CHAPTER 22

Injuries

Dawn N. Castillo, Timothy J. Pizatella, and Nancy A. Stout

Occupational injuries are caused by acute exposure in the workplace to physical agents, such as mechanical energy, electricity, chemicals, and ionizing radiation, or from the sudden lack of essential agents, such as oxygen or heat. Examples of events that can lead to worker injury include motor vehicle crashes, assaults, falls, being caught in parts of machinery, being struck by tools or objects, and electrocutions. Resultant injuries include fractures, lacerations, abrasions, burns, amputations, poisonings, and damage to internal organs.

Occupational and nonoccupational injuries represent a serious public health problem (Box 22-1). More than 5,500 workers died from occupational injuries in the United States in 2002.[1] Another 4.4 million workers sustained nonfatal injuries in 2002[2]; this estimate is conservative because it relies on employer reporting and excludes important groups of workers, such as the self-employed, workers on small farms, and government employees. An estimated 3.9 million workers were treated in an emergency department for a work-related injury or illness in 1999, with an estimated 70,100 of these workers being hospitalized. Although these data include illnesses, more than 90 percent are injuries.[3] The direct cost of serious occupational injuries and illnesses in the United States in 2001 was $45.8 billion[4]; this amount includes only wages and medical payments to workers whose injuries resulted in more than 5 days away from work.

CAUSES OF INJURY

Although the immediate cause of injury is exposure to energy or deprivation from essential agents, injury events arise from a complex interaction of factors associated with materials and equipment used in work processes, the work environment, and the worker. These factors include physical hazards in the workplace or setting, hazards and safety features of machinery and tools, the development and implementation of safe work practices, the organization of work, the design of workplaces, the safety culture of the employer, availability and use of personal protective equipment (PPE), demographic characteristics of workers, experience and knowledge of workers, and economic and social factors.

An 18-year-old laborer, working for a brick and masonry contracting business, was cleaning a portable mortar mixer at the end of the workday at a residential construction site. The laborer used a garden hose to spray water on the paddles and inside of the mixing drum while the engine was running and paddles were rotating. A painter working for another employer at the same site heard a scream and saw the laborer's arm being pulled into the mixer. The painter was unable to turn off the mixer and yelled for help. The laborer's co-worker ran to the machine and turned it off, but the laborer had already been pulled into the machine, with just his leg protuding. The laborer died from asphyxia due to compression of neck structures.[5]

This case illustrates how the occurrence of occupational injury events can be influenced by a variety

BOX 22-1

Injuries Are a Major Public Health Problem

In addition to the workplace, injuries occur at home and school, while traveling, and during recreation. In the United States, injuries are the leading cause of death for infants, children, and young adults, surpassing deaths from cancer, heart disease, and infectious diseases. In 2001 in the United States, 157,078 injury deaths occurred (55 per 100,000 persons). In 2002, a total of 284 million nonfatal injuries required treatment in an emergency department (9,858 per 100,000 persons).

Many injury causes are common in multiple environments, such as the workplace and home; others are more common in the workplace. Transportation events, violence, falls, and being struck by objects are examples of injury causes that are common in multiple settings; machinery, electrocutions, and explosions are more common in the workplace. Strategies for reducing and preventing injuries in multiple settings include changes to the environment (such as changes in roadway design), regulatory policy (such as specifying product safety parameters), and educational approaches. Broad injury prevention measures, such as those focused on improving roadway safety, improve workplace safety, and injury prevention measures in the workplace complement those occurring in other settings.

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of factors and circumstances. Some of the contributory factors are clear, others are surmised. The victim was using a hazardous piece of equipment that he and co-workers had used without serious incident in the past. It is not unlikely that the same unsafe procedure had been used previously. Reportedly, the victim was using a procedure that was different from what was demonstrated during a hands-on training by the company owners, in which a safety guard would have been placed over the mixing drum. Training was informal and not documented. The company did not have a written safety program that specified safe work practices and the potential for injury if not followed. Given the young age of the laborer, he likely did not have other training and work experience that would have helped him recognize the hazards of cleaning the machine while the engine was running without the guard in place. It is not clear if the company owners or foreman had previously observed this unsafe practice or if the laborer had been provided feedback to correct this unsafe practice. The procedure the victim was using also differed from that specified in the manufacturer's operator's manual, which specified that the spark plug should be disconnected prior to cleaning inside the mixing drum.

When manufactured, the portable mortar-mixing machine comes with warning labels including a label for safe cleaning procedures, a label that the engine should be stopped when cleaning, and a label that the machine should not be operated without the cover. These labels were not visible on this machine which had been purchased approximately 5 years prior to the incident. Replacement labels that are available from the manufacturer may have helped foster safer working procedures. The absence of clear labeling on the machine and an obvious mechanism for shutting off the machine may have contributed to the painter not being able to quickly turn off the machine. The nature of the work environment (a residential construction site) and work (only one other employee who was working at another part of the site) precluded a quick response to the victim being pulled into the mixer. The portable mortar mixer did not include safety features that would prevent operation when the guard or cover were not in place. The employer was a small business in which two co-owners employed five laborers. A number of factors may have accounted for the absence of a comprehensive safety and training program, including the employer's perceptions that workers know how to conduct work safely and need little guidance or training and the cost to hire workers with safety and health expertise.

This case illustrates how injury events can arise from a complex array of factors, not all of which contribute equally to an injury event. In addition,

the responsibilities for a safe work environment and safe work practices are not borne equally by all involved parties. Employers bear the greatest responsibilities, as they are responsible for providing a safe work environment, including the identification of potential safety hazards and the implementation of hazard controls and safe work practices and procedures. Workers are responsible for following established procedures and for reporting safety hazards to employers.

THE EPIDEMIOLOGY OF INJURIES

Occupational injuries are not random events. They cluster or are associated with specific types of workplaces and jobs, workplace exposures, and worker characteristics. Because occupational injuries are not random, they can be anticipated, and steps can be taken to prevent them.

