

9

FACTORS THAT DETERMINE INJURY

INJURY SPECIFICITY	537
THE RECENCY OF INJURY CAUSATION RESEARCH	538
INTRINSIC AND ACQUIRED RESISTANCE TO INJURY	610
THERAPEUTIC APPROACHES TO ACCIDENT PREVENTION	610
FACTORS WHICH DETERMINE THE SUBSEQUENT EFFECTS OF ACCIDENTS	611

THE READINGS:

Mechanical Analysis of Survival in Falls from Heights of Fifty to One Hundred and Fifty Feet	539
The Historical Development of the Crash-Impact Engineering Point of View	547
Human Tolerance to Deceleration	554
Accident Survival—Airplane and Passenger Automobile	562
Crash Survival Study: National Airlines DC-6 Accident at Elizabeth, N. J., on February 11, 1952	568
Automobile-Barrier Impacts, Series II	583
Penetrating Wounds of Skull due to Metal Axle of Collapsible Toy Cars	595

IN CHAPTER 2 WE POINTED OUT that accidents are usually defined as the unexpected occurrence of damage to animate or inanimate objects. We also pointed out: (1) that much of the research concerned with accidents has emphasized their unexpectedness and the factors leading up to their occurrence rather than the nature and prevention of the damaging insults themselves; (2) that this is a very different approach from that successfully adopted in connection with such other pathologies as the infectious diseases; (3) that this difference in approach is not justified by present knowledge; (4) that this emphasis has delayed progress in research and prevention; and (5) that, although "multiple factors" set the stage for accidents to occur, no unexpected injury can take place without the occurrence of one or more of a small number of abnormal energy exchanges which correspond closely to the "agents" of infectious and other diseases.

Viewed in this light, the research discussed in the preceding chapters has been concerned almost exclusively either with the counting of accidents or with the heterogeneous factors which may lead up to their occurrence. Such emphasis would restrict investigation of the characteristics of nutritional diseases to the heterogeneous physical, biological, and behavioral factors which determine diet, or the investigation of poliomyelitis to the factors which lead up to infection with one of the polio viruses. In both these examples, the most effective countermeasures do not stem from such an approach. And in accident prevention this lopsided emphasis has become increasingly indefensible with the development of research concerned with the unexpected insults themselves rather than with the factors leading up to them. Such research is the concern of this chapter.

INJURY SPECIFICITY

Without exception, all of the forms of energy which may reach the human body can produce injury if either their amounts or their rates of application exceed the corresponding local or whole-body tolerances. This is true whether they are released deliberately or inadvertently. In this respect, also, the forces that are initiated in accidents have their parallels in the infectious disease area, since there too it is the nature and dose of the agent and the susceptibility of the host which determine the resultant disease, not the means, deliberate or inadvertent, by which the agent is brought into action.

The chief forms of energy involved in accidents include the various forms of chemical energy, ionizing and electromagnetic radiation, and mechanical forces performing work (in the physicist's sense of the term). Each of these produces its characteristic type of injury, regardless of the antecedent cultural, social, personal, and environmental causes of the accidents in which it is the cause of injury. The characteristics of the injury are determined by the nature of the energy per se and by the level of body organization at which it is dissipated. For example, in a causal sequence in which bodily damage is produced by ionizing radiation, the primary injury, as is well known to those who are concerned with nuclear accidents, will occur at the cellular and molecular levels, the locus at which the resultant ionization takes place. By contrast, the physical forces which result from the collision of the body with another object, or vice versa, usually result in damage at the tissue and organ levels,

and this also holds true regardless of the antecedent causes. Further, in parallel with the specific nature of the lesions produced by the causes of illness, the injuries resulting from the various forms of energy exchange are specific and cannot usually be produced by other means.¹

If this view of the accident process is foreign to the reader, he should again consider the parallels with the sequences which lead to other types of morbidity. Many and diverse events, for example, may lead to the ingestion of pathogenic microorganisms, and each may be considered a cause of the resultant disease. However, the form of that disease and, in particular, its classification and treatment are determined only by the nature of the pathogens present, and without such agents no such disease can be produced. Precisely the same holds for the various forms of energy as the immediate, necessary, and specific causes of both deliberately and inadvertently initiated injuries, and this will be clearly illustrated later in this chapter.

We have noted that injuries can be produced either by the delivery of above-threshold amounts of energy or by interference with the body's normal energy exchange, metabolism, or physiology. This second group parallels the first in the specificity of the injuries produced and, like the first, may involve either the entire body or only some portion of it. The whole-body case is well illustrated by such antecedent causes as submersion, suffocation, and the inhalation of carbon monoxide and other gases which, through interference with oxygen exchange, produce specific kinds of damage to the entire body. Accidents in which whole-body heat exchange is prevented provide an additional illustration. Finally, local interference with energy transport is excellently illustrated by the specific local results of the various acute interferences with local blood flow, appropriately described by the medical profession as "vascular accidents."^{*}

THE RECENCY OF INJURY CAUSATION RESEARCH

Since the transfer of energy or interference with its exchange is the common denominator of injuries of all types, it might be expected that research would long ago have been undertaken to determine the nature of such interactions and whether injury might be prevented or lessened by their modification. Nevertheless, prior to 1942 there was no literature illustrating work of this type. However, beginning with De Haven's classic paper, published in that year, an extensive and rapidly proliferating literature has developed which, because of its size, can only be sampled here.

