [219] Identifying particular groups of people likely to drive under the influence of drugs is especially important for effective preventive efforts; unfortunately, data for such identification are very limited.

Numerous studies have attempted to correlate personality traits and other behavioral factors with injuries; their results have been of limited practical use in predicting who will be injured. The bulk of the evidence suggests that the behavioral factors studied are very transient.[163] Constant monitoring of those behavioral factors in the population would be necessary for identifying persons at acute risk. Such monitoring is not feasible or acceptable in this country.

PRODUCT, VEHICLE, AND ENVIRONMENTAL FACTORS IN INJURY CAUSATION

Much more attention has been paid to identifying the role of people in initiating injury events than to identifying the role of products, vehicles, and other environmental factors. Only minimal information is available on the often subtle interaction of human and environmental factors in event initiation, because the necessary epidemiologic studies have never been done.

Specific environmental contributions have occasionally been identified, as in motor-vehicle or home-product investigations leading to either voluntary or compulsory product recalls. More often, excessive injury experience is found to be associated with an environmental factor whose exact role cannot be proved. For example, Utah uses a dense material to build its roads, with resulting low coefficients of friction, and has more wet-weather crashes—in which poor road friction is often a factor—than do surrounding states, which use a less dense material.[135] Specific design features have been associated with high error rates not seen with other designs. The arrangement of knobs on some stoves, for example, makes it much easier for people to turn on the wrong burner and burn themselves or start a fire than it is with other knob arrangements.[34] In World War II, the reverse positioning of controls for landing gear and flaps resulted in more than 500 plane crashes.[113]

More is known about characteristics of specific environmental and vehicle design and construction features as determinants of the severity of injury, because of the attention, especially during the last 15 years, to features of motor vehicles and the road environment that produce or prevent injury. Some studies have been particularly successful because they have involved multidisciplinary approaches based on epidemiology, clinical medicine, pathology, and biomechanics. The knowledge gained has led to important interventions, such as improved door locks and windshield glass, energy-absorbing steering columns, removal of roadside obstacles, and development of breakaway signs and lamp-posts.[39] [54] [122] [166] [178] But important aspects remain largely unknown, and we still need information about product features that contribute to injury and death in fires, falls, and recreational and other injuries.

ELEMENTS OF AN INJURY SURVEILLANCE SYSTEM

Injuries have definable and correctable causes. Local, state, and federal authorities can make decisions about how to prevent injuries when they understand the elements of effective preventive measures and know who is at high risk, what types of injuries are sustained, the severity of their consequences, and when, where, and under what circumstances injuries occur. By comparing such information over time and among different populations, they can observe changing patterns of injuries and identify and implement strategies of intervention. When specific interventions are carried out, the same information can be used to evaluate their effectiveness.

Development of effective intervention strategies requires an adequate national surveillance system for monitoring injuries, their causes, and their short-term and long-term consequences. Continued monitoring of the most severe injuries and of a representative sample of less severe injuries is an essential component of efforts to implement and evaluate the effectiveness of measures to reduce injuries. Table 2-1 lists some typical data needs for effective injury surveillance. The data listed would not all be developed in a single surveillance system, but rather would emerge in a coordinated program involving several systems—some continuous and others periodic, some simple but geographically broad and others more complex but limited to a few representative communities. Such a mix of systems can yield necessary information on which to base and evaluate safety programs at lower cost and with greater feasibility than a single complex and continuous surveillance system.

TABLE 2-1 Examples of Data Needs for Injury Surveillance

Category	Data Needs
Time	Date and time of injury event
Place	State, county, city; indoor, outdoor, road, etc.
Person	Demographic characteristics of injured and uninjured persons: age, sex, race, SES, physical characteristics, occupation, place of residence
Types of injuries	Types and severities of injuries
Causation	Agents causing injury; other mediating factors (such as vectors and vehicles)
Circumstances	Host factors (alcohol, underlying diseases, debility), intention (suicide, homicide, accident), environmental conditions ("human-environment mismatch"), vector-vehicle factors (material failure, misuse, etc.), nonmedical emergency activities
Medical care	Resuscitation, EMS, ER, hospitalization, rehabilitation, long-term care
Health outcome	Death, amputation, permanent disability, disability days, costs, causes of morbidity and mortality

EXISTING INJURY SURVEILLANCE SYSTEMS AND THEIR LIMITATIONS

Information on injuries and injury-related events must be obtained from various sources and through different means. For example, information on severe injuries may be available only from hospital records, but information on vehicle crashes typically originates in police reports. Moreover many reportable and even serious crashes are not reported to the police. A surveillance system aimed at injury prevention therefore requires a combination of methods for both gathering and integrating information from a variety of sources. It also requires the interest and ability to carry out a collaborative endeavor among the several groups that may be collecting or analyzing the data.

Today, no national system can provide comprehensive information about injuries and disabilities. Surveillance systems have been important in controlling and studying other serious health problems, especially infectious disease and cancer. They involve collection of data at local, state, and federal levels by such organizations as the Centers for Disease Control, the National Cancer Institute, and the separate state cancer registries.

Most of the data sources currently available for the study of injury have serious inadequacies. National mortality statistics on injuries are collected by the National Center for Health Statistics (NCHS) and are based on the International Classification of Diseases (ICD) codes.[199] These codes divide fatal injuries, according to the apparent intent of the persons involved, into three categories—unintentional, homicide, and suicide. They specify injury types and also classify the events and circumstances related to the injuries. The current codes are seriously limited; for example, there is no way to identify work- or recreation-related deaths. In addition, it is not possible to determine from NCHS files the location or time of an injury; with respect to location, only the residence of the deceased and the place and date of death are specified. Another problem related to the NCHS mortality data is the delay (typically about 3 years) in their availability.

More detailed, and more useful, mortality data are collected on all motor-vehicle crash deaths by the National Highway Traffic Safety Administration (NHTSA). The Fatal Accident Reporting System (FARS) is a computerized data base that describes fatal crashes since 1975 on the basis of information collected by agencies in each state government under contract to NHTSA.[127] The sources include police accident reports, state vehicle registration files, state driver licensing files, state highway department files, vital statistics, death certificates, and coroner or medical examiner reports. The FARS information, which contains 90 data elements for each fatal crash, has proved invaluable to researchers concerned with reducing motor-vehicle crash deaths and injuries.

Recently, NHTSA began another major data collection program: the National Accident Sampling System (NASS), which is designed to produce a nationally representative sample of all tow-away motor-vehicle crashes.[131] The NASS uses specially trained crash investigation teams at 50 sites across the country to collect data. Each team is responsible for collecting detailed information about the people, vehicles, and environment involved in a sample of motor-vehicle crashes. The resulting data are much more detailed than those available from police reports. They include specific hospital and other information on the injuries involved, as well as on the deformation of vehicles—information that should be invaluable in relating vehicle crash forces to the injuries sustained. The NASS teams investigate about 10,000 crashes a year.

Routinely collected data on nonfatal injuries are seriously limited. As part of the National Health Interview Survey, NCHS collects information on injuries, *but* the samples are small, details are few, and the data have only slight utility for epidemiologic research.

The Consumer Product Safety Commission (CPSC) collects data only on injuries and fatalities associated with most consumer products (excluding automobiles and work-related equipment not used in the home). Through the National Electronic Injury Surveillance System, CPSC collects data on injury circumstances and the products involved from a sample of 73 hospitals.[40] Occupational injuries were recently included.

CPSC also collects death certificates involving injury, but reporting is incomplete and state confidentiality laws limit the amount and type of information about products associated with those deaths. To understand the characteristics of products that are involved in injury, researchers must have detailed information on the products. With the notable exception of motor vehicles, however, most injury reporting systems do not record brands or models of involved products.

The Occupational Safety and Health Administration (OSHA) reporting forms do not include the type, manufacturer, or model of industrial machines involved in worker injuries. When information that might identify a manufacturer is part of the CPSC files, it must be expurgated before the file can be made available to anyone outside that agency, including those seeking information under the Freedom of Information Act, unless the manufacturer gives permission to divulge the information.

Thus, the only national data on injury and death related to most products cannot be used to identify the

hazardous characteristics that may be peculiar to, or most common among, specific brands or models. This lack of brand or even generic information on products associated with injuries is clearly a major barrier to the prevention of injuries. In contrast, the presence of motor-vehicle identification information in police and national data files, available to private researchers, has resulted in substantial specification of the characteristics of vehicles that are associated with excessive crashes either alone or in combination with various driver characteristics. Recalls of vehicles with modifiable hazards and changes in designs of new vehicles have resulted from this free flow of information.

EPIDEMIOLOGIC USES OF INJURY DATA

Surveillance systems can enable identification of important shifts in patterns of injury or injury complications; e.g., some occur suddenly or locally and others occur more slowly or over wider geographic areas. If a system for identifying the immediate cause of death from injury had been available, it would have been apparent much sooner after World War II that the immediate cause of death shifted from shock that resulted from blood loss to kidney failure, then to respiratory failure, and then to delayed infection caused by usually harmless organisms that overwhelm immune mechanisms and cause multiple organ failure. What each surgeon was identifying as an apparently unique problem involving his patients was in each of the above modes of death, after considerable delay, found to be a national trend affecting thousands of patients.

In contrast, the National Electronic Injury Surveillance System (NEISS), a modest surveillance system developed by CPSC to identify new injury patterns, permitted early identification of a true epidemic of skateboard injuries and resulted in many local programs to deal quickly with this new phenomenon. It also helped to identify quickly a shift away from skateboards to skates and thus led to avoidance of safety legislation that had been predicated on continued growth in the popularity of skateboards. Surveillance systems should be able to identify and respond to new and potentially threatening patterns, such as the occurrence of death and injury resulting from apparent outbreaks of suicide attempts among students attending specific high schools.

To understand whether a particular product, behavior, or other factor is hazardous, epidemiologists consider it essential to know not only about the frequency of its involvement in injuries, but also whether that frequency is greater than its frequency in noninjury situations. This sort of exposure information is not collected by the NASS, the NEISS, or OSHA and is collected only rarely by most other data collection systems.

A number of states have computerized files of police crash reports that are available for research purposes. These files contain little information on injuries. Typically, motor vehicle-related injuries are divided into only four categories—one for death and three to cover the entire spectrum of nonfatal injuries. Moreover, police data tend to underestimate—sometimes substantially—the numbers of injuries that occur.[15] Despite these limitations, police data on crashes are valuable, especially when relatively great sample size is more important than detailed injury data.

A variety of specialized data sources for specific injury types, such as burns, are available, but all have serious limitations for epidemiologic research. Trauma center registries, for example, are not population-based and cannot relate their selected cases to less seriously injured or noninjured populations. Indeed, for nonfatal injuries, there is no alternative to specially focused and often expensive data collection projects. Little is known about the less severe injuries that cause most of the visits to physicians and restriction of normal activities. The long-term consequences of what may appear to be minor injury are essentially unknown. For example, the long-term effects of brain injuries that initially are considered minor are unknown, although data from recent studies of boxers suggest that even apparently minor head injury can have serious long-term sequelae.[31 157]

Many types of injuries produce a wide range of chronic disabilities, but the long-term impact of injuries in the United States is unknown. For many other health problems, such as cancers and cardiovascular diseases, long-term longitudinal studies have provided valuable epidemiologic data on which to base intervention strategies. There is every reason to believe that similar studies of injuries would yield similarly valuable information.

High-quality epidemiologic data are essential for the planning, development, and evaluation of efforts to prevent injuries. Despite this essential intertwining of epidemiology and prevention, many preventive activities have not been based on epidemiology; nor have they been evaluated epidemiologically. For example, the huge federal effort supporting high-school driver education as a means of reducing injuries was not evaluated before such education was greatly increased. More than 10 years later, research showed that driver-education programs actually increased injuries by encouraging teenagers to drive earlier and that such education did not reduce the crash involvement of those trained.[163] Valuable resources were wasted, because the interventions chosen were not based on adequate data or sound epidemiology. However, even with limited resources for research into injury control, considerable advances in the state of knowledge have been made in specific cases, through sound research based on adequate data and epidemiologic principles. Many more such advances involving a wide range of injuries are possible.

For almost any generally homogeneous set of injuries that has been studied, it has been possible to identify factors that greatly increased risk and factors that could be changed. For example, when children's fatal falls in New York City were studied in adequate detail, researchers found that such fatalities resulted mainly from falls from windows in multistory buildings. Fatal falls of children were reduced substantially by an intervention program that combined distribution of window coverings, education regarding the problem, and required use of the coverings by landlords.[18]

Drowning is an example of a phenomenon on which more refined epidemiologic knowledge than is now available is needed, if better prevention strategies are to be developed. To prevent drowning, information is needed about the bodies of water involved, the activities of the drowned persons and others in their company at the time of the drownings, and the environmental conditions. If most children who drowned wandered alone into unfenced, unattended swimming pools, the appropriate intervention strategy would be different from that if most children who drowned did so because they played in streams or ponds. Unfortunately, where data are available at all, this kind of specification of circumstances is usually not included.

Injuries and injury-related deaths can be greatly reduced in the next several decades. The reductions will require substantial programs of national surveillance, epidemiologic analysis, and evaluation. Major research questions that could be addressed with proper epidemiologic data are discussed in the next chapter.

RECOMMENDATIONS

1. The United States requires effective injury surveillance systems for gathering and integrating information from a variety of sources on which to base the planning and evaluation of control efforts. This would include long-term longitudinal studies of injuries and the collection of more refined data on specific types and causes of injuries and exposures to injurious environments.
2. A national capacity should be developed for the quick identification and control of outbreaks of specific injuries.
3. A consistent and accurate system for coding the causes of injuries needs to be used by hospitals.
4. Research is needed to determine the short- and long-term costs of injuries.

3

Prevention of Injury

GENERAL APPROACHES TO INJURY PREVENTION

A number of approaches for identifying injury-control options have been developed. One of the more useful (the three-phase approach discussed in Chapter 1) was first presented by Haddon[74] and elaborated on by numerous authors for various types of injury.[12 48 49 53 72 73 75 160 161 163 164] Three general strategies are available to prevent injuries:[161]

- Persuade persons at risk of injury to alter their behavior for increased *self-protection—for* example, to use seatbelts or install smoke detectors.
- Require individual behavior change by law or administrative rule—for example, by laws requiring seatbelt use or requiring the installation of smoke detectors in all new buildings.
- Provide automatic protection by product and environmental design—for example, by the installation of seatbelts that automatically encompass occupants of motor vehicles or built-in sprinkler systems that automatically extinguish fires.

Each of these general strategies has a role in any comprehensive injury-control program; however, a basic finding from research[163] is that the second strategy—requiring behavior change—will generally be more effective than the first, and that the third—providing automatic protection—will be the most effective. A fundamental reason for this is that members of high-risk groups tend to be the hardest to influence with approaches that involve either voluntary or mandated changes in individual behavior. Teenagers, for example, are much less likely than adults to wear seatbelts, whether or not a law requires them to do so.[221] Programs intended to change alcohol-related behavior voluntarily have not produced sustained reductions in death rates.[169] Elderly pedestrians admonished by police for jaywalking were no less likely to do it again.[216] Scofflaw drivers whose licenses had been revoked were more likely than the average licensed driver to be involved in fatal crashes.[167] And not only are young children hard to influence, but intensive efforts at a well-baby clinic, for example, had no effect on dangerous maternal behavior, such as leaving knives and matches within the reach of small children.[12]

Education

The tendency to attribute injuries to "human error" has nourished the hope that they can best be prevented through voluntary behavior change. Yet neither safety-education campaigns nor driver-education programs have been shown by scientific evaluation to justify the faith and large budgets accorded them.[110] [162] Educational and informational programs should be held to the same standards of efficacy as other prophylactic interventions; furthermore, it should not be assumed that such programs cannot do harm.

Many injuries (including highway injuries) result less from lack of knowledge than from failure to apply what is known. Failure to use available information is found not only in the persons who may be injured—teenagers who know that seatbelts will reduce the likelihood of death or injury, but fail to use them, or parents who know that children can be burned by stoves, but fail to keep their children away from stoves—but in decision makers who can influence the probability of injury to others, including manufacturers who must consider that their products will be used by less-than-perfect people. One problem with relying on educational approaches is the counterinfluence of the mass media in implicitly encouraging violent or hazardous behavior; children burned while imitating televised activities are a tragic example. Many television shows aimed specifically at young children show frequent high-speed car chases and crashes from which occupants emerge uninjured—a gross distortion of reality.[12]

If automatic protection has not been developed or implemented and behavior is not amenable to legal countermeasures, persuasion might be the only strategy available. For example, pedestrian injuries to children have been reduced by an in-school education program.[157] However, behavioral research is too often confined to behavioral responses of college students, and the relevance of most such research to injury control has not been established. Furthermore, funds, manpower, and motivation for research on education programs are often lacking. Educational efforts, advertising campaigns, and incentive programs—many on a large and costly scale—are therefore typically introduced with no knowledge of their effectiveness.

Another problem with education-based approaches is that, despite the large body of research on human behavior, individual traits that are easily modifiable for injury control have thus far not been identified. Identification of age, sex, and racial groupings with widely differing risks can be useful for targeting control efforts, including education programs, but those factors are not modifiable.

