Characterizing the Burden of Occupational Injury and Disease

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Objectives: *To review the literature on the burden of occupational disease and injury and to provide a comprehensive characterization of the burden.* ***Methods:*** *The scientific and governmental literature from 1990 to the present was searched and evaluated. Thirty-eight studies illustrative of the burden of occupational disease were reviewed for findings, methodology, strengths, and limitations.* ***Results:*** *Recent U.S. estimates of occupational mortality and morbidity include approximately 55,000 deaths (eighth leading cause) and 3.8 million disabling injuries per year, respectively. Comprehensive estimates of U.S. costs related to these burdens range between $128 billion and $155 billion per year. Despite these significant indicators, occupational morbidity, mortality, and risks are not well characterized in comparative burden assessments.* ***Conclusions:*** *The magnitude of occupational disease and injury burden is significant but underestimated. There is a need for an integrated approach to address these underestimates.* (J Occup Environ Med. *2005;47:607–622*)

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The burden of occupational injury and illness is substantial among America's 139 million workers.[1–7] For 2002, the Bureau of Labor Statistics (BLS) reported 5524 fatal work injuries, 4.4 million nonfatal injuries, and 294,500 illnesses.[2] The National Institute for Occupational Safety and Health (NIOSH) estimates that 3.6 million occupational injuries and illnesses are treated annually in U.S. hospital emergency rooms.[4] Estimates for occupational disease mortality vary, although recent estimates suggest that occupational disease deaths exceed 55,000 per year.[5] Employers paid $72.9 billion in workers' compensation premiums in 2002, with total direct and indirect costs estimated to range between $128 and $155 billion.[6,7] Using 1992 data, Leigh et al estimated that the cost of occupational morbidity and mortality was more than five times the cost of HIV/AIDS, three times the cost of Alzheimer's disease, 91% of the cost of cancer, and 82% of the cost of heart disease.[7] Despite these relatively large numbers, ranked lists of the causes of disease or disability (such as shown in Table 1) make no explicit mention of occupational factors (risks, diseases, or injuries). The reason, in part, is that occupational risk factors and associated health conditions contribute to various causes of death and generally are not captured as a unique category in International Classification of Diseases codes. It is widely appreciated that one risk factor can lead to many outcomes, and one outcome can be caused by many factors.[9–11] Clearly, occupational causes exist for cardio-

TABLE 1
Rank of Cause of Death or Disability by Disability-Adjusted Life-Years (DALYs) (U.S.), 1996

Rank	Cause	Percent of Total DALYs	Deaths
	All conditions	100.00	1,163,569
1	Ischemic heart disease	10.75	286,990
2	Road traffic collisions	5.10	29,105
3	Lung, trachea, bronchus cancers	4.44	102,071
4	HIV/AIDS	4.22	25,307
5	Alcohol abuse and dependence	4.02	5231
6	Cerebrovascular disease	3.68	63,126
7	Homicide and violence	3.10	17,391
8	Chronic obstructive pulmonary disease	2.98	52,489
9	Self-inflicted	2.96	25,647
10	Unipolar major depression	2.60	12
11	Drug use	2.55	1194
12	Diabetes mellitus	2.51	27,983
13	Osteoarthritis	2.26	182
14	Congenital abnormalities	2.24	6340
15	Dementia and other degenerative and hereditary central nervous system disorders	2.09	14,051

Adapted from Michaud et al.[8]

vascular diseases (stress, carbon monoxide, carbon disulfide), road traffic collisions (construction work, long work hours for truck drivers), lung cancer (asbestos, crystalline silica, hexavalent chromium), and so on. Nearly every cause of death or disability ranked in Table 1 may have an occupational component, but these are not characterized in the ranked lists.

Nonetheless, there is value in assessing risk factors in a unified framework so that comparisons can be made within and across countries so that there is an evidence base for priority setting and resource allocation.[9] However, this comparative assessment of the burden of disease and injury is an infant and problematic science.[12] Only recently has the World Health Organization started to assess occupational risk factors on a global basis.[10,11]

There is a need for further characterization of the burden of occupational injury and disease to meet the requirements of public and private decision-makers.[13] This article begins to address that need by reviewing studies of the burden as a result of occupational disease and injury and identifying important methodologic issues. The article provides an overview of the burden in terms of magnitude, attributable risks (ARs), and disability-adjusted life-years (DALYs) and then in terms of costs, social consequences, and disparities. Ultimately, the article provides an approach for improving the characterization of burden.