Epidemiologic data allow those involved in injury prevention efforts to target groups and settings with high numbers or rates of occupational injuries and to anticipate and take steps to prevent injuries in specific workplaces or settings. Epidemiologic data on fatal and nonfatal occupational injuries differ and thus are addressed separately. Both categories of injuries require attention: fatal injuries, because they represent the most severe consequence of occupational injury and are devastating to families, communities, and workplaces; and nonfatal injuries, because of the sheer volume and aggregate costs to workers, families, employers, and society as a whole.

Fatal Injuries

The distribution and risks for fatal occupational injury differ by demographic characteristics of workers. Men account for more than 90 percent of occupational fatalities and have occupational fatality rates approximately 10 times higher than those for women.[1,6] Approximately 71 percent of occupational fatal injuries are among white, non-Hispanic workers, 15 percent among Hispanic workers, 9 percent among black, non-Hispanic workers, and 2 percent among Asian workers. Hispanic workers have the highest occupational injury fatality rates—27 percent higher than black workers and 43 percent higher than white workers.[1] Hispanic workers are a priority population for fatal occupational injury prevention (Box 22-2). Of all fatal occupational injuries, 66 percent occur to workers between 25 and 54 years of age, with approximately 10 percent of the fatalities among workers younger than 25 years of age and 23 percent of the fatalities among workers 55 years of age and older. Rates of fatal occupational injury generally increase with age, with the highest rates among workers 65 years of age and older.[1,6] Decreased ability to survive injuries may account for some of the increased fatality rates among older workers.

Of all occupational injury deaths, 81 percent are among wage and salary workers; the remainder are among the self-employed, whose fatality rate is approximately three times greater than that of wage and salary employees.[1] The types of jobs held by self-employed workers explain some of this difference.[7] For example, high proportions of the self-employed work in agriculture and construction, two industries with the highest rates of fatal injury.[7,8]

Transportation-related events accounted for 43 percent of the 5,524 occupational injury deaths in the United States in 2002. These events involved motor vehicles and mobile equipment, such as tractors and forklifts; occurred on and off the highway; and included pedestrians and bystanders as well as operators and drivers.[1] Work-related road crashes provide unique challenges and opportunities for prevention (Box 22-3). Assaults and violent acts accounted for 15 percent of fatalities in 2002, with most of them involving homicides and some involving suicides. Violence-related injuries occur in a variety of work situations, and consequently prevention strategies vary (Box 22-4). Contact with objects or equipment accounted for 16 percent of the fatalities, including being struck by falling objects, being caught in running equipment or machinery, and being caught in or crushed by collapsing materials, such as in trench cave-ins or collapsing buildings. Falls, mostly to a lower level, accounted for 13 percent of fatalities. Exposure to harmful substances or environments, such as electric current, temperature extremes, hazardous substances, and oxygen deficiency, accounted for 10 percent of fatalities, with more than half of these being electrocutions. Fires and explosions accounted for 3 percent of the fatalities.[1] Demographic characteristics vary; for example, homicide is frequently the leading cause of death for women.[1,6,8]

The incidence of occupational injury deaths varies by industry division (Table 22-1), and among subgroups of industries within industry divisions. The occupational injury fatality rate averaged

BOX 22-2

Hispanics Are a Priority Population for Occupational Injury Prevention

Concomitant with increases in the U.S. population of Hispanics, the proportion of Hispanics in the workforce has increased and is expected to continue to increase. The number of Hispanics in the U.S. workforce increased 43 percent between 1990 and 2000 and is expected to increase another 36 percent by 2010 to nearly 21 million employed Hispanic workers.

Hispanics work more frequently in the most hazardous jobs, which helps explain their higher rates of fatal and nonfatal injuries. Fatality rates are highest for foreign-born Hispanic workers, while native Hispanic workers have occupational fatal injury rates comparable to those of the U.S. workforce. Most of the fatally injured foreign-born Hispanic workers are from Mexico, with fewer but substantial numbers from Central America and the Caribbean. It is not known to what extent language, literacy, culture, and vulnerable employment situations (such as work as a day laborer and illegal immigration status) contribute to the high injury death rate among foreign-born Hispanics. NIOSH and NIEHS have funded research projects to identify unique risks for Hispanic and immigrant workers and to develop and evaluate unique prevention approaches, such as using community-based organizations to communicate safety and health information to Spanish-speaking and immigrant workers.

Many groups are responding to the need for communication of occupational safety and health information to Spanish-speaking and foreign-born workers, addressing issues of language, literacy, and culture.

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across all industries in the United States in 2002 was 4.0 per 100,000 workers.[1] Dozens of specific industries have injury rates far in excess of the average for all industries.[1,6,8,9]

The incidence and patterns of injury death also vary by occupation. Table 22-2 provides information on the incidence and patterns of fatal injury for occupations, selected to be illustrative of occupations with a range of fatality rates and injury patterns. In some occupations, one type of injury predominates, such as highway transportation incidents among truckers; in other occupations, such as groundskeepers/gardeners, a variety of events contribute to injury death. Data on additional occupations are available from several sources.[1,6,8,9]

Nonfatal Injuries

The two primary national sources of data on nonfatal work-related injuries are data from emergency departments[3] and the Bureau of Labor Statistics (BLS) annual survey of employers.[10] The BLS annual employer survey excludes the self-employed, farms with fewer than 11 employees, and government employees. Data on worker demographics and the circumstances of injuries are available only for lost workday cases in the BLS survey. Information on industry and occupation are not currently available in the emergency department data. Illnesses, such as dermatitis, are included in both the emergency department data and lost workday data from the BLS employer survey, but they represent less than 10 percent of cases in both systems.