Laws

Education by itself has rarely proved to be an adequate preventive approach. Individual behavior change to prevent injuries has been more successful when the behavior was easily observable and required by law. For example, in the absence of laws requiring the use of protective helmets, only about 50 percent of motorcyclists voluntarily wear them, but helmet-use laws result in almost 100 percent use.[212] Laws mandating individual behavior are clearly more effective than education and protect more members of society. Many laws, however, have limitations; for example, even with intensive enforcement, many motorists violate speed limits and ignore laws on seatbelt use and child-restraint use.[78 198 220]

As with voluntary behavior change, laws and regulations aimed at changing individual behavior tend to be least effective among the very groups that are at highest risk of injury. For example, in several countries with seatbelt-use laws, seatbelt use was observed to be substantially less among teenagers and among persons with high blood alcohol concentrations—two groups with a high risk of involvement in serious motor-vehicle crashes.[218] As a result, seatbelt-use laws typically do not reduce fatalities as much as would be expected on the basis of the known effectiveness of belts when used.[165]

Factors that have increased or decreased the effectiveness of laws include the extent to which prohibited or required behavior can be directly observed by law-enforcement officers, the probability of arrest for violation of a law, the extent to which enforcement is augmented by members of the community other than the police (e.g., parents, bartenders, and gun dealers), and the severity of punishment of those convicted of violations. The relative effects of these factors are only partly understood.[164]

Despite the overwhelming evidence of the injury-reducing benefits of many mandated injury-control measures—such as federal motor-vehicle safety standards, seatbelt-use laws, and motorcycle helmet laws—the value of such measures has been challenged.[145] The challengers hypothesize that the effectiveness of mandatory approaches is partially or wholly offset by changes in behavior by persons who take greater risks to compensate for their increased safety. A number of variations on this notion of human behavior have been developed, and they have been variously referred to as the "risk-compensation" and "risk-homeostasis" hypothesis.[217] This view of human behavior has been the subject of much theoretical debate, as well as prolonged dispute on the extent to which the benefits of federal motor-vehicle safety standards might have been reduced because of such compensation.[66] [142] [158] [159] The debate continues, but the evidence is overwhelming that the federal motor-vehicle safety standards have substantially reduced car-occupant fatalities.[51] Furthermore, in careful assessments of risk compensation based on direct observations of behavior—as opposed to the mainly theoretical arguments of the proponents of these hypotheses—no evidence of increased risk-taking has been found.[111]

Product and Environmental Design

The most successful injury-prevention approaches have involved improved product designs and changes in the man-made environment that will protect everyone. Such built-in or automatic protection, now taken for granted in insulated electric hand tools and household fuses, is gradually gaining acceptance in other realms, because of its great potential for preventing deaths and injuries.[12]

A basic finding from health-behavior research is that, as the frequency and amount of required individual effort increase, the proportion of the population that will respond by adopting the recommended behavior decreases.[161] Consider, for example, the protection of children from toxic substances. Limiting the amount of substance in each container sold to a subtoxic dose does not require any effort by the parent or child and is the method most likely to prevent fatal poisoning; child-proof closures on containers of toxic materials have greatly reduced fatal poisonings, but occasionally the closures are left off and children gain access to the contents; admonitions to lock cabinets after each use of a toxic substance are the least effective.[10] Furthermore, even in homes where poisoning has already occurred, measures to prevent a recurrence remain rare.[209]

Some product and environmental changes achieve important changes in behavior. For example, experimental equipping of fleets of vehicles with high-mounted brake lights substantially reduced the incidence of rear-end crashes.[154] [155] Such experiments are outstanding examples of the research needed to test the effectiveness of new and developing technology, including ergonomic designs for human-vehicle and human-environment interaction.[155]

The perception of, and reaction to, motion (one's own and that of other moving objects) and the effect of environmental factors on such perception and reaction have not been sufficiently researched. Results of experiments with the placement of brake lights,[154] daytime use of headlights,[195] and reflective lines[130] on roads suggest that environmental changes to improve perception of hazards can effectively reduce the incidence and severity of injuries.

PREVENTION OF SPECIFIC TYPES OF INJURY

Transportation Injuries

Although safety standards have reduced the motor-vehicle death rate per mile of travel,[160] the total number of deaths remains high, because of growth in the number of vehicles and particularly growth in the use of less regulated and less protective vehicles, such as motorcycles. Motorcycle deaths were estimated to have increased by 158 percent between 1968 and 1979.[14]

Although much research has been conducted on passenger vehicles, little analogous research has been done on motorcycles and large trucks or on ways to reduce the damage they inflict on pedestrians, bicyclists, and other road users. Large trucks are substantially over involved in crashes, and when they collide with other vehicles, they are especially hazardous to the occupants of those vehicles.[90]

There is convincing evidence that high speed is a factor in many serious highway crashes.[198] An obvious way to reduce the kinetic energy of vehicles is to reduce their maximal speed. Those who oppose such an approach claim that the engine power is needed in some situations. However, it has not been determined whether that is true for specific types of vehicles or whether designs could be developed to allow power for legitimate needs, but not for substantially exceeding legal speed limits.

If fish is measured in terms of deaths per person-mile of travel, light aircraft rival motorcycles. About half the planes used in general (noncommercial) aviation can be expected to be involved in a potentially injury-producing mishap at some time, but most occupant protection standards have not been upgraded for more than 30 years.[183] As a result, hundreds of people die each year in plane crashes who could survive if seats, fuel systems, etc. were designed to protect occupants in a crash.

Workplace Injuries

The kinds of equipment especially likely to cause severe injury to workers can be identified—such as tractors and forklifts that are likely to overturn, cranes and other machinery with booms that can contact electric wires, and farm equipment with exposed moving parts that can entangle or amputate limbs. But little research has been done on designs for safer machinery and operating procedures.

Some research should also focus on the prevention of injuries during operations, such as repairs and cleaning, that are associated with a high incidence of injuries.

Research on work-related injuries has generally emphasized industrial settings, with little attention to many high-risk *occupations*, such as fire fighting and truck driving. Unlike approaches to work-related diseases, many approaches to work-related injuries have tended to emphasize unproven educational programs to make workers more careful, rather than reducing exposure to job hazards.

Recreation Injuries

The prevention of injuries related to most types of recreation remains nearly unresearched. For example, the effectiveness and use of protective sports equipment and of environmental modifications—such as energy-absorbing playground surfaces and gymnasium walls—are largely unknown. Research showed the risk of spinal cord injury associated with trampolines to be so great that many schools stopped trampoline activities; as a result, spinal cord injury rates decreased.[170] In boxing, football, and other contact sports, rules permitting or restricting particular maneuvers are a major determinant of rates of severe injury to the brain and neck; research is needed in many sports to identify the most hazardous aspects and to evaluate corrective measures.

Programs to reduce drowning and other forms of asphyxiation have seldom been studied before implementation. Boating-related deaths per 1,000 boats decreased after standards for flotation of the boats and readily available personal flotation gear were introduced, but we do not know whether those standards made the difference. We do not know whether more visible swimwear, underwater lighting in pools, or belts that inflate at the push of a button would affect drowning rates. The value of child-proof fences in reducing pool drownings has been demonstrated,[144] but further research is needed on the relative effectiveness of various barriers and of measures to increase their use.

Falls

More than 14,000 people die of injuries from falls each year, but the causes and possible countermeasures are rarely researched. Little is known about the effectiveness of energy-absorbing materials, either worn by persons at high risk or incorporated in the surfaces onto which they fall. Research on such materials would have application in homes and institutions that house children and the elderly, as well as in environments, such as playgrounds and high-risk workplaces, where epidemiologic studies have indicated that severe injuries from falls occur most frequently. Architectural designs that should reduce injuries from falls are known, but research on how to increase their use is lacking.

Fires and Burns

Nearly 7,000 people die each year from fires and burns, most of which occur in the home. Little is known about the effects of gases from burning materials and about the flammability of many materials used in houses, furniture, and bedding. Adequate escape routes from buildings and aircraft are essential for reduction of asphyxiation and burns in fires, but they are often lacking. More widespread use of smoke detectors and automatic fire-extinguishing systems would help to reduce the toll taken by housefires. Designs of such ignition sources as cigarettes, matches, and lighters to prevent inadvertent ignition are available and can be further improved and used.

Assaultive Injuries

Nonfatal assaultive injuries and homicides have been subjected to little prevention-oriented research. Typically, they have been regarded as a "crime problem," rather than as a health problem, and blame and punishment of the perpetrators have been emphasized, rather than measures to reduce the frequency and severity of such injuries. Firearms could probably be designed with safety catches and trigger tension to keep small children from firing guns when they find them and play with them. The firearms laws in various jurisdictions and the changes in laws when they are enacted or amended have not been thoroughly researched to measure their effects on the frequency and severity of injuries caused by firearms. In addition to research on laws, research on the effectiveness of other measures to reduce firearm homicide is needed. Assaultive injuries involving other weapons or personal force are virtually unresearched.

Self-Inflicted Injuries

Much research on suicide and on nonfatal self-inflicted injury has emphasized personal characteristics and methods of treating depressed or suicidal people. Changes in the physical and social environment and their effect on suicide rates have been the subject of little research and need to be evaluated. The validity of the widespread assumption that nonfatal suicide *attempts* represent a lack of desire to kill oneself, and therefore involve the choice of less lethal means, should be subjected to scientific scrutiny; there is evidence that reducing the availability of popular means of committing suicide can cause a major reduction in the suicide rate.[80] Research on reducing the lethality of common means of committing suicide should be encouraged; for example, changes in the formulation, number of pills per bottle, and prescribing practices related to antidepressants should be implemented on a trial basis and evaluated.

Relationship of Alcoholic Beverages To Injury

Alcoholic beverages are involved in a large proportion of all types of injuries, including workplace and intentional injuries. Most of the alcohol-related injury research, however, has focused on the effectiveness of various programs to reduce drunken driving. In addition to continued evaluation of such efforts, other questions should be addressed. Will the marketing of low-alcohol beverages result in less alcohol-related impairment leading to injury, or will most people, and heavy drinkers in particular, consume more to obtain the same dose of alcohol? Is it possible to reduce absorption across the stomach and intestinal walls or otherwise reduce impairment among persons who abuse alcoholic beverages? Are there environmental designs, signals, or conditions that reduce the risk of crashes by intoxicated drivers?

STATUS OF INJURY-PREVENTION PROGRAMS AND RESEARCH

The prevailing injury rates represent the failure of society to address today's major public health problem. Despite the injuries associated with light aircraft, boats, farm and industrial machinery, firearms, and cigarette-related fires, federal agencies with relevant responsibilities have conducted very little injury-related research.

Research to evaluate programs, laws, and regulations should be insulated from the agencies responsible for the injury control efforts. It is the rare organization that can objectively evaluate its own activities. Such self-evaluation all too often ends in justification of the status quo, rather than a critique of what is being done relative to what could be done. At present, very little evaluation of injury control efforts is undertaken by the responsible agencies, and even less by organizations independent of the agencies charged with injury control.

Schools of public health and medical schools are a potential source for independent evaluations, but they generally do not have courses aimed at training in injury epidemiology, prevention-program development, or evaluation of injury-control measures. The few knowledgeable teachers and researchers in those settings are expected to raise all or most of their salaries and research funds from sources outside the universities.

The shortage of health professionals and other scientists with relevant training is a major impediment to injury control. Partly as a result of the lack of trained research personnel and partly as a result of the lack of a coordinated injury-control policy at the federal level, most state and local health departments have little involvement in efforts to control injury. As in the case of water come disease, which was a major health problem until recent decades, many injuries result from local conditions and can be prevented only by local programs designed to deal with those conditions. Without knowledgeable and interested persons trained in the sciences relevant to research and programmatic efforts, the injury toll from local, regional, and national conditions will continue.

A wide variety of researchable questions related to the prevention of injuries must be addressed, if we are to make progress in reducing injuries and the disabilities, deaths, and societal losses that result. Funding is critically needed, not only for research, but for training researchers in injury control and keeping them active in this field. Some general recommendations for research on the prevention of injuries follow.

RECOMMENDATIONS

1. Education, training, and information programs intended to control injuries should be evaluated experimentally.
2. Laws and regulations aimed at controlling injuries

should be scientifically evaluated. The separate influences of degree of enforcement, severity of punishment, and speed of administration of punishment should also be researched.

3. Continuing research is needed on efficacy of product designs and environmental modifications in protecting people effectively and automatically.
4. Research is needed to understand the barriers to implementing existing effective injury control measures that are not widely applied.
5. Research is needed in the prevention of injuries in the recreational, occupational, and home environments.
6. Training health professionals and other scientists in injury research and the basic concepts of injury control is crucial, if we are to develop and apply new knowledge about the prevention of injury.

4

Injury Biomechanics Research and the Prevention of Impact Injury

Improved protection against injury can be realized through a better understanding of the biomechanics of injury and disability. This chapter reviews the current state of knowledge on injury biomechanics and presents recommendations to advance the field by forming university centers for research, by training engineers and scientists in injury biomechanics, and by ensuring a long-term commitment of funds and leadership. By investing in the needed research, we can reduce injuries and preserve the well-being of countless people.

STATE OF INJURY BIOMECHANICS RESEARCH

Impact injury of the human body occurs by deformation of tissues beyond their failure limits, which results in damage of anatomic structures or alteration in function. Even if there is recovery from structural injury, normal physiologic function does not always return. For example, bony fractures can heal, but associated damage to the central nervous tissue might result in a permanent loss of motor and sensory function.

Injury biomechanics research uses the principles of mechanics to explore the mechanisms of physical and physiologic responses to mechanical forces. Injury is caused by penetrating or nonpenetrating blows to the body, and the energy delivered and the area of contact are important determinants of the results. Penetrating injuries are caused by high-speed projectiles, such as bullets, or by sharp objects moving at lower speeds, such as knives.[1] [168] Penetrating injury generally involves a concentration of mechanical energy in a small area of the body. Nonpenetrating injuries are caused by blunt objects that distribute energy over larger areas at a wide range of speeds.[43, 101, 177, 193] Although injury can occur by slow deformation of the body, such as in crushing, the predominant features of impact injury are speed and violence, as in the rapid impact of the chest on the instrument panel of an automobile or a bullet's penetration into the chest cavity.

Research in biomechanics involves a variety of disciplines, including engineering, physiology, medicine, biology, and anatomy. Thus, there is no unified approach or single area of training, education, or experience. Research is often conducted by teams of engineering, medical, and other personnel, and the combining of such disciplines is an important element of a successful study. Detailed reviews of the literature on various aspects of injury biomechanics are available,[82, 96, 101, 181, 194, 205] but the research is so broad that no publication can cover the entire scope of this subject.

MECHANISMS OF INJURY

The severity of an impact depends not only on the velocity of the collision that produces it, but also on the shapes of the colliding objects and their rigidity. It can be reduced by energy-absorbing structures and padding material by allowing simultaneous deformation of the body and of the surface collided with.[156, 186, 187, 189, 191, 193] This extends the duration of impact and reduces the risk of injury.

Because of the inertial resistance of the body tissues and the elastic and viscous compliance of body structures, force is developed on the body during impact. Force deforms and accelerates the body. Injury (Figure 4-1) can be caused by:

- Crushing deformation of the body, such as through chest compression, rib fracture, and aortic laceration.
- Impulsive impact, such as by violent sternal motion that deforms the heart beyond its viscous tolerance and causes contusion and rupture.
- Acceleration of the skeleton and tearing of internal organs, because of their inertia; for example, during head impact, the skull accelerates and the loosely attached brain lags,[44, 71, 121, 129, 141] so injury is due in part to deformation of brain tissues beyond their limit of recovery.

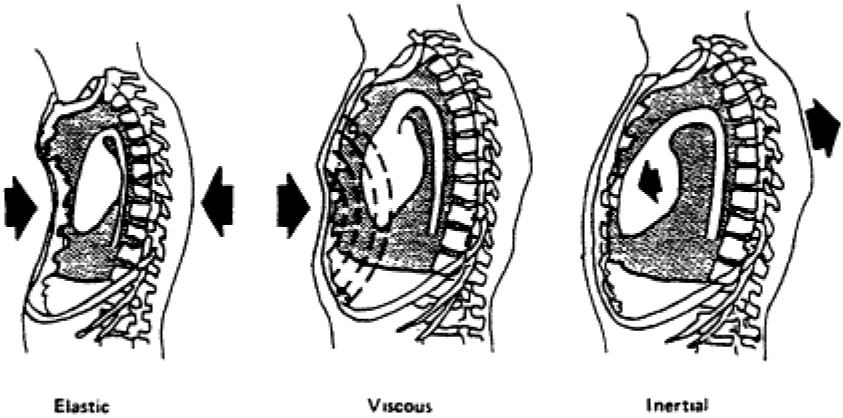


Figure 4-1
Three principal mechanisms of impact injury: left, compression of the body and injury when the crush exceeds elastic tolerances; center, high-speed impact with injury when violence exceeds viscous tolerance; and right, body acceleration when internal organ motion lags the skeleton with injury due to organ inertia.

A mechanism of injury involves the mechanical deformations and physiologic responses that cause an anatomic lesion or functional change. Knowledge of injury mechanisms is fundamental to the science of injury biomechanics, because it points to the appropriate biomechanical measurements that characterize injuries.

The human body has viscoelastic tissues that absorb energy and protect vital organs from the effects of impact. As long as the energy delivered to the tissue is below the limit of injury—whether it be the crush limit,[101 104 137 201] the viscous limit,[105 106 203] or the acceleration limit[116 193]—the energy will be absorbed without causing injury. The resistance of the human body to impact is responsible for survival of falls from extreme heights[58 180 182] and survival of severe motor-vehicle crashes.[186 187 191] Even though the body can survive great impact, the frequency and variety of impact incidents are so great that they constitute one of the leading causes of serious injury, death, and disability in the United States. Effective injury-prevention strategies must be based on knowledge of the mechanisms of injury and disability, as well of the body's biomechanical responses and tolerances and techniques for assessing the injury-prevention benefits of safety technology.

Deformation of tissues beyond a recoverable limit is the most common origin of injury.[59 65 121] From an engineering point of view, deformation of a tissue or structure is measured according to change in shape (such as the change in length divided by the initial length) or strain. [61] The two main types of strain (Figure 4-2) that can damage tissue are tensile strain and shear strain; a third type is compressive strain, which is responsible for crushing injuries. Stretching of an artery increases its length and increases strain. If the strain is too great, the tissue will break. There are many ways to stretch tissue and thus produce tensile strain. For example, the motion of the heart during

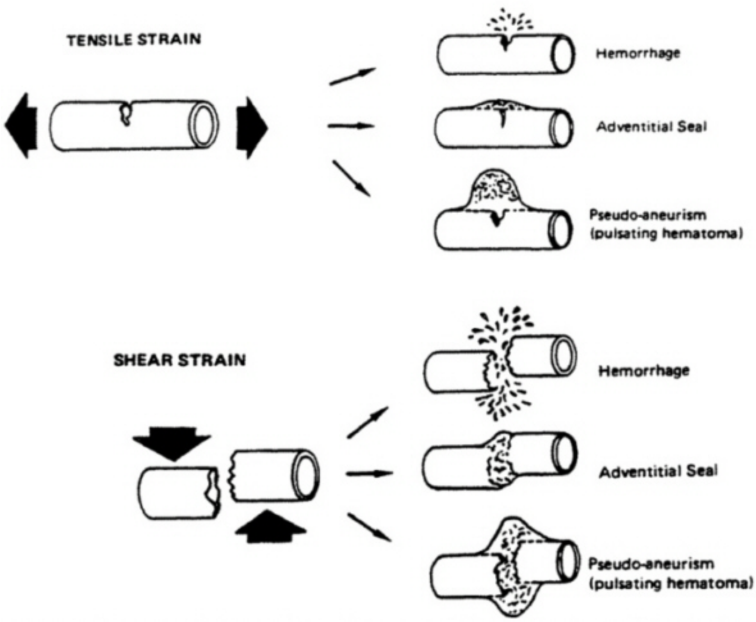


Figure 4-2
Stretch of vessel can tear tissue (partial tear shown) with loss or containment of blood. Opposing forces across vessel can cause shear injury (complete tear shown) with or without loss of blood.

chest compression stretches the aorta near points of attachment; the stretch is primarily along the axis of the vessel and generally leads to a transverse laceration when the recoverable limit of tissue strain is exceeded.[19] An increase in vascular pressure dilates blood vessels and produces tensile strain in the tissue; in this case, the strain is in both axial and transverse directions (i.e., it is biaxial), and pressures beyond the recoverable limit cause a bursting of the tissue.

Axial impact on the femur causes an increase in its curvature, tensile strain on its anterior surface, and compressive strain on its posterior surface. Midshaft failure of the femur occurs when the tensile strain exceeds the recoverable limit.[52 204] This mechanism is common in the ribs, where compression of the chest causes tensile strain on the outer surfaces. Bending failure of bone and failure of vessel walls are two common examples of tensile failure due to tissue stretch.

