An Overview of Where We Are and Where We Need To Be

Julian A. Waller, MD, MPH, Professor of Medicine, University of Vermont, College of Medicine, Medical Alumni Building, Burlington, VT 05405

IN 1960, THE STATE OF KNOWLEDGE and action in injury research could be described as follows. Several health departments were involved for at least a few years in injury control activities. The Public Health Service (PHS) was establishing an accident prevention branch. The American Public Health Association was showing interest. The National Safety Council had been involved to some extent since 1904. The American Medical Association (AMA) had an active committee in highway safety. The American Association for Automotive Medicine (AAAM) was 3 years old. The National Highway Traffic Safety Administration (NHTSA) and the Consumer Product Safety Commission (CPSC) were not to appear until about a decade later.

A small amount of research money was available in 1960 through the grant mechanism of the PHS. However, most research was aimed at identifying what was wrong with people who got into crashes and at motivating them to do better, preferably before the event.

Interesting changes occurred in the next several years. The most important was the conceptual shift that began in the field. Based on Gibson's observation in 1961 that the agents in all injury events are the five forms of physical energy, Dr. William Haddon developed the concept of preinjury, injury, and postinjury phases of injury events, the matrix of human and environmental factors that needs to be examined across all three phases, and an integrated model for intervention programs based on the control of physical energy as the injury agent.

Current research and intervention activities increasingly are built on this foundation. There is lessening animosity for the approach that considers injury control largely—but not entirely—as an area of environmental health, rather than almost entirely one of behavioral modification.

During the next several years the AMA moved almost completely out of the field, as did PHS. The National Safety Council modestly expanded its interests in research, AAAM became a strong proponent of the multidisciplinary approach to research, and NHTSA and CPSC were born. NHTSA has contributed to highway injury research through contracts, but rarely has tested new ideas that did not originate with NHTSA. For various reasons, CPSC has not done much nonhighway injury research. Until about a year ago, nonhighway injury research was moribund.

Building on the 1985 report of the National Research Council's Committee on Injury Research, and the interest of Centers for Disease Control (CDC), responsibility for developing a center for injury control was delegated to CDC. The specific goals were to strengthen the injury research community, injury research, and those injury programs that are based on sound scientific and administrative principles and which show close interaction between researchers and administrators. That approach is beginning to pay off: health departments are back in the game, and medical schools and schools of public health are beginning to teach related courses.

The first five injury research centers have been chosen from among 39 applicant institutions. There were 381 grant proposals submitted in competition for $5 million in research grant funds designated to support 31 projects. This is barely enough, however, even to start to study injury, which is the major cause of lost person-years of productive life in the United States.

The agenda for research lists these key issues:

- The body of grant money remains far too small and too evanescent to attract and maintain a critical mass of competent researchers and research concerning injury.
- Publishing injury research findings is difficult because of the lack of appropriate journals that are also recognized as acceptable by one's academic peers. As a result competent researchers sometimes have problems getting tenure or promotions and are lost from the field because their work and publication routes are poorly understood by colleagues in their primary disciplines.
- Although some good human-factors research is being carried out by psychologists, epidemiologists have largely ignored the area. Consider, for example, that most studies of highway crash causation start with the antiepidemiologic assumption that vehicles and roadways are ignored as contributors to crashes unless they clearly acted in a manner contrary to the way they were built. That some-

thing could be built so that its planned function would increase crash likelihood is considered irrelevant.

- There continues to be relatively little research into the long-term effects, costs, and cost distribution of injuries.
- Although the number and diversity of injury control programs may be increasing, well-designed and properly implemented evaluations remain a scarce entity.
- Studies of socio-political and economic factors that affect the adoption and maintenance of injury control efforts are almost nonexistent. The research agenda of the future must include attention to such political and administrative research.
- In October 1986, a congressional committee report, "OMB Review of CDC Research," documented how the Office of Management and Budget was making its own decisions on research to be carried out by CDC. The letter of transmittal states "the report found that OMB officials were seven times more likely to reject CDC's environmental and occupational research projects than research relating to infectious or other disease processes" (*1*). One of the projects scuttled was an epidemiologic study of injuries in falls from ladders.

The changes in these seven areas will indicate whether injury control progresses or merely continues alternating periods of ups and downs.

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Epidemiology: an Academic Perspective

Jess F. Kraus, PhD, MPH, Professor of Epidemiology, School of Public Health, University of California, Los Angeles, CA 90024

ONE OF THE MOST IMPORTANT contributions of academia to injury research is the variety of disciplines and expertises that can be applied to the study of a problem. Only recently have the social and behavioral sciences researchers taken a serious view of developing and testing theories to explain injury phenomena. In these disciplines, initiatives in injury research will come with the availability of research funding. These scientists need to develop fundamental understanding of injuries as a social problem. Without well-planned and implemented training programs, injury research will remain an academically uninteresting and unrewarding career goal.

Evaluation is a legitimate role of academia. For decades, numerous countermeasures and strategies for prevention or control have been implemented as environmental controls, legal or social sanctions, or attempts at behavioral change through education. The evidence to support the effectiveness of most of these strategies or countermeasures is weak or nonexistent.