The effort represented by this literature often comes as a surprise to those who have not been familiar with this aspect of accident research. Its magnitude is indicated in part by the fact that its cost has already totaled several million dollars in the United States alone, and similar work is under way in a number of other countries. The U. S. Public Health Service by August 1962 had granted approximately \$3,600,000 for this purpose,² and large expenditures have also been made by other federal agencies and by the aircraft, space, and automotive industries. Such research, however, is still in its infancy, and much remains to be done, particularly with respect to nontransport accidents.

* Many of the points discussed in this chapter, including the specific nature of the injuries produced by the various types of abnormal energy exchanges, are discussed in greater detail in reference 1.

The recency of this research development is especially surprising because the principles involved have been empirically understood and applied for millenia in the development of military devices for protection and offense, and it is ironic that only during the past two decades has there been organized effort to apply these same principles in the prevention of injuries resulting from peaceful pursuits. This lag has resulted in large part from the failure of many accident research workers to recognize as fundamental the problem of injury causation *per se*. It has also resulted from their substantial lack of familiarity with the significant variables.†

MECHANICAL ANALYSIS OF SURVIVAL IN FALLS FROM HEIGHTS OF FIFTY TO ONE HUNDRED AND FIFTY FEET

—Hugh De Haven

Although breakthroughs in science have very frequently resulted from the recognition and investigation of seeming paradoxes, De Haven's work provides one of the very few illustrations of this in accident research. It resulted from his refusal to attribute either to "luck" or to extranatural causes his own survival in a World War I plane crash. As Hasbrook has noted in a subsequent selection, it is remarkable "that although hundreds of combat pilots and observers died as a result of injuries sustained in crashing . . . there is no record of anyone [else] having given any consideration to the direct causes of injury and death in aircraft accidents. . . ." This may have resulted in large part from the tendency of many then as now to attribute the causation of accidents to "bad luck," "acts of God," and similar factors long since rejected in the analytic consideration of other causes of human morbidity and mortality.

DURING THE INTERVAL of velocity change in aircraft and automobile accidents many typical crash injuries are caused by structures and objects which can be altered in placement or design so as to modify the large number of severe and constantly recurring patterns of injury in these accidents. In order conscientiously to approach some of the engineering problems encountered in reduction of the potential injury hazards of windshield structures, seats, instrument panels, safety belts, etc., it was necessary to have some understanding of the limits of mechanical strength of the human body.

The objective in studying the physiologic results of rapid deceleration in the following instances of extraordinary survival—after free fall and impact with relatively solid structures—was to establish a working knowledge of the force and tolerance limits of the body. On the basis of these data certain engineering improvements can be considered for aircraft and automotive design.

Loss of pilots through injury due to the increased landing speeds of military planes has become more and more frequent; this loss and the ever present toll by accident in the automotive field are matters of grave

[Reprinted, with permission, from *War Medicine*, 2:586-596, July 1942. Copyright by the American Medical Association.]

† The fact that the medical profession has also largely missed the parallels we are emphasizing here may be due in part to the scant exposure to physics that most physicians have in their medical and premedical curricula.

national concern. Injuries in these fields are mechanical results stemming from localized pressures induced by force and applied to the body through the medium of structure. It is an axiom in the mechanical arts that modification of cause will change results, but the nature and the degree of structural alteration to modify injury to human beings effectively depend on the reactions of the body to abrupt pressure and its distribution. The strength of human anatomic structure and its tolerance of pressure increase are centrally important elements in any proposed increase of safety factors through engineering effort.

Obviously, if the body could tolerate pressure within only narrow limits, few improvements would be worth consideration, since the force and resulting pressure of a severe crash are at best formidable. Evidence, on the other hand, that the body can tolerate the force of an extreme crash—without injury—would indicate that (1) extreme force within limits can be harmless to the body; (2) structural environment is the dominant cause of injury; (3) mechanical structure, at present responsible for recurring injury, can be altered to eliminate or greatly modify many causes and results of mechanical injury, and (4) the greater the evidence of body tolerance of force and pressure, the wider the possibility for considering engineering improvements. Evidence of the extreme limits at which the body can tolerate force cannot be obtained in laboratory tests for obvious reasons, nor can it be gained satisfactorily from most aircraft and automobile accidents, because the variables of speed and angle are difficult to appraise. Estimation of the exact speed of a crash is difficult under most conditions. Also relative movements during structural demolition generally make it impossible to know the position of the body at the time the injuries were sustained and whether the head or some other injured part overtook the structure before it came to a stop or after it had stopped. In these circumstances, the speed, deceleration, im-

pact and force of the body and their relation to the structure can seldom be fixed.

With the thought of overcoming many of these difficulties and in order to observe physiologic reactions to force under more simple conditions, a study of cases of free fall was undertaken. In several of the cases outlined here speed of fall, striking position, deceleration and relation of resultant injuries to structure could be determined with great precision. Other cases are included because of some specific interest or because they are relevant to the cases in which the evidence is clear.