Shear strain occurs when forces oppose each other across a tissue (see Figure 4-2). The movement of tissue in opposite directions separates it when the recoverable limit is exceeded. For example, the differential movement of the brain with respect to the accelerated skull during head impact causes a combination of shear and tensile strain at the interface between brain and skull.[44 141] Damage occurs when the strain exceeds the resistance of the tissue. Differential motion of lobes of the liver can shear and lacerate hepatic vessels when the strain exceeds the recoverable limit.[104 106]

Stretch and shear of tissue are the primary mechanisms of laceration, fracture, rupture, and avulsion in the human body. The strain mechanisms commonly occur when an organ moves relative to its attachment during deformation of the body. This strain explains major vessel ruptures in the liver during deformation of the abdomen and laceration of the aorta due to compression of the chest.

Deformation or strain is also a principal factor in contusion injury (Figure 4-3). In this case, the surface of the tissue is not damaged, but the deformations stretch and shear internal vessels and increase intraluminal pressures, which can damage vessels and initiate hemorrhage.

The rate of loading, or strain rate, is important in the production of injury. Biologic tissues are viscoelastic, and their response and tolerance depend on both strain and strain rate.[61 65 200] For example, compact bone fails at a lower strain applied at higher rates, even though the load it carries at failure is higher.

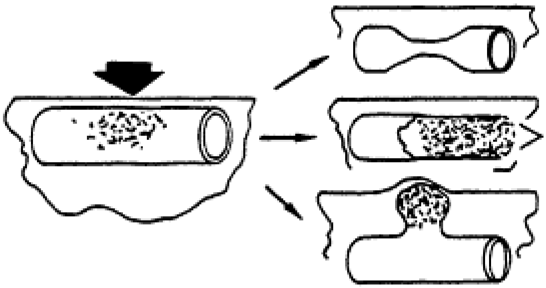


Figure 4-3
Vessels beneath skin can be torn by stretch or shear with laceration of skin, resulting in bruise, or contusion.

The rate of loading is critical in soft-tissue injury, particularly when the viscous tolerance of the tissue is exceeded.[106 203] This tolerance is proportional to the product of loading rate and amount of compression. The faster a tissue is loaded, the lower is its tolerance to compression. The viscous injury mechanism is important in cases of high-speed impact, particularly when rupture and contusion occur.

RESEARCH NEEDS

Injury Mechanisms

Gaining knowledge of the mechanisms of injury is the first step in injury biomechanics research. It permits an understanding of the deformations associated with gross anatomic lesions or damage to biologic tissues that result in functional change. The study of injury mechanisms makes use of clinical and accident data and data from experiments with human cadavers and anesthetized animals. Mechanisms of many of the important injury-related anatomic lesions have been studied. For example, the mechanisms of heart and great-vessel rupture have been discussed extensively;[19 107] the sequence of events that follow blunt impact and lead to rupture and laceration has been described; and fracture of the femur and dislocation of the knee are generally well understood,[139 202] although much less is known about injuries of the other long bones and many joints.

Cervical spine injury has been emphasized, because of the serious functional consequences associated with spinal cord damage.[38] Neck injuries occur in rollover *automo*bile crashes, shallow-water diving, and contact sports. Although the literature and hypotheses on fracture-dislocation of the neck are extensive,[84 94 150 172] little of the underlying sequence of injury events has been verified. The mechanisms of functional damage to the central nervous system (CNS) are less well established, primarily because the problem has not been studied from the point of view of impact deformation and functional loss. Although isolated tissue preparations have provided information on the underlying mechanisms of functional change, the problem is complicated by the abundance of physiologic responses to injury. But CNS injury is paramount, because it so often causes functional disability.[99 134 157 192] We need to study the sequence of events and biomechanics of impact injury to the CNS. Many of the mechanisms responsible for functional change are speculative and generally unknown, but they deserve a balance of biomechanical and physiologic research.

Measurement of Biomechanical Responses

The first step in understanding biomechanical responses is to measure changes in shape of the body, organ, or tissue caused by impact.[101 121 193] The elastic and viscous resistance of biologic tissue to impact deformation and the inertial resistance of the body to motion must be characterized. Measurement of biomechanical responses is used to analyze the injury process. Studies of volunteers, limited by rigid regulations and guidelines, can be conducted with impacts below the pain threshold. Several military research facilities use military volunteer subjects, but the United States has only a few research facilities for civilian impact experiments. Although noninjurious responses can be measured in volunteer experiments, the basic study of impact responses must use surrogate humans.

The primary research tools to evaluate injurious biomechanical responses are human cadavers and anesthetized animals that are exposed to impact and detailed response measurement. Cadavers are suitable research models that simulate gross geometric and material properties of living humans, and they are often used to study kinematics, such as the motion of a body during deceleration, or the mechanical response of a body segment, such as deformation of the chest. Animal research is vital in obtaining information on physiologic responses triggered by injury; there is no other way to simulate pathophysiologic responses critical to developing information on disabling brain and spinal cord injuries and life-threatening arrhythmia or shock.

Mathematical models[97, 188, 190] and anthropomorphic dummies[57, 121, 128] are used extensively as predictive tools, particularly in connection with body kinematics and acceleration during impact. However, simulations are only as accurate as the biomechanical information used in their formulation. Mathematical models generally lack accuracy for interactive forces developed during contact. In many instances, the lack of basic research data on biomechanical responses has retarded the development of more sophisticated models or dummies.

Tolerance

The threshold of injury is a degree of deformation, energy absorption, or biomechanical response beyond which damage occurs to the tissue or structure. Damage in this case can be a gross anatomic lesion or an injury that results in a permanent alteration of function. The threshold is not fixed, but is a function of a variety of characteristics, including the type of tissue and the type of test subject. Our current knowledge concerning human impact tolerances is sparse, and experimentally derived data on women, children, and other segments of the population are highly limited.

Determination of human tolerances to impact is complicated by many factors, including the magnitude, direction, distribution, duration, and pulse shape of the force of the impact; the body orientation; tightness and configuration of restraint; and structure of the striking object. Biologic factors may also influence human tolerance, including sex, age, physical and mental condition, and body size.[70, 180, 194] Individual variability must be considered, because tolerance under identical test conditions can vary in the same person, as well as from one person to another. Furthermore, although data are available on impact forces in some body orientations, such as forward or rearward, less is known about the effects of lateral or multiple-direction impact.

Thus, it is not possible to state the human tolerance to impact definitively without knowing specific conditions, because tolerance depends on so many conditions. In fact, there is likely to be a distribution of tolerances for a given population and a given impact.

Falls provide a means of estimating human tolerances to impact, and particularly to extreme impact beyond which volunteers may not be subjected.[58] [180] [182] [184] Data from falls have limited value, however, because responses are not measured during the event, and information on the impact dynamics must be reconstructed after the fact. Other estimates of impact tolerance are obtained from clinical studies of impact injury and from reconstruction of automotive crashes[188] and aircraft crashes.[114] [136] [179] In these cases, although the resulting injuries are known, impact conditions can only be estimated.

Assessment of Safety Technology

A research goal is to develop a test tool, such as a dummy, and a test method, such as a crash simulation, to study the effectiveness of safety technology.[121] [189] If a test is sufficiently representative of a range of exposures in which injury might occur, the test tool and method can be used to assess the risk of injury and disability.

Automotive crashes are violent events of short duration, so they are typically studied in the laboratory with dummies. The purpose of such studies is to evaluate methods for reducing the overall risk of impact injury to humans, but dummies provide only the most basic information, which usually cannot be correlated accurately with human response and injury. For anatomic injuries, the predictive capacity of dummy tests is marginal. More important, current dummies cannot be used to evaluate functional changes that result in severe cognitive dysfunction, in quadriplegia, or in fatal ventricular fibrillation.

Advances have recently been made in the mathematical simulation of crashes,[186] [190] and this simulation can be used to study the effects of a wide range of design changes and improvements.

Thus, current tools and techniques constitute only a first step in the development of adequate evaluative procedures based on understanding of trauma mechanisms, biomechanical responses, and tolerance of humans.

Other Factors in Injury

Many factors influence the occurrence, severity, and outcome of impact. Hypertension and arteriosclerosis tend to increase the severity of cardiovascular injury and might be important in injuries among the older population. Osteoporosis, a disease of the skeleton that reduces the impact resistance of bone,[52 59 65] is a factor in skeletal injury, particularly in compression fractures of vertebrae and fractures of the femoral neck and ribs. This disease is more likely to affect older women, reinforcing the belief that age, sex, and well-being influence injury.

Chronic use of alcoholic beverages interferes with normal body repair processes and is important in injury causation. It is now becoming evident *that* use of alcoholic beverages predisposes to more severe and extensive injury than would be experienced by nondrinkers, given impact of the same severity.[24 56 65 107] Alcoholic beverage use that produces even moderate or low blood alcohol concentration can significantly increase the fatality rate associated with cardiac injury and the debilitating effects associated with CNS damage.

Physiologic experiments have demonstrated a higher fatality rate associated with a combination of acute alcoholic-beverage use and blunt thoracic impact than that associated with impact alone.[107 108] The combination of alcohol and impact impairs cardiac performance, and death is caused by electromechanical dissociation, or decoupling, of the excitation-contraction process. Because of the high incidence of alcoholic beverage use by seriously and fatally injured road-accident victims (33 percent of seriously injured and 50 percent of fatally injured), the reduced tolerance associated with moderate blood alcohol concentration might be one of the most important factors influencing injury, but little is known about the mechanism for this.

CONCLUSIONS

The current state of knowledge of injury mechanisms, the understanding of impact responses and tolerances, and the availability of useful technology for injury evaluation were analyzed by the Committee on Trauma Research and are summarized in Table 4-1. There is a reasonable understanding of mechanisms of anatomic damage, but the

TABLE 4-1 Summary of Known and Needed Information Regarding Injury Mechanisms

Known or Available	Unknown/Needed
Head	
Some knowledge of injury mechanisms of skull fracture and brain contusions is available. Response and tolerance data on anatomic injuries to brain are crude, but assessment technology for head injury exists.	Functional injury mechanisms to brain are poorly understood. There are no data on the functional response and tolerance of brain to linear and angular acceleration. Assessment technology does not exist.
Face	
Fracture data on a few facial bones are available. Tolerance data are sparse, and assessment technology is at research state.	Fracture data on smaller facial bones are not available. Response and tolerance data need to be acquired to improve assessment technology.
Neck	
Only a few injury mechanisms are known. Response and tolerance data are available, but only for few impact modes. Assessment technology is crude and limited to flexion and extension.	There are many injury mechanisms for the neck, most of which are poorly understood. Response and tolerance data need to be acquired for a combination of impact loads. Long-term research needs to be done to study biomechanics of the neck, including experimental work and mathematical modeling. Effect of neck motion on spinal cord has not been fully explored, including cord concussion and tolerance of cord to bending and stretching. Functional

Known or Available	Unknown/Needed
	response and tolerance of cord to are unknown. There is no assessment technology for cord-injury simulation.
Thoracolumbar spine	
Mechanisms for vertebral fracture are understood for vertical acceleration. For combined accelerations, mechanisms are speculative and poorly understood.	Response and tolerance data for combined modes of impact are extremely limited. Range-of-motion data are sparse. Assessment technology is crude and requires considerable improvement. Data on impact responses of soft tissues of thoracolumbar spine are needed.
Thorax	
Mechanisms of injury for ribcage are somewhat understood. Knowledge regarding rupture of heart and great vessels due to frontal impact has been given to emergency room physicians, but precise mechanism of injury is still being sought.	Response and tolerance data of thoracic viscera (heart, great vessels, and lung) are unknown. Injury criteria for thorax have been proposed, but their validity needs to be verified. Dummy thorax cannot fully simulate human response to impact.
Abdomen	
Failure pressure for liver impact is known for isolated organ. Injury mechanisms are somewhat understood, but detailed information on differences in mechanisms between solid and hollow organs is not available.	Response and tolerance of abdominal viscera (solid and hollow) are largely unknown. Development of surrogate for simulation of abdominal viscera is in its early stages.

Known or Available	Unknown/Needed
Extremities	
Injury mechanisms for fracture of long bones are well known and understood. Failure mechanism is tensile strain. Tolerance data are available for adult femur. Multiaxis transducers are available to measure forces in dummy femur and tibia.	Response and tolerance of most long bones are unknown. Response and tolerance of joints of extremities are also largely unknown. There is even less information on functional response and tolerance. Assessment technology is crude, because dummy extremities do not have biofidelity.
Skin and muscle	
Lacerative and thermal injury to skin is somewhat understood. Assessment technology exists for skin, but is very crude and unreliable.	Response and tolerance of skin and muscle to thermal and mechanical injury are largely unknown. Assessment technology is not available for burn injuries.
Sensory organs	
Pressures that cause noise-induced threshold shifts for hearing are known.	Mechanical response and tolerance of eye, tympanic membrane, and olfactory organs are largely unknown. Assessment technology does not exist for any of these organs.
Reproductive organs	
Fetal injury mechanisms in frontal crash are somewhat understood.	Response and tolerance of reproductive organs are unknown. No assessment technology is available for these organs.

mechanisms of functional changes are less well understood. Very little is known regarding the mechanisms of brain and spinal cord damage. These tissues control life processes and cannot be adequately protected if the mechanisms of functional injury to them are not better understood. A better understanding of impairment of cardiac function due to thoracic impact is also needed.

The understanding of *impact* responses and tolerances is not as advanced as that of mechanisms of anatomic injury, because of the lack of experimental models for research to measure biomechanical responses and tolerances of humans. The use of human cadavers has allowed the assessment of the response of the ribcage to impact and the response of the femur to axial loading at the knee,[35] [101] [200] but most recent research has emphasized the biomechanical responses and tolerances of the chest and extremities. Earlier cadaver experiments involving head impact provided the basis for the current understanding of the head t s impact response and tolerance.[121] [129] However, the current techniques are not sufficient to assess the risk of severe and moderate injury to the brain with confidence. The measurement of head-impact responses and tolerances is an urgent subject for research and must use a physiologic model for study. The frequency of head impact is high, and the consequences of brain damage are severe.[79] [99] [129] [130] [134] [157] Of similar importance is development of response and tolerance data on the spinal cord. The seriousness of quadriplegia is obvious, and useful measures of the risk of damage to the central nervous system are needed.[134] [147] Although hypotheses are available for the mechanism of cervical spine fracture-dislocation, there is a paucity of experimental verification and a lack of correlation of fracture-dislocation with spinal cord damage. Information on the impact responses of the abdomen and external tissues is also sparse.

Test dummies are the primary tools for predicting injury, but only a few measures of potential injury are assessed with current techniques during impact tests. The most common ones are the acceleration responses of the head and chest and the measurement of force applied to the femur.[57] [121] [128] The measurement of femoral forces is well accepted and used, but the assessment of femoral injury is not based on the underlying mechanism of injury, which is bending and not axial compression. The criterion for evaluating the risk of head injury has been well publicized, but it has limited experimental verification and has not been correlated with the risk of brain damage or facial injury. Limited experimental criteria are available for evaluating neck injury, but they do not assess functional changes associated with the risk of quadriplegia. Clearly, the two most important body regions, the head and neck, are inadequately evaluated with the current testing technology, but they are regions that suffer the most harm in motor-vehicle crashes.[29]

RECOMMENDATIONS

1. A multidisciplinary approach to injury biomechanics research should be coordinated to include:

- Injury investigation, injury-mechanism study, biomedical research on response and tolerance, study of pathophysiologic response to impact, and research on disabling injuries, particularly to the central nervous system.
- Support for the training of scientists and engineers in injury biomechanics, to overcome a serious shortage of such workers.
- Support and incentives for established investigators on university faculties to develop curricula in the mechanics and physiology of injury.
- Development and nurturing of a core of leaders by establishing university centers for scientific study of injury and disability. Adequate support for long-term and applied research should be emphasized and an effort made to curb the rapid loss of trained researchers primarily to service as expert witnesses in lawsuits.
- Maintenance of a balanced extramural research program managed by engineers, physiologists, and physicians.
- Fostering of cooperation and exchange of information with existing federal organizations.
- Promotion of the development of information on important problems in trauma, independent of the regulatory function of the government.

2. High priority should be given to research that can provide a clearer understanding of injury mechanisms. The crucial subjects of research are as follows:

- The relative contribution of linear and angular acceleration of the head to deformation and injury of brain and spinal cord.
- Verification of proposed mechanisms of injury to the neck—head motion can impose a variety of combined axial, bending, and shear loads that result in many kinds of injury.
- Verification of mechanisms of injury to the thoracic and abdominal viscera; these mechanisms vary from unknown to slightly understood.
- Musculoskeletal injury that leads to functional joint disability.

3. Research in mechanical responses requires sustained support. The responses of most body regions to mechanical loading have not been measured adequately. The critical regions are the following:

- Central nervous system, where the accurate measurement of linear and angular acceleration is needed for use in biomechanics experiments.
- Thoracic viscera, including motion of internal organs and vessels that leads to injury.
- Abdominal viscera.
- Joints, with the possible exception of the knee.
- Muscles and peripheral nerves.

4. High priority should be given to obtaining and defining limits of human tolerance to injury, particularly with regard to the following general subjects:

- Segments of the population on which data are extremely limited, including children, women, and the aged.
- Both whole-body and regional tolerances, to provide an improved basis for design of less hazardous products and environments.
- The effect of variables that influence and modify tolerance, such as substance abuse and energy-attenuating and restraint systems.
- Physiologic tolerances, particularly in the central nervous system.
- Long-term effects of rapid deceleration on the body, particularly the brain, spinal cord, and joints.

- Survival of extreme impact, to provide a better basis for understanding the limits of tolerance.

5. Improvement in injury-assessment technology is needed. Although some tools and techniques are available for this purpose, they are inadequate, because of the wide diversity of potential injury and disability. Work in this field should include:

- Development of means of assessing the important debilitating injuries and causes of fatality.
- Improvement of anthropomorphic dummies.
- Development of computer models that can be used to predict injury and response in complex crash conditions.

5

Treatment

The severity of an injury depends on the amount and distribution of the energy absorbed by the body. A major injury to the respiratory system, to the cardiovascular system, to the brain (which controls both), or to the upper spinal cord (which controls respiration) results in early death. A patient with a less severe injury enters the medical care system, but a cascade of events has been set in motion by the primary damage; unless this can be interrupted, death or disability can ensue. If the patient survives, the intensity of this cascade and the skill with which it is managed will play a major role in determining the degree of functional recovery. Problems lie in resuscitation and transportation of the injured patient, in immediate care in an emergency department, and in the speed with which diagnosis and surgical care become available. Control of continuing hemorrhage from any site, establishment of an adequate airway, and removal of blood clots from the brain are the immediate surgical tasks, and they require a wide range of advanced surgical expertise.

PREHOSPITAL CARE

Prehospital care of the injured has been improved over the last few years. Rapid evacuation of the injured was stressed during our recent military conflicts. The use of helicopters in Vietnam saved many lives by getting severely injured patients to definitive care in a minimum of time.[91] In civilian life, the system is varied and unstructured, but good ambulance standards have been set in some areas, and helicopter services are available in others.[36] The civilian use of local military helicopters has also improved the transport system.