Currently, the greatest single resource for funds for injury research in the United States is the National Highway Traffic Safety Administration. However, equal efforts should be given to solutions involving injury causes that are not related to motor vehicles. The most rational approach is to expand the funding base for all injury research under one agency equal to the level of that currently provided for motor vehicles.

There are several crucial technical needs that can, or should, be addressed from an academic setting. Classification is one of those needs. The forthcoming 10th Revision of the International Classification of Diseases will demonstrate a dramatic departure and improvement in the system of classification of injuries by external cause. Yet, with these changes, problems remain of discordant methods of classification for fatal injuries, as opposed to nonfatal injuries. In addition, a fair amount of the classification system is not exposure-based, but appears to be injury-mechanics-based. An attempt to recognize the role of exposures, either quantified or qualified, is an important step forward in understanding the etiology of injuries.

Nationwide injury surveillance never can be accomplished with the injury resources available now or in the foreseeable future. Since one-quarter to one-third of the entire U.S. population sustains a medically attended injury per year, it is easy to imagine the effort needed to construct, implement, and evaluate a truly useful nonfatal-injury surveillance system. The most logical approach, therefore, is to encourage local surveillance efforts. A study is needed on how to do injury surveillance rather than simply instituting surveillance programs based on untried methods and incomplete information or understanding of the myriad data-recording systems now in place. Perhaps the first priority should be to focus on surveillance of fatal injuries and those injuries that have the most devastating social, family, and personal impacts, including a high probability of future medical or psychological disability. At a minimum, surveillance of brain and spinal cord injuries, burn injuries, and nonfatal immersion injury should be included.

A related surveillance question is record linkage. Injuries and the facts surrounding them are recorded in a variety of places and ways. Yet attempts to connect these injury-data sources have been thwarted because of genuine concerns over confidentiality, access to information, and the citizen's right to privacy. There must be further focused research into efforts on how record linkage can be accomplished, keeping the safeguards of the citizen in mind.

One approach to wider availability of injury information is data pooling. Efforts from within academia to study how these pooling projects might be formulated and how inconsistencies in definitions and recording might be overcome would be a productive approach to using to the fullest what is already available.

Injury surveillance cannot be discussed without addressing the prospect of, and problems associated with, injury registries. The validity of registries is well established; however, within the context of injuries, there is a need to identify which classes of injuries would benefit most from a registry and why the registry is essential. To justify a registry of injuries requires that many unresolved, crucial questions be answered. Important questions remain for injuries to the central nervous system, burns, and immersion injuries. These injuries are catastrophic, having the most severe social, medical, and economic impacts. Yet the amount of data that is epidemiologically useful is quite limited; further, what information is available often is not consistently collected, recorded, coded, or analyzed. From the academic perspective, efforts to establish baseline criteria and data needs for injury registries are worthwhile.

There is a need to continue national or international conferences on selected methodological issues or substantive problems. In addition, although the amount of information now being gathered is impressive, and a quantum improvement from several decades ago, technical studies are needed to explain major variations in rates and causes of injury. More classic epidemiologic approaches are required, such as case-control studies, prevalence studies, or studies within existing cohorts to address relevant gaps in data.

Further, it is not certain that the available information has been used effectively. A more aggressive approach is needed in implementing known solutions. Perhaps the academic community is the place for "think tank" attempts to understand why these solutions have not been effectively implemented.

Finally, there are a few efforts in the United States to distribute basic information from the meager injury resources available. However, a national, or even international, information network—possibly within a Federal agency with input from State and local governments, academic institutions, voluntary agencies, and the World Health Organization—might be a worthwhile mechanism for disseminating information. Information would be available not only for existing, new, or emerging injury problems, but for successful and unsuccessful solutions as well.

Research Trends in Injury Prevention

B. J. Campbell, PhD, Director, University of North Carolina, Highway Safety Research Center, Chapel Hill, NC 27514

FROM 1965 TO 1985, mileage exposure for the United States population increased from about 900 billion miles per year to 1,700 billion miles per year, an increase of 93 percent. However, highway deaths decreased 7 percent. Within that decrease, the pedestrian death subset decreased 6 percent—very close to the overall decrease. Motorcycle deaths increased 300 percent, however, reflecting the great increase in the use of those vehicles. Truck deaths increased 55 percent, a disproportionate increase relative to truck registration.

The number of passenger car deaths decreased 27 percent during this period. Progress has been made in making vehicles more crash-worthy, and reducing and preventing injury and death. This is the result of several factors, in part linked to the development of better information on human tolerance to impact, and of data bases used to identify injury sources and evaluate injury prevention countermeasures. Note that this considerable accomplishment in reducing motor vehicle death and injury was achieved without substantial progress on the issue of occupant restraint.

Where do we want to be 20 years from now? The driving and riding population will be using physical restraint devices, whereas as recently as 2 years ago it was essentially unrestrained. If vehicle designers could assume that occupants would be restrained, it might be easier to increase the burden of crash energy management on the vehicle structure itself.

