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Comparing Injury and Illness Risk Assessments for Occupational Hazards

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ABSTRACT

One common framework for describing the evaluation and assessment of hazards in the workplace includes the four steps of hazard identification, exposure assessment, exposure-response modeling, and risk characterization (NAS, 1983). We discuss hazards for occupational injury and illness in light of this framework, and we contrast the evaluation of injury hazards with the evaluation of illness hazards. In particular, the nature of the hazards, typical exposure patterns, quantification of exposure, and the attribution of outcome to exposure are discussed. Finally, we discuss the management of occupational illness and injury hazards and issues encountered when evaluating efforts designed to mitigate the effects of occupational hazards.

Key Words: hazard identification, exposure assessment, exposure-response modeling, risk characterization, risk management, intervention research

INTRODUCTION

Risk assessment for acute traumatic injury, in contrast with occupational disease, appears to have received less attention in the research and regulatory arenas. We compare and contrast the assessment and evaluation of occupational injuries and diseases in the context of a widely used risk assessment model (National Academy of Sciences, 1983). The assessment and evaluation of the effects of occupational illness and injury are both challenging activities.

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The risk assessment process requires that a series of questions be answered. How should such "effects" be defined? Can we easily link exposure to some hazard in the workplace to a particular adverse response? What sources of human and experimental data are available that might give insight into this problem? If we can identify relevant data sources, are they of sufficient quality for use in the quantification of the "risk" associated with exposure to occupational hazards? If positive answers can be found for each of the questions above, can we determine exposure limits to hazards that are both protective to the health of the worker and yet are technologically and economically feasible? These questions span the gamut of concerns encountered in the risk assessment and management of occupational hazards.

For the discussion that follows, "risk" is used to refer to the likelihood of some adverse response associated with an occupational hazard that has the potential for causing harm to the worker. Examples of occupational illnesses and their associated hazards include chronic obstructive pulmonary disease associated with coal dust exposure and leukemias or other cancers associated with benzene exposure. Examples of occupational injuries include a fatal injury associated with being crushed in a machine during maintenance as a result of the failure to use a lockout/tagout system or breaking a limb as a result of a fall from a scaffold. As we discuss in later sections, the nature of both the hazard and the response may differ when considering the risk assessment of injuries and illnesses.

The model we use to discuss the risk assessment of occupational hazards was first summarized by the National Academy of Sciences (1983). In this model, risk assessment is considered a four step process comprised of the following components: (1) hazard identification; (2) exposure assessment; (3) dose-response modeling; and (4) risk characterization. A summary of how occupational illnesses and injuries differ with respect to these four components is presented in Table 1. An integration of the pieces of a risk assessment with the economic costs and considerations associated with risk regulation and control technologies is often labeled "risk management". Finally, an evaluation of the effectiveness of risk regulations and other control measures, so-called "intervention research", is also of concern. A summary of how occupational illnesses and injuries differ with respect to risk management and intervention research is presented in Table 2. While our focus is on the four risk assessment pieces, we will describe some differences between risk management and intervention research for occupational illness and injury.

HAZARD IDENTIFICATION

How do we know that some agent might be a hazard? Hazard identification describes the step in the risk assessment process during which an exposure is identified as having the potential to lead to some adverse health response. With hazards that might be associated with occupational cancers, we might have information on the mutagenicity of the hazards based upon genetic toxicology tests or we might have the results of long-term animal carcino-

Table 1. A comparison of occupational illness and injury with respect to the components of a risk assessment.

Risk Assessment component[a]	Occupational Illness	Occupational Injury
Hazard Identification		
Does exposure to an agent increase the incidence of a health condition? Nature / evidence of causation? Carcinogenicity tests? Short-term tests? Structural activity relationships?	Difficult Causation may be difficult due to the latency between exposure and disease Disease mechanistic data may be critical Same exposure may have multiple outcomes and single outcomes may have multiple causes	Immediate effect of exposures generally makes hazard identification easier for injuries Causation between exposure and injury easily established Mechanistic data not critical
Exposure Assessment		
Intensity, frequency, duration of human exposures? Hypothetical exposures for new chemicals Magnitude, duration, route of exposure Size, nature and classes of human populations exposed Uncertainties Extent of exposure before or after regulatory controls	Estimates of historic exposure difficult to obtain May appeal to industrial hygiene job-exposure matrices or other tools	While intensity of exposure may not be critical, duration and frequency of use may be key feature Information on exposure of the victim and other members of the cohort difficult to ascertain Job safety analysis or job hazard analysis can be done for each discrete job or task
Exposure Response Modeling		
Characterizing the relation between agent dose and adverse response incidence Incorporates intensity of exposure, other variables (confounders, effect modifiers) Extrapolation issues (dose, species) Uncertainties (statistical, biological)	Exposure generally continuous Disease mechanism may be considered to suggest a particular statistical model	Exposure generally discrete Mechanistic data generally not considered Statistical modeling, if done, is mostly empirical
Risk Characterization		
Nature / magnitude of human risk	Lifetime estimates of risk generally presented	Most often expressed as rates or years of potential life lost Working lifetime risk occasionally considered

[a] Follows framework / definitions suggested by NAS (1983) report.