Although not as dramatic as for fatal injuries, differences are seen across demographic categories for nonfatal injuries. Men account for approximately 70 percent of nonfatal work-related injuries, and based on data from emergency department visits, have rates approximately 1.6 times higher than those for women. Data on race and ethnicity are

BOX 22-3

Unique Challenges for Prevention of Roadway Occupational Deaths and Injuries

Roadway crashes are the leading cause of occupational fatalities in the United States. Between 1992 and 2000, nearly 12,000 workers died in roadway crashes, nearly four deaths daily. Truck drivers account for more roadway fatalities than any other occupational group and have the highest rates for roadway worker deaths. However, work-related roadway crashes are not limited to the transportation industry, and many workers in occupations that are not related to transportation are killed each year. Some workers are killed while using vehicles provided by their employers, and others are killed driving their own vehicles to perform their jobs.

Preventing work-related roadway crashes is especially challenging. Unlike most workplaces, the roadway is not a closed environment. Although employers cannot control roadway conditions, they can take a number of steps to help keep their workers safe when driving, such as:

- Implementing and enforcing mandatory seat belt use policies.
- Ensuring that no workers are assigned to drive on the job if they do not have valid driver's licenses, appropriate for the types of vehicles to be driven.
- Providing fleet vehicles that offer the highest possible levels of occupant protection in the event of a crash.
- Maintaining complete and accurate records of workers' driving performance. (In addition to driver's license checks for prospective employees, periodic rechecks after hiring are critical.)
- Incorporating fatigue management into safety programs.
- Ensuring that workers receive the training necessary to operate specialized motor vehicles or equipment.
- Offering periodic screening of vision and general physical health for all workers for whom driving is a primary job duty.
- Avoiding requiring workers to drive irregular hours or to extend their workday far beyond their normal working hours as a result of driving responsibilities.
- Establishing schedules that allow drivers to obey speed limits and follow applicable hours-of-service regulations.
- Setting safety policy in accordance with State graduated driver licensing laws[a] so that company operations do not place younger workers in violation of these laws.
- Assigning driving-related tasks to young drivers in an incremental fashion, beginning with limited driving responsibilities and ending with unrestricted assignments.

Employees can also take steps to increase their safety while driving in the performance of their work, including:

- Using safety belts.
- Avoiding placing or taking cell phone calls while operating a motor vehicle, especially in inclement weather, unfamiliar areas, or heavy traffic.
- Avoiding other activities, such as eating, drinking, or adjusting noncritical vehicle controls, while driving.

[a] *Graduated driver licensing (GDL) laws exist in many states to address high crash and injury rates among teenage drivers. A GDL is a phased licensing process that gradually eases restrictions off teenage drivers as they become more experienced at driving.*

Excerpted from Pratt SG. NIOSH hazard review: Work-related roadway crashes: Challenges and opportunities for prevention. Cincinnati: NIOSH, 2003. (DHHS [NIOSH] publication no. 2003-119.)

missing from more than 20 percent of records in nonfatal work-related injury databases.[3,10] Most nonfatal injuries (50 to 63 percent) occur among white, non-Hispanic workers; with fewer among black, non-Hispanic workers (9 to 12 percent), Hispanics (6 to 13 percent), Asians or Pacific Islanders (2 percent), and American Indians or Alaskan natives (less than 1 percent). An analysis of emergency department data that did not separate out Hispanic ethnicity found that black workers had an injury rate approximately 1.3 times that of white workers.[11] Most nonfatal injuries

BOX 22-4

Workplace Violence: A Complex Workplace Injury Phenomenon

Homicide is a leading cause of occupational injury death and accounts for many nonfatal injuries each year. Because of news coverage of sensational and more "newsworthy" events, many assume that disgruntled co-workers and former employees account for the bulk of these injury statistics. In reality, violence caused by co-workers or former employees is a relatively small part of the workplace violence problem.

Violence in the workplace has been categorized into four different types of events:

- *Type I: Criminal intent*: These situations are typically associated with crimes such as robbery, shoplifting, and loitering. A preexisting relationship does not exist between the employee and the perpetrator, and the perpetrator does not have a legitimate reason for being in the workplace.
- *Type II: Customer or client*: These situations involve customers or clients who have a legitimate reason for being in the workplace. The violence is associated with a business transaction or service. Perpetrators include customers, clients, patients, and inmates.
- *Type III: Worker-on-worker*: These situations involve violence between co-workers or violence perpetrated against an employee by a former employee.
- *Type IV: Personal relationship*: In these situations, the perpetrator has a pre existing relationship with the employee and the violence is associated with the relationship rather than the business. These situations include acts of domestic violence against the employee while they are at work.

Workplace violence occurs in a variety of workplaces and occupations, although there are some worker groups at increased risk for the more common type I and II events, including police, corrections officers, taxi drivers, health care providers, and employees in retail settings.

Although workplace violence is a complex phenomenon, there are a variety of strategies that employers and workers can take to reduce the risks for violence. Some are specific to work settings and tasks, and others are more general. Workplace violence prevention strategies include modifying the work setting and tasks to reduce the risks for robbery and/or assault (such as by posting signs in retail settings that minimal cash is kept on hand, providing physical barriers between employees and potential criminals or violent clients, and using surveillance cameras and/or security guards); establishing workplace policies for zero violence tolerance and procedures for reporting and following up on all threats or violent acts; and employee training on how to handle criminals or violent customers or clients.

