Reducing Injuries and Their Results: The Scientific Approach

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The problem of human injury has been misunderstood and neglected for too long. Although scientific approaches have been applied to the problem of human damage from traditionally recognized environmental hazards—such as lead and pathogenic organisms—analogous approaches for controlling injuries have been largely ignored. This paper describes the etiologic agents of injuries and methods of preventing or reducing their harmful effects on man. Effective strategies for reducing human losses due to injuries go far beyond traditional concepts of "accident prevention": even when "accidents" cannot be prevented, there are many ways to prevent or reduce the frequency and severity of injuries and their sequelae. Important considerations in choosing injury countermeasures include effectiveness, economic constraints, and reduction of the amount of individual cooperation that is necessary.

As infectious diseases gradually yield to scientific approaches, injuries assume increasing importance as a major health problem. In many countries, injuries are now the leading cause of death from early childhood through most of the fourth decade of life.

Among the very young and the aged, injury deaths are primarily due to non-motor-vehicle accidents such as falls and fires. During the most productive years of life, and in many countries during childhood as well, motor-vehicle fatalities comprise the largest category of injury deaths. Increases in the number and use of motor vehicles have been accompanied by dramatic increases in the number of deaths and injuries, especially among teen-agers and young adults (Aldman and Thorson, 1971).

Despite its magnitude, the problem of injury has been the subject of more folklore and less competent scientific attention than has any other serious problem in medicine. Most of the folklore has been associated with the word "accident," with its connotations of fate, chance, and unexpectedness. However, the notion of "fate" is inappropriate, because injuries can be prevented or reduced in their severity; they are not "chance" or random events but the predictable results of specific combinations of human and environmental factors; and they are no more "unexpected" than most diseases.

An essential first step in the control of most diseases has been clarification of the nature of their etiologic or causative agents and the means by which they harm people. In this paper we describe the etiologic agents of injuries and methods of preventing or reducing their harmful effects on man.

For the majority of injuries—including most that involve vehicles, falls, and weapons—the etiologic agent is mechanical energy. Thermal energy, electrical energy, and ionizing radiation are the agents in burns, electrocutions, and radiation damage, respectively. Analogous categories of harmful interactions include poisoning and drowning; guidelines and general principles for their prevention closely parallel those for energy damage (Haddon, 1967).

De Haven (1942; 1952; 1968) was the first to recognize and deal quantitatively with injury from an energy-exchange standpoint. It is from his work that much of the core of the modern field of injury reduction derives. While properly restrained, Stapp (1955) personally sustained deceleration from 632 mph to zero in 1.4 seconds without permanent injury, proving that with proper environmental management the human body can withstand tremendous forces. This confirmed De Haven's earlier work on survival of falls from up to 150 feet, and indicated that most fatal injuries are preventable (Haddon et al., 1964).

Haddon (1973) has described basic strategies that prevent energy from reaching people at rates or in amounts that are harmful. These strategies can be summarized as: not producing energy or potential sources of energy, or reducing the amount of energy (e.g., not making gunpowder, reducing the speed capabilities of cars); preventing or modifying the release or transfer of energy (e.g., having safety catches on guns, slowing the burning rate of cloth, padding automobile dashboards); and separating people from potentially injurious sources of energy (e.g., using barriers, phasing traffic, putting electric lines out of reach). In addition, there are ways to make people more resistant to injury—for instance, by treating osteoporosis, which increases the risk of fractures in postmenopausal women. Finally, when a person has been injured, the outcome will be greatly influenced by society's ability to respond to the emergency and provide subsequent medical treatment.

The aim of all these strategies or general principles is to *reduce human losses due to injuries.* Failure to recognize and apply these basic principles of injury reduction means that each year millions of unnecessarily severe injuries occur. The old concept of "accident prevention" ignored the fact that there are many ways to prevent or reduce the frequency and severity of injury, even when an "accident" (for example, a collision) cannot be prevented.

One approach to the problem of reducing injuries is to consider the three major phases that determine the final outcome (Haddon, 1972). These three phases are shown in Table 1, with examples of countermeasures related to impact injuries, burns, electrocutions, poisonings, and drownings. The same three phases, which also apply to reducing human losses due to diseases, will be described in detail, with special emphasis on highway injuries.

I. The *first phase,* or "pre-event phase," includes all the factors that increase the likelihood that a person will be exposed to a particular environmental hazard. In the case of poliomyelitis before vaccine was available, pre-event measures were exemplified by attempts to keep children away from swimming pools and crowds during epidemics, in order to reduce their exposure to the virus. In the highway field, the first or "pre-crash phase" involves factors that determine whether potentially damaging energy exchanges will take place—that is, whether vehicles will crash.