Table 2. Differences in risk management and intervention research between occupational illnesses and injuries.

	Occupational Illness	Occupational Injury
Risk Management		
Compare regulatory options (consider public health, economic, social, political concerns)	Exposure-response required by some agencies	Exposure-response information usually not considered/ required
Intervention Research		
Examine the efficacy of the regulatory intervention suggested in the risk management component of the risk assessment process	May only monitor reduction in exposure with hopes that incidence of adverse response will also be reduced because of long latency	Incidence rates can be directly monitored (at least in theory)

genicity experiments suggesting that a particular compound induced cancer in a mammalian model, or we might recognize that a particular agent shares structural similarities with a known hazard. For occupational diseases, knowledge of the disease process might be critical in the identification of disease. For example, if decreased lung function is associated with the clearance mechanism of the lung being overwhelmed, then a hazard (*e.g.*, silica dust) might be identified as an agent that would inhibit lung clearance. The hazards for occupational illness are often chemicals and particulates, although radiation and noise are also recognized as hazards. There are two particular challenges in recognizing illnesses associated with particular exposures. One special challenge associated with identifying hazards associated with occupational illness is that the disease process initiated by exposure to the hazards may not be manifest for many years following exposure. The long latency between exposure and illness makes the attribution of disease to hazard exposure very difficult. The other challenge comes from the diseases resulting from occupational exposure often having non-occupational etiologies as well. Thus, vinyl chloride was easily recognized as a cause of angiosarcoma of the liver since this disease only rarely occurs otherwise. In contrast, it is more difficult to discern that bladder cancer has resulted from a specific occupational exposure as its non-occupational incidence is substantial.

In contrast, the identification of hazards associated with occupational injury appears obvious at one level. Injuries result from the transfer of energy and have been characterized using concepts from infectious disease epidemiology

(Robertson, 1992). Thus, any situation in which it is reasonably anticipated that energy in any form (*e.g.*, mechanical, electrical, heat) can be transferred to a person or from a person (*e.g.*, falling to a stationary surface) at a sufficiently high intensity to cause injury would be identified as hazardous. While a chemical might easily be identified as a possible hazard of occupational illness, industrial processes or situations are more commonly identified as hazards for occupational injuries. For example, when multiple serious injuries were observed as a result of tractor rollovers, the high center of gravity and the lack of a roll bar on tractors along with the use of tractors on inclines were identified as hazards (NIOSH, 1993). However, while the direct cause of an injury is often obvious, the difficulty in establishing the sequence of events that lead to the injury should not be underestimated. For example, while it may be obvious that a victim fell from a ladder, there is often inadequate information to reconstruct if the ladder feet slipped out, or the ladder slipped sideways, or the victim slipped from the rung.

EXPOSURE ASSESSMENT AND EXPOSURE-RESPONSE MODELING

Once a hazard has been identified, we want to know the size of the exposed population and level of exposure. In addition, we want to know the pattern, amount and route of exposure. These are the questions that make up the exposure assessment phase of a risk assessment.

In general, it is easier to determine if someone is exposed at work than it is to determine the magnitude of their exposure. Often the manufacturing process will immediately suggest the types of hazards present. For example, 1,3-butadiene is associated with manufacture of synthetic rubber while methylene chloride is encountered in the photographic film manufacturing industry. Taking the next step to determine who is exposed and to how much of the chemical is more difficult.

The nature of exposure patterns suggests a possible difference between occupational diseases and injuries. The usual pattern of exposure for hazards associated with occupational diseases is often a long-term, chronic pattern. As noted above, defining this cumulative level of exposure in the workplace may be difficult. Job classifications using the input of industrial hygienists is typically used to identify exposure levels associated with various job titles while individual worker exposure levels are often inferred from job histories in conjunction with the previous industrial hygiene assessments. Environmental monitoring and biologic monitoring can, however, provide a benchmark from which to estimate prior exposures. For occupational illness, this is an important exercise since the cumulative exposure to occupational hazards is often employed in later exposure-response assessments of chronic illness and disease. This calculation is based on the assumption that a worker exposed to an agent suspected of causing an occupational illness may spend their entire shift exposed to the agent at a constant level of exposure associated with their job title. For occupational disease, there is usually some historical record that gives an approximation of the level of exposure of members of the cohort, whether diseased or not. While cumulative exposure has been commonly employed as a exposure metric in occupational illness risk assessment, many of the models of cancer allow for the possibility that a single exposure to a cancer-causing agent may be sufficient to initiate the disease process which may not be observed for many years. Thus, an acute exposure event may induce an occupational illness.