The development of the basic emergency medical technician and paramedic systems has provided professional care at the scene. Well-trained paramedics are able to attend to airways, treat shock with the administration of fluids, and monitor a patient's condition.[87] In addition, they can notify a receiving institution with an estimate of that condition and an estimated time of arrival.

A need for intensive study of what should be done at the scene of an injury event under different geographic circumstances remains. For example, patients in some urban areas might benefit from a system of "scoop and run," in which the emphasis is on speedy transport to a nearby injury center. In such a case, the need is for an effective transportation system. In other urban areas, a lack of municipal organization still constitutes a major problem, and patients might be taken to inadequately staffed and poorly equipped facilities. If an injury occurs in a rural area miles from a major center, it might be better for treatment to begin at the scene. If so, major questions must be answered. For example, should paramedics be trained to intubate a patient, start intravenous fluids, and give medications? What is the best method of getting a patient to a major center—by air or ground transport?[6] Between the extremes of urban and rural, consideration should be given to a system of movement to the nearest hospital, where resuscitation can be initiated, the severity of the injury assessed, and arrangements made for transfer to a center. We need to know whether and under what circumstances patient care is improved by providing emergency surgery at a local hospital and then transferring a patient to a center immediately for continuing support. Each of these possible approaches to treatment has advocates, but little information is available to support any one approach over another.

Assessment based on an injury severity score needs to be implemented at all levels of care, including prehospital care.[33] This allows a receiving unit to have some idea of what is coming and to be prepared. It is of particular value in a small hospital, where a physician is not even called until a patient arrives; that can impose a delay before definitive medical attention is available. The use of a graded system of evaluation is essential for measuring results. One example is the

Glasgow Coma Scale for head injury, which is now internationally accepted.[86 89]

A reasonable immediate goal might be to document more fully the extent of national failure in transportation, in emergency room equipping and staffing, in provision of diagnostic equipment (e.g., a computed tomographic scanner is essential in head injury, and an ultrasonic scanner and a computed tomographic scanner are necessary in torso injury), and in immediate availability of diversified surgical help.[8] The presence of differences in geographic distance, in type of injury (e.g., automobile, gunshot, or fire), in site of injury (e.g., head or chest), and in age and general health of the injured all call for an extensive and versatile survey. Comparisons with the few centers where optimal treatment appears to be available and with foreign centers where alternative models are available (e.g., the West Germany helicopter service and the southern Sweden community hospital system) are essential. For our several population patterns, we might require some combination of the above. Continued review and updating of systems will be needed as we strive toward the optimal system for delivery of care. At the moment, neither the small community hospital nor the hospital devoted exclusively to injury (as in Birmingham, England) appears to be the perfect means for providing adequate care in all instances.[215] One thing is known: optimal care is not universally available, and this lack results in otherwise avoidable mortality and morbidity.

HOSPITAL CARE

Shock

One major result of injury is bleeding, either internally or externally. There can also be major shifts of fluid in the body, which has three fluid compartments — intravascular, interstitial, and intracellular. The resulting reduction in vascular blood volume (shock) leads to a reduction in cardiac output (blood pumped by the heart) and affects most organs and their cells. Another effect of the decrease in circulating blood is a reduction in blood pressure. Thus, the entire system is compromised by this phenomenon.[7 118 176]

As blood pressure decreases, baroreceptors (pressure-sensitive areas) in the heart and great blood vessels detect the loss of blood volume and in turn stimulate various neuroendocrine responses. Neuroendocrine receptors (see below) in turn trigger many responses that are believed to compensate for, or protect against, the decrease in blood pressure.[62]

A reduction in circulating blood volume can be assessed by measuring various functions, such as blood pressure, central venous pressure, and urinary output. The problem can be corrected in a crude way by adding to blood volume with whole blood, blood substitutes, and electrolyte solutions intravenously.[28] [119] [174] But there is a need for a better understanding of the response and the factors that serve as mediators of the response (such as kinins, prostaglandins, and myocardial depressant factor). What stimulates these mediators? Should we interfere with them? Are they all protective, or might they at times be destructive?

Further information on the internal shifts of fluid is also needed. Until these are fully elucidated, optimal treatment will not be possible.

Neuroendocrine Response

The brain and its closely associated neuroendocrine system are the controllers of heart and lung function, of water and electrolyte dynamics, of temperature regulation, of hormone regulation, and of the compensatory and reparative responses of the body to stress.

Injury that does not involve the brain directly can nevertheless lead to myriad changes in function of the neuroendocrine system. The precise mechanisms by which changed hormonal function leads to changed metabolism have not been defined. Some metabolic changes lead to increased availability of glucose to the wound and to some critical tissues, such as the heart and brain, and also support the restitution of lost blood volume. However, as injury becomes more severe, the compensatory mechanisms tend to fail. The mechanisms underlying such failure await definition.

Some hormonal and metabolic responses to injury can be detrimental—e.g., loss of protein, retention of salt and water, and the loss of immune competence, which predisposes an injury victim to infection. Consequently, the elucidation of the mechanisms of these responses is important in providing opportunities to limit or prevent them. Studies are needed to determine the degree to which therapy, such as the administration of fluids, improves a patient's response. The best therapeutic approach might bypass the neuroendocrine response and consist of substitution therapy. When the brain is injured, it loses the ability to control its own metabolism and the metabolism of the body as a whole. This loss of control leads eventually to a total collapse of the respiratory and cardiovascular systems.

Infection

It was recognized years ago that most exposures of most people to bacteria did not result in infection, because of natural resistance. Eventually, this resistance was demonstrated to be due to the immune system of the body, but how this works and how to alter it (if we should) are still under investigation.[3]

In more recent years, it has been found that vital and fungal agents play a role in injury. Control and treatment of fungal disease have been learned to some extent, but there is almost no information on the effects of vital agents in injury.

Sepsis is a major cause of death among injury patients who survive beyond the first 6 or 12 hours after injury. There is no way to predict which patients will become septic. A morphologic change in the white blood cells (part of the immune system) can often be identified within 60 minutes after injury, but whether and how it should be altered are not known. An extensive investigation of what this response means and whether it is helpful or harmful is needed.

CHARACTERISTICS OF INJURIES THAT REQUIRE TREATMENT

Options for treatment are vast, because treatment can involve every organ and its cellular components and every type of injury. It seems prudent to classify injury into several broad categories and discuss specific examples of them, rather than dealing with each specific organ system. Three broad categories can be considered: injuries in which cellular changes alter function; injuries in which deformation of a physical structure produces major problems; and injuries that lead to loss of an organ.

Cellular Changes That Alter Function

Bruised, burned, or otherwise damaged tissue undergoes a local reaction of which swelling, or the accumulation of fluid, is a prominent part. In some regions of the body, such as the ankle, this reaction can be incidental. In others, such as the intestine, it can seriously complicate fluid and nutritional regulation. In the inexpansile skull, brain swelling results in high intracranial pressure and brain displacement within the skull, in failure of blood to reach the brain, and finally in loss of ability of the brain to regulate body function. Brain swelling is commonly the major factor that determines survival, death, or disability and the degree of disability—physical, intellectual, behavioral, and epileptic.

We do not know what happens in the brain cells and in their immediate surroundings to interrupt their function and cause them to swell. This problem will be the central theme of basic research in head injury during the next few decades.

Lack of cerebral oxygen (anoxia) or lack of available glucose impairs cellular metabolism and function. Potassium, sodium, calcium, and water concentrations change, and a disadvantageous acidity develops. Calcium-activated proteases affect the basic structure of the brain. Blood vessels become distended, and intracranial blood volume increases. As vascular function fails, the barrier between blood and brain becomes impaired, and fluid leaks from the bloodstream into the brain tissue. Brain cells, with impaired energy, suffer further as fluid separates them from their blood supply. Brain cell failure results in disturbance of the brain's regulating hormones and chemicals. Lack of blood to the cells results in liberation of free fatty acids that are toxic. A small amount of work at this cellular level is being undertaken in this country and abroad by basic biochemists, membrane physiologists, cell biologists, pathologists, and surgeons. This work needs to be greatly expanded and intensified, because it is from such labors that future progress will emerge.

Physical Alterations That Produce Major Problems

Injury to a major blood vessel or nerve or fracture of a major bone are examples of physical alterations that produce major problems. When a blood vessel is divided or becomes obstructed as a result of an injury, movement of nutrients to tissues beyond the point of injury ceases, and organ and cellular dysfunction—including cellular death—occurs. For each tissue of the body, there is a small period during which circulation can be diminished or absent without preventing partial or complete recovery. For example, injury to a major vessel to the brain can produce a stroke within a matter of minutes; an extremity can withstand up to about 8 or 12 hours of diminished circulation and yet recover completely when circulation is restored. Most other organs and tissues are between those extremes. Most tissues can recover if repair is accomplished and the blood supply is restored. There will be a scar at the site of repair, but normal or almost normal function will still be possible.

Nervous tissue presents a special case. Even if damaged brain heals, function might not return. Damage to the brain can result in epilepsy, owing to the scar in the healing process.

The spinal cord does not heal to the extent that function returns if it has been cut or severely contused. Hemorrhage or inappropriate movement of the body (the so-called second injury) can destroy function that had been spared by the initial injury; bedsores, lung and urinary infections, and skeletal contractures are all too frequently the affliction of the inadequately treated paraplegic.

Peripheral nerves might regenerate if they are carefully repaired, but the process is extremely slow, often requiring 1-2 years for regrowth. In the meantime, tissues distal to the point of injury are paralyzed and undergo severe atrophy. Frequent physical therapy might prevent some of the atrophy and has led to major improvement in patients with injured nerves.

The whole class of skeletal injury comes under the heading of physical alterations that cause major problems—from milder injuries that cause a greenstick angulation or accentuate intervertebral disk degeneration, through hip fractures and hand injuries, to major injuries that dislocate the spine or sever a limb. The optimal management of all these involves research into microsurgical methods of repair, the use of synthetic prosthetic materials, and the introduction of methods that not only restore function early, but prevent late degenerative changes.

Loss of an Organ

Obviously, some organs can be lost without killing a person, including limbs, spleen, a kidney, ovaries, and testes. But the loss of others cannot be survived, such as the brain, heart, and liver. Sometimes, an organ is damaged severely enough to suggest that its function will be temporarily lost, but physical repair is possible. Examples are a smashed liver, kidney, pancreas, and lung. In such a case, we need to tide the patient over for a few days or a few weeks, until repair has occurred; e.g., if a damaged kidney is in failure, dialysis allows survival of the patient until renal function is restored.

CONCLUSIONS

Injury can be superficial or deep, and it can affect one organ or area of the body or several organs or areas.

Acute treatment of the injured demands a special approach. It requires a team effort, often involving several specialists who lend their expertise in particular organ systems. Injury is a time-demanding phenomenon whose peak incidence is late in the day and on weekends, when hospital staffing is minimal.

There is a need for designated centers for the management of the severely injured. Many hospitals and many physicians cannot manage the complexities of the severely injured, nor should they be able to. As important as knowledge are the backup facilities, including well-stocked blood banks, computed tomographic scanners, and capacity for cardiopulmonary bypass and renal dialysis.

We have come a long way in the last 40 years in the management of injury, but much remains to be learned.[7] Table 5-1, at the end of this chapter, summarizes what we know in a broad, general way and what we need to learn. Not every known or needed item is listed; the intent is to present rather broad categories, to demonstrate the desperate need for research in a variety of problems that affect the care of injury victims.

We have tried in this brief chapter to show where we are and to suggest some of the things that need to be done. Only through continued research will these problems be solved. We must recognize that injury is an epidemic. The same effort and funding for research should be applied to it that we would apply to any other health problem that is attended by similar morbidity and mortality.

RECOMMENDATIONS

1. Long-term collaborative studies should be instituted by epidemiologists, statisticians, biomedical engineers, trauma physicians, rehabilitation physicians, behavioral scientists, and health economists, to identify and evaluate factors that produce optimal results, to identify factors that result in less than optimal results, and to institute programs for promulgating optimal management techniques.
2. Programs in basic research should be instituted and supported, in collaboration with morphologists, biochemists, membrane physiologists, pharmacologists, neurobiologists, bacteriologists, virologists, and others, to study shock, infection, tissue responses and healing, and brain and spinal cord swelling.
3. Biomedical and biomechanical programs should be instituted and supported in relation to injury mechanism and prevention and the development and evaluation of biomedical materials, including prostheses and artificial organs.
4. Clinical studies should be instituted and supported in development and evaluation of pharmacologic options, surgical techniques, and management options.
5. Programs designed to train professionals in the research and care of injury should be instituted and supported.

TABLE 5-1 Summary of Known and Needed Information Regarding Treatment for Injury

Known or Available	Unknown/Needed
Shock	
Crude knowledge of the effects of loss of blood volume on some organs, such as heart, brain, kidneys, and liver; this has improved the ability to resuscitate many, but not all, patients.[9 42 47 109 211]	New knowledge on how cells function in shock. what internal mechanisms fail? What can we do to prevent or correct cellular dysfunction in shock?
Metabolism	
Much has been learned about integrated organ response to injury; we know how some organs respond to injury and stimulate others, this permits us to look for responses to prevent or correct them; the process of integrated organ function, generally termed "neuroendocrine response," appears to be mediated from injured tissue through the brain.[62]	Knowledge of which systems are turned on. How much is for patient's benefit, and when should some or all systems be turned off? What support can be supplied, if needed, by various therapeutic maneuvers?
Infection	
Rapid identification of bacteria and determination of their sensitivity to antibiotics are possible; there is some understanding of what infection does to host in a general way (septic death) and some knowledge of bodily defenses against infection; local and systemic immune responses are known.[4]	Role of fungi and viruses in injury. What antimicrobials can be developed to control them? Is immune response always helpful? Should it be manipulated for patient's benefit? How do microbes attack cells and systems? Why do cells and systems fail in presence of some microbes and not others?

Known or Available	Unknown/Needed
Open wounds	
Quite a bit is known about general management of wounds. Healing process is understood in general way. Role of foreign bodies in wound has become clearer, as has management under these circumstances.[115]	What controls healing process? Why do some wounds fail to heal and others develop excessive healing (pileup scar)? Can healing process be instituted in non-healing wound?
Brain	
Severes: Need to control intracranial pressure is universally accepted. Urgency of surgical removal of intracranial blood clots and management of pressure with mannitol is accepted. Useful international classification and international cooperation are developing. Insight into dynamic and physiclogic consequences of injury is coming from animal models and clinical studies. Some basic information is available on dynamics and morphology of brain swelling.[2 6 16 17 22 28 41 64 66 99 109 112 119 117]	Severes: Comparison of present systems of optimal on-site care, transport, e.g., West Germany and southern Sweden. Intracranial pressure monitoring. and emergency management with those developed in other countries, Role of controversial glucocorticoids and barbiturates in management of swelling. Role of nuclear magnetic resonance in imaging. Clinical facilities to measure cerebral blood flow. Role of neuroendocrine system and of nutritional failure. Development of teams of clinical investigators, statisticians, and rehabilitation workers to evaluate clinical methods. Establishment of several trauma centers to maximize effort directed toward specific tasks. Above all, long-term dedication to train and support core of basic scientists, morphologists, biochemists, membrane physiologists, pharmacologists, and neurobiologists to make lifetime scientific careers in studying brain swelling and nerve cell regeneration. Control of cerebral swelling (which seems imminent) should decrease mortality from injury more than any other factor.

Known or Available	Unknown/Needed
Brain	
Mild: Recent clinical, experimental, and pathologic evidence offers understanding of "postconcussion syndromes," source of major social and economic disability and of consequent litigation.[26 64 153 157 196]	Mild: Development and refinement of clinical methods for evaluating severity of injuries and of appropriate management and rehabilitation.
Spine	
Much basic information on mechanics and physiclogic dynamics of cord injury is available (animal models). Multiple slightly effective therapies are available for these models. Actual human injury involves vastly greater range of force.[99]	Clinical evaluation of most promising methods derived from animal models. Evaluation of current surgical methods to stabilize bony spine (without affecting spinal cord). Are claims for psychologic, physical, and economic benefits valid? Are there universally acceptable indications? What needs to be done to create spinal cord injury centers equivalent to those in other western countries? Basic research into swelling (as with brain). Major research goal is spinal cord regeneration (only hope for most paraplegic injuries)—task equivalent in time, effort, and feasibility to curing cancer. Current knowledge of prevention and management of second injury and prevention of bed sores, contractures, and infections needs wider dissemination and stricter application.

Known or Available	Unknown/Needed
Chest	
Mechanism of various types of chest injury is well understood. Management of injury has made progress, but is incomplete. Role of sepsis in acute respiratory distress syndrome has been somewhat clarified. Internal stabilization (respirator) has become method of choice for flail chest. Role of arteriovenous shunting can be measured and has focused attention on better methods of oxygenating lung. bung function and circulatory dynamics are better understood.[20 22 146 175 214 222]	What is best method of stabilizing flail chest? Internal or external splinting? Does internal splinting cause complications? What can be done to reduce shunting due to pulmonary contusion? Can better methods of ventilatory support be developed?
Abdomen	
Diagnostic techniques with ultrasound, computed tomographic scans, and arteriography have improved. Management of major injuries has improved. Bench repair of injuries is being tried. Transplantation offers some hope in some types of injury.[45 109]	What will magnetic resonance do diagnostically and in adding information on repair process? Better methods of repair and more effective synthetics to patch and repair organs. Support methods, such as extracorporeal liver support. Role of early feeding in repair process. Can repair be speeded up? Can intestinal function be improved? Better methods of preventing infection when intestine is opened.

Known or Available	Unknown/Needed
Genitourinary system	
Good diagnostic techniques are available. Fluid therapy to maintain renal function has improved greatly in the last 25 years.[67 69 146 212]	Better methods of repair and more effective synthetics. Simple, quick method of diagnosing renal vascular injury. Information on methods of managing neurogenic bladder. Prevention of infection in paraplegics. Bench surgery for renal repair. Simpler, more effective means of dialysis to tide patients over periods of renal failure.
Vascular system	
Good diagnostic techniques are available. Methods of repair are crude, in that hand suturing is only method of repairing vessels.[46 95]	Better nonclotting synthetics. Improved nonsuture method of connecting or repairing vessels, such as glues. Immediate fitting of prosthetic extremities. More effective prosthetics that are lighter and easier to apply. Better methods of rehabilitating amputees.
Soft tissues	
Large defects can be managed with tissue flaps, free flaps, and microvascular techniques. Infection management has improved in recent years.	More and better microvascular techniques. Improvements in transfer flaps. Increased understanding of how infection works and how to prevent and treat it. Skin substitutes. Improvement in cosmetic repair and functional recovery.