A restrained occupant population might permit other improvements. With unrestrained occupants, it is inadvisable to have a stiff underride structure on the rear of a truck. If designers could assume that occupants were restrained, then a stiff underride structure on trucks could become a net benefit. If that sort of tradeoff is true for trucks, it might be true for bridge rails and median dividers, for which little lateral excursion can be tolerated. With restrained occupants, higher overall levels of protection might become reasonable.

There have been decades of progress in developing motor vehicle official data bases that are useful for some levels of research, monitoring trends, and evaluation. Police accident reports offer a potential ready-made data collection capability because an officer is present at the scene with responsibility for managing the crash scene and collecting certain information. Some States have a mechanism for compiling and transferring individual crash reports to a centralized data base, enabling researchers to analyze data, test for shortcomings, ascertain benefits, and use the results to improve the data.

One goal that might be set for injury prevention in nonmotor vehicle areas, such as home fires and gunshot wounds, is to build more official data bases that are of interest to the injury prevention research community and useful for research. The requirement for officials to be present at the scene opens the possibility of gathering data in a way similar to the reporting of motor vehicle crashes.

In the future, hopes will be realized for better quality research in the injury prevention area. The multiple factors that mediate injury, complex relationships among factors related to injury, and the low probability of the event make good study design a challenge and a necessity.

A corollary of this point is the need to focus on the dual roles of injury prevention advocates and injury prevention researchers. Because there is an ever-present potential for conflict between the requirements for objective research, such as the need to proceed slowly and deliberately, and the need for advocacy to produce action, those who frequently serve in both roles must remember these different requirements.

Research Trends in Acute Care of Injury

Alasdair K. T. Conn, MD, Department of Surgery, Boston University School of Medicine, Peabody I, 818 Harrison Ave., Boston, MA 02118

ACUTE CARE RESEARCH comprises basic research, which examines the physiological and pathophysiological responses at the cellular level; clinical research, which applies changes to the clinical management of traumatic injury in the hope of improved survival; and systems research, which analyzes the contributions of individual components of a trauma system to overall patient care. By necessity, systems research includes fiscal analysis to determine the true cost of an increment in medical care in terms of improved survival, and to examine where these resources need to be placed.

Basic Research

Acute injury causes a vast array of metabolic disturbances that are as yet poorly understood. Although acute restoration of blood volume will prevent many late sequelae, much needs to be done to determine what changes occur because of acute injury. Can manipulation of the various vasopressors and kinins that are released improve survival in animal models? One still needs to be able to control spinal cord and central nervous system swelling and potentially improve the survival of patients with combinations of injuries. Research is continuing on the defense mechanisms (both humoral and cellular) in order to be able to manipulate these systems and prevent the septic complications of injury. Particular attention needs to be paid to research on head and spinal cord injuries because this is an area with high benefit potential.

Clinical Research

Clinical research on injury deals primarily with the resuscitative, operative and acute care phases of acute care. The clinical management of pulmonary and cardiac complications is well understood, and there are techniques to manage acute renal failure. Research trials in several new antibiotics are ongoing, and research into the manipulation of the neuroendocrine response is being performed. As funding for clinical research on injury diminishes, consideration should be given to centers that have demonstrated excellence in academic and clinical research. Appropriate trauma populations of sufficient size can provide statistically meaningful answers to many current questions.

Systems Research

Trauma systems research is still in its infancy. Trauma systems work, and do reduce mortality, but more research is needed in:

System components. What components of the system are essential for success; what are their relative weights?
Triage research. Although it is known which physiological values are of use in triage, more information is needed on the mechanisms of injury, which patients can benefit from the system, and how to identify those patients.
Morbidity data. Although morbidity data are available, they need to be organized and developed.
Data application. The data for acute care systems evaluation should not only be linked to data on rehabilitation and outcome, but should be used to identify populations at risk.
Trauma registries. The use of trauma registries should be encouraged; several States are developing trauma registries similar to cancer registries to follow systems development and evaluation.

Research Trends in Rehabilitation of Injury

J. Paul Thomas, PhD, Director, Medical Sciences Program, National Institute of Disability and Rehabilitation Research, U.S. Department of Education, Switzer Building NTS-2305, Washington, DC 20202

TRAUMA CARE IMPLIES advanced life support, the essence of the life-saving process itself. A question that comes to mind is: life-saving for what? Trauma usually is not limited to impairment of a single bodily system. In many cases, numerous impairments or potential impairments are present. These require much work on the part of the total treatment team, the patient, and the patient's family.

Rehabilitation is the comprehensive, multidisciplinary delivery of services for long-term, chronic, or catastrophic problems. The goal is to achieve optimal return of function or maintenance of function. Functions are physical, psychological, social, and vocational.

Among the problems presently of interest in the rehabilitation community is the pathophysiology of trauma or the disease process. Research in the clinical course is also important; it focuses on identifying rehabilitation problems that accrue. Of particular interest is the enhancement of function, the maintenance of function in a progressive disorder, and all aspects of psychological and social adjustment, vocational success, and community reintegration. The prevention and treatment of secondary medical complications deserve mention.