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occur among workers 25 to 54 years of age—70 percent of injuries treated in emergency departments and 75 percent of injuries requiring at least 1 day away from work reported in an employer survey. Those younger than 25 years of age account for 23 percent of injuries treated in emergency departments and 14 percent of injuries reported by employers; those older than 54 years of age account for 7 percent of injuries treated in emergency departments and 11 percent of injuries reported by employers.[3,10] Based on emergency department data, workers 18 to 19 years of age have the highest annual rates of injury (6 per 100 full-time workers). With the exception of workers 16 to 17 years of age, injury rates decrease with increasing age.[3]

Twelve percent of employer-reported cases occurred among employees who had worked for less than 3 months for the employer, 18 percent among employees with 3 to 11 months of service,

TABLE 22-2

Number and Rate of Fatal Occupational Injuries, by Industry Division, United States, 2002

Industry Division	Number of Fatalities	Fatality Rate[a]
Mining	121	23.5
Agriculture/forestry/fishing	789	22.7
Construction	1,121	12.2
Transportation/public utilities	910	11.3
Wholesale trade	205	4.0
Manufacturing	563	3.1
Retail trade	487	2.1
Services	680	1.7
Finance/insurance/real estate	87	1.0
Unknown	561	NA
Total/Overall	5,524	4.0

[a]Rate per 100,000 workers.
Source: Bureau of Labor Statistics. National census of fatal occupational injuries in 2002 [USDL 03-488]. Washington, DC: U.S. Department of Labor, Bureau of Labor Statistics, 2003.

33 percent with 1 to 5 years of service, and 25 percent with more than 5 years of service; length of service with the employer was not available for 12 percent of the reported injuries.[10]

The number and rate of nonfatal injuries by industry division varies greatly from the number and rate for injury deaths (Table 22-3). The occupational injury rate averaged across all industries in 2002 was 5.0 per 100 full-time workers. A number of specific industries have injury rates in excess of the average rate, including several in the manufacturing industry division. Workers in the manufacture of primary metal products, lumber and wood products, furniture and fixtures, and fabricated metal products have higher than average injury rates.[2] Because the BLS annual survey of employers excludes farms with fewer than 11 employees, the numbers and rates of nonfatal occupational injuries reported for agriculture/forestry/fishing should be considered as conservative estimates.

Table 22-4 provides information on the estimated incidence and patterns of nonfatal injury for selected occupations.[10] Many nonfatal injury events are common across a variety of occupations.

Clinical Presentation and Course of Injuries

Of all workers with occupational injuries, 34 percent are treated in emergency departments[12]; the remainder are treated at the workplace, physician's offices or clinics, or other medical treatment facilities. Table 22-5 provides information on diagnoses and anatomic sites of occupational injuries treated in emergency departments in the United States in 1999. Almost 2 percent of occupational injuries resulted in hospital admission.[3] Among an estimated annual average of 4 million work-related emergency department visits for occupational injuries in the United States in 1996, wound care was provided to 34 percent of patients, extremity x-rays were ordered or provided to 30 percent, and orthopedic care was provided to 21 percent of patients.[11]

Of the estimated 1.5 million injuries and illnesses with lost workdays in 2001, the median time away from work was 6 days. Among the more frequent injuries, median time away from work was highest for dislocations (30 days); amputations, excluding fingertips (24 days); and fractures (21 days).[10]

PREVENTION OF INJURIES

The Hierarchical Approach to Occupational Injury Control

Over the years, a number of models for occupational injury control have evolved. Many of these models categorize worker protection strategies based on a hierarchical approach,[13] such as the five-tier model (Table 22-6). William Haddon, Jr., proposed 10 basic strategies for injury prevention that have a number of similarities to the hierarchical approach, such as hazard elimination, hazard reduction, and use of barriers for protection.[14] Haddon also introduced the concept that injury causation was a chain of multifactorial events, each of which provided opportunities for intervention. Herbert Linn and Alfred Amendola suggested an approach that combines the public health model with safety engineering analysis for injury prevention.[15] The disciplines of epidemiology, safety engineering, biomechanics, ergonomics, psychology, safety management, and others form a multidisciplinary approach that is useful for identifying injury risk factors and developing control strategies.

TABLE 22-2

Fatality Rate and Frequent Events Leading to Occupational Injury Death for Select Occupations, United States, 2000

Occupation	Number of Deaths	Rate[a]	Frequent Events (Percent of Deaths)
Timber cutting and logging operations	95	143.9	74% struck by object
Extractive occupations	69	53.9	19% struck by object 13% caught in equipment or object 13% fire and explosions 12% highway transportation incident
Roofers	65	30.2	74% fall to lower level 11% contact with electric current
Farmers, except horticulture	251	28.4	39% nonhighway transportation 16% struck by object 11% caught in equipment or object
Construction laborers	288	28.3	29% fall to lower level 14% pedestrian 13% struck by object
Truck drivers	352	27.6	70% highway transportation incident
Firefighting, including supervisors	43	15.4	28% fires and explosions 26 % highway transportation incident
Groundskeepers and gardeners, except farm	130	14.9	25% struck by object 19% fall to lower level 12% nonhighway transportation 11% pedestrian
Laborers, except construction	178	13.2	16% pedestrian 15% struck by object 15% caught in equipment or object 12% fall to lower level
Electricians and apprentices	89	10.3	45% contact with electric current 17% fall to lower level
Supervisors and proprietors, salespeople	185	3.7	60% homicides 12% highway transportation incident
Machine operators, assemblers, and inspectors	237	3.2	23% caught in equipment or object 18% struck by object
Cleaning and building service workers	78	2.5	32% fall to lower level 15% homicides

[a] Rate per 100,000 workers.

Source: Bureau of Labor Statistics. Fatal workplace injuries in 2000: A collection of data and analysis (Report 961). Washington, DC: U.S. Department of Labor, Bureau of Labor Statistics, 2002.