Known or Available	Unknown/Needed
Replants	
This is a relatively new approach to injury.	Improved preservation after traumatic amputation. Improved methods of neural repair. Increased knowledge of microvascular techniques.
Thermal injury	
Understanding of fluid translocation has provided better resuscitation and reduced early mortality. Airway management has improved with ventilation support, Infection control is better with new antimicrobials, substitute skin (pig and cadaver), and synthetic skin. Rehabilitation and reconstruction have shown some improvement.[9]	Information on best fluid regimen— hypertonic versus colloid. Better understanding of fluid shifts, particularly at cellular level. Increased knowledge of prevention and treatment of pulmonary problems in thermal burns. Better and more plentiful synthetic skin. Methods to speed or control wound healing. Better methods of prevention and treatment of infection. Better understanding of immune responses.
Fractures	
Good methods of management are available! nonunion is still problem, Some knowledge of healing—of what stimulates and what retards.[61]	Fracture healing, especially how to stimulate and protect. What is role of precursor cell? Of osteogenic factor? Of mineralization process? Of electric stimulation and immobilization? Information on prevention and treatment of fat embolism. Implants and synthetics to improve repair. How to manage avascular necrosis and nonunion. Can they be prevented?

6

Rehabilitation

Rehabilitation is the process by which physical, sensory, and mental functional capacities are restored or developed after damage. In the context of injury control, rehabilitation is the process by which biologic, psychologic, and social functions are restored or developed to permit an injured person to achieve maximal personal autonomy and an independent noninstitutional lifestyle. Rehabilitation is achieved not only through functional change in the person (e.g., development of compensatory muscular strength, use of prosthetic limbs, and treatment of postinjury behavioral disturbances), but also through changes in the physical and social environment, such as reductions in architectural and attitudinal barriers that hamper those requiring use of a wheelchair.

In the last decade, improvements in emergency medical systems, in immediate management by trauma centers, and in care of the injured en route to hospitals have increased the survival of persons with nervous system injuries, multiple injuries of the musculoskeletal system and viscera, or extensive burns. Trauma units have increased the need for defined referral to special rehabilitation programs and follow-up services. More persons survive major injuries, and survivors often have severely disabling effects from the injuries themselves and from untreated complications. Many need functional restoration of cognition, sensation, movement control, and mobility after brain, spinal cord, and musculoskeletal injury. Further negative effects on health and performance in daily life that result from the loss of body parts and from inactivity and immobility must be prevented.

The increase in rate of survival after nervous system injury was a natural consequence of the merger of medical and allied interests, knowledge, and technologies developed during and after World War II. Experience with the early care and rehabilitation of persons with war injuries led to a new emphasis on the establishment of multidisciplinary centers like the spinal cord injury centers in Veterans' Administration hospitals. Specialists in physical medicine joined orthopedic surgeons in developing restorative and reconstructive surgery. They directed hospital units for rehabilitation. Free-standing and hospital-based civilian rehabilitation hospitals and centers promoted academic development by means of exemplary service, research, and training in medical rehabilitation, physical and occupational therapy, rehabilitation nursing, social work, speech therapy, psychologic services, orthotics and prosthetics, vocational counseling, and rehabilitation engineering. These specialized programs rapidly demonstrated the benefits and loss prevention possible through the use of organized restorative and rehabilitative care in controlling disability and maximizing use of residual capabilities.

Rehabilitation units found improved methods for amputations, prosthetics, and management of multiple musculoskeletal injuries and neurotrauma. Reconstructive surgical procedures evolved in orthopedic and plastic surgery for improved function and correction of deformities. Therapies of medical origin, physical and occupational therapies, and psychologic, social, vocational, and behavioral techniques were developed. Peer counseling of successfully rehabilitated persons promoted the use of restored functions in daily life, and that led to independent noninstitutional living. The increase in clinical experience with major burns and their continued occurrence in industrial and home settings promoted the development of regional burn centers.

With comprehensive care, the profound biologic, psychologic, and social responses to paralysis and movement disorders, disfigurement, and loss of body parts are controllable to a remarkable extent. Although limited resources for clinical programs have been provided through private and publicly supported efforts, parallel research and educational resources for the development and dissemination of knowledge and technology have been seriously inadequate. The development of expanded special regional centers and programs has been lacking for the large number of unserved persons who could benefit.

The evolution of needed basic and clinical research directed to clinical problems of rehabilitation and to the development and application of technologies for better mobility, environmental control, and replacement of sensory deficits has been supported at a rate of one-thousandth or less of the funding for research in curative medicine. The emphasis has been on investigator-oriented basic research, in contrast with program-oriented and center-based cross-disciplinary research by scientists, engineers, clinicians, and behavioral and social scientists to solve problems in and evaluate postinjury and rehabilitation care. Many important research questions and activities have been identified, but only a small fraction are fundable in traditional ways.

The use of effective methods and procedures for improving clinical care is not widespread. The technologies and methods of care available in trauma centers and rehabilitation centers are available to few victims. Failure to control the preventable consequences of injury through treatment and rehabilitation results in a needless yet major health care cost to society, as well as losses due to the effects of injury on the patient, on the family, and ultimately, as a public and socioeconomic burden, on all of us. Yet, for every dollar spent on rehabilitation several dollars are saved by state and federal governments.

Among persons severely disabled from all causes, including injury, approximately 1 in 10 of the newly disabled uses rehabilitation facilities. There are 15 regional spinal cord injury centers, and less than 10 percent of the 5,000-10,000 persons with new spinal cord injuries every year enter a system of care pioneered by these centers.[223] Help to brain-injured persons is even less.

For example, in the greater Houston area of 3.5 million persons, with three major trauma centers, the incidence of new spinal cord injury is 50 per million of population, or 175 persons per year added to approximately 1,500 survivors on hand. There are 5 times as many brain-injured persons, or 875 new ones per year, with several thousand survivors estimated in the last decade.[37] [93] For the head-injured, there are only 45 organized "center" beds in two institutions, and fewer than 100 persons are admitted per year.[133]

Neurologic injury is probably the most costly kind of injury and produces a great need for more organized systems of acute, subacute, restorative, and rehabilitative care. As with burn care, such a system must build on specialized knowledge, skills, experience, and technology with continuity of service and follow-up. Rehabilitation and independent-living service can provide deinstitutionalization for more than three-fourths of the patients; the cost of this over a lifetime is estimated at one-tenth the cost of custodial care with repeated hospitalizations.[120 133]

The data base for the spinal cord injury center program among the 15 regional centers revealed that the intake and follow-up process saved one-third of first-cost dollars, achieved home placement in 85 percent of over 6,000 first admissions, and decreased the incidence of complications and later hospitalizations for complications.[223] The relatively low incidence and prevalence of neurologic injuries, multiple musculoskeletal injuries, and burns fail to imply how important and costly the problems that result can be. In fact, this situation is the emerging important issue of injury. The social and economic impacts on the patient, the family, the community, and the state and nation are substantial. There are no aggregate statistics on the lifetime impact of these conditions. The problem has become more frequent and complex in the last 10 years, because survival with residual disability of the injured has increased. There is no mandatory reporting for even the occurrence of these conditions or the attendant disability, as there is for births, deaths, or even vehicle registration. We count expenditures as health care costs and transfer payments for disability. But we have failed to use losses prevented and costs decreased by improved care as factors in benefit-versus-cost estimates for rehabilitation.

Accounting must omit the intangible and the uncounted. Yet, the consequences are found in the fabric and activities of our family life, our productivity, and our community life and in the loss of pride in connection with the values we profess as a nation—independence, quality of life, and pursuit of the opportunity to be an equal member of society. Perhaps the implicit threat of disability, unlike the inevitability of death, is a hidden concern that causes us to turn our heads away from its possibility until it strikes us or one we know and love. Because of the current long-term survival with disability, we cannot afford to be unprepared to prevent the losses of function after injury.

RESEARCH ISSUES AND NEEDS

Proper and enlightened management during pickup and delivery to trauma centers and during hospital care can profoundly reduce the extent of disability and prevent complications that would retard later rehabilitation. Therefore, rehabilitation of an injured patient and prevention of and early care for injuries pose inseparable questions for research policy. The goal of injury care should be not simply to achieve medical stabilization, but rather to minimize disabling effects and complications. The goal is not accomplished fully until the injured person achieves the maximal possible functional effectiveness in all aspects of life, including daily living, work, education, and recreation. Systems of care for patients with spinal cord injuries that coordinate management from the site of the injury through trauma center care, intensive rehabilitative treatment, and transitional services, to independent living are proving more humane and cost-effective than uncoordinated efforts.[60 133 152]

Too often, knowledge of effective rehabilitation goes unused. The following discussion illustrates the spectrum of issues and conditions that requires both research and the application of existing knowledge.

Musculoskeletal Injuries

Musculoskeletal injuries are among the most common injuries. Evaluations of causes of work disability indicate that, in persons 16-65 years old,[185] musculoskeletal conditions are the predominant cause of loss of work and eligibility for social security disability benefits and unemployment compensation. Back disorders are most common, but serious musculoskeletal injuries are apt to prolong disability—fractures, amputations, and hand injuries. According to a recent document of the American Academy of Orthopedic Surgeons[5] on current and future research needs, "approximately one of every eight beds in general hospitals in the United States is occupied by an accident victim, and injuries involving the musculoskeletal system are the most frequent sustained by that group of victims." These injuries include joint dislocations, extensive soft-tissue swelling, rupture of tendons, injuries to nerves, and damage to major blood vessels. This document further states: "Approximately sixteen million significant upper extremity injuries occur each year, which are responsible for ninety million days of restricted activity and sixteen million days of lost work." Similarly, injuries to the musculoskeletal system are the commonest injuries in athletics and sports recreation. Spinal cord injury associated with athletic and recreational activities accounted for 12 percent of 5,635 cases of spinal cord injury in which patients were rehabilitated in spinal cord injury centers from 1973 to 1981.[223] Musculoskeletal and neurologic injuries of all types result in severe work disability (65 percent) in our working-age population (127.1 million persons in the United States in 1978). The other personal and family losses are inestimable, uncounted,[185] but real.

Pathophysiology of Soft-Tissue Injury and Nerve Regeneration

Effects of soft-tissue trauma at the molecular and cellular levels overlap basic research on tissue injury described in Chapter 5. Studies on the pathophysiology of muscle, nerve, and microcirculatory (and lymphatic) systems during and after increases in tissue pressure are needed. Mechanisms of nerve regeneration and repair in the peripheral nervous system and the effect of electricity on nerve regeneration have been insufficiently studied.

Fracture Healing Processes

Fracture healing processes are not fully understood. Research is needed on injured bone with regard to the origin of the precursor cell of osteogenesis, the chemical nature of the bone-inducing substance (s), its mechanism of action, the organic matrix elements of bone, and the cellular control mechanisms of bone mineralization.

Fracture Nonunion

Nonunion, or failure of a fracture to heal, is a serious and disabling complication of fracture repair. Studies of causes and predisposing factors are needed, with evaluation of treatment. The usefulness of engineer ing techniques for prevention or treatment analysis, the effect of bioelectricity, and the development of biomaterials that could bridge nonunion sites and promote bone growth are important in restorative surgery and for restoration of function.

Microsurgical Techniques

Replantation of amputated parts and transplantation of vascularized and innervated muscle and bone flaps can be improved. Tissue perfusates and microvascular repair techniques that promote healing need to be identified.

Structural and Ultrastructural Anatomy

Efforts to identify the structural and ultrastructural anatomic details of bone, disk, ligaments, and joints of the spine need support. Measurements of motion in normal and injured states in all spinal segments and knowledge of muscular control of segmental motion are needed for a mathematical model to test effects of forces, loads, and supports.

Bioengineering and Biomaterials

Ideas and technologies are needed to predict the interaction of artificial materials and structures with natural biologic tissues—such as cortical bone, cancellous bone, and cartilage—so that the effects of metallic internal fixation devices, joint prostheses, etc., can be learned. Improved designs and fixation factors of prosthetic devices are needed. Studies are needed for measurement of real forces and motion patterns and for testing the strength and fatigue of prosthetic components. Use of theoretical modeling techniques should be explored to improve configuration, positioning, and interface characteristics of prosthetic implants.

Burns

Burns accounted for 100,000 hospitalizations in 1976, according to the only recent study (C. D. Herndon, personal communication). It was estimated that 50,000 persons per year were disabled because of burns.

In the opinion of physicians specializing in burn therapy, there have been few advances in treatment of inhalation injuries in the last 20 years (C. D. Herndon, personal communication; Michigan Burn Data Exchange Center, personal communication). Extensive rehabilitation is required of survivors of major burns to control contractures that limit, for example, useful hand and arm movements, facial expression, and intelligible speech. Therapy is needed to minimize scarring and thus permit mobilization of joints after surgery; disfigurement hinders social acceptance of the burn victim. Specialized resources for comprehensive burn treatment and rehabilitation were first established by the military, and more recently centers were established for children by the Shriners. Several tertiary referral hospitals with burn centers have added burn rehabilitation programs, as have some rehabilitation centers. An accessible rational system does not exist for all burn victims.

Many experts in this field consider research needs to be extensive and greatly underfunded. There have been very few rehabilitation-related research efforts. Most research has been related to grafting and debridement techniques and the management of acute injury. There is need for evaluation of alternative methods of management both immediately after injury and later.

Pathophysiology of Fire-Related Gas Inhalation

Basic and clinical research on the pathophysiology and treatment of pulmonary insufficiency and failure caused by inhalation of toxic fire-related gases—the greatest cause of death from fires—is urgently needed. Long-term pulmonary scarring and ventilatory insufficiency greatly affect exercise capacity and need to be minimized for effective rehabilitation.

Problems in Cutaneous Debridement and Replacement

Clinical research for comparative evaluation of long-term disabling effects of alternative methods of debridement—early and late and with different techniques to identify viable tissue in third-degree burns with early debridement of dead tissue—is important for successful grafting and control of extent of debridement and secondary infection. More research on technology for mass production of homologous skin-cell culture, etc., is needed.

Prevention and Control of Tissue Contractures and Hypertrophic Scarring

Comparative evaluation of methods for control of contracture formation—e.g., early splinting and pressure bandaging—is needed, as well as basic research on methods for inhibition of excessive collagen formation in scarring.

Disabling Pain

Disabling pain that retards activity, purposeful movements, and ambulation and that is occasioned by dressing changes, periodic debridement, reconstructive surgery, and grafting requires basic and clinical research on alternative methods of pain control, including electric stimulation of the spinal cord.

Psychosocial Research and Prosthetic Methods

There has been little research on the behavioral and social aspects of burn disfigurement with respect to patient reactions and effects on parents and siblings — e.g., the consequences for schooling and vocational opportunities. Children seem to adapt better than adults, but the reasons are not known. The role of facial and missing-part prostheses has not been evaluated on the basis of materials, cosmetic success, utility, etc.

Second Injury of the Spinal Cord

Second injury of the spinal cord after injury of the neck vertebrae is tragic, not uncommon, and preventable. Second injury can occur at the time of emergency pickup, during initial emergency hospital treatment and evaluation (e.g., during x-ray examinations), and even later, as a result of failure to recognize severe vertebral instability.

Major malpractice suit settlements often result from failure to prevent second injury. For example, in 1975 a judgment of approximately $1.5 million was awarded against a Veterans' Administration hospital for its involvement in causing second injury to a patient with neck instability after a motor-vehicle collision.[55] That award equals approximately one-fifth of the entire 1984 Veterans' Administration budget for rehabilitation and engineering research.

Training

Training of ambulance and emergency medical technicians and emergency room staff and technicians can reduce the frequency of second injury.

Transportation

Devices for safer transport of neck-and-head-injured persons are being developed and need to be evaluated, produced, and distributed, but little or no funding is available.

Preservation of Spinal-Cord Function

Not all injured spinal cords believed to be completely severed are devoid of residual functional neurones and connections to higher levels of the brain and lower levels of the spinal cord. Recent clinical neurophysiologic research on 2,000 persons with spinal cord injuries has shown that nearly two-thirds of so-called complete injuries, in fact, are not complete.[50] Involuntary-movement disorders like spasticity overlie and conceal residual voluntary-movement control and sensory functions. Even late disorders of the injured spinal cord, such as dissecting cystic swelling in the central cord, can be diagnosed early and treated surgically to limit further loss of function.

The scientific and intellectual effort required to "cure" spinal cord injury is akin to a total cure of cancer in scope and resource needs. It represents one end of the spectrum of research need. Waiting for a "cure" will leave millions of persons unable to achieve what human adaptive capacities make possible with proper rehabilitation, a less handicapping living environment, and an opportunity to recover personal autonomy through control of one's life. Both basic experimental research and clinical neurophysiologic studies of persons with brain and spinal cord injury reveal extraordinary adaptability of the brain. Recovery of lost motor control, control of abnormal central nervous system activity, and training for motor relearning through the use of other systems and pathways of the nervous system are all feasible to a degree—generally unrecognized and rarely facilitated. These become the new potential processes for improving basic human adaptability.

Preservation of Residual Function

Much research remains to be done on preservation of residual function and control of neurologic functional disturbances to regain bladder control and useful movement.

Nerve Regeneration

Basic animal research has already demonstrated some features of central nervous system regeneration. Tissue implants of peripheral nerves in the central nervous system show some potential for reconnection across surgically produced gaps in neural connections.

Pressure Sores

Failure to prevent pressure sores in the acute phase of injury or at any time during the course of disability creates misery, debilitation, and social and economic losses. This entirely preventable complication occurs in 35-40 percent of persons with spinal cord injury who have sensory and motor losses.[223] It may develop in the first weeks after injury or later, even in young adults actively engaged in school, work, and recreation. It is very common among elderly bedridden persons in custodial care. The costs of hospitalization, surgical skin repair, and control of infection (which can proceed to chronic severe osteomyelitis, even requiring amputation) now average $25,000-$28,000 per pressure sore.[102] An estimate of the direct costs in hospital and medical care is about $1.5 billion a year. The magnitude of loss of income due to prolonged and recurrent hospitalization is unknown, but is at least as much.

Management of Pressure Sores

More clinical research, development of care systems that use what is known, and augmentation of training are urgently needed.

Consequences of Injudicious Injury Care

The failure to anticipate and prevent a variety of metabolic, circulatory, respiratory, genitourinary, and musculoskeletal consequences of inactivity and immobility prolongs expensive care, delays active rehabilitation, and leads to failure to regain a state of health and preservation of residual functional capacity for purposeful activities. Injudicious timing of surgical intervention can augment postinjury stress responses and lead to such life-threatening complications as massive bleeding, uncontrollable infections, and respiratory insufficiency and failure.

Management of Sequelae

Research is needed on ways to protect residual neural tissue viability and to control serious complications that make rehabilitation difficult or impossible.

CONCLUSIONS

A national effort is needed to achieve appropriate emphasis on disability-related basic and applied research, technologic research and development, service systems, education and training, and social understanding. Great savings and increased quality of life would result from improved application of what is already known, but there is a need for substantial increases in research in many subjects. Table 6-1, at the end of the chapter, summarizes what is known and what is needed in rehabilitation research.

The prevention of disability provides some of the economic fuel for continued research on long-term approaches to minimizing the costs and losses incurred in disability. Social and economic losses due to injury-initiated disability and chronic medical care and institutionalization could be prevented, and that would yield funds for other health purposes. In addition, restructuring of the physical environment to reduce social and economic losses caused by failure to include handicapped persons of all ages in community life will help injury victims. Long-term institutionalization of able-bodied young adults who could be self-sufficient is the poorest possible solution, but it is the most frequent one today.