Assessments of the Burden of Disease and Injury Resulting From Occupation

A summary of recent assessments of the burden of disease and injury resulting from occupational exposure are shown in Table 2 and Figures 1 and 2. Some of these are highlighted here for consideration.

Nurminen and Karjalainen[14] calculated that 4% (1800) of all the deaths in Finland in 1996 were attributed to occupational factors. They estimated that the number of occupational deaths was larger than those for suicide (1247) or diabetes (593). Relatively rigorous criteria were used for selecting component studies. Selected occupational attributable risks identified by Nurminen and Karjalainen included 18% for asthma, 12% for chronic obstructive pulmonary disease (COPD), and 17% for cardiovascular disease.[14] However, two biases could have affected the findings. First is the criteria by which occupational exposures were accepted as causes of diseases, and second is the dichotomous classification of exposures (present or absent), when for almost all hazards, the risk may vary according to the intensity and duration of exposure.[56] Conversely, the exclusion of the age category of ≥65 years for cancer could have resulted in a marked underestimation of the total number of work-related cancer deaths, many of which may not occur until after age 65.

Steenland et al[5] calculated that 7.4% (55,200 of 738,000) of deaths among people aged 15 to 69 years in 1997 were estimated to result from occupational injury and disease. They determined that occupational deaths were the eighth leading cause in the United States after diabetes (64,751) and greater than motor vehicle accidents (43,501) and suicides (30,573). The limitations of this study are 1) that there were incomplete data for many of the underlying epidemiologic studies because the United States lacks a comprehensive national mortality surveillance system for occupational diseases, 2) that this analysis depends on accepted causal linkages and estimates of the prevalence of exposure, 3) that many diseases were not included, and 4) the study only included mortality, not morbidity data.[5] Attributable fractions were restricted to only diseases with well-established occupational causes and likely to be underestimated.

The global burden of disease and injury resulting from occupational factors was reported by Leigh et al. in 1999.[36] Using the published literature, it was estimated that 100 million injuries and 11 million occupational diseases occur each year in the world leading to 800,000 deaths.

TABLE 2
Selected Studies That Demonstrate the Burden of Disease and Injury Resulting From Occupational Factors

Burden	Methods	Limitations	Reference
Health Effects			
AF* of work-related mortality (Finland); 1800 work-related deaths; 6.7% (6.2–9.7) in ages 25–64	Calculated AF using causes of death, number of subjects exposed, and risk ratios from epidemiologic studies Exposure based on job-exposure matrix	• Criteria by which occupational exposures were accepted as causes of disease • Dichotomous classification of exposure; exclusion of ages ≥65	Nurminen and Karjalainen[14]
AF of work-related mortality (U.S.); 55,200 (32,200–78,200) work-related deaths; eighth leading cause of mortality	Calculated AF using 1997 U.S. mortality data and information from epidemiologic studies Data on exposure prevalence from U.S. studies	• Limited to selected diseases • Limited exposure data • Evidence for causality • Assuming independence of multiple exposures; use of RR from 1980s	Steenland et al[5]
AF (global) — Percent Low back pain 37 Hearing loss 16 COPD 13 Asthma 11 Unintentional injuries 8 Lung cancer 9 Leukemia 2 DALYs 1.5% of total global burden	Based on labor force aged 15 and above; use of CAREX database for carcinogens	• Limited diseases were included • Lack of uniform quality exposure data worldwide • Variation in outcome definition and registration practice between countries • Does not include workers less than 15 yrs old	WHO[11,15]
Fraction of air flow obstruction attributable to workplace exposure by race/ethnic group (U.S.) Whites 22.2% (95% CI = 9.1–33.4) Black 23.4% (95% CI = 2.2–40.0) Mexican-American 49.6% (95% CI = 32.1–62.6)	Use of NHANES III data to calculate AF for ethnic groups based on prevalence odds ratios	• NHANES III not designed for this use • Small sample size • Definitions of air flow obstruction • Inability to control for confounding	Hnizdo et al[16]
Burden of COPD attributable to occupations (U.S.): PAR 20% (95% CI = 13–27%)	Random survey of 2061 U.S. residents on health status and occupational history; exposure assessed with job exposure matrix; COPD defined by self-reported physician's diagnosis; adjustment for smoking status and demographic factors	• Self-reported data • Small sample size • Exposure assessment based on longest job held rather than quantitative exposure data	Trupin et al[17]
Proportion of lung and bladder cancers attributable to occupation Lung 1–40% Bladder 0.3%–24%	Systematic review of studies of lung and bladder cancer Inclusion criteria included requirement of control for smoking status	• Used on case–control studies • Considerable variation in proportion of lung cancer studies attributable to occupation	Vineis and Simonato[18]
Attributable fraction resulting from occupational risk factors (%) (M/F) N: Pneumoconioses 100/100 Ischemic heart disease 12.1/7.8 Asthma 17.8/18.4 Bladder cancer 14.2/7.1 Leukemia 18.5/2.5 Lung cancer 12.3/2.6	Selected diseases based on Steenland[5] and Nurminen and Karjalainen[14]	• Evidence for women generally weaker than for men • Little information based on risk factor prevalence for New Zealand used Nurminen and Karjalainen • Age range may not be appropriate	Driscoll et al[19]