Occupational injuries usually result in response to an acute exposure event. To illustrate, suppose a worker is injured from the failure of a lockout/tagout system that was intended to protect workers during the maintenance of a machine. The worker may spend a small fraction of their shift at risk for the failure of the lockout/tagout system. While injuries may result in response to an acute exposure event, the precursor to this event may occur frequently without incident. For example, a worker may use a ladder many times without injury occurring prior to having an injury resulting from a fall from the ladder. Thus, the number of times a ladder was used might provide a cumulative measure of exposure to the injury hazard. Furthermore, there are some musculoskeletal injuries, such as carpal tunnel syndrome, which are the result of repetitive trauma and thus truly are best represented by cumulative exposure.

The concept of a "working lifetime" may be an important quantification of exposure and its use in risk assessment (Fosbroke *et al*, 1987). The period of time over the course of a worker's employment history when a worker is employed in a given craft or job category (*e.g.*, loggers, forklift operators) may provide a cumulative measure of exposure for the hazard of injury. One potential difficulty with this type of exposure measurement is that workers are assumed to be at the same risk of injury at all ages and that the workplace risk of injury remains constant for a long period of time. Both of these assumptions are questionable. Older workers generally experience higher rates of injury (See and Bailer, 1998) and the workplace has tended to become safer over time (Bailer *et al.*, 1998).

Dose-response or exposure-response modeling are general phrases for describing the component of the risk assessment process in which hazard exposure levels are related to the adverse response of interest. This requires some confidence that the response can be attributed to exposure. This may be quite difficult for occupational illnesses and diseases. As noted previously, occupational illnesses often occur long after exposure to the suspected hazard. This long latency between exposure and disease makes the study of exposure-disease relationships very difficult. In contrast, exposure to energy, the occupational hazard for injury, and the adverse response often are directly and clearly related.

Assessment of exposure to injury hazards has not typically been determined. Often measurements of the hazard are neither available for the injured worker, for example how high was the victim on the ladder, nor is similar information available to characterize other members of the cohort who have not been injured. Once an injury occurs in the workplace, a "job safety analysis" or "job hazard analysis" may be conducted. In this analysis, the jobs are broken down into tasks where the hazards and control measures employed are documented. If these analyses are conducted within a particular company, these data are generally not available on a national basis, and hence are not available for occupational injury risk assessments conducted on a very broad scale. The investigation of occupational injuries by OSHA and others have attempted to document the sequence of events preceding the injury using a case study approach. This approach is not amenable to estimating risks or modeling exposure-response relationships.

Selecting a mathematical form that underlies many risk assessments for occupational hazards is somewhat arbitrary since many empirical models may fit the available data equally well. Unfortunately, the choice of statistical models may result in dramatically different estimates of risk for low exposure scenarios. For illness, a variety of statistical tools are employed to study how illness is related to the effects of the hazard, a risk factor of interest, along with other variables, potential confounders or effect modifiers. Logistic regression, Cox regression models and a host of other relative risk regression models are used for this exercise. Examples of how risk estimates differ with regression models can be found in Stayner *et al.* (1997). In addition, models reflecting mechanisms of disease might be considered when describing exposure-illness response patterns (for example, the multistage and mutation-clonal expansion models for carcinogenesis). In contrast, the use of exposure-response models for injury outcomes are fairly rare. Typically, stratified analyses of injury outcomes by levels of certain classification variables are conducted. For example, injury rates might be represented separately for different industries or for different worker ages. Models that are employed for analyzing occupational injury data include Poisson regression (Bailer *et al.*, 1997) while recent research efforts are focused on defining and estimating lifetime risk for occupational fatal injury (Fosbroke *et al.*, 1997; See and Bailer, 1998). We believe that there is a strong need to continue research to determine the most valid models for evaluating injury events and to critically evaluate the validity and utility of current approaches. In conclusion, the definition / quantification of exposure may be more difficult in injury hazards relative to illness hazards while the attribution of disease to hazard exposure may be more difficult for illness hazards relative to injury hazards.