RECOMMENDATIONS

The following are some recommendations that, if implemented, would substantially reduce disability due to injury in this country. Not all are stated in the form of *researchable* questions, although many lend themselves to various kinds of research, demonstrations, evaluations, and increased use of existing knowledge. Research is not the sole solution to key issues in public policy needed for control of a problem as complex as comprehensive rehabilitation of injury victims.

1. Major research centers should be developed for clinical neurophysiology programs on evaluation and management of neural injury residua, neural system function, and technologic replacement of lost function.
2. Funding priority should be given to research on the identification and preservation of residual functions, development of substitute functions, psychosocial management of the patient and family, and deinstitutionalization.
3. Research programs aimed at minimizing the effects of injury to the musculoskeletal system, including both bone and soft tissue, that result from physical, chemical, and thermal causes should be promoted.
4. Research programs should be established in the behavioral and social sciences for cross-disciplinary studies of adaptive behavior and its relationship to brain function in environmental adjustment and learning.

5. Wider application of existing knowledge related to rehabilitation and prevention of second injury is needed.
6. Development and evaluation of model systems of rehabilitation should be promoted.
7. Research should be greatly expanded on behavioral and social factors related to stigmatization of and discrimination against the disabled.
8. A system is needed that can identify disabled persons and persons with injuries that are likely to produce severe disability, so that services for those who might benefit can be planned. Linked local, regional, and national reporting systems for the disabled are necessary to go beyond social security studies limited to work disability; these systems could be built into the surveillance system recommended in Chapter 2.
9. Hospitals and physicians and surgeons managing injury cases should be provided with communication networks for reporting, obtaining information, and arranging triage, therapy, and referral.
10. Professional education and experience should be revised to include familiarity with model *trauma* centers and comprehensive rehabilitation centers.

TABLE 6-1 Status of and Deficits in Rehabilitation-Related Research

Known or Available	Unknown/Needed
Control of disabling complications: Role of inactivity and immobility; effects of conventional treatment on cardiopulmonary musculoskeletal metabolic and stress effects, including pressure sores and infection.	Understanding of how to provide effective prevention and treatment during active physical rehabilitation and after deinstitutionalization in habitat, work, and recreational settings; methods for individualizing reactivation, energy expenditure, use of protective and energy-conserving activities and devices, and pressure-relief systems.
Use of anticipatory management: Amputations; improving Successful use of prosthetics; reconstructive microsurgical, macrosurgical, and plastic surgical and nonsurgical procedures for skeletal immobilization; functional mobility for self-care, environmental control, physical and occupational therapy.	Understanding of how to achieve wider use through demonstration models for educational revisions and postgraduate training; improved technology and assessment procedures for effectiveness and for innovations in procedures; biomaterials technology for transplantations, artificial joints, and internal instrumentation; improvement in structure, stability, function, and cost of care and cosmetic devices.
Techniques for prevention of contractures, muscular atrophy, and skeletal deformity: Available modular orthotic systems for hand, arm, back, and leg control and protection and use of residual controllable muscle strength	Knowledge of mechanisms of tissue contractures, muscular atrophy, and Joint fixation limiting residual motor power; control of bony demineralization with reduced strength and losses of living activities (from falls and transfer injuries);

Known or Available	Unknown/Needed
	research on effectiveness of early activities of living and postural weight-bearing effects on collagen structure and function; utility of new types of temporary corrective splints for deforming forces, and use of functional electric stimulation.
Restoration of function and use of residua: Existence of hidden residual voluntary motor control and mechanisms for production of involuntary movement, spasticity, etc.; various surgical, microsurgical, and neurosurgical techniques; medical treatment, e.g., external and implanted electric stimulation to control spasticity and pacing ventilation and biofeedback techniques in neurotrauma treatments pharmacologic and cognitive retraining systems and technologies for the brain-injured.	Means of selecting persons with potential to benefit; studies of comparative cost-effectiveness of alternative treatments; creation of model tertiary evaluation and treatment referral centers aimed at individualized selection and new treatments and technologies as well as at research, education, and dissemination of results to handicapped persons and professionals.
Devices and systems to replace missing functions: Sensory substitutes for deaf, blind, and deaf and blinds environmental control systems for paralyzed; vehicle control systems, safety designs for access and egress.	Development, testing, pilot production, and distribution; financing of devices and systems, both simple and complex, such as technology for reading and communication; affordable robotic systems and understanding of adaptive factors defining appropriate use of assistive devices and systems and long-term adaptations.
Bioelectric prostheses	Research on combined orthotic and functional electric stimulation systems for safe walking.

Known or Available	Unknown/Needed
Orthotic systems	New techniques to stabilize head and neck movements after injury during healing and to permit early activities.
Mobility systems	Less expensive powered wheelchairs; new seating and posture designs to minimize pressure sores.
Pressure sore control and prevention	Development of research results into widely available systems to prevent pressure sores; training centers for care personnel with wider use of audiovisual aids; self-management resource centers for handicapped persons (independent-living centers).
Self-care technology	New independent living to aid kitchen, bathing, and similar activities of daily life; self-care equipment usable by handicapped persons of all ages, including elderly.
Physical, environmental, and social attitudinal handicaps: Design standards for physical-barrier reduction and for transportation system access.	Development of performance standards to permit wider variation in workable solutions for homes, commercial buildings, and public transportation; further architectural research and development to simplify retrofitting of existing buildings.

Known or Available	Unknown/Needed
Origin and reinforcement or diminution of social attitudes and behaviors	Sociologic and psychologic research with prospective designs and evaluation of alternative educational, informational, and behavioral modification research to reduce discrimination in education, job placement and Job retention, recreational access, etc.
Service delivery system: Service delivery models and systems restricted primarily to spinal cord injury.	Uniform reporting systems; reporting of disability days from severe disabling injuries, as death and morbidity are reported; development and cost effectiveness evaluation of tertiary rehabilitation treatment systems connected to trauma centers for management of brain-injured, brain- and spinal-cord injured, and multiinjured persons.
Regional technology delivery systems	Establishment, operation, and evaluation of regional technology service centers for information dissemination, prescription, use training, maintenance, and follow-up; research and development for practical applications of high- and low-technological devices and systems for mobility, controls, self-care, environmental controls, communication, and sensory and movement substitutes.

Known or Available	Unknown/Needed
Financing of comprehensive restorative and rehabilitative services	Study of effect of alternative financing schemes, such as DRGs and prepaid systems, on access and availability of rehabilitative care; studies of employment incentives and disincentives by rehabilitation services and in acute hospitals and of early referral to rehabilitation centers.
Independent-living centers and services	Expansion of urban and rural independent living systems of support and services and role of community centers and studies of cost-effectiveness with respect to long term care, nursing-home care, and conventional vocational rehabilitation services and assistance; studies of effectiveness of independent-living centers and services in promoting deinstitutionalization and reducing economic and social costs; alternative methods of financing separate from medical care model; study of effect of current laws, policies, and administrative procedures on availability of access to and completeness of financial support, with study of economic and social benefits.

7

Current Federal Expenditures for Injury-Related Research

The committee was charged to determine, to the extent possible, the adequacy of total federal funding of the major kinds of trauma research and to explore the importance of private research and funding contributions from private, nongovernment sources. This chapter describes the extent of support from the various federal agencies and categorizes them according to the types of research that the committee has identified as necessary if the nation is to move toward reducing injuries and injury-related deaths.

The motor-vehicle and insurance industries support some research, mainly on motor-vehicle injuries, but the support is modest relative to the need. We know of no major source of private funds for research on injury. In contrast, large amounts of money are raised by private groups interested in cancer, heart disease, and respiratory diseases. Although no private organization, even one as large as the American Cancer Society, can alone support a large portion of the research in the subject of its interest, private organizations do play a critical role. They can provide seed money for the initiation of research centers. They can support innovative research that has not received attention from the federal agencies. As important, but not as tangible, private organizations focus interest on various subjects and keep the public, the federal agencies, and the Congress aware of the importance of those subjects. Whether a major fund-raising effort for injury research comparable with that devoted to the noted diseases is feasible in a society where mailboxes are clogged with computerized appeals to support all sorts of causes is problematic.

To assess current federal support for injury-related research, the committee reviewed research expenditures in relevant federal agencies during the 1983 fiscal year. The agencies were asked to respond with lists of projects and budgets; these were supplemented by a search of records in a few instances where it appeared that the work of some agencies was not listed. This survey was not exhaustive, but it is unlikely that major expenditures were overlooked. The survey was based on reports of projects from the agencies and computerized indexes of research expenditures. This summary deals only with expenditures by civilian agencies. Much of the information from the military services was too sketchy for refined categorization. Some of the military research might be relevant to the prevention and treatment of civilian injuries, but most of the military research is oriented to military operational activities, such as the Air Force's development and testing of pilot ejection seats.

Each listed project was coded according to the interests outlined by the committee, which are substantively reviewed in the individual chapters of this report: epidemiology, prevention, biomechanics, treatment, and rehabilitation. Many projects deal with more than one category; in such cases, the committee determined the major emphasis of the research and assigned a code accordingly. These data are mostly from fiscal 1983 budgets, but that is ambiguous in some cases.

Expenditures for research in the various aspects of injury epidemiology are presented in Table 7-1. Most of the funds allocated to epidemiology were expended on surveillance programs both for research purposes and for identifying problems to be addressed by regulatory agencies. The major expenditures were related to motor-vehicle injuries and those associated with some other consumer products. The Fatal Accident Reporting System (FARS) and the National Accident Sampling System (NASS) developed by the National Highway Traffic Safety Administration (NHTSA) are designed to monitor trends in motor-vehicle fatalities (FARS) and nonfatal crashes (NASS). Both are used extensively by extramural researchers. The National Electronic Injury Surveillance System (NEISS) is the major research activity of the Consumer Product Safety Commission. Through NEISS, a sampling of hospital emergency rooms provides information on consumer products (with exceptions, such as motor vehicles and firearms) that are involved in injuries treated in hospitals. Relatively small amounts were expended in fiscal 1983 to document psychologic consequences and calculable dollar

TABLE 7-1 Federal Support for Research on Injury Epidemiology in Fiscal 1983

Subject and Source of Support	Thousands of Dollars
A. Incidence and severity	
Federal Aviation Administration	193
National Highway Traffic Safety Administration	7,526
National Institutes of Health	988
Centers for Disease Control	160
Consumer Product Safety Commission	2,999
B. Costs	
National Institutes of Health	104
C. Psychologic consequences	
National Institute of Mental Health	245
D. Methodology	
National Highway Traffic Safety Administration	9,104
National Institutes of Health	810
E. Behavioral factors	
National Institutes of Health	27
Alcohol, Drug Abuse, and Mental Health Administration	975
National Institute of Occupational Safety and Health	115
F. Product-related factors (e.g., guns, cars, industrial machines)	
National Highway Traffic Safety Administration	1,241
National Institutes of Health	79
National Institute for Occupational Safety and Health	99
G. Social environmental factors	
National Institutes of Health	432
H. Physical environmental factors other than products	0
TOTAL	25,097

costs of injuries. The relatively large amount listed under "Methodology' includes capital funds for computers and computer time that are no doubt used for a variety of tasks in addition to processing and maintaining injury surveillance data.

In addition to surveillance, epidemiology includes studies of factors involved in initiation and severity of injury. Categories E through H in Table 7-1 refer mainly to field research. Behavioral research was directed primarily at the effects of alcohol and drugs on injury incidence. Relatively small amounts were expended to study the effects of vehicle and environmental factors as causes.

The major expenditures for prevention research (Table 7-2) were provided by the Federal Highway Administration (FHA) and NHTSA. They were directed at the behavior of motor-vehicle operators and pedestrians and at modifications of motor vehicles and road environments that would prevent collisions or ameliorate their severity. Almost two-thirds of the National Institutes of Health (NIH) expenditures for research on preventing injurious behavior was for evaluations of measures to counter driving by alcohol-impaired persons—the type of research that would normally be supported by NHTSA. Despite the remarkable success of vehicle and environmental modifications in reducing fatalities and severe injuries, such as the reduction in deaths of children caused by falls from tall buildings in New York,[18] very little investigation of that type of prevention of other than motor-vehicle injuries was supported in fiscal 1983. The major efforts were NHTSA's crash-testing programs listed under "Product-related factors" and programs in FHA on roadside hazards, listed under "Environmental factors." The FHA effort on implementation of safety research and development, listed under "Organization and delivery," is also a noteworthy exception to the general lack of effort in that subject.

The funds devoted to injury mechanisms and biomechanics are shown in Table 7-3. A substantial proportion of the NIH allocations is directed at basic science in pursuit of spinal cord regeneration and understanding of the consequences of injury at the cellular level. The categories and dollar amounts in some instances suggest more activity in the research discussed than was seen to be the case when the project descriptions were examined in detail. For example, virtually none of the NIH funding under "Mechanisms" was directed at research in biomechanics. Support of research

TABLE 7-2 Federal Support for Research on Injury Prevention in Fiscal 1983

Subject and Source of Support	Thousands of Dollars
A. Behavioral factors	
Coast Guard	150
Federal Highway Administration	3,220
National Highway Traffic Safety Administration	2,394
National Institutes of Health	910
National Institute for Occupational Safety and Health	63
B. Product-related factors	
Federal Aviation Administration	637
Federal Highway Administration	450
National Highway Traffic Safety Administration	7,293
Consumer Product Safety Commission	320
C. Environmental factors	
Coast Guard	318
Federal Aviation Administration	181
Federal Highway Administration	7,305
National Institutes of Health	48
National Institute for Occupational Safety and Health	141
D. Organization and delivery	
Federal Highway Administration	1,507
National Institute for Occupational Safety and Health	33
E. Host physical susceptibility (e.g., osteoporosis)	
National Institutes of Health	480
TOTAL	25,450

in biomechanics is included in the $1.7 million listed for NHTSA, and the military services contributed an unknown amount. Many projects listed by the NIH computer as injury-related were excluded from our accounting, on the grounds that the connection was not evident in the project abstracts. These included projects investigating psychic "trauma" not related to physical injury, laboratory "accidents" involving biologics, birth injury, and the like. Had the NIH computer totals for "trauma and injury" been used without project-by-project examination, grants for cancer center core support, aplastic anemia centers, etc., would have been included. Some of the included projects are of questionable relevance, but they do deal with infection, which often complicates the outcome of injury.

TABLE 7-3 Federal Support for Research on Injury Mechanisms and Biomechanics in Fiscal 1983

Subject and Source of Support	Thousands of Dollars
A. Mechanisms	
National Highway Traffic Safety Administration	1,676
National Institutes of Health	5,891
National Institute for Occupational Safety and Health	570
B. Biologic response and adaptation	
National Institutes of Health	13,142
National Institute for Occupational Safety and Health	21
Veterans' Administration	3,039
C. Secondary consequences (infections, etc.)	
National Institutes of Health	6,002
TOTAL	30,341

Research expenditures relevant to treatment of the injured are indicated in Table 7-4. All such funds in fiscal 1983 were allocated for technology, such as surgical techniques and devices. No funds were allocated directly for training or for organization and delivery of services, although some of the funds for multidisciplinary centers include such research. All the funds allocated for treatment research were directed at treatment in hospitals. No research on emergency response and treatment at the site of the injury event was included in the data submitted to or found by the committee.

The funding for long-term care and rehabilitation, summarized in Table 7-5, was more balanced among medicine and technology, training, and organization and delivery of services than was funding for research on acute care, but the total was low, in the light of the enormous costs of taking care of persons who survive injuries with major loss of function.

In addition to the support shown in the tables, the National Transportation Safety Board (NTSB) expended $14 million for investigations, technology and safety programs in fiscal 1983 that could not be categorized because of the interdisciplinary nature of the work. Although the interdisciplinary approach of the NTSB-supported work is commendable, the lack of a sampling plan results in questionable generalizability of the findings. The investigation of fatal motor-vehicle crashes by NTSB duplicates much of the effort of NHTSA's FARS program, albeit in greater detail, but without a sampling scheme.

TABLE 7-4 Federal Support for Research on Acute Care of the Injured in Fiscal 1983

Subject and Source of Support	Thousands of Dollars
A. Technology	
National Institutes of Health	4,125
Health Resources and Services Administration	451
B. Training	0
C. Organization and delivery	0
TOTAL	4,576

TABLE 7-5 Federal Support for Research on Long-Term Care and Rehabilitation of the Injured in Fiscal 1983

Subject and Source of Support	Thousands of Dollars
A. Medicine and Technology	
National Institutes of Health	1,382
Veterans' Administration	6,020
National Institute of Handicapped Research	2,117
B. Training	
Veterans' Administration	800
National Institute of Handicapped Research	733
C. Organization and delivery	
Veterans' Administration	800
National Institute of Handicapped Research	612
Health Resources and Services Administration	128
TOTAL	12,592

The specification of research allocations in a given year might not reflect the extent of involvement of agencies in relevant fields in other years or unsuccessful attempts by the agencies to find investigators to study problems that are recognized as needing attention. Nevertheless, in some cases where one would expect some expenditures under current agency missions, there were none.

Expenditures in a given year are perhaps more relevant when compared with allocations to other health-related research in the same year. The total expenditure for injury research by NIH, about $34.4 million, is less than 2 percent of the total NIH research budget.[86]

In 1980, motor-vehicle injuries alone cost the federal government $1.5 billion in public assistance programs, $86 million in federal employees' worker compensation and sick leave, and $5.6 billion in revenue losses.[130] Although the costs of all injuries have not been researched adequately, they were undoubtedly two to three times those amounts. Even a modest reduction in current death and injury rates would save hundreds of millions, if not billions, of dollars in government expenditures and in loss of revenues, not to mention the costs to individuals and organizations not associated with government.

The total federal expenditures for nonmilitary research on injuries were approximately $112 million in fiscal 1983. Although injury results in the loss of more economically productive years of life than cardiovascular disease and cancer combined, the support for research on injury control is relatively small (Figure 7-1, on page 108), about 11 percent of that for research on cancer and 18 percent of that on cardiovascular disease. This is not intended to imply that the retirement years are inherently any less valuable than the preretirement years. But the welfare of the retired depends substantially on the productivity of the working population.

The committee believes that substantial inroads in current injury rates would result from research reguiring substantially less support than is now expended on cancer and cardiovascular disease. An increment in current funding witch close monitoring of the application of the research results could illustrate the investment value of such expenditures for the entire population.