In 1968, the Rehabilitation Services Administration (DHEW) began to explore what could be done for one of the catastrophic injuries, spinal cord injury. After a few years of development, a "model system of care" was conceptualized. The important phases of the model system included emergency and acute care, acute physical restoration and rehabilitation, psychosocial adjustment services, vocational preparation, life-time followup care, and prevention. As early as 1970, DHEW was beginning to conceptualize primary prevention as an important component of this model system program.

The program began with one system in 1970 and has 13 projects today. The National SCI Statistical Center at the University of Alabama in Birmingham is the coordination point for an established nationwide standardized data base that has been developed by this research program.

This data base is crucial because of the protocol designed to pool and do statistical analysis of the data from the numerous sites in a standardized way. The National Institute of Disability and Rehabilitation Research (NIDRR) is building a data base for physicians and rehabilitation teams. As of 1985, this data base included 9,647 patients as research subjects and 28,951 patients whose progress had been followed for up to 12 years. Data are available on each patient as a research subject from point of injury through long-term followup. NIDRR also has a designated pediatric trauma research and training center with more than 3,000 patients representing 34 different participating trauma centers.

Where are we going in the field of trauma rehabilitation? Progress has been made in brain injury, thanks to the National Head Injury Foundation, concerned physicians, and allied health professionals. Progress has been made with burn rehabilitation, which requires more resources, information, and coordinated efforts.

Progress has been made in orthopedic trauma and musculoskeletal disability, with such specific problems as the knee and shoulder injuries, and in terms of the needs of the whole patient, particularly children.

Improved service delivery models—a part of the continuum of care described for spinal injury—can and should be applied to brain injury, severe thermal injury, major orthopedic trauma, and maxillofacial rehabilitation. We need development, testing, and evaluation of new modalities for functional restoration and the enhancement of function, and existing methods and techniques should be evaluated. Although much is being done in rehabilitation, it is not known if some new techniques work. We need to develop improved measures of functional appraisal of clinical outcomes. Every institution working in rehabilitation is collecting data, which should be shared with clinicians and scientists. We need as well increased emphasis on psychosocial outcomes and community adjustment.

Finally, new approaches are needed to involve families early in acute care and in acute rehabilitation settings. Policy research can help to eliminate disincentives to work, encourage community reintegration and independent living, stimulate major research efforts for the prevention and treatment of secondary medical complications, and further the development and testing of innovative public education programs for the primary prevention of disability.

The Role of Biomechanics in Vehicle Design for Control of Injury

David C. Viano, PhD, Assistant Department Head, General Motors Research Laboratories, Biomedical Sciences Department, Warren, MI 48090-9055

THE DESIGN OF AUTOMOTIVE occupant protection systems is a process based on an understanding of the mechanisms of injury and human impact tolerance. Injury mechanisms are the physical processes that result in tissue damage and functional impairment. Human impact tolerance refers to the levels of stress or load that the human system can withstand with little or no injury. This field of research is called injury biomechanics (*1*). It focuses on the nonpenetrating types of injuries that can occur among restrained and unrestrained occupants of highway vehicles involved in crashes.

Given sufficient information about injury mechanisms and tolerances, engineers can develop systems that will provide maximum occupant protection across the full range of crash configurations. Effective systems are achieved through developing realistic anthropomorphic test devices, or dummies, that respond with biomechanical fidelity to impact. Their characteristics provide criteria for evaluating engineering measurements in relation to human injury risk. In turn, the dummy and criteria are used to assess the effectiveness of protective systems in the development stage as well as in actual crashes.

Crash Injuries

There are two basic mechanisms involved in blunt, nonpenetrating impact injury to persons: localized loading of the human body and acceleration in the direction of loading. In the automotive environment, the primary collision of the vehicle with whatever it strikes is followed by an impact of the occupant with the inside of the vehicle. Local loading of a part of the human body against the instrument panel, or a seat belt, is referred to as the "second collision." There is a "third collision" between soft tissue and skeletal structures that takes place inside the body as it is stopped by the vehicle's interior or restraint system. The contribution of the two types of impacts to the injury process differs, depending on the body region and the severity of impact. The basic function of an occupant protection system is to reduce the severity of these impacts and thus their potential for causing injury. Several examples of occupant protection systems currently in passenger cars will demonstrate the role of biomechanics in vehicle design for injury control.

Early Years in Automotive Safety

The earliest automotive safety technology emphasized structural integrity of the passenger com-

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partment to provide containment of the occupant in frontal and roll-over crashes. In the 1960s, the concept of energy management through crushable front-end structures was added. This combined approach attempted to preserve the occupants' space, while the vehicle's crushing structures absorbed crash energy, lengthened the stopping time and distance of the passenger compartment, and thus reduced impact decelerations acting on the occupant. Further improvements were achieved by isolating the front-end structures from the passenger compartment to minimize intrusion or deformation around the occupant. This method of controlling the vehicle's impact is an important part of the total occupant protection system in current automobiles.