The *hierarchical approach* focuses on (a) eliminating hazards through design; (b) using safeguards that eliminate or minimize worker exposure to hazards; (c) providing warning signs or devices to identify hazards; (d) training workers in safe work practices and procedures; and (e) using personal protective equipment (PPE) to prevent or minimize worker exposure to hazards or to reduce the severity of an injury if one occurs. Three main categories of control strategies correlate with the hierarchical

TABLE 22-3

Number and Rate of Nonfatal Occupational Injuries by Industry Division, United States, 2002

Industry Division	Number of Injuries	Injury Rate[a]
Construction	408,000	6.9
Manufacturing	1,029,000	6.4
Agriculture/forestry/fishing	90,000	6.0
Transportation/public utilities	362,000	5.8
Retail trade	878,000	5.1
Wholesale trade	312,000	5.0
Services	1,202,000	4.3
Mining	22,000	3.8
Finance/insurance/real estate	103,000	1.5
Total/Overall	4,406,000	5.0

[a] Rate per 100 full-time workers.

Source: Bureau of Labor Statistics. Workplace injuries and illnesses in 2002 [News Release USDL 03-913]. Washington, DC: U.S. Department of Labor, Bureau of Labor Statistics, 2003.

approach: engineering controls, administrative controls, and the use of PPE.

Engineering Controls

Engineering controls, also known as *passive controls*, involve eliminating hazards through design or the application of safeguards to prevent worker exposure to hazards. Effective hazard elimination and safeguarding are designed, or retrofitted, into equipment, work stations, and work systems to provide protection without direct worker involvement—thus the term *passive controls*. Experience has shown that to be most effective, engineering controls must be designed so that they do not adversely interfere with the work process or introduce additional hazards.

The optimal injury control strategy is to eliminate a hazard completely. Frequently, hazard elimination or the reduction of hazard severity can be accomplished through equipment design.

A 27-year-old male painter was fatally electrocuted when the aluminum ladder he was using contacted a 7,200-volt power line. The worker was standing on a 24-foot, fully extended, aluminum extension ladder while painting a gutter on an apartment building. The gutter was located 18 feet above the ground and approximately 9 feet horizontally from a 7,200-volt power line. The power line was parallel to the gutter and was 19 feet 6 inches above the ground. As the worker was moving the ladder to a new location on the gutter, the ladder came in contact with the power line and the worker was electrocuted.

Although a number of factors contributed to this worker's death, one of the National Institute for Occupational Safety and Health (NIOSH) recommendations was to use ladders made of nonconductive materials when working near energized power lines.[16] A ladder made of fiberglass greatly reduces the risk of electrocution in the event it contacts an energized electrical power source.

Because hazard elimination is not always possible, other control strategies in the hierarchy must be implemented to achieve worker protection. If a hazard cannot be eliminated completely, then the next control level should be to prevent worker exposure through protective safeguarding approaches. These types of safeguards prevent worker exposure to the hazard, as long as the control is in place and functions properly.

For example, many types of industrial equipment require power transmission units that include belts, pulleys, gears, shafts, and other mechanisms necessary for the equipment to function. Workers can be exposed to serious, or even fatal, injury hazards if they come into contact with these rotating or moving components. A fixed barrier guard that completely encloses the power transmission unit is an engineering control that protects workers from these types of hazards. As long as the barrier guard remains in place, the worker is protected from injury. Another engineering control is an optical sensor, also called a light curtain, used to protect the worker from injury when operating a mechanical power press (Fig. 22-1). The optical sensor is integrated into the press control mechanism so that if any part of the worker's body breaks the plane of light in front of the hazardous point of operation, the downward motion of the press ram cannot be initiated or, if motion has begun, the press ram is automatically disengaged.

Many engineering controls are interlocked to ensure that they cannot be removed without disabling the machine or equipment. An interlock is a device that is integrated into the control mechanism of a machine or work process to prevent the work cycle

TABLE 22-4

Incidence and Selected Events Resulting in Nonfatal Occupational Injuries and Illnesses Requiring Days away from Work for Selected Occupations, United States, 2001

Occupation	Estimated Number of Injuries	Most Frequent Events (Percent of Injuries, by Occupation)						
		Contact with Object	Fall to Lower Level	Falls to Same Level	Overexertion	Repetitive Motion	Exposure to Harmful Substances	Transportation
Truck drivers	129,068	18	10	10	29	1	2	13
Nursing aides, orderlies, and attendants	71,017	11	1	12	54	1	2	2
Laborers, except construction	68,896	33	4	8	30	3	4	4
Construction laborers	44,102	45	8	7	20	1	4	3
Janitors and cleaners	38,628	22	3	18	27	2	6	2
Carpenters	32,746	39	16	5	21	3	2	2
Assemblers	31,065	30	2	7	27	16	4	1
Cooks	27,819	27	2	23	14	1	23	—
Stock handlers and baggers	25,657	30	3	10	38	3	2	2
Registered nurses	24,719	11	3	15	43	1	5	4

Source: Bureau of Labor Statistics, Occupational injuries and illnesses: Counts, rates, and characteristics, 2001 [Bulletin 2560]. Washington, DC: U.S. Department of Labor, Bureau of Labor Statistics, 2003.

from being initiated until the interlock is closed, signaling the equipment that the work cycle can be initiated. Interlocks, which are usually electrical or mechanical controls, need to be designed so that they are not easily bypassed or disabled.

Although engineering controls should be viewed as primary tiers of prevention, it is not always possible to develop such controls for all potentially hazardous work situations. Administrative controls are the next tier for reducing or minimizing worker exposure to injury hazards.