For crashes resulting in serious injury or death, probably the most important human factor in the pre-crash phase is alcohol intoxication. Studies show that between half and three-fourths of the drivers apparently responsible for initiating crashes in which they were killed had been drinking alcohol, usually in large quantities (U. S. Department of Transportation, 1968). In general, the more violent a crash, the more likely it is that the driver was intoxicated. High blood alcohol concentration are also common among fatally injured adult pedestrians as well as among persons killed by drowning, falls, and other non-highway injuries (Haddon et al., 1961; Waller, 1972; Dietz and Baker, 1974).

The relative importance of alcohol as a factor in fatal injuries varies substantially with age, time of day, and other factors. A study of pedestrian deaths showed that most pedestrians killed in the city of Baltimore, Maryland, were either very young or elderly or intoxicated. In the city of Rio de Janeiro, Brazil, on the other hand, the majority were adults of working age who had *not* been drinking. For this latter group, the per capita death rate was approximately 20 times the Baltimore rate. The difference appeared to be due in part to a traffic environment in Rio that was especially

TABLE 1
Examples of Tactics for Reducing Injury Losses

Type of Event	*Pre-Event Phase*	*Event Phase*	*Post-Event Phase*
Impacts (e.g., from falls)	Alcoholism programs Handrails on stairs	Fire nets Padding on floors Football helmets	Trained ambulance crews Well-equipped ambulances Pneumatic splints
Exposure to heat	Childproof matches Eliminating floor heaters Venting explosive gases	Flame retardant clothing Reducing surface temperature of heaters and stoves Sprinkler systems in buildings	Burn centers Skin grafting Rehabilitation
Exposure to electricity	Covered electric outlets Insulation on electric hand tools and wiring	Circuit breakers Fuses	Cardiopulmonary resuscitation Equipment
Ingestion of poison	Childproof medicine containers Separation of CO from passenger compartments of autos	Making cleaning agents inert or less caustic Packing poisons in small, non-lethal amounts	Poison information centers Detoxification centers
Immersion in water	Fences around swimming pools Draining ponds	Life jackets Training to tread water or swim	Lifesaving training Teaching mouth-to-mouth resuscitation techniques to general population

hazardous to pedestrians (Baker, 1973b).

Traditionally, the emphasis in accident prevention has been on human behavior and attempts (commonly unsuccessful) to change it. The concept of "human error," however, is much less appropriate than concepts that emphasize the relationship between human capabilities and the complex demands of a task such as driving (Klein and Waller, 1970). At present, the driver or pedestrian is expected to compensate for any inadequacies of vehicles, highways, or other drivers—that is, inadequacies in the driving system. As a result, collisions are generally regarded as someone's *fault*, rather than as a failure that could have been prevented by some change in the system. In illustration, if a driver fails to see a car coming from his right side at an intersection, the resulting crash is likely to be blamed on the driver, rather than being attributed to the fact that structures near the intersection blocked his view, or to the limited field of vision that most cars provide the driver.

Thus, the vehicle can contribute to crash initiation, either by placing excessive demands or restrictions on the driver, or through mechanical inadequacies or failure. Steering, tire, and brake failures sometimes initiate crashes, but seldom are searched for after crashes. Their prevention will probably require stringent regulation of vehicle manufacture and effective inspection procedures.

In the U. S., federal standards pertaining to new motor vehicles are set by the National Highway Traffic Safety Administration. These standards are broad in their coverage and extensive in detail (Code of Federal Regulations, 1972). Some of the standards are designed to decrease the likelihood of crashes—for instance, standards pertaining to brakes, emergency flashers, and lighting systems. The U.S. government sets standards for these and many other safety features for all vehicles sold in the U.S., but sets no safety requirements for U.S. cars sold in foreign countries. The governments of several other countries, such as Sweden, Canada, and Australia, have adopted most of the U.S. standards and in some cases have developed standards that are more rigorous than those of the U.S.

Other pre-crash countermeasures relate to the environment, and here the principle of *separation* plays an extremely important role. Pedestrians, for example, can be separated from motorized traffic through use of stoplights or barriers, or by being placed at different levels. Usually the apparent cost of such measures prevents sound traffic engineering because the price of *not* providing safer pedestrian routes is ignored. The price of inadequate separation is extremely high; it includes, for example, the lives of 10,000 pedestrians every year in the U. S. alone.