For an unrestrained occupant, the controlled deceleration of the vehicle in a frontal crash is followed by the impact of the occupant against the vehicle interior. During this "second impact," the unbelted occupant continues to travel forward at the vehicle's precrash velocity and strikes the interior, which has come to rest in front of the occupant. The protection of the occupant in this situation depends upon energy-absorbing interior structures and load-distributing surfaces that reduce the occupant's deceleration while spreading the impact forces over a broad portion of the body's strongest parts.

Interior Safety Engineering

The concept of impact energy absorption has two aspects. First, the deceleration of the occupant should be extended as long as possible. This can be done by having the occupant interact with something that deforms in a controlled manner, thus increasing the body's stopping distance. Second, it is important that the yielding structure does not spring back at the occupant, but deforms permanently or recovers very slowly. Otherwise, the impact energy is returned to the occupant and not absorbed by the deformed structure.

Although one method to achieve energy absorption and load distribution is with thick, slow-recovery foam padding, there are practical limitations on its effectiveness in severe crashes. As a result, more complex systems have been developed to improve occupant protection. This has been achieved for the driver by the development of an energy-absorbing (EA) steering system, which uses a force-limiting column to safely decelerate the driver's chest, and a high-penetration-resistant (HPR) windshield, which uses a stretchable plastic layer between two sheets of glass for head impact protection.

Energy-Absorbing Steering System

In the early 1960s, automotive safety engineers were seeking information on the force tolerance of the chest. This information was needed for the development of an EA steering system to safely decelerate an unrestrained body contacting the steering wheel. The basic concept was to design a steering column to crush at a prescribed load, one not great enough to cause significant rib fracture. This device would increase the driver's stopping distance, decrease thoracic deceleration, and absorb impact energy.

However, the design effort stalled because the available human tolerance data did not provide specific information on the appropriate yield force for the system. In addition, the calculated tolerable force using the accepted 60-g whole-body deceleration tolerance, and an approximately 30-kg chest mass, indicated a 17.6 kilo-Newton (3,960-lb.) tolerance that seemed unrealistically high for system design. The basic safety objective was to design the yield force as high as practicable, consistent with human tolerance; to maximize the energy-absorbing capacity; and to extend the range of safety function of the system.

Faced with uncertain information on the force tolerance of the chest, researchers developed a crash simulation facility and conducted experiments on human tolerance in automotive crash situations. The first experiments (*2*) involved sled tests with embalmed cadavers in order to simulate the response of an unrestrained occupant interacting with loadmeasuring surfaces. Data derived from head, chest, and knee contacts against padded load-cells provided the first information on human tolerance to impact forces. The resulting data on force tolerance of the rib cage provided the necessary biomechanical information to permit design of the energy-absorbing element in the steering system. Subsequent experiments (*3*) with a prototype EA steering system confirmed that a 3.29-kN (740-lb.) maximum hub force on the sternum and an 8.00-kN (1,800-lb.) maximum load on the shoulders and chest allowed column compression with only minor risk of rib fracture for a well-centered impact. These tests demonstrated the benefit of load sharing between the chest and shoulders, which was accomplished through load distribution over the rim, spoke, and hub surfaces of the steering wheel.

The EA steering system was introduced in 1967-model vehicles. The final system included a compressible ball-sleeve column, a steering wheel with improved load distribution and stiffness, and an anti-intrusion mounting bracket to reduce rearward motion of the steering system resulting from crush of the engine compartment. When the load of the driver on the steering wheel exceeds the compressive force of the energy-absorbing element, the column slips out of the shear capsule, compresses, and absorbs energy. This system has proved effective in saving lives and reducing injuries.

An evaluation by the National Highway Traffic Safety Administration (NHTSA) (*4*) found the overall risk of driver fatality in a frontal crash reduced by 12 percent since the introduction of the EA steering system. The risk of serious injury (including fatality) specifically from contact with the steering assembly was reduced by 38 percent. More recent safety developments of the steering system have focused on the steering wheel to improve protection of the face of the lap-shoulder-belted driver, and the abdomen of the unrestrained driver, and on better methods of assessing crash protection.

High-Penetration-Resistant Windshield

Injury research during the early 1960s indicated that the windshield glass in use was a possible source of deep facial laceration. These windshields were constructed of two glass layers with a thin (0.38-mm or 0.15-in) layer of plastic tightly bonded between them. The laminated glass was thus fairly brittle and would break and be penetrated by the head in severe crashes. This often resulted in the face being raked against the jagged edge of the hole made by the head. A proposal was made that better occupant protection could be achieved if the head could be kept from passing through the glass during impact, while ensuring that the head would be safely decelerated to protect against concussion injury.

Extensive collaboration between engineering and medical experts was required to determine an injury assessment procedure for the evaluation of prototype head protection systems. Evaluation of head protection systems was needed to develop a laminated glass that would yield under impact to increase the head's stopping distance, yet still resist head penetration at higher impact speeds. The collaboration resulted in a series of head impact experiments (*5*) and led to a weighted impulse criterion based on average head acceleration raised to the 2.5 power ($A^{2.5}$; GSI = $A^{2.5}T$) and impact duration to assess concussion injury risk. This so-called Gadd Severity Index (GSI) became a widely accepted method of head injury assessment in anthropomorphic dummy tests and was the forerunner for the current Head Injury Criterion (HIC).