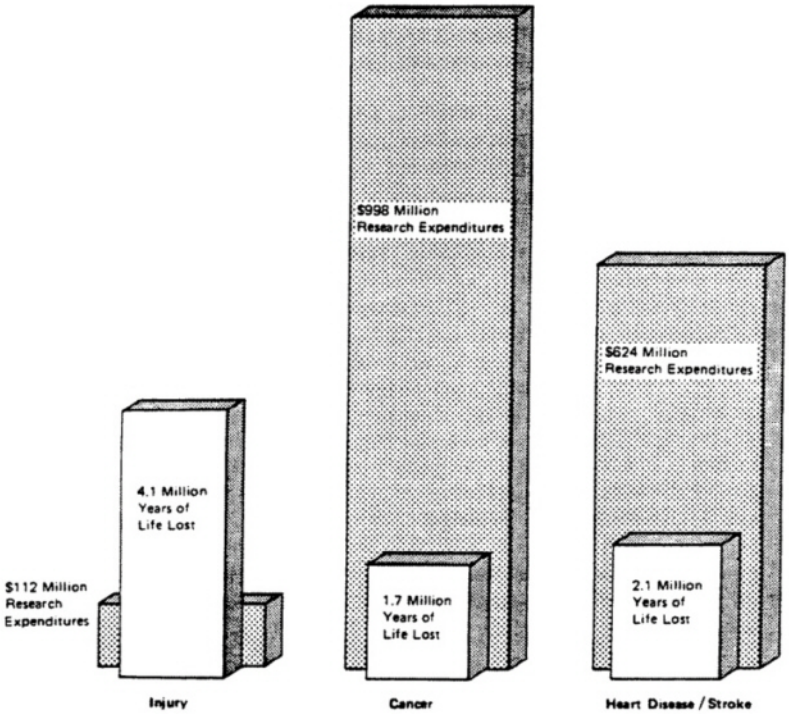


Figure 7-1
Preretirement years of life lost annually and federal research expenditures for major causes of death in the United States. Years of life lost derived from National Center for Health Statistics.[126] The total federal expenditure for injury research is the sum of the amounts discussed in this chapter plus a 5 percent increment for administration, the latter in line with NIH administration costs. Expenditures for research on neoplasms and cardiovascular diseases are the 1983 fiscal year budgets of the National Cancer Institute and the National Heart, Lung, and Blood Institute.[86]

8

Administration of Injury Research

As part of its charge, the committee was asked to examine whether and how the federal government could efficiently manage an injury research program and to consider among the alternatives the possible benefits of an interdisciplinary, comprehensive approach to injury research.

Research on the various aspects of injury outlined in this report has been fragmented and poorly financed. Although the field has been substantially defined in terms of the scope of the problem and the enormous costs to society, important parts of the field have lacked the recognition of the scientific community and the support of the government—recognition and support that have contributed to the amelioration of other health problems. Effective research on injury control and prevention requires strategies and programs that differ from those used for other leading public health problems. An integrated multidisciplinary approach involving physicians, epidemiologists, engineers, physicists, behavioral scientists, and others is needed. The present fragmented approach, with various agencies handling some of the pieces of the problem, virtually guarantees that injuries will continue to constitute a major public health problem and that progress in combating the problem will continue to be slow and inefficient. With injury research spread among a variety of institutes, departments, and regulatory agencies, there is no means of considering the implications of research on one aspect of the problem for the others, and unnecessary duplication of effort is a strong possibility.

Although reasonably large current expenditures for injury-related research can be identified in the budgets of a number of federal agencies, the amounts are mis leading. Much of that research is only peripherally related to injury, and its principal focus is other health problems. In addition, because of the narrowly defined missions of the individual agencies that do the research, it is not nearly as comprehensive as is needed. Much important research is never funded at all, because it does not fit the programs of any of the agencies that support injury research.

Nothing short of a program with principal responsibility for injury research will suffice. Leaving the effort fragmented will mean that yet another opportunity to reduce a continuing public health problem will have been lost. The foregoing chapters of this report have defined the dimensions of the field and identified numerous research needs and opportunities that merit the attention of the scientific community. (It should be noted that important factors that have been less neglected, such as alcohol and drug research, have not been discussed at length.)

The various agencies of the federal government use several approaches to administering research. Some agencies are engaged in both research and regulation (for example, the Food and Drug Administration and the Environmental Protection Agency); others are limited to research (the National Institutes of Health, NIH) or regulation (the Occupational Safety and Health Administration, OSHA). In occupational health, the research function is performed by the National Institute for Occupational Safety and Health, a part of the Department of Health and Human Services, and the regulatory function is carried out by OSHA, a part of the Department of Labor. In addition, research programs like the National Toxicology Program (NTP) comprise research components from more than one agency.

This chapter examines a number of those approaches and recommends a means by which research on injury could be efficiently and effectively administered.

CRITERIA FOR ORGANIZING INJURY RESEARCH

The committee first sought to identify criteria by which to find the organizational structure that would best meet the need to make research on injury efficient and effective. The criteria established by the committee reflect its recognition, gained in its examination of current efforts on injury research, that these efforts are too narrowly focused and underfunded.

To correct the present situation, the committee considered the following criteria for determining the organizational setting and structure for the study of injury:

- Research efforts should be organized in such a manner that all aspects of injury can be addressed by one unit—i.e., research on epidemiology, prevention, biomechanics, treatment, and rehabilitation; information gathering and dissemination; and training.
- The unit should be so placed in the federal organizational structure that it fits the mission of the department that houses it, can receive continuing attention, and has a degree of visibility commensurate with the importance of injury to the nation's public health.
- The unit should be so placed that it will be recognized as the leader in injury research and will be able to initiate cooperative efforts among appropriate federal agencies and serve as a contact point for private organizations and individuals.
- It should be so placed that it will be able to improve communication, management, priority-setting, and accountability.
- It should be part of a research organization, rather than part of a regulatory organization, and should itself be organized accordingly.

FUNCTION OF A FEDERAL CENTER TO ADMINISTER INJURY RESEARCH

Agencies are not uniform in their definitions of injury, and many agencies consider some of their activities in this field to be oriented toward "service" or "operations," rather than "research." The solutions to problems addressed by injury research programs often involve many disciplines. The objectives of a research program must consider the diverse elements of present research efforts, fully assess the resources available, establish priorities, and address the solutions that have the best cost-effectiveness relationship. But the objectives should not focus solely on cost. They should recognize the necessity of a balanced national program, consider all projects that might prove fruitful, and support projects that have the potential to reduce injury morbidity, even if the beneficial effects will be evident only in the longer term.

The program objectives of the unit must be related to specific injury problems and focus on timely solutions. The program must include data collection, as well as research on and implementation of injury prevention, treatment, and rehabilitation. Data collection and analysis are critical factors in enabling the new unit to focus its research efforts on specific problems.

On the basis of evaluation of the needs for research on injury, examination of the existing models for the organization of research, and the criteria for a unit that could effectively manage research on injury, the committee believes that it is essential to establish an injury research unit that would be administered by an agency of the federal government and whose sole interest is reduction of injury morbidity and mortality.

The function of the unit would be to carry out a national injury research program in the following manner:

- Conduct and support research in biomechanics, injury epidemiology and prevention, and treatment and rehabilitation of the injured.
- Establish injury surveillance systems, collect and analyze data on injury, and conduct injury prevention projects.
- Promote professional education and training in injury control.
- Establish centers of excellence in injury biomechanics, epidemiology, prevention, treatment, and rehabilitation.
- Serve as a clearinghouse, coordinator, and lead agency among federal agencies and private organizations interested in injury research and control.

LOCATION OF A FEDERAL CENTER TO ADMINISTER INJURY RESEARCH

The committee considered the placement of a new entity in the private sector, but believed that no single private industry, foundation, or university could be expected to undertake a research program of the scope and magnitude necessary to pursue the wide-ranging needs outlined in this report. Although individual citizens would be the ultimate consumers of the product of injury research, the committee thought that location of the new unit within the federal government would be in keeping with its responsibility to promote public health. For tat reason and because the government would be a major beneficiary if the costs associated with federally funded health-care programs were reduced, the committee concluded that the new unit should be established in the federal government structure. Having the federal government administer and coordinate the research would also facilitate communication with executive and legislative agencies of the government.

Many federal agencies already have injury research programs, and development of a new organizational structure must consider the consequences of leaving those programs in place or incorporating them into the new unit. The committee felt that existing agency programs should not be moved, but rather coordinated with the new unit to support the overall objectives. Part of the new unit's mission, therefore, would be to serve in a coordinating role for the various agencies that have research programs.

The location of the unit is of the utmost importance, if it is to be successful in carrying out the functions enumerated above. If it is placed in an existing agency, the primary concerns are compatibility of mission, receptivity to the research approach, and possibilities for application of research findings. The committee discussed many possible locations for the unit and concluded that five existing federal agencies could reasonably be considered: the National Institutes of Health (NIH), the Department of Defense (DOD), the Department of Transportation (DOT), the National Bureau of Standards (NBS), and the Centers for Disease Control (CDC). The committee offers the following opinions on how well the placement of the unit to administer injury research in each of these agencies would meet research program needs.

National Institutes of Health

Persons concerned about the neglect of injury research have recently advocated the establishment of a national institute of trauma research in NIH. Although NIH is an attractive model to follow, the committee rejected this approach for two main reasons:

- NIH is oriented more toward basic research than toward the problem-oriented research essential for injury control. The traditional focus of NIH on basic biomedical research does not match the interdisciplinary needs of injury research, e.g., the need for research in biomechanics and rehabilitation.
- The establishment of additional institutes does not have priority. A recent report[86] by the Institute of Medicine on the organizational structure of NIH stated that "NIH is now at a stage where there should be a presumption against additions at the institute level."

Department of Defense

DOD is the only agency that might currently have extensive programs in all the fields of research needed. However, its efforts concentrate on defense-related applications of injury research. The committee rejected DOD as a home for the new unit, because the department's mission does not match the needs of injury research.

Department of Transportation

Although DOT has the largest and most comprehensive injury-related program, the committee rejected placement of the new unit in DOT, because of its regulatory responsibilities and because its transportation-related mission was too narrow to fit the needs of the new unit. The committee acknowledges, however, that separation from the regulatory setting might reduce the unit's ability to influence regulatory decisions with relevant data.

National Bureau of Standards

NBS is highly respected for its research activities and could be considered to administer many technical aspects of an injury research program. However, much as NIH focuses on basic biomedical sciences, the NBS research programs are too narrowly focused on engineering applications.

Centers for Disease Control

The mission of CDC is the prevention of disease, disability, and premature death through interdisciplinary research and dissemination of information. That is the type of approach needed in injury control and injury research. In CDC, both laboratory and field research are integrated into a comprehensive public health program. CDC has authority to give grants, but most of the research funds are allocated by contract or cooperative agreement. Specific instructions for a proportion of funds to be used for investigator-initiated, peer-reviewed grants would be necessary, to guarantee a more complete range of research ideas. Although CDC has modest regulatory responsibility, it maintains a strong liaison with state health departments and can quickly disseminate information and technology nationwide. The committee acknowledges that location outside the Washington, D.C., area could be a disadvantage with respect to coordinating with other research efforts or maintaining informed support in Congress. However, the committee points to CDC and the National Toxicology Program (NTP) as examples of successful research programs which are administered outside Washington, D.C.

CONCLUSIONS AND RECOMMENDATIONS

The committee believes that improvements are needed in the current approach to administering injury research in the federal government. The nation needs a coordinated injury research program with clear objectives and more focus on critical needs, with adequate funding, and with the support of Congress and the executive branch.

The substance of a national injury research program is important, but the organizational structure established to administer the program is also important. Adequate communication among the agencies involved in injury research and the ability to focus research efforts on problems are essential. The structure of the organization should be such that it would facilitate the achievement of those objectives.

In keeping with the federal government's interest in promoting the public welfare, the committee concludes that the new entity should be in the federal government structure. Such placement would facilitate communication with the executive and legislative agencies of the federal government.

The committee believes that a new independent agency modeled after components of the Centers for Disease Control could best provide the needed national focus for injury research—focus that is difficult to obtain in any other way.

The committee concludes that a Center for Injury Control (CIC) should be established as part of CDC. This would take advantage of the existing mission-oriented epidemiologic interests and data-collecting abilities of CDC. Although CDC does not now have programs in biomechanics, emergency care, acute care, and rehabilitation, it does have authority to give grants and a mechanism to establish study sections. It can also conduct demonstration projects.

The general mission of CIC would be to direct a coordinated research program to reduce morbidity, mortality, and disability from injury. To accomplish these objectives, CIC must be a visible organizational entity in the government.

Clearinghouse and coordinating functions in CIC are essential, although the injury research problem is much greater than a problem simply of coordination. CIC should coordinate information on the efforts of various agencies now supporting injury research to avoid inappropriate duplication of effort and to identify gaps in knowledge. It should also develop and maintain liaison with public and private agencies involved in injury control, to disseminate the knowledge and technology developed in their efforts, to redirect efforts known to be ineffective, and to provide expertise in the study of efforts of unknown effectiveness.

Because of the complex and broadly based scientific tasks that would be within the mission of CIC and the need to integrate the programmatic activities of several agencies, CIC should have an advisory council that includes representatives of federal agencies and other organizations engaged in injury research, as well as those which implement injury control programs. The council would provide guidance in identifying research subjects that need additional work and help to avoid inappropriate duplication of effort. CIC research priorities, however, should be established from within CIC.

CIC must have a clearly identified budget authorization within that for CDC. It would be justified by identi fiable research and training needs and by the availability of competent researchers required to meet those needs. The mission for CIC should be established by statute within CDC.

The director and staff of CIC would be appointed to review priorities, establish specific research goals, identify scientists capable of implementing the research, and coordinate peer review. It is imperative that all appropriate disciplines be represented and that the director be a scientist with recognized research accomplishments and successful experience in interdisciplinary investigation of injury. No single discipline or disciplinary orientation will produce the broad spectrum of research needed for injury control.

An appropriate structure of CIC is shown in Figure 8-1. Divisions dedicated to the major fields of needed research—epidemiology, prevention, biomechanics, acute care, and rehabilitation—would be coordinated by the CIC director. The center would report administratively to CDC, and the director of the center would have authority to appoint and convene the advisory council.

CIC should foster and support research directed to filling the knowledge gaps that inhibit the control of injury. To do this, it should contain special study sections and a granting mechanism in each that would provide for continued, rather than year-by-year, funding of research projects. Funding should cover demonstration programs, multiple centers of excellence, and training of researchers in appropriate fields. CIC funds should

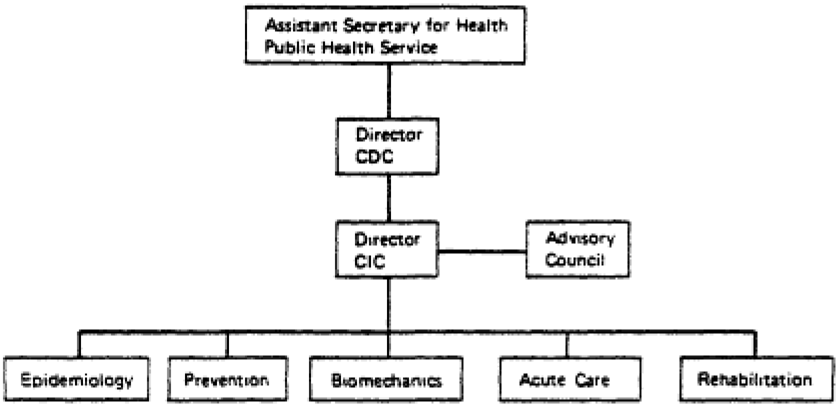


Figure 8-1
Suggested location and organizational structure of proposed center for injury control.

supplement, rather than replace, funds currently allocated to other agencies, such as DOT, DOD, and NIH; and their funding related to injury research should not be channeled through CIC.

The director and the advisory council should be charged with the development of an annual plan and report to Congress—an approach similar to that followed by the National Toxicology Program. This administrative mechanism would encourage the CIC director and representatives of other agencies to consider the scope of what is being done, in view of the various agency mandates, and to avoid inappropriate duplication of effort.

An independent review of CIC should be conducted within 5 years of its establishment to assess its progress in accomplishing the objectives recommended in this report. At that time, consideration should also be given to the elevation of this center to independent agency status.

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Appendix A

Recommendations For An Injury Research and Training Agenda

The body of this report describes research issues and needs in various stages of the injury process: prevention, biomechanical response, treatment, rehabilitation, surveillance, and longitudinal follow-up. Current research in each of these subjects is often done without consideration of the overlap with others. In addition, each type of injury is treated as a separate problem, without integration of research results. Surveillance systems for motor-vehicle injuries, injuries associated with consumer products, and occupational injuries are operated separately at a greater cost than would be necessary for a general injury surveillance system, which would have the additional advantage of including injuries not followed in any current system. For such a system to have maximal benefit, it must include data that speak to the questions important in each stage of the injury process. Data on the causal factors that form the basis for choices among preventive approaches must be included. The system must make it possible to relate biomechanical research in the laboratory to the variety of persons and circumstances involved in actual injuries. Acute-treatment facilities must be organized to provide the necessary data without disruption of the treatment process. Follow-up data that lead to understanding of the implications of acute treatment for rehabilitation can be included only if experts in rehabilitation are involved. Preventive strategies that do not take into account the limits of human beings to perceive and respond to motion are unlikely to be successful. Similarly, modifications of the environment or products to reduce severity of injury that are undertaken without knowledge of human tolerance and biomechanical responses will be less than maximally effective. Understanding of biomechanical functioning of the human organism can be used in planning movement of patients in emergency medical systems and in restoration and rehabilitation of function in acute- and long-term-care facilities.

This appendix contains examples of the many neglected problems and presents the committee's recommendations for addressing them. It is not intended to be either an exhaustive or rank-ordered research and training agenda. Although discussed separately, these problems are part of a pattern that must be approached in an interdisciplinary, holistic program for maximal impact.

SURVEILLANCE AND DATA COLLECTION

PROBLEM With the exception of injury related to motor-vehicle and aircraft crashes, data on the incidence and severity of injury are not adequately detailed. In the motor-vehicle data, identification of cases is based on police reports, despite the fact that research on medically treated injury victims in various areas of the United States and elsewhere in the world has shown that police reports underestimate the problem by 20 percent or more. The discrepancy between police-reported and actual assaultive injuries is probably much greater than that in the case of motor-vehicle injuries. To the extent that factors that contribute to injury are correlated with reporting, inference of causation can be distorted substantially by the selective reporting of cases to police. The Consumer Product Safety Commission (CPSC) maintains a system for gathering data from selected hospital emergency rooms, but the cases reported exclude intentionally inflicted injuries and are limited to injuries from one or more of the products in the regulatory jurisdiction of CPSC. This system could form the basis of a comprehensive injury surveillance system. Many states now have computer-coded data on all hospital discharges, but the specific cause of injury is not included. Its inclusion would greatly increase the value of those data for research and the development of control strategies.

RECOMMENDATION The federal government should establish a nationally representative random sample of the nation's hospital admissions, discharges, and emergency room cases. A system of continuous surveillance of injury incidence and severity, contributing factors (including specific vehicles and vectors), populations at high risk, and costs of the injuries of patients treated in those facilities should be established. This program should be supplemented by the collection of comparable information on fatal cases not handled in medical facilities, but reported on death certificates. (The details of the minimal information needed are presented in Chapter 2.)

PROBLEM The distribution and use of motor vehicles are documented to an extent that permits some measures of exposure to them, but the amounts and types of exposure of various segments of the population to most hazards are unknown. For example, we do not know whether the decrease in injuries associated with particular toys and household products among children as they grow up results from improvement in the ability to handle these items as a function of development, learning, or reduced exposure. These potential explanations lead to different possibilities for intervention during the periods of life in which specific types of injuries are prevalent.