RISK CHARACTERIZATION

The last stage in the risk assessment process according to the National Academy of Science model is the risk characterization step. At one level, this step focuses on integrating the previous steps of the risk assessment. The results of the exposure-response model are integrated with the assessment of worker exposure with a goal of evaluating the degree and extent to which an occupational hazard poses a risk to human health. In particular, lifetime risk projections for occupational illness are often produced to address this goal. While this is common in illness risk assessment, it is rarely, if ever, considered in injury risk assessment. One difference between illness and injury risk assessments is that the populations at risk of adverse response might be quite different. For many occupational hazards associated with illness, the population at risk may be employed in a very specific industry. In contrast, with many hazards associated with occupational injury, the populations at risk may span many different industries. To illustrate, any industry in which electricity is employed may have workers at risk of electrocution while 1,3-butadiene might be used in a very small group of industries manufacturing a particular product. Finally, because of the requisite interval from exposure to onset, illness is more likely to occur in older workers in contrast to injuries. The median age of death in a large database of occupational fatal injuries was 35 years (Gilbert *et al.*, 1998). The effects of occupational illness may not be manifest until a much later age. Thus, the years of potential life lost due to occupational fatal injuries might be larger compared to the years of potential life lost due to occupational illness.

Prediction of risk outside the range of human observation is problematic for occupational disease and injury. For disease, the controversy primarily centers on two issues. One is the shape of the dose response curve at low levels of exposure and whether there is a threshold below which adverse effects are not observed. The other difficulty is predicting illness in humans from data that is derived from experimental animals. There are similar difficulties in predicting human injury from studies of mannequins, and in predicting injury across age, size, and other body characteristics.

RISK MANAGEMENT AND INTERVENTION RESEARCH

After a risk assessment is completed, a decision must be made as to what intervention is warranted. The level of intervention may range from alerts to notify workers of the possible danger associated with certain hazards to a regulatory intervention in which a standard is promulgated mandating a reduction in exposure to a hazard (*e.g.*, OSHA standards for 1,3-butadiene or methylene chloride) or mandating a control technology (*e.g.*, respirators or lockout/tagout devices).

The 1980 Supreme Court decision on benzene firmed up the need for OSHA to do risk assessments for both health and safety standards rulemaking (Reed *et al.*, 1994; Martonik *et al.*, 1998). In this ruling, an initial mark of 1 in 1000 additional cancers was suggested as significant risk associated with exposure to a hazard while a 1 in 1,000,000,000 additional cancers was not. Obviously, much room exists between these two levels, and this has been a topic of continued debate in the setting of regulatory standards. While lifetime risk has been employed to set occupational health standards, it has not been used for safety standards. Recent work (Fosbroke *et al.*, 1997; See and Bailer, 1998) describing lifetime risk for injuries among different occupations is promising for allowing similar arguments to be employed for setting safety standards.

Intervention research could assess the effectiveness of an intervention such as a regulatory standard or a change in design, such as air bags in automobiles, after it has been promulgated or implemented. This research evaluates that effectiveness of a standard. Did the regulatory standard induce changes that improved worker health and safety? If this activity is initiated shortly after the passage of a standard, insufficient time may have passed to observe the desired outcome. This is especially true for standards that were passed to control hazards associated with occupational illnesses and diseases that occur with a fairly long latency after exposure. In this situation, it may only be possible to assess if the workplace exposures have been reduced to levels that are considered to possess minimal risk based upon projections from exposure-response modeling. We may also need to wait until the standard is fully implemented prior to seeing if improvement in health or safety is observed. For intervention research associated with occupational injuries, an effective rule might be expected to have immediate impact on the occurrence of occupational injuries. One difficulty in assessing such a change is that industries may begin modifying the workplace while the standard requiring such modifications is being debated. Given that it takes years to bring a standard from suggestion to law, changes associated with the rule could be difficult to determine. To address this concern, the monitoring of worker injury and illness must be an ongoing activity. To see changes designed to influence to safety in the workplace, we need a long record of observation that extends from before a standard is even proposed to 3-5 years or more after a standard is in effect.

SUMMARY

Our objective was to provide an introduction to the process of risk assessment for occupational hazards with an exploration of the similarities and the differences that exist between evaluating illness and injury. We see that illness and injury might pose different challenges both during and after a risk assessment. Both illness and injury risk assessments would benefit from greater assessment of the magnitude and frequency of occupational exposures to hazards. This type of data would be available if broad and ongoing industrial hygiene evaluations were conducted. These data would provide a better basis for exposure assessment and exposure-response modeling. A special problem that may arise in exposure-response modeling arises with non-fatal injuries in which particular workers may experience the adverse response on more than one occasion. Techniques for analyzing recurrent events may need to be employed to address these problems. Risk characterization needs include continued investigation in the appropriate means of evaluating the lifetime risk of illness and injury hazards. Recent work has extended these concepts for injury outcomes; however, adjustments for age-specific injury rates and time trends in injury rates are only now being explored. Finally, if we want to assess the effectiveness of regulatory interventions, we need to have better monitoring of illness and injuries in industries both before and after regulatory interventions.

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