(*Continued*)

TABLE 2
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Burden		Methods	Limitations	Reference
Parkinson's disease	16/4.9			
Stomach ulcer	29/29			
15% of both asthma and COPD estimated to be work-related (U.S.)		Direct use of PARs in published studies and estimation of PARs from epidemiologic studies with adjusted relative risks; used measure of total exposure burden; 55 studies evaluated	• Lack of standardization of definition of COPD • Estimation of numbers of cases exposed • Only used occupational categories	Balmes et al[20]
Population attributable risk of lung cancer resulting from occupation: 9.2%		Multicenter case–control study of 1793 male lung cancer cases; control for age, race, hospital, year, smoking	• Occupations with high risk of lung cancer were underreported	Morabia et al[21]
Population attributable risk for hypertension resulting from job strain, 27% males based on review		Used Cornell longitudinal study methods	• Magnitude of job strain—CVD association possibly underestimated	Schnall and Landbergis[22]
Population attributable risk for cardiovascular disease, 25–40%		Critical review of 14 longitudinal studies; rigorous inclusion criteria	• Data quality better for men than women	Belkic et al[23]
			• Although association is strong, some large studies have been nonconfirmatory	Schnall[24]
Population-attributable risk for forearm pain in various working populations associated with		Prospective study of 782 workers initially free of pain; study length: 1 yr; adjusted for age, sex, occupational group	• Self-reports of exposures • 15% of subjects lost to follow up • Some potential psychologic covariates not assessed	Nahit et al[25]
Repetitive wrist and arm movements	36%			
Monotonous work	23%			
Working with hands above shoulder level	18%			
Attributable risk for asthma resulting from occupational exposures, 5–10%; based on a random sample of 15,637 young men and women, aged 20–44, in Europe and other industrial countries		Population-based sample; used two definitions of asthma involving symptom and bronchial responsiveness questionnaires Used methacholine challenge	• Unable to differentiate between new cases of asthma and asthma exacerbated by work • Occupational classification based on current job	Kogevinas et al[26]
AF from occupational percutaneous injuries (global)		Adjusted for smoking modeled incidence of infections attributable to percutaneous injury in 14 geographical regions on the basis of probability of injury, prevalence of infection, susceptibility of the worker, and percutaneous transmission potential	• Number of HCW at risk is likely to be underestimated • Quantity and quality of data on the number of sharps injuries per year was limited • Study limited to sharps injuries and did not include mucocutaneous and skin exposures • Prevalence of infections based on general population prevalence	Prüss-Ustün et al[27]
Hepatitis C virus	39%			
Hepatitis B virus	37%			
HIV	4.4%			
Occupational injuries are responsible for 8.8% of the global burden of mortality resulting from unintentional injuries		Used the economically active population as surrogate of the population at risk for occupational injuries Applied occupational injury rates for insured workers by country to estimate regional rates	• Underestimates impact of occupational risk factors by using only insured populations • Incomplete reporting of mortality data • Did not include mortality from intentional injuries such as homicides in the workplace	Concha-Barrientos et al[28]