Other research (*6*) led to the development of a chamois covering for the dummy head, which provided an objective indication of laceration protection of prototype windshields. Eventually, cadaver impact experiments were conducted using various prototype windshields in simulated vehicle crashes. These tests showed that a thicker (0.76-mm or 0.30-in) plastic interlayer bonded more loosely to the two outer sheets of glass could provide a stretchable structure with greater energy-absorbing capability, while still safely keeping the head from penetrating the windshield at high-impact speeds.

The optimum characteristics for occupant protection were worked out in a joint effort between the auto industry and the glass manufacturer, so that it was possible to introduce the new windshields in 1967-model vehicles. Since then, the HPR windshield has proved remarkably effective in reducing injuries to the face while not increasing the risk of brain concussion. A recent evaluation by NHTSA (*7*) found a 70-percent reduction in nonminor facial lacerations and fractures through the use of HPR windshields. More recent safety developments of windshield glass have focused on (a) antilaceration inner shields, whereby a layer of plastic lines the inner surface of the windshield to further prevent laceration of the face and scalp, and on (b) a better method of assessing head dynamics and facial contact force during glass impact.

The Need for Occupant Restraint

Although interior safety in the form of energy-absorbing structures and load-distributing surfaces has achieved tremendous gains in occupant crash protection, the crush distance available is only a fraction of that which is needed to achieve safe

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occupant decelerations in high-speed vehicle crashes. Further enhancements of occupant protection can only be achieved with restraint systems, which allow the occupant to take better advantage of the vehicle's crash-worthy structure.

A snug-fitting lap-shoulder belt ties the occupant directly to the passenger compartment and allows that occupant to "ride-down" the crash as the vehicle's front-end crushes. This coupling and ride-down decelerates the occupant more gradually and over a longer distance than is possible with energy-absorbing interior structures, while minimizing the more severe occupant-to-interior impacts. Belts are designed to distribute restraining loads over strong skeletal structures, including the shoulder, rib cage, and pelvis, while minimizing the level of whole-body deceleration in recognition of human tolerance. Finally, belts provide significant control over the occupant's motion, particularly in roll-over crashes, and virtually eliminate the risk of ejection. A lap-shoulder belt restraint system adds significantly to the effectiveness of the total occupant protection system. When used, seat belts reduce the risk of fatality by 43 percent (*8*) and serious injury by 40 to 70 percent (*9*) in motor vehicle crashes.

Air-bag restraints were developed to overcome the primary weakness of belt systems: to be effective, belts must be fastened in advance, usually by the occupant. Using a pyrotechnic device to generate nitrogen gas, a bag can be rapidly inflated during the early phase of vehicle frontal crash without action by the occupant. The bag then fills some of the space between the occupant and the interior, which couples the occupant to the passenger compartment and achieves some of the safety benefits of ride-down and load distribution. This coupling is only temporary, however, because the bag must be vented and deflated, so that it will not act as a spring. However, injury biomechanics research (*10*) has found that the rapid development speed of an air bag can present a risk to those who may be close to the bag during inflation. Thus, air bag design requires a tradeoff between a long inflation time, to reduce the risk of inflation injury, and a rapid inflation, to quickly fill the space between the occupant and the interior. Because air bags neither remain inflated nor provide lateral restraint, seat belts are needed to adequately control occupant kinematics over the range of crash types.

Occupant Crash Protection

The current safety thinking is focusing on combinations of safety systems to further improve occupant protection in a crash. In this context, inflatable restraints are viewed as a supplement to seat belts. The lap-shoulder belts would provide the primary coupling to the vehicle and control of kinematics, whereas the air bag would provide the additional protection of load distribution and crash energy absorption in the more severe frontal crashes.

This effort is part of the car industry's goal that new car development continue to seek improvements for the protection of the unrestrained as well as the restrained passenger. Although challenging, strategies may exist for improving protection for both by vehicle design. But as there is an effort to introduce more sophistication in safety systems, there is a greater need for sensitive measures of occupant protection to objectively determine the most effective combination of systems (*11*). The resulting combination of safety technologies can work with crash-worthy vehicles and safe interiors to further enhance occupant protection.

As our understanding of injury mechanisms and biomechanical responses expands, we are developing more refined injury criteria and better anthropomorphic test dummies. The Hybrid III dummy measures more than 50 different responses to assess occupant protection systems. It is currently the most sophisticated dummy available for frontal crash testing. Efforts are underway to expand its capability to assess head and facial injury (*12*), and chest and abdominal injury (*13*). We are also moving rapidly to interpret injury risk as a continuous function of dummy responses rather than as a strict tolerance threshold. This approach recognizes the distribution in tolerance of the population at risk and the range of crash severities resulting in injury, and is leading to a scientific basis for safety engineering (*14*).