Similarly, it is important to separate cars from heavy trucks on the highways, because the discrepancies in their speed and braking capabilities increase the likelihood of crashes (Haddon, 1971). Collisions with heavy trucks are especially likely to generate forces that are not survivable by the occupants of cars. The possibilities for separating different types of vehicles include requiring them to travel at different hours or by separate routes. Separation also reduces injury rates on high-speed freeways when well-designed barriers or wide medians are used to minimize chances of head-on collisions.

II. The *second phase,* or "event phase," involves the interaction of the human with the etiologic agent. Just as vaccinaction prevents the polio virus from causing paralysis, so certain countermeasures prevent harmful energy exchanges even when there is a crash. Adequate guardrails beside the highway, for example, can reduce the likelihood of severe injury when a car leaves the highway. Safe roadside design also necessitates removing solid structures from beside the road. Structures that cannot be eliminated should be moved farther away, covered with compressible materials (such as a series of oil drums), or replaced with structures that will be less damaging. It is possible, for instance—and even economical—to install sign posts that yield gently when a car hits them, rather than staying firmly in place and increasing the chances that occupants will be injured (Insurance Institute for Highway Safety, 1970, 1972; Kelly, 1973).

An important principle in the "crash phase" is *protective packaging* of the occupants. As the word "packaging" suggests, the same principles that apply to sending a fragile article through the mail without breakage can and should be applied to safely transporting human beings inside vehicles. Just as a vase tossed out of a box is likely to break, people thrown out of cars are at greatly increased risk of severe or fatal injuries. Lap and shoulder belts prevent these unnecessary injuries by keeping people inside vehicles. They also prevent people from being thrown against damaging surfaces inside the car. As a result, serious or fatal injuries are substantially more common among people who are not wearing safety belts when they crash, compared to those wearing safety belts (Griffin, 1973).

Examples of federal standards related to crash-phase countermeasures are: steering assemblies that cushion rather than spear drivers; head restraints to reduce whiplash injuries; door locks and windshields that prevent ejection; reinforced vehicle sides to protect passenger compartments from inward deformation; safety belts and interior padding to make crashes more survivable; and crash-resistant fuel systems to prevent fires. As in the case of the federal standards related to crash initiation, the U. S. does not require that cars sold abroad meet these standards.

III. The *third phase,* or "post-event" portion of the sequence, involves maximizing salvage once damage has been done, reducing the likelihood of death or disability. Again using polio as a parallel example, the objectives in the third phase are to save life, prevent or reverse paralysis, and rehabilitate the patient to the greatest extent possible.

Emergency rescue services, medical treatment, and rehabilitation are important components of the "post-crash phase." In the event of serious injury it is important to provide expert medical care as quickly as possible. The many time-consuming elements of the post-crash phase—such as signaling the location and requirements of injured persons, dispatching emergency vehicles, traveling to the scene, providing whatever immediate care is essential, and transporting patients to the most appropriate medical facilities—make it essential to have emergency systems that integrate communications, transportaion, and treatment (Committee on Acute Medicine . . . , 1968). Because physicians often are not available to provide essential treatment in the early post-injury period, an excellent textbook has been developed by the Committee on Injuries of the American Academy of Orthopedic Surgeons (1971) to teach ambulance attendants and emergency room personnel lifesaving skills such as maintaining the airway, controlling hemorrhage, and countering shock, as well as how to manage many emergency situations.

There is growing recognition that seriously injured persons should be treated, whenever possible, by physicians who have special training in the management of trauma. One study of patients who survived long enough to permit definitive treatment showed that, even in a major U. S. city, the most basic principles of management of the injured often were not applied (Gertner et al., 1972). Better training of medical personnel must be combined with systematic efforts to ensure that the most seriously injured patients are taken to facilities that are equipped and staffed to treat them.

Information collected at the time of emergency treatment may be extremely useful in helping to evaluate the success of emergency and subsequent medical treatment (Baker et al., 1974) and in preventing similar injuries to other people. In the U. S., the National Electronic Injury Surveillance System (NEISS) collects information from 119 emergency rooms selected so as to comprise a representative sample. Every evening each hospital lists the day's product-related injuries on a brief form placed in a simple electronic device. During the same night a central agency in Washington collects the data by automatic means, over telephone lines. Examples of injuries for which data are collected are those associated with: sports equipment, toys, tools, lawnmowers, stoves, glass bottles, baby cribs, high chairs, cleaning agents, and liquid fuels. Results of the analyses are used for public-information releases and as the bases for national safety standards and design changes (U. S. Consumer Product Safety Commission, 1973).