Administrative Controls

Administrative controls are management-directed work practices or procedures that, when implemented consistently, will reduce the exposure to hazards and the risk of injury. They are sometimes referred to as *active controls* because they require worker involvement to be effective. The use of warning signs and devices, along with worker training, is considered an administrative control because workers must be actively involved for this to be effective. Workers must adhere to warning signs that identify potential injury hazards and apply properly the training they have received. Another example of an administrative control is housekeeping procedures requiring that spills or debris be cleaned up quickly to reduce the potential for a slip, trip, or fall injury (Fig. 22-2). Implementation of a hazardous energy control policy for workers performing maintenance activities on a machine is also an example of administrative controls. Lockout/tagout procedures are important components of a hazardous

TABLE 22-5

Occupational Injuries Treated in Emergency Departments, by Diagnosis and Anatomic Site, United States, 1999

Diagnosis	Estimated Number	Percent of Total[a]	Part of Body Affected (Percent of Injuries, by Diagnosis)[a]					
			Trunk, Back, Groin	Leg, Knee, Ankle	Arm, Wrist Shoulder	Head, Face, Neck	Hand/ Finger	Other
Sprain or strain	1,033,400	26	45	22	20	7	4	2
Laceration	822,700	21	<1	6	10	15	67	2
Contusion, abrasion, or hematoma	736,800	19	14	17	16	21	20	12
Dislocation or fracture	229,700	6	9	14	21	2	36	18
Burn	142,600	4	<1	6	16	35	29	14
Other	974,400	25	13	7	10	26	27	17
Total	3,939,600	100	19	13	15	17	29	7

Source: NIOSH. Work-related injury statistics query system. Available at: <www.wwww2a.cdc.gov/risqs>
[a]Percentages may not add to 100 because at rounding.

energy control policy (Fig. 22-3). However, to be effective, the procedures must be written and consistently implemented, and workers must be trained in their use.[17]

Personal Protective Equipment

PPE consists of devices worn by workers for protection by reducing (a) the risk that exposure to a hazard will injure the worker or (b) the severity of an injury if one does occur. Although the hazard still exists, the potential for worker injury is mitigated by the use of PPE. The use of PPE in many work environments and situations is essential for worker protection. However, PPE is usually viewed as the

TABLE 2

Safety Hierarchy

Priority Rank	Safety Action
1	Eliminate hazard and/or risk
2	Apply safeguarding technology
3	Use warning signs
4	Train and instruct
5	Use personal protective equipment

Adapted from Barnett RL, Brickman DB. Safety hierarchy. J Safety Res 1986;17:49–55.

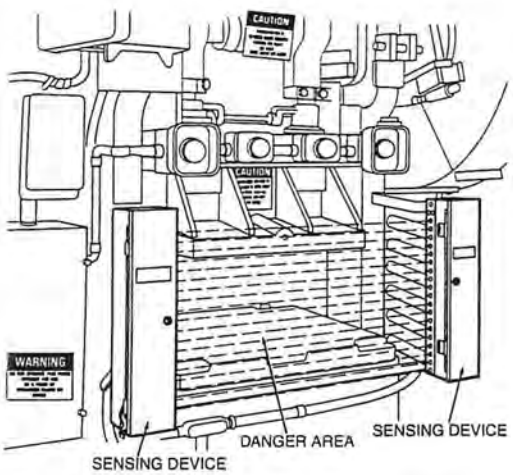

FIGURE 22-1 • Photoelectric (optical) sensor installed on a mechanical power press to protect the point of operation. (Source: OSHA, Concepts and techniques of machine safeguarding. Washington, DC: OSHA, 1980.)

FIGURE 22-2 • Example of poor housekeeping on a construction site. Loose bricks, lumber, and other debris create a potential tripping hazard for workers.

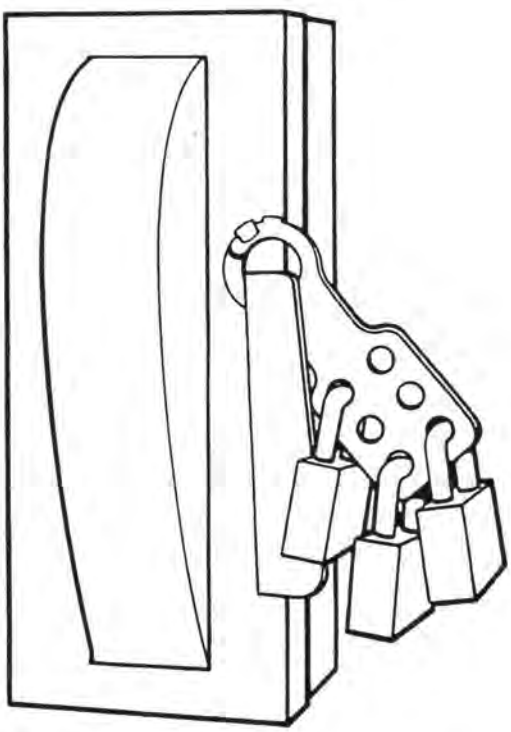

FIGURE 22-3 • Lockout hasp on an electrical control panel, which provides a method for applying a lock (lockout) to the panel during maintenance or repair to ensure that the equipment is not energized until the work has been completed. The control panel should also be tagged (tagout) with a label indicating that work is being performed. Workers should be provided with individually keyed locks, and only the worker who applied the lock should remove it. (Source: OSHA, Concepts and techniques of machine safeguarding, Washington, DC: OSHA, 1980.)

lowest tier in the hierarchy of controls. If hazardous exposures cannot be eliminated through engineering controls or the application of administrative controls, then PPE provides another opportunity for worker protection. Examples of PPE designed to reduce worker injuries include protective hard hats, eyewear and face shields, steel-toed safety shoes, fall restraint devices, and personal flotation devices (Fig. 22-4). When worn properly and consistently, these devices can prevent, or at least reduce the severity of, traumatic injuries. Fall restraint devices, such as lanyards and body harnesses, do not prevent workers from falling but protect them from suffering more serious injuries or fatalities due to falls from elevations (Fig. 22-5).

Combined Application of Controls

A comprehensive approach to worker injury prevention efforts inevitably includes all tiers of the control hierarchy to achieve maximum worker protection. In most work environments, a combination of engineering controls, administrative controls, and PPE will be required to have a complete and effective injury prevention program. The following examples illustrate how the combined application of controls can be used to achieve an enhanced level of worker protection.