The material is presented with the hope that additional instances of force survival may be closely observed and recorded in order to further an understanding of the strength of the body and the type of structure, position, etc. contributing to force survival.

It is, of course, obvious that speed, or height of fall, is not in itself injurious. Also a moderate change of velocity, such as occurs after a ten-story fall into a fire net or onto an awning need not result in injury, but a high rate of change of velocity, such as occurs after a ten-story fall onto concrete, is another matter. Between these two extremes lies important evidence of physiologic force tolerance.

In using the expression "free fall," a fall free of any obstruction other than that encountered at its termination is implied.

The word deceleration and its derivative decelerative are used in preference to negative acceleration, etc.; "velocity at contact" is preferred to "impact velocity."

The force of gravity—denoted by the symbol g —is used as a measure of the force of a positive or a negative acceleration.

A deceleration exerting a force one hundred and fifty times the normal pull of gravity on a body will increase its normal weight one hundred and fifty times during the time this increase of force acts. Thus, a force of 150 g acting on a man normally weighing 150 pounds (68 Kg.) would increase his apparent weight to

22,500 pounds (10,200 Kg.) during the force interval. This increase of force—and weight—would be distributed over, or applied to, his body as pressure in areas of contact dictated by resisting structure.

The velocities reached in the following cases of free fall are estimated from the acceleration equation $v = \sqrt{2gs}$, in which the falling object is accelerated by the force of gravity in a vacuum— v being the velocity, g the value of gravity in the acceleration (32 feet [976 cm.] per second per second) and s the distance fallen.

Deductions in velocity made on account of the resistance of the air are rather arbitrary and are estimated on the basis of weight, clothing worn and whether the body was observed to be falling head first, flat or with a tumbling motion. The higher distances of fall are based on an Air Corps technical report.

The estimated forces of deceleration are made from an inversion of the equation for acceleration, $v^2 = 2gs$, in which s equals the distance in feet through which a known velocity is decelerated. The resultant expression of decelerative force in pounds must be divided by the force of gravity factor (32 feet per second per second) to give the increase times normal gravity.

Minor contusions and lacerations have been omitted in referring to sustained injuries unless they were of special significance.

REPORT OF EIGHT CASES

CASE 1.—A woman aged 42, 5 feet 2 inches (157 cm.) tall and weighing 125 pounds (57 Kg.), jumped from a sixth floor and fell 55 feet (17 meters) onto fairly well packed earth in a garden plot, landing on the left side and back.

Deceleration and Acceleration of Gravity.—The deceleration distance was about 4 inches (10 cm.) as indicated by marks of the body in the earth. The velocity at contact was 54 feet (17 meters) per second (37 miles [60 kilometers] per hour), and the average gravity increase, 140 g .

Injuries.—There was no evidence of material injuries or shock. Examination of a sample of spinal fluid showed it to be clear and colorless; there were no red cells in the urine. There was

no loss of consciousness or abdominal tenderness.

Comment: The superintendent of the building reached the victim immediately after she struck the ground. She raised herself on her left elbow and remarked: "Six stories and not hurt."

CASE 2.—A woman aged 27, 5 feet 3 inches (160 cm.) tall and weighing 120 pounds (54 Kg.) jumped from a seventh floor window and fell 66 feet (20 meters) onto a wooden roof, landing head first with progressive contact of the shoulders and the back.

Deceleration and Acceleration of Gravity.—This woman broke through a roof of $\frac{3}{4}$ inch (2 cm.) pine boards which were supported on 6 by 2 inch (15 by 5 cm.) beams 16 inches (41 cm.) apart and landed lightly on the ceiling below. Velocity at contact was 60 feet (18 meters) per second (40 miles [64 kilometers] per hour). The average gravity increase was unknown. A hole approximately 16 by 16.5 inches (41 by 42 cm.) was sheared in the roof by the force of the fall. Three of the 6 by 2 inch beams were broken.

Injuries.—The scalp was lacerated (occiput), but there was no evidence of other head injuries. The victim suffered abrasions over the dorsal portion of the spine and an oblique intra-articular fracture of the sixth cervical vertebra. There was some spasticity of the abdominal muscles on the right side. Urinalysis yielded normal results. There was evidence of mild shock.

Comment: The fall was first known to have occurred when the woman appeared at an attic door and asked for assistance. She sat up in bed at the hospital later in the day. It is difficult to reconcile the structural damage to the beams with the absence of greater bodily injury in this case.

Another case in which injury occurred under similar circumstances but in which survival was only temporary is summarized as follows:

A man fell 121 feet (37 meters), landing in a supine position on a wooden roof after having jumped from a fourteenth floor. In this case the roof was broken in at one point to a depth of 8 inches (20 cm.), but this point was not directly under the area of force. The average force was undoubtedly in excess of 200 g . The victim walked away from the spot where he landed. His right arm had struck a 12 by 2 inch (30 by 5 cm.) beam and stopped abruptly; the torso had continued in movement, with a resultant tearing action in the shoulder area. There were other injuries. Death was