As is true for U. S. standards for motor vehicles, standards for other products do not apply when the products are manufactured for export. For example, children's nightclothes that are sold in the U. S. now must meet certain specifications relating to susceptibility to ignition, burning, and heat retention. U. S.-manufactured nightclothes that do not meet these specifications can be exported for sale in countries that lack their own protective standards. Even where they apply, U. S. standards are not always sufficiently strict, and for some sources of injury no standards are in existence.

Choosing Strategies

Several considerations should be kept in mind when planning programs or choosing countermeasures to reduce injuries. First, economic considerations are important. The often heard statement: "It's worth it, if it saves just one life" is not true if, for the same amount of money or other resources, *more* than one life can be saved. Unfortunately, the actual benefits of proposed programs are often difficult to determine, since adequate evaluation of safety measures is a rarity. In the past, most decisions have been made on the basis of "seeming reasonable," without considering the high cost and limited effectiveness of many measures such as educational programs and safety campaigns (Baker, 1973a). Recently, a U. S. television campaign that would have cost about seven million dollars if presented nationally was carefully evaluated in a community with dual television cables. Viewers on one cable saw a variety of high-quality, professionally prepared television messages designed to encourage people to wear safety belts. The evaluation revealed that the TV messages, although shown many times, did not increase safety-belt usage (Robertson, et al., in press).

Another important point to be considered is that "passive" protection, whenever feasible, is preferable to "active" protection (Haddon, 1974; Robertson, in press). "Passive" protection refers to measures that do not require individual cooperation in order to be effective. (In illustration, purifying public water supplies is a passive measure; requiring people to boil their own water is an active measure.)

An excellent example of a passive measure for reducing vehicular injuries is the airbag. Airbags are like empty pillows that are stored in collapsed form, usually in the steering wheel and dashboard. When a crash of specified severity occurs, the airbags automatically inflate immediately with compressed gas, cushioning the driver and front-seat passenger. The bags remain inflated only during the very brief interval when they are needed and do not interfere with steering. In the U. S., airbags are the subject of extensive field tests, especially by General Motors Corporation and insurance companies. Results to date indicate that they are extremely reliable and offer effective protection to front-seat occupants in a wide range of frontal and front-corner collisions—that is, in the types of collisions associated with the majority of severe and fatal injuries.

One of the main arguments for making airbags standard equipment in cars is that they protect the occupant without requiring any action on his part, whereas safety belts require an effort that must be repeated each time someone gets into a car. Attempts to obtain sufficient voluntary use of safety belts generally have not been successful. Reminding people with "buzzer-lights," added to 1972 model cars, had no substantial effect on seat-belt usage (Robertson and Haddon, 1974); most people found ways to circumvent the devices.

More recently, starter-lock systems, introduced in 1974 model cars, have increased safety belt usage by making it impossible to start a car unless front-seat occupants follow a certain sequence of events which includes manipulation of the belts. Early results indicate that in cars with starter locks, approximately half the drivers are wearing safety belts, compared to one fourth of those in cars without starter locks (Robertson, 1974). Although these results suggest substantial improvement in usage, it must be emphasized that almost half of the drivers still were *not* wearing safety belts, despite starter-lock systems. Furthermore, because the latest models of cars constitute a very small proportion of all automobiles, many years must elapse before most cars have starter-lock systems. The same will be true for airbags when and if they become standard equipment in new cars.

Finally, it is extremely important that selection of countermeasures should not be determined by the relative importance of contributing factors. In illustration, the fact that psychological and cultural factors may be important in the initiation of many crashes does not mean that psychological screening of drivers or attempts to manipulate cultural factors necessarily deserve emphasis. Rather, priority should be given to measures that will be *most effective* in reducing injury losses. Airbags and well-designed guardrails, for example, can save lives under a wide variety of circumstances—for example, in crashes initiated by intoxicated, inexperienced, or suicidal drivers or by blowouts, brake failures, or icy roads.

In summary, effective reduction of injury losses results from prevention of potentially harmful events, reduction of human damage when such events occur, and minimization of the short- and long-term effects of injuries. Success requires a rational mixture of countermeasures from pre-event, event, and post-event phases, with their choice and emphasis based on the extent to which each one can reduce losses due to injuries.

Physicians and other health professionals have used scientific approaches to reduce human damage due to traditionally recognized environmental hazards, such as lead and pathogenic organisms. Analogous approaches that have long been available for controlling injuries have been neglected. This discrepancy is not scientifically defensible and should no longer be tolerated.

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