Tractors equipped with a rollover protective structure, an engineering control, significantly reduce the risk that the operator will be injured in a rollover event (Fig. 22-6). However, additional protection can be achieved if a seat belt, an administrative control, is worn to keep the operator within the protective envelope of the rollover protective structure. A similar example is the increased protection afforded by the combined use of seat belts, mandated in company safety policies and programs, in motor vehicles that are also equipped with air bags.

Training

Training refers to methods to assist individuals in acquiring knowledge (safety information on potential workplace hazards), changing attitudes (perceptions and beliefs regarding safety), and practicing safe work behaviors (organizational, management, or worker performance). Despite a paucity of data on the direct relationship between training and injury, evidence suggests a positive impact of training on establishing safe working conditions.[18]

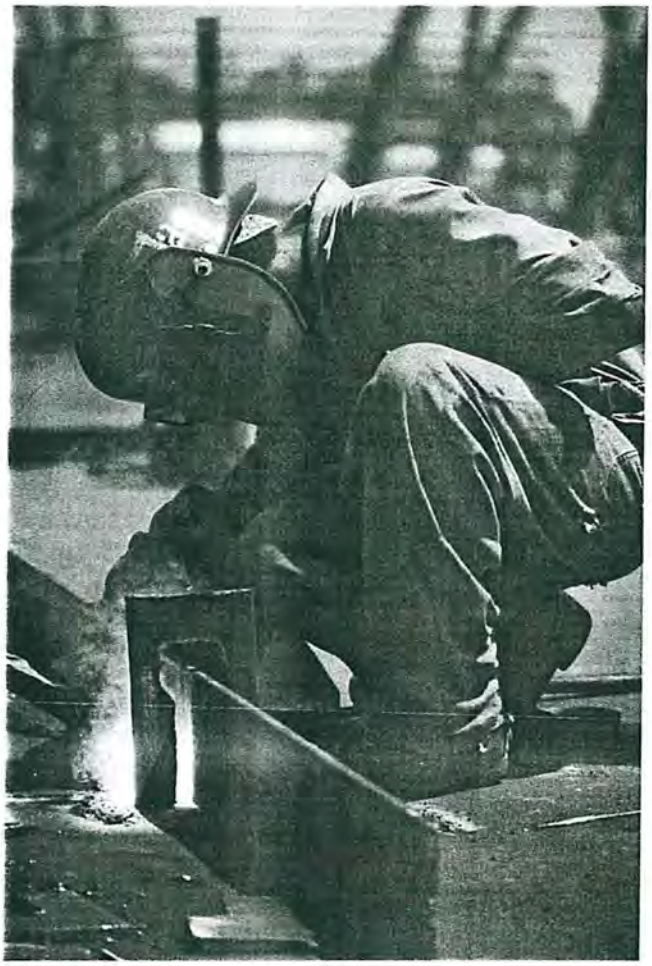

FIGURE 22-4 » Example of worker using multiple forms of personal protective equipment: hard hat to minimize and protect the worker's head from falling objects; a shield and safety glasses to protect the worker's face and eyes from flying particles and damaging irradiation; and gloves to protect the worker's hands from burns, cuts, and flying particles. (Source: Photo Disc, Inc.)

Training is one of the key factors accounting for differences between companies with low and high injury rates. It is often critically important for developing and implementing effective hazard control measures.[18,19] Training increases hazard awareness and knowledge, facilitates adoption of safe work practices, and leads to other workplace safety improvements. Training is an administrative control, as workers must properly use training they have received on a consistent basis for it to be effective in preventing injuries.

The elements of effective training programs are (a) assessing training needs specific to the work task; (b) developing the training program to address these needs specifically; (c) setting clear training goals; and (d) evaluating the post-training knowledge and skills and providing feedback to the workers.[18] Other important characteristics of a successful program are management commitment to safety and training that is initiated as soon as a worker is hired and then is followed up with periodic retraining and reinforcement.[18,19]

Unique characteristics of the specific workforce must be considered when developing or implementing safety training programs. Language, literacy, cognition, and cultural issues may diminish the effectiveness of training when programs are not tailored to account for unique or diverse characteristics of the workforce. Workplace safety training appears to be most effective when it includes active learning experiences that stress worksite application and when it is developed and implemented in the context of a broader workplace-based prevention approach.[18]

Standards

Many *standards* aim at protecting workers from traumatic injury. These standards cover a multitude of hazards and address the work environment, work

FIGURE 22-5 ▸ Worker wearing a full-body harness with attached lanyard (Photograph courtesy of the Construction Safety Council.)

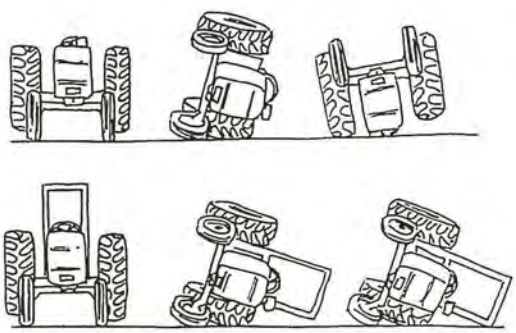

FIGURE 22-6 ▸ Tractor with a two-post rollover protective-structure (ROPS) frame installed. ROPSs are designed to reduce the risk of injury or death by preventing the tractor from rolling onto and crushing the operator. A properly fastened seat belt greatly improves the chances that the operator will stay within the protective envelope provided by the ROPS (the seat). (Source: NIOSH. Safe grain and silage handling. Washington, DC: NIOSH, 1995. [DHHS [NIOSH] publication no. 95-109.])

practices, equipment, PPE, and worker training. The two primary types of worker protection standards consist of (a) *mandatory standards*, such as those promulgated by the Occupational Safety and Health Administration (OSHA) or another regulatory agency, and (b) *voluntary standards*, such as those developed through independent organizations, such as the American National Standards Institute (ANSI), through a consensus process involving various stakeholders in an industry—typically including representatives from labor, management, and government. Numerous specifications, codes, and guidelines for machinery, equipment, tools, and other materials can also assist engineers and designers in developing safer products and systems, many of which have application in the workplace. Examples include the National Electric Code (NEC) published by the National Fire Protection Association (NFPA) and numerous consensus standards from the American Society of Mechanical Engineers (ASME) and the American Society for Testing and Materials (ASTM).