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TABLE 2
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Burden	Methods	Limitations	Reference
16% (7–21%) of noise-induced hearing loss attributed to occupation (global) Effects in males greater than in females	Used proportions of workers exposed to noise based on U.S. estimates; these were combined with risk measures for NIHL to estimate attributable fractions	● Assumed that given the same level of exposure, all persons would develop same hearing loss ● Comparison group for underlying studies is often white collar populations ● Use of U.S. estimates for whole world	Nelson et al[29]
37% (21–41%) of low back pain (LBP) attributed to occupation (global)	Calculation of attributable proportions from epidemiologic literature LBP defined as any "nontraumatic musculoskeletal disorder" affecting the low back Occupation-specific estimates of relative risk for LBP applied to compute attributable fractions by WHO subregion, age, gender	● Use of occupation to represent average combinations of exposures may introduce error when transposing the risk values to various geographic region ● Strength of the underlying epidemiologic literature regarding control for confounding and healthy worker effect	Punnett et al[30]
DALY by sex (M/F) (global) Risk factors for injuries 2071/1054 Carcinogens 962/220 Airborne particulates 4130/1224 Ergonomic stresses 485/333 Noise 2788/1362	Expert group calculated DALYs; used counterfactual exposure distribution to calculate AFs expressed as DALYs Calculations were based on ages 18–64 except for cardiovascular diseases, which used age 20–69 for calculations	● Uncertainty of exposure and disease causation	Ezzati et al[9]
Burden of disease and injury attributable to occupational exposure (Australia, 1996), 2005 deaths (1.6% of total) DALYs (1.7% of total) 44,000 DALYs—1.7% of total burden (1996) Of these Cancers 41% Injuries 33% Chronic diseases 25%	Based on Kerr et al[31] and NOHSC,[32] AF derives from Australian Institute of Health and Welfare database	● Excluded people who died from diseases, even if there appeared some connection to work	Mathers et al[33,34]
Global burden attributed to occupational factors 38 million DALYs (2.7% of world DALYs) 100,000,000 occupational injuries 100,000 occupational deaths 11,000,000 occupational diseases 700,000 deaths	Requested data from countries Direct approach: used counts of injuries and fatalities and attributable disease data; used methods from Leigh et al[35]; indirect approach: calculated expected numbers of cases; applied results to calculation of DALYs	● Aggregation of approaches ● Incomplete data on worldwide exposure ● Selection of attributable proportions from higher end of generally accepted range ● Lack of uniformity in counting work-relatedness of injuries ● Underreporting in some countries	Leigh et al[36]
6.6 million DALYs: Non-malignant respiratory disease (global) Asthma 1.6 million DALYs COPD 3.7 million DALYs Pneumoconioses resulting from exposure to occupational airborne particulates 1.2 million DALYs	Used CAREX database to estimate proportions of workers exposed to particulates and their levels of exposure Used relative risk obtained from epidemiologic literature for asthma and COPD and absolute risks for the pneumoconiosis to develop estimates of DALYs	● Did not assess extent to which risk of developing an occupational respiratory disease diminishes when exposure ceases ● Same summary risk estimates applied to each geographic region ● Used rough surrogates for occupational exposure to asthmogens or dust	Driscoll et al[37]

(Continued)

TABLE 2
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Burden	Methods	Limitations	Reference
1.6 million DALYs: occupational carcinogens (global) Lung cancer 969,000 DALYs Leukemia 101,000 DALYs Malignant mesothelioma resulting from exposure to occupational exposure 564,000 DALYs	Used CAREX database to estimate proportion of workers exposed to selected carcinogens Used relative risk obtained from epidemiologic literature for lung cancer and leukemia or absolute risk for mesothelioma to develop estimates of DALYs	• Did not assess the extent to which the risk of developing various cancers diminishes as a result of exposure ceasing • Same summary risk estimates applied to each geographic region • Assumed incidence rate ratios were comparable to mortality rate ratios • Many exposures to known occupational carcinogens were not included	Driscoll et al[38]
Work-related injuries (U.S.) for 1997: 5100 injury deaths; 3.8 million disabling injuries; 125 million lost workdays; 45 million from injuries in previous yr	Based on Census of Fatal Occupational Injuries (CFOI): time lost is the number of cases and the average time lost per case; used ICDA codes: for nonfatal injury estimates, the concept of "disabling injury" from NHIS was used	• Injuries are reported on a national basis but totals are approximations based on ratios of disabling injuries to deaths	NSC[39]
Severe hearing difficulties attributable to work (U.K.) No. Affected Men 153,000 Women 26,000 Persistent tinnitus Men 266,000 Women 84,000	Questionnaire to 22,194 randomly selected adults of working age; calculation of prevalence ratios (PRs); attributable numbers calculated from PRs and an estimate of prevalence of exposure to noise, nationally; adjustments for age, sex, smoking habits, frequent complaints of headaches, tiredness, or stress	• Self-reported data • Possible misestimates of national exposure	Palmer et al[40]
Years of productivity lost in Washington State (1986): 14,624 yr of lost productivity (3.8 million work days); 28,027 future-predicted lost productivity (7.3 million work days)	Estimates based on only compensated losses; used nonfatal work-related injury and illnesses	• Estimates are likely to be underestimates since many workplace diseases are not submitted for workers' compensation	Fulton-Kehoe et al[41]
Costs			
Total direct and indirect costs $155 billion (U.S. 1992) Injuries $38.4 billion (direct) $94.3 billion (indirect) Illnesses $13.4 billion (direct) $9.4 billion (indirect)	Costs assessed using human capital methods[42]; incidence and mortality of occupational injury and illnesses were assessed by review data from national surveys, then applying attributable risk proportion method	• Numerous assumptions in cost assessments • Human capital methods underestimates some types of costs and do not allow for substitution effects	Leigh et al[7]
Cost of lost wages (Wisconsin) $530 million (1994 dollars) Workers' compensation only replaces 64% of after-tax projected losses	Regression techniques to estimate losses relative to a comparison group Assessed all reported injuries in the state	• Conservative estimates because many workers do not enter workers' compensation system • Incomplete cost information: some disabled workers experienced wage loss after benefits ceased	Boden and Galizzi[43]
Cost of occupational injuries $127.7 billion in 1997 (U.S.); this includes wage and productivity losses of $63.4 billion, medical costs of $20.7 billion, administrative expenses of $26.5 billion, and employer costs of $11.9 billion	Deaths from BLS, Census of Fatal Occupational Injuries (CFOI) A benchmark unit cost for each component, adjusted to the appropriate year was used	• Numerous assumptions in cost assessments • Human capital methods underestimates some types of costs and does not allow for substitution effects	NSC[39]

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TABLE 2
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Burden	Methods	Limitations	Reference
	Costs assessed using human capital method	• Present value of after-tax wage and fringe benefits highly sensitive to discount rate	
Workplace injury costs $140 billion annually (US) $17 billion medical and emergency services $60 billion: lost productivity $ 5 billion: insurance costs $62 billion: lost quality of life	Used national expenditure data: incidence data (1989) Medical costs and insurance from workers' compensation Quality of life based on a willingness to pay approach	• Various assumptions used to supply missing data • Assumption on length of work loss • Arbitrary assumptions on work disruption and productivity loss • Coefficient of variation for the value of a statistical life is on the order of 30%	Miller and Galbraith[44]
Costs of job-related osteoarthritis (OA) (US): $3.41 billion to $13.23 billion job-related OA contributes approximately 9% of total costs for all OA 51% of job-related costs result from medical costs; 49% from lost productivity	Used proportional attributable risk models to estimate percentages of acute and repetitive injuries resulting in osteoarthritis Human capital method	• Underreporting of costs because they are not covered by workers' compensation. • Does not include costs of pain and suffering and of family caregiving • Limited number source studies for PAR estimates; extent of causal linkage unclear • Counted diseases for only 1994	Leigh et al[45]
Total costs — $20.7 billion (California, 1992) Injuries — $17.0 billion Illness — $2.9 billion	Human capital/cost of illness method for calculating costs Used incidence-based costs for injury and morbidity estimates and prevalence-based cost method for deaths	• Assumptions about: percent of injuries that were disabling; pre-tax replacement rates; and that self-insured firms have average costs similar to those from Telles and Fox (1997),[46] which were the basis for direct costs for injuries • Omitted collateral damage to innocent third parties	Leigh et al[47]
Medical costs of 14 occupational diseases ((U.S. 1999) Overall $14.5 billion (range $9.6–19.4 billion) $10.7 billion (men) $3.8 billion (women) Diseases generating highest costs: Circulatory (age 24–64) — $4.7 billion Cancers — $4.3 billion COPD — $2.2 billion Asthma — $1.5 billion	Used prevalence of occupational disease to measure overall burden Used "topdown" approach (Rice et al)[42] PAR used were from the study Nurminen and Karjalainen (2001)[14] sensitivity analysis to consider different PAR	• Obtaining consensus on appropriate PARs • Cost data are estimates • Did not estimate indirect costs • Did not include job-related osteoarthritis • Did not explicitly address costs for dermatitis, hearing loss, and carpal tunnel syndrome	Leigh et al[48]

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TABLE 2
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Burden	Methods	Limitations	Reference
Costs of workplace injuries and deaths (U.S. 2003): $156.2 billion Value of goods or services each worker must produce to offset the cost of occupational injuries: $1120/employee Cost per death $1,110,000 Cost per disabling injury $38,000 Total lost workdays 115 million days	Deaths from BLS, Census Fatal Occupational Injuries A benchmark unit cost for each component, adjusted to the appropriate year Costs assessed using human capital method	• Numerous assumptions in cost assessments • Human capital methods underestimates some types of costs and does not allow for substitution effects • The present value of after-tax wage and fringe benefits highly sensitive to discount rate	NSC[49]
Total costs for fatal and nonfatal occupational injuries ranked by SIC code Ranked top 50 industries by average cost SIC — Industries — Billion 421 Trucking/courier services (except air) $4.4 58 Eating/drinking places $3.3 806 Hospitals $2.8 541 Grocery stores $2.7 805 Nursing/personal care facilities $1.9 371 Motor vehicles/equipment $1.3 531 Department stores $1.3 514 Groceries/related products $1.3 179 Miscellaneous special trade contractors $1.2 162 Heavy construction (except highway) $1.2	Average cost = total costs/number of workers Relied on BLS data; accounted for pain and suffering Medical cost data came from the National Health Interview Survey and the Detail Claims Information Data Set Expressed in 1993 dollars; detailed methodology was developed for ranking industries by total cost and cost per worker	• Excluded governmental and self-employed workers and workers on farms with fewer than 11 workers • Underestimate of illnesses • Workers' compensation costs may be over- or underestimates depending on whether they are adjusted for the costs to physicians and providers for paperwork and litigation	Leigh et al[50]
Costs of occupational COPD and asthma (1996) COPD $5.0 billion 56% direct; 44% indirect Asthma $1.6 billion 74% direct; 26% indirect	Used data from the National Center for Health Statistics and the Health Care Financing Administration Used human capital method, calculated proportionally adjusted costs for plausible PARs Used PARs from Balmes et al[20]	• Only counted deaths and hospitals occurring in 1996 • Used ICD-9 CM codes and could not distinguish different subtypes of COPD • Cost estimates depend on the selec tion of the appropriate PAR for U.S. population • Ignored costs of pain and suffering and family caregivers	Leigh et al[51]
Cost of occupational injuries in agriculture $4.57 billion (range $3.14–13.99 in 1992) 30% more than the national average for occupational injuries	Assess costs of 841 deaths and 512,539 nonfatal injuries Used human capital cost of illness method Used CFOI and BLS data	• Possible undercounting of deaths in CFOI • Cost estimates not adjusted for current employment status • Did not include pain and suffering or family caregiver costs	Leigh et al[52]

(*Continued*)

TABLE 2
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Burden	Methods	Limitations	Reference
Total costs of workplace injury and disease (Australia) for 2000–2001 estimated to be $34.3 billion; equivalent to 5% of GDP 3% borne by employers, 44% by workers, and 53% by community Estimates that cost of pain and suffering could add additional $48.5 billion to the total cost figure	Applied results of study of 1992–1993 financial year to get estimates for 2000–2001 Used "human cost" method of work-related injury and disease Used an incidence-based approach to estimate measured annual occupational injuries and disease and distributed costs according to an "ex-post" approach Estimated cost of suffering using willingness to pay model	• No direct measure of pain and suffering costs • Assumed estimates of indirect to direct costs for 1992–1993 stayed constant	NOHSC[53]
National cost of workers' compensation (U.S.—2002) for 50 states and federal programs Benefits paid $53.4 billion Employer costs $72.9 billion Coverage for 125.6 million workers in 2002 compensation exemptions 1.08 million workers in small firms 0.99 million workers in agriculture	Estimates of benefits paid and employer costs based on annual survey of state agencies and data purchased from AM; best survey response from 43 states, AM; best data available for every state Special method to estimate benefits from self-insured employers	• Accuracy of survey reports • Does not include compensation costs for portion of black lung benefits financed by federal funds and smaller federally funded programs to compensate workers who became ill as a result of the production and testing of nuclear weapons • Does not include compensation costs paid by Social Security or Medicare that are work-related • Does not cover costs accrued by workers in very small firms, certain agricultural workers, household workers, some employees of religious and charitable organizations, and some units of state and local government	Williams et al[6]
Costs of occupational disease not covered by workers' compensation $7.6–$23.1 billion (1999)	Compared estimates of deaths from epidemiologic studies with estimates of numbers of workers' compensation cases from 16 states	• PAR methodology is imprecise • Compensating wage hypothesis • Underestimates of nonfatal disease costs • No inclusion of Radiation Exposure Compensation Program and Energy Employees Occupational Illness Compensation Program • Variation across states in which diseases are compensable • Underestimates of indirect costs	Leigh and Robbins[54]

Attributable risks (AR) have been referred to by various terms in the literature. Some include "attributable fraction" (AF) and "population attributable risk" (PAR).[55]
* AF (attributable fraction) = [P(E)(RR-1)]/[1 + P(E)(RR-1)] where P(E) = proportion of the population exposed.[55]
RR = relative risk of death in exposed population compared with unexposed population.
DALY (disability-adjusted life years) = years of life lost (YLL) + years of life disabled (YLD).[10]
COPD, chronic obstructive pulmonary disease; CI, confidence interval.

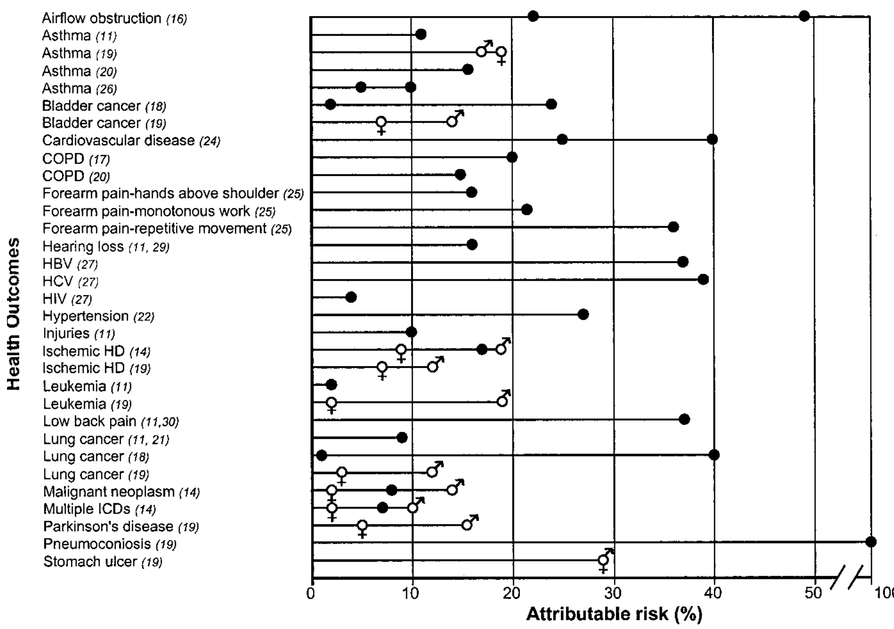

Fig. 1. Attributable risks of morbidity, mortality, and injuries resulting from occupational factors. *Based on assessments of attributable fraction, population attributable risks, and attributable proportions in Table 2. Solid circles represent data from both sexes; two solid circles on a line represent a reported range of values. Numbers (#) pertain to references in Table 2.

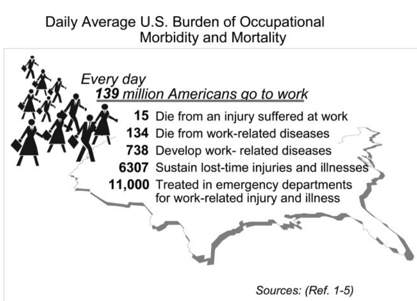

Fig. 2. Daily average U.S. burden of occupational morbidity and mortality.

Subsequently, the World Health Organization examined the burden of disease for selected occupational risk factors by assessing the contribution of 26 risk factors to the global burden of disease and injury.[15] Similar exposure and risk information was put in a single model to make comparisons possible. The study indicated that selected occupational risk factors were responsible for approximately 37% of low back pain, 16% for hearing loss, 13% for COPD, 11% for asthma, and 8% for injuries.[15]

The limitations of both of these studies are that they may underestimate the magnitude of occupational deaths (eg, ILO[57] estimates 2 million occupational deaths per year; however, these estimates may be limited by the quality of the source data).[58] Also, many occupational risk factors were not included nor were data on child workers.

An extensive visual characterization of the burden of occupational morbidity and mortality is in the NIOSH publication "Worker Health Chartbook, 2004." This document includes more than 400 figures and tables describing the magnitude, distribution, and trends of U.S. occupational injuries, illnesses, and fatalities.[1] In addition to the charts, electronic versions of the chartbook allow linkage of the summary statistics back to the original data.

Costs of Occupational Injury and Disease

Leigh et al have provided the most thorough cost assessments (Table 2).[7,45,47,48,50–52,54] As noted earlier, using 1992 data, Leigh et al reported a combined direct and indirect cost of $155.5 billion per year.[7] Direct costs included medical care and workers' compensation.[7] Indirect costs included wage and productivity losses, higher consumer prices, and nonworkers' compensation costs borne by the medical insurance systems. The Human Capital approach, which has been applied to a variety of injuries and illnesses, was used in part because it allowed for comparison of costs of occupational and nonoccupational diseases and injuries; however, it is limited in not including costs related to productivity, pain, and suffering.[59,60] In 2003, Leigh et al assessed the medical cost associated with 14 occupational illnesses in the United States using 1999 data.[48] The population attributable risk (PAR) model with PARs based on the study by Nurminen and Karjalainen[14] estimated that medical costs were $14.5 billion ($9.6–$19.7 billion) with the largest being $4.7 billion (circulatory diseases), $4.3 billion (cancer), $2.2 billion (COPD), and $1.5 billion (asthma). These studies are dependent on the quality of the available cost data, which are most likely underestimates of true costs. The analysis by Leigh et al[7] was also limited by: 1) inability to account for the economic effects of occupational injuries and illnesses on the relatives of victims or the cost of caregivers' time and energy,[61] 2) restriction of job-related circulatory disease deaths to under age 75 years, 3) ignoring costs of pain and suffering and those transferred from employers to society, and 4) omission of reproductive problems from disease calculations.[7] In addition, data sources had well-known deficiencies such as the inability of Occupational Safety and Health Administration statistics to capture occupational transportation injuries and deaths, work-related assaults, and violent acts leading to significant underestimation of these events.

The National Safety Council, using the Census of Fatal Occupational Injuries (CFOI) for 1997, estimated the costs of occupational injuries to be $127.7 billion (NSC, 1998).[39] This included wage and productivity losses of $63.4 billion, medical costs of $20.7 billion, and administrative expenses of $11.9 billion.

Weil reviewed the methods for valuing the economic costs of occupational injury and illness and found most studies tended to underestimate the true economic costs from a social welfare perspective, particularly in how they accounted for occupational fatalities and losses arising from work disabilities.[62] Many of the estimates of costs of occupational disease and injury depend on a combination of methodologic assumptions, extrapolation methods, and known and unknown biases. Weil found that there were significant divergences between theoretical and actual valuation in the area of occupational fatalities, workplace disabilities, and nonworkplace disabilities.[62]

Social Consequences of Occupational Illness and Injuries

In assessing the burden of occupational illnesses and injuries, most of the focus has been on the magnitude in terms of morbidity, mortality, and direct costs. Despite the large descriptive literature on the impact of disease and injury on patients' emotional health, family dynamics, and social networks as well as the longstanding recognition of social impacts of occupational injuries and disease, there is not an extensive body of literature documenting significant social costs of work-related illness and injury. Dembe has developed a conceptual framework for identifying and analyzing the "hidden" social consequences of occupational injuries and illnesses.[63] The investigation of the social consequence of occupational injury and illness is complicated by the multifactorial influence of personal, social, organizational, and environmental variables. These consequences can include implications of work-induced disorders for labor relations, family dynamics, domestic activities, community involvement, and personal mental health.[64–66]

Disparities in Population Burdens

The burden of occupational injury and disease can be portrayed by its uneven distribution in various populations and work environments. Despite social and economic determinants, an extensive but incomplete scientific literature documents work-related racial, ethnic, and gender health disparities between groups.[67–77]

Methodologic Issues

Impediments to Collection of Valid Occupational Injury and Disease Data

Occupational injuries and disease are often underreported.[78–83] This has been well documented and particularly well described by Azaroff et al,[79] who concluded that "the lack