Biomechanics programs are establishing the different tolerance levels and injury patterns of expectant mothers, children, and the elderly, as well as the type of crashes resulting in their injury. In addition, we are identifying factors (*15*) such as intoxication and osteoporosis that influence impact tolerance. Finally, injury biomechanics research is addressing the issue of brain and spinal cord injury impairment and seeks to define the mechanism of injury and tolerance of neural tissues. This eventually will lead to better interpretations of the risk of injury disability from laboratory tests with dummies. The goal is to provide the means to effectively evaluate safety systems and optimize their benefits for the protection of the driving public.

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The Role of Biomechanics in Preventing Occupational Injury

Donald B. Chaffin, PhD, Professor and Director, Center for Ergonomics, The University of Michigan, 1205 Beal, Ann Arbor, MI 48109-2117. Partially supported by NIOSH ERC Training Grant, OH07207.

AS IN VEHICLE ACCIDENTS, when a worker slips and falls or is struck by moving equipment in industry, the force of the impact, often over a short period and applied to a localized tissue, causes serious injury and even death. Workers' compensation data indicate that these "impact trauma" events account for about 37 percent of all injury and illness claims (*1*). Further, when a worker is required to perform a manual exertion, occasionally or very repetitively, the physical stress of the exertion(s) causes a large variety of serious, disabling injuries (figure 1). Worker's compensation data indicate that such "overexertion trauma" accounts for more than 31 percent of serious injury and illness claims (*1*). In both impact- and exertion-related trauma, biomechanics knowledge is essential to understand the mechanism of injury and to devise scientifically valid strategies for control of the risk factors so identified.

Biomechanics trauma research in industry. Epidemiologic studies by Kelsey and White (*2*), Pope and coworkers (*3*), Snook and Jensen (*4*),

Figure 1. Two different types of biomechanical injury mechanisms common in industry

Event	Type of trauma	Typical medical outcomes
Sudden force	Impact	Contusions Lacerations Fractures Amputations Joint subluxations Concussion
Volutional activity	Overexertion	Tendonitis Tenosynovitis Myofascial disorders Nerve entrapment disorders (CTS) Low back pain

and others show that overexertion injuries are prevalent and costly to industry. They produce 31 percent of all Workers Compensation claims; comprise 60 percent of lower back pain in reported injuries; permanently disable about 60,000 workers a year and temporarily disable about 4.2 million workers a year; and cost the economy an estimated $15 to $20 billion a year, the equivalent of about $400 per worker.

Most often, lifting, pushing, or pulling objects is associated with the incidence of overexertion-related back problems (*5*). Recently it has been shown that maintenance of awkward postures for sustained periods and highly repetitive hand or arm exertions are major risk factors in different types of overexertion-related trauma (*4, 6*). Frequently, there is not simply one risk factor causing injury, but several combining in the workplace to raise the probability of harm. As an example, a 1978 review of the literature sponsored by the National Institute for Occupational Safety and Health (NIOSH) on the cause of occupational low back pain listed 17 potential risk factors (both personal and workplace-related). An expert panel assembled by NIOSH 2 years later listed five workplace risk factors as the major cause of occupational low back pain but included five others as major contributing factors (*5*).

A suggested plan for occupational biomechanics research on musculoskeletal injuries. Research is needed to help measure the types of forces to which workers are subjected in different job situations, and to provide postural and motion description data in jobs suspected of causing excessive numbers of injuries. Fortunately, recent advances in video and force measurement systems make it possible to acquire such data and classify the kinesiological aspects of manual labor in many industries (*7*).

Data on human size, shape, flexibility, and strength are not being acquired with the detail necessary to represent the large variations that exist in different ethnic, gender, and age groups. Despite the limitations of the existing population and job descriptive data, some human kinetic models have been devised to predict the forces and moments within various joints while performing common industrial tasks (*7*).

One of the biggest limitations of the existing models in predicting the stresses on various tissues is the lack of knowledge on the neurological motor control strategies used to activate various muscles during a given situation. However, with the advent of multiple electrode electromyography systems and computerized data acquisition and processing systems, such muscle activation rules are slowly being revealed (*8*). Until computerized tomography and magnetic resonance imaging are more widely used, the precise shape and relative positions of distinct musculoskeletal components will not be known. Tissue stress models have been devised to help define potential injury mechanisms, but with limited validation to date. One reason for the lack of tested validity is that the parameters of stress leading to failure of various relevant musculoskeletal tissues are only now being estimated in laboratory studies. True models to predict tissue injury will result as tissue failure data are acquired. These models will then need to be validated by epidemiological studies.

By using simplifying assumptions, it has been possible to learn how different risk factors in the workplace combine to cause overexertion-related low back pain and sciatica, carpal tunnel syndrome, and finger flexor tendonitis and tenosynovitis (*9–11*). Recent studies (*12*) have disclosed how fibers are destroyed by certain types of stretching and repetitive exertions. Brinckmann and Johannleweling (*13*) have disclosed that the spinal discs fail at relatively low loads when repeatedly stressed. Human gait analysis studies have documented how important appropriate shoes are in preventing certain types of lower extremity injuries (*14*). Studies of industrial activities have shown how important it is to maintain high levels of foot traction in certain tasks (*15*) and that many industrial floors do not provide such traction (*16*). Slipping and falling often result from a lack of certain types of muscle coordination, which varies among people and with age (*17*).