Injury Control: Roles and Responsibilities

Occupational injury prevention is not the sole responsibility of a single person or group. Employers, workers, regulators, and policymakers each share in the responsibility for prevention. A multidisciplinary approach involving interaction among diverse groups within an organization and active participation by both management and workers is crucial to an effective safety program.

Employers are responsible for establishing written safety policy, developing a comprehensive safety program, and effectively implementing that program at the workplace. A competent person or committee should be designated with responsibility for company safety policy. This person or committee should have sufficient knowledge concerning safety policy, standards, regulations, and hazard abatement and should actively participate with managers and workers in overseeing the safety program.

An effective safety program will strive to identify hazards through job safety analysis or other methods of systems safety analysis and eliminate or control identified hazards through the various approaches previously described. Workers, managers, and safety specialists should work together to analyze the job and potential hazards and to recommend changes or controls to abate them to avoid an injury event. In industries or jobs where the work environment is not constant, site hazard assessments should be performed prior to beginning work in any new environment. Occupations such as farming, logging, construction, and mining are characterized by frequently changing work sites and require a site hazard assessment prior to commencing work in any new or changed environment. This requirement is particularly important in construction, where work sites change not only from job to job, but also from day to day—even hour to hour, with constant potential for new hazards.

Employers are also responsible for ensuring proper maintenance of vehicles, equipment, and machinery and their safety features, such as machine guarding, interlocks, and barriers. Where job hazards cannot be eliminated or controlled, employers are responsible for providing appropriate PPE, such as fall-arrest systems, respirators, hearing protection, hard hats, or eye protection.

Employers must also ensure that workers receive appropriate training in minimizing their risk—including training on safety policy and practice, hazard recognition and control technologies, and the appropriate use of PPE. Enforcement of safety policy is also a crucial employer responsibility. The demonstrated commitment of management to safety is a major factor in successful workplace safety programs.[20–22] Employers who demonstrate concern and support for safety activities have top managers personally involved in safety activities and routinely involve workers in safety matters and decision making. These employers are more likely than others to have successful safety programs. As part of a comprehensive safety program, employers should require systematic reporting and tracking of occupational injuries and assessment of this information for corrective action to prevent similar occurrences.

Workers also play a vital role in workplace safety. Their participation is essential. Workers share in the responsibility for complying with safe work practices and policies, maintaining a safe work area, and using appropriate PPE when required by their employer to do so. Workers should also participate in company-sponsored training. They should report unsafe conditions for corrective action. As the experts in their jobs, workers should be involved in systems safety analysis and development of safe solutions. Workers input into recommended design or modification of safety controls, processes, or technology and into the development of safe work practices increases the acceptance of positive changes and, thus, the success of safety programs.

An effective workplace safety program that minimizes injuries results from a multidisciplinary effort that actively involves every level of the workforce, from the employer and upper-level managers to employee representatives and hourly workers. Each must assume some responsibility for safety and must work together interactively to achieve the common goal of preventing injuries.

Occupational injuries continue to exert too large a toll on the workforce. Although the rate of fatal injuries in the United States has decreased markedly over time, the rate of nonfatal injuries has not been reduced as much.[10] The prevention of workplace injuries requires concerted and consistent efforts from multiple parties using multiple strategies. In addition to the primary stakeholders in the workplace, additional groups can help reduce occupational injuries. These groups include manufacturers and distributors of industrial equipment and tools who

design and promote safety features of equipment, insurers who provide monetary incentives for good safety records, and health care providers who provide their patients with information on preventing workplace injuries.

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The findings and conclusions in this chapter are those of the authors and do not necessarily represent the views of the National Institute for Occupational Safety and Health.

FIFTH EDITION

OCCUPATIONAL AND ENVIRONMENTAL HEALTH

RECOGNIZING AND PREVENTING DISEASE AND INJURY

Barry S. Levy, MD, MPH
Adjunct Professor
Department of Public Health and Family Medicine
Tufts University School of Medicine
Boston, Massachusetts

David H. Wegman, MD, MSc
Dean
School of Health and Environment
University of Massachusetts Lowell
Lowell, Massachusetts

Sherry L. Baron, MD, MPH
Coordinator, Priority Populations
National Institute for Occupational Safety and Health
Cincinnati, Ohio

Rosemary K. Sokas, MD, MOH
Professor and Director
Division of Environmental and Occupational Health Sciences
University of Illinois at Chicago School of Public Health
Chicago, Illinois

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Cover photo by Earl Dotter [www.earldotter.com <http://www.earldotter.com>]

530 Walnut Street
Philadelphia, PA 19106 USA
LWW.com

Printed in the USA

Library of Congress Cataloging-in-Publication Data

Occupational and environmental health: recognizing and preventing disease and injury/editors, Barry S. Levy, et al. — 5th ed.
p. ; cm.
Rev. ed. of: Occupational health/editors, Barry S. Levy, David H. Wegman. 4th ed. c2000.
Includes bibliographical references and index.
ISBN 0-7817-5551-4
1. Medicine, Industrial. I. Levy, Barry S. II. Wegman, David H.
III. Occupational health.
[DNLM: 1. Occupational Diseases—prevention & control.
2. Environmental Health. 3. Occupational Exposure—prevention & control.
4. Occupational Health. WA 440 0149 2006]
RC963.022 2006
616.9'803—dc22

2005022903

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