RECOMMENDATION Data on exposure to various products and types of energy, identified in clinical surveillance as often involved in injury, and the characteristics of the populations exposed should be gathered systematically. The goal should be to link incidence, severity, and exposure in particular populations, to identify points at which intervention is most appropriate. The identification of abilities and limits of specific populations in the use of particular forms of energy and products should be a high priority in such research.

PROBLEM Knowledge of the chronic effects of injury on personal abilities in occupations, recreation, and social and psychologic functioning is lacking. The eventual results of damage to the brain and nervous system and to sensory organs and of loss of limbs and organs have been investigated in only a few projects, which were severely limited by sample size and time constraints. This knowledge can be gained only through longitudinal studies of the outcome of injury in populations stratified by type and severity of injury.

RECOMMENDATION Support should be generated for longitudinal studies of injured persons and otherwise comparable noninjured persons, to assess the eventual consequences attributable to injury.

PREVENTION

PROBLEM Relatively small-scale special studies of injuries concentrated in space and time, such as fatal falls of children in New York, have resulted in specification of factors that can be modified to reduce incidence and severity. With the exception of investigation of air crashes and a few other disasters by the National Transportation Safety Board and the military services, there is no federal response to most types of injury comparable with the response to diseases, such as the response to the deaths of legionnaires following a convention a few years ago, or the current emphasis on acquired immune deficiency syndrome. This lack of response is due at least partly to the previously mentioned lack of surveillance, which would reveal the concentration of particular types of cases in space and time.

> RECOMMENDATION Teams of injury epidemiologists should be established with a mission of investigating the causes of concentrations of specific types of injury in space and time, and recommending points in the injury process where intervention programs could be introduced by federal, state, or local authorities or by private individuals and groups.

PROBLEM The enormous contribution of kinetic energy to injury and the substantial reductions in crashes related to modest changes in motor-vehicle lighting and improvement in road definition suggest that subtle problems in the perception of motion relative to the ability to react are important in injury causation. The psychologic propensity for perception of personal invulnerability and physical limits on perception and reaction are little understood. Discovery of injury-reducing changes in vehicles and the environment to improve perception of hazard and ability to react has been mostly fortuitous, rather than based on fundamental understanding of perception and reactive abilities.

> RECOMMENDATION. Support should be initiated for a program of research aimed at understanding the physical limits and abilities of people to perceive motion of themselves and others in a variety of environments, particularly those in which injuries occur most frequently. The nature of personal perception of hazard, relative to

subjective perception of ability to avoid harm from the hazard and objective assessment of that ability, should be included in the research efforts, which should compare groups with high and low incidences of injury. The effect of environmental insults to the nervous system, such as those caused by industrial solvents and lead from motor-vehicle exhaust and paint chips, on hazard perception and ability to react should also be included in the research.

PROBLEM Preliminary evidence indicates that physiologic, as well as psychologic, contributors are involved in assaultive behavior. Research on large differences in hormone concentrations between assaultive and nonassaultive persons has not been replicated or followed up—a situation that would be unlikely if a disease, such as cancer, were involved, rather than injury. The parallel in age and sex distribution of persons involved in some types of unintentional and assaultive injuries suggests the possibility that similar mechanisms contribute to both.

RECOMMENDATION A program of research in physiologic factors in assaultive and other injuries associated with persons in similar age and sex categories should receive support.

PROBLEM Various efforts aimed at injury control are adopted with little or no experimentation regarding effectiveness. In some cases, evaluation has found programs ineffective or harmful. But most programs are never evaluated.

RECOMMENDATION Support should be increased for research programs of randomized experimental-control studies of the effect of injury-control efforts on injury rates and severity. Where experimental-control studies are not possible — e.g., in the case of laws—evaluation using quasiexperimental and other research designs should be supported.

PROBLEM Testing of the injury potential of materials and products before their marketing is sparse. Large businesses *have the* resources to undertake such research, but it may be necessary to provide test facilities for research on the products of small businesses, perhaps on a cost-sharing basis, depending on the costs of the research relative to the assets of a business. The consequences both to the injured and to the businesses, when large lawsuits jeopardize their existence, could be avoided in many instances by prior research on injury potential and appropriate improvements in products as they are developed.

> RECOMMENDATION The federal government should require research on the injury potential of materials and products before marketing to the public, preferably by researchers who have no financial interest in the business enterprises that intend to market the materials or products.

BIOMECHANICS

PROBLEM Scientists have understood the physics and chemistry of most of the forms of energy by which people are injured much longer than they have understood bacteria and viruses, but research on injurious encounters with energy has lagged far behind research on biologic infection. As discussed in detail in Chapter 4, design of less injurious environments depends at least partly on knowledge of the effects of specific energy exposures on specific human tissues. Although we know the approximate limits of forces that can be tolerated by healthy persons in rapid deceleration, we do not have refined data on effects on nervous tissues and tissues outside particular size and structural ranges.

> RECOMMENDATION Research on the mechanisms of injury associated with mechanical energy should receive increased support.

PROBLEM The extent of reversibility of damage to tissues that have experienced specific loadings of environmental energy is poorly understood. The technology of culturing skin cells for burn patients is an exciting result of advancement of knowledge. Research on the response of tissue to mechanical loads could lead to analogous technology for other types of tissue.

> RECOMMENDATION Sustained support should be generated for research on the responses of various tissues to mechanical and other forms of energy.

PROBLEM Design of environments and protective equipment depends partly on knowledge of the variations in tolerance to hazards among the persons who will live, work, and play in those environments. Adequate research in injury mechanisms and human tolerance has not been developed, because of the lack of sustained research support of teams to integrate knowledge of physics, anatomy, physiology, and function. Indeed, the haphazard availability of scarce funds results in the periodic assembly and disassembly of research groups, which prevents sustained development of knowledge and expertise. It also results in an inadequate research base and in expenditures that in the long run are greater than those which would be necessary in sustained research efforts.

RECOMMENDATION Programs should be established for sustained research on the tolerance of tissue to mechanical and other forms of energy in different rates and amounts to which humans are commonly exposed.

TREATMENT

PROBLEM Speed of response and training of emergency medical personnel have improved, but we do not know the optimal combination of resources to allocate to the initial phase of injury. Conditions in different areas of the country suggest that no system is ideal for all areas. The opportunity remains to experiment with new systems and to compare those in use, to find the optimal combinations for local conditions.

RECOMMENDATION Research on the effects of extant and experimental emergency response systems on survival and disability should be increased.

PROBLEM The lack of knowledge of acute treatment vis-à-vis eventual outcome is outlined in Chapter 5. Research is particularly needed on stabilization of the injured, control of shock, neuroendocrine responses, metabolism, and prevention and control of postinjury infection.

RECOMMENDATION Sustained support should be provided for research on the various biologic systems involved in the response to injury. The short- and long-term effects of attempts to control the numerous injury response systems should be investigated more intensively. Protocols for research on treatment for injury should meet the same standards for experimentally demonstrated efficacy as research on treatment for diseases.

PROBLEM The best treatment for injury is often available only in specialized emergency facilities. The organization of emergency response systems and treatment facilities may have as much hearing on outcomes as their availability. Local and regional systems that result in each injury patient's being in the most appropriate facility for treatment should be the goal.

> RECOMMENDATION Research in the organization and delivery of emergency response to and acute care of the injured should be supported.

PROBLEM Damage to the spinal cord is sometimes exacerbated by inappropriate movement of the injured patient, reducing the potential for normal function or rehabilitation.

> RECOMMENDATION Research on the stabilization of the spinal cord, transport and diagnosis of the spinal-cord-injured, development of technology, and training of emergency personnel to minimize damage to the spinal cord should be increased.

PROBLEM Contracture from burn injuries limits functional body movement, and resulting disfigurement leads to social withdrawal and accompanying problems.

> RECOMMENDATION Research on the pathophysiology of burn injury should be increased, with an eye to reducing the degree of contracture and disfigurement.

PROBLEM Smoke and gas inhalation in fires results in scars in lung tissue and pulmonary insufficiency.

> RECOMMENDATION Support for research on the treatment and rehabilitation of persons with damaged lungs should be increased.

REHABILITATION

PROBLEM Evidence is increasing that injury, especially injury to the nervous system, has long-term adverse consequences, not only for the obviously disabled, but also for those who seem to have recovered. As noted in Chapter 6, the development of aids and the provision of services for the disabled are often undertaken without adequate study of the contribution of the efforts to recovery or adaptation.

RECOMMENDATION Research on the outcomes of physical and psychologic rehabilitation efforts should be increased. Such research should focus on the identification of the optimal combinations of factors that contribute to restoration of as nearly normal function as possible, including removal of architectural and social barriers. Reduction of adverse consequences in the patient's family and friends and in persons whose actions might have contributed to injury should be included in such research.

PROBLEM Research on treatment for long-term disability is fragmented. For example, surgical procedures commonly do not now take into account the fitting of prostheses, disfigurement, and self-image.

RECOMMENDATION Interdisciplinary teams of investigators should be supported to find ways of integrating treatment and long-term rehabilitation in the interest of the total functioning of the injury patient.

PROBLEM Preventable pressure sores occur frequently in injured (and other immobilized) patients.

RECOMMENDATION. Support for research on technology and training for long-term-care personnel to prevent pressure sores should be increased.

TRAINING AND ORGANIZATION FOR INJURY CONTROL

PROBLEM Given the neglect of injury in academic training centers and the small number of researchers who have developed the knowledge and skills to produce competent science in the field, it is unlikely that all the identified research tasks could be undertaken immediately even if funding for such efforts were available. This is partly a chicken-and-egg problem, in that the best research training occurs in settings where sustained research programs are in progress. Support of research in academic settings will indirectly contribute to training of researchers. Without funds for scholarships and faculty support, however, such training cannot grow to meet the need.

RECOMMENDATION The numbers of researchers and teaching personnel should be monitored, to show the need for expertise in each of the specified fields of research. Follow-up study of the production and productivity of researchers should be included, to permit assessment of the extent to which research and training programs are accomplishing their goals. The funds needed to reach the research and training goals in specific periods should be estimated.

PROBLEM Present organizational arrangements have proved incapable of allocating resources or activating and managing the needed epidemiologic, preventive, biomechanical, clinical, and rehabilitative research and development needed for rational programs to prevent injury and treat and rehabilitate its victims. Injury research is fragmented, diffuse, and insufficiently organized and administered. Resources are not allocated on the basis of any overall assessment of need and feasibility of achieving new knowledge and technology. The potential is high for duplication of effort. There is no leadership or oversight to avoid inappropriate duplication.

RECOMMENDATION. A new agency of the federal government, the Center for Injury Control (CIC), should be established in the Centers for Disease Control (CDC) to administer the planning, solicitation, funding, and evaluation of coordinated research and development directed at control of injury. CIC should be directed by a scientist with a broad interdisciplinary view of the problem. The director should be authorized to convene a council of scientists from other agencies that administer injury research, to coordinate the total federal effort. The budget for CIC should be a clearly identified part of the CDC authorization.

Appendix B

Committee Biographies

WILLIAM H. FOEGE, Chairman, is assistant surgeon general and special assistant for policy development at the Centers for Disease Control, where he served as director from 1977 to 1983. Dr. Foege is president-elect of the American Public Health Association. He is project director for a national health policy project chaired by former President Jimmy Carter and director of an international task force for child survival cosponsored by the World Health Organization, Rockefeller Foundation, United Nations Development Program, World Bank, and UNICEF.

SUSAN P. BAKER, Vice-Chairman, is professor of health policy and management and of environmental health sciences at The Johns Hopkins University School of Hygiene and Public Health, with a joint appointment in pediatrics at the School of Medicine. An epidemiologist specializing in injury control, Dr. Baker is senior author of The Injury Fact Book and chaired the advisory panel for the Department of Transportation's National Accident Sampling System. Her research has addressed injuries from motor-vehicle crashes, fires, and poisoning and occupational injuries.

JOHN H. DAVIS is professor and chairman of the Department of Surgery of The University of Vermont College of Medicine, Burlington, Vermont. Dr. Davis also serves as associate dean for clinical affairs in the College of Medicine and chief executive officer of the University Health Center. He is the editor of the Journal of Trauma, serves on the board of directors of the American Trauma Society and the American Association for the Surgery of Trauma, and is a past member of the Committee on Trauma of the American College of Surgeons and of the National Research Council. He is past chairman of the Surgery Study Section of the National Institute of General Medical Sciences.

PARK E. DIETZ is associate professor of law and of behavioral medicine and psychiatry and medical director of the Institute of Law, Psychiatry and Public Policy at the University of Virginia Schools of Law and Medicine. Dr. Dietz is a psychiatrist and sociologist specializing in criminal violence. He is vice-president of the American Academy of Psychiatry and the Law, a consultant to the FBI Academy Behavioral Science Unit, and principal investigator for a National Institute of Justice study of mental disorder and violent crime.

DONALD S. GANN is chairman of the Department of Surgery at Brown University and chief of surgery at Rhode Island Hospital. Dr. Gann specializes in surgery of the injured patient and in the hormonal and metabolic response to injury. He has been chairman of the National Research Council Committee on Emergency Medical Services since 1974. He is secretary of the American Association for the Surgery of Trauma and chairman of the Subcommittee on Education of the Committee on Trauma of the American College of Surgeons.

ALBERT I. KING is professor of mechanical engineering and director of the Bioengineering Center at Wayne State University. Dr. King's principal research is in injury biomechanics and low back pain. His research is supported by U.S. government agencies and industry. He is a fellow of the American Society of Mechanical Engineers and an associate member of the American Academy of Orthopaedic Surgeons.

ROBERT R. MCMEEKIN is director of the Armed Forces Institute of Pathology. Dr. McMeekin is both a physician and an attorney. He was selected as a Robert wood Johnson Health Policy Fellow in 1980. His major health policy interests are the health and safety aspects of transportation systems, medical issues in national defense, and the relation of military medicine to other health care systems. He is a recognized authority on aircraft accident investigations, directed the medical investigation of the 747 collision in the Canary Islands and the Jonestown homicides/suicides, and recently led a forensic team to Grenada. He served with the Rockefeller

Commission on CIA activities in the United States regarding the assassination of President Kennedy.

JOHN F. MULLAN is professor and chairman of the Division of Neurological Surgery at the University of Chicago and until recently was director of the Brain Research Institute of the university. Dr. Mullan is a fellow of the American College of Surgeons, assistant secretary of the World Federation of Neurological Societies, a member of the American Association of Neurological Surgeons (Harvey Cushing Society) and the American Academy of Neurological Surgery, and president of the Society of Neurological Surgeons. He serves on the editorial boards of the Journal of Neurosurgery and the AMA Archives of Neurology.

BRIAN O'NEILL is executive vice-president of the Insurance Institute for Highway Safety. Mr. O'Neill is head of the Institute's research and communication programs and is responsible for developing and implementing programs to reduce the losses—deaths, injuries, and property damage—resulting from motor-vehicle crashes. He is vice chairman of the National Safety Council's Committee on Alcohol and Other Drugs and a member of the National Research Council's Committee on Geometric Design Standards for Highway Improvements. He has also served on the advisory committee for the Department of Transportation's National Accident Sampling System.

JAMES B. RESWICK is director of the Rehabilitation Research and Development Evaluation Unit at the Veterans' Administration Medical Center in Washington, D.C. Dr. Reswick has directed centers at Case Western Reserve University and the University of Southern California Rancho Los Amigos Hospital that develop technologic devices for disabled persons. He is a member of the Institute of Medicine and the National Academy of Engineering and served as senior scientist at the National Institute of Handicapped Research for 3 years. He was the founding president of the Rehabilitation Engineering Society of North America, is a fellow of the Institute of Electrical and Electronic Engineers, and is a member of the American Academy of Orthopaedic Surgeons.

LEON S. ROBERTSON is a research scientist in the Department of Epidemiology and Public Health of the Yale University School of Medicine. For the past 15 years, Dr. Robertson has conducted research on the epidemiology of injuries and the effectiveness of injury control programs. He has served on the faculties of The Johns Hopkins University, Harvard University Medical School, and Wake Forest University, and has taught for several years in the summer session in epidemiology at the University of Minnesota. He was also a senior behavioral scientist in the Insurance Institute for Highway Safety.

RICHARD G. SNYDER is director of the National Aeronautics and Space Administration Center for Excellence in Man-Systems Research, a research scientist at the University of Michigan Transportation Research Institute and Institute of Science and Technology, and professor of anthropology. Dr. Snyder served as head of the Biomedical Department of the Highway Safety Research Institute for 14 years, has taught at various universities, and has managed biomechanics and impact injury research at Ford Motor Company and, as chief of the Physical Anthropology Laboratory, at the Civil Aeromedical Research Institute of the Federal Aviation Administration. He has written some 400 scientific publications, reports, and presentations, primarily on human tolerance, occupant crash protection, and impact injury.

WILLIAM A. SPENCER is president of The Institute for Rehabilitation and Research at the Texas Medical Center in Houston and professor and chairman of the Fleming Department of Rehabilitation at Baylor College of Medicine. Dr. Spencer, a member of the Institute of Medicine, is a consultant to the National Institute of Handicapped Research and a consultant in rehabilitation to numerous hospitals in Texas. He serves on the scientific advisory board of the Paralyzed Veterans of America Technology and Research Foundation and the scientific merit review board for rehabilitation research and development of the Veterans' Administration and is a member of the executive committee of the board of the National Association of Rehabilitation Research Centers. He is also on the editorial boards of several journals in the fields of computers, information handling, and physical medicine and prosthetics.

C. THOMAS THOMPSON is a general surgeon in private practice in Tulsa, Oklahoma. Dr. Thompson has a long-standing interest in injury dating back to his residency years in New Orleans after he received his medical degree at Harvard University Medical School in 1949. He has held various positions on the Committee on Trauma of the American College of Surgeons, culminating in appointment as chairman in 1978. He is currently governor and a senior member of the Committee on Trauma of the American College of Surgeons: His interest in standards of injury care has led to publication of the optimal care documents. He has been an administrator at St. Francis Hospital, Tulsa, and chairman of the executive committee of its board of directors.

DAVID C. VIANO is assistant head of the Biomedical Science Department of General Motors Research Laboratories. Dr. Viano is in charge of the research program dealing with the biomechanics and pathophysiology of automotive crash injuries. He is a specialist in the biomechanics of whole-body, internal-organ, and soft-tissue injury and has identified the viscous mechanism of soft-tissue damage. He has degrees in applied mechanics from the California Institute of Technology and has completed postdoctoral research in biomedical sciences. He is on the adjunct faculty at Wayne State University, where he has taught graduate courses in biomechanics and conducted research.

JULIAN A. WALLER is professor of medicine at The University of Vermont. Dr. Waller, an epidemiologist and public health specialist, has carried out research and intervention programs in both highway and nonhighway safety for the last 25 years. He is a past president of the American Association for Automotive Medicine and has served on the National Highway Safety Advisory Committee and the National Academy of Sciences Review Panel for the National Bureau of Standards and as a consultant on injury to the World Health Organization and the National Commission on Causes and Prevention of Violence. He received the National Safety Council's Metropolitan Life Award for Accident Research.

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