Figure 2. Opportunities for biomechanics research to contribute needed science for prevention strategies: Stages of overexertion trauma, prevention levels, and appropriate strategies

Stage of overexertion trauma	*Stage of prevention*	*Prevention strategies*
Stage 0: Population performing manual exertions	Primary	Ergonomic design of jobs for all workers
Stage 1: Mild symptoms but still able to work normally with some personal days lost	Secondary	Screening Training Job rotation Job modifications
Stage 2: Severe symptoms; substantial impairment of work with temporary disability	Tertiary	Aggressive medical follow-up and rehabilitation, with job special accommodations
Stage 3: Recurrence of symptoms after treatment or development of muscle weakness and loss of motion	Permanent disability	

Biomechanics and prevention of overexertion and impact trauma in the workplace. Biomechanics research has and should continue to contribute to understanding of the following areas to prevent overexertion- and impact-related injuries in industry: (*a*) the effects of various types of floors and shoes in different tasks known to cause slips, falls, and lower extremity impact trauma; (*b*) the kinetic effects and resulting neuromuscular reactions during a slip or trip; and (*c*) personal protective clothing.

Overexertion trauma in workers may be described in symptom stages corresponding with suggested prevention strategies which depend upon biomechanical studies to obtain the required scientific understanding. Primary prevention strategies for the total worker population performing manual exertions entail ergonomic design of jobs for all workers. Secondary prevention strategies consist of screening, training, job rotation, and job modification. These are directed toward such problems typically resulting in mild symptoms, but with the worker still able to work normally, but with some personal days lost. The third prevention strategy level calls for aggressive medical followup and rehabilitation with special accommodations on the job. Symptoms at this level are severe, with substantial impairment of work with temporary disability. At the next level, recurrence of symptoms after treatment, or development of muscle weakness and loss of motion, leads to permanent disability (figure 2).

In primary prevention, biomechanics knowledge is critical in defining the job and personal risk factors and the engineering guidelines necessary to redesign jobs. In this context, biomechanics becomes the foundation discipline for ergonomic job improvements. In secondary prevention, biomechanics knowledge can provide the means to evaluate those who perform certain types of hazardous manual work, such as by providing muscle-strength testing parameters (*18*). Biomechanics becomes important when prescribing certain types of manual training, such as lifting methods (*19*), and under what conditions job rotation should be considered. Tertiary prevention strategies, if a person is impaired, require more precise knowledge of the person's performance capability within the context of the manual jobs for which the person could qualify. Knowing the biomechanical requirements of various jobs and the capabilities of impaired individuals can greatly expedite the disability evaluation process, and thus reduce lost time and rehabilitation costs.

Summary. Overexertion and impact trauma are the major cause of occupational injuries and deaths. These types of injuries result from a lack of biomechanics knowledge, combined with ineffective dissemination and use of existing biomechanics knowledge. The cause of these type of injuries is not single factored, and hence both the research and prevention strategies must be comprehensive and multidisciplined. Understanding the cause of these injuries in industry will also have direct relevance to many sport activities that cause similar injuries, but may be less easily controlled and prevented, owing to the competitive nature of most sports.

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Interventions: Measuring the Progress of Injury Control Objectives

Objectives for Injury Control Intervention—The Department of Health and Human Services Model

Ned Calonge, MD, MPH, Assistant Professor, Department of Family Medicine, University of Colorado Health Sciences Center, 1180 Clermont Street, Denver, CO 80220

IN THE 1980 PUBLICATION "Promoting Health/Preventing Disease: Objectives for the Nation" (*1*), the Department of Health and Human Services (HHS) described objectives to be achieved by 1990 for injury prevention and control. These objectives were designed to meet some of the goals set forth in "Healthy People: The Surgeon General's Report on Health Promotion and Disease Prevention" (*2*). These objectives targeted several broad areas of injury for reduction, specifically motor vehicle injuries, falls, drownings, burns, gunshot wounds, and poisonings. This paper reviews these objectives, describes currently available and other potential intervention strategies for achieving these objectives, and briefly reports on the status of meeting these objectives.

Motor Vehicle Injuries

The 1990 objectives include a 25-percent reduction in the motor vehicle fatality rate from 1978 levels (to 18 per 100,000 people), a 40-percent reduction in this rate for children under age 15 (to 5.5 per 100,000 people), and a 75-fold increase in the proportion of motor vehicles with automatic restraint protection (to 75 percent from a 1979 level of 1 percent). Potential interventions suggested by HHS can be grouped into education and information strategies, product design or technological improvement strategies, legislative and regulatory strategies, and economic strategies. Data from 1984 reveal that deaths from motor vehicle injuries for all ages dropped to 19.6 deaths per 100,000 people, and for children aged 0–14 years, to 5.9 deaths per 100,000. These statistics indicate that two of the 1990 objectives are within reach.

Using data from the 1985 National Health Interview Survey (NHIS) to indirectly assess the nation's progress toward the 1990 objectives, Hofman reports that 36 percent of households report use of safety belts all or most of the time, 98 percent have heard of child restraint seats, and 47 percent were instructed in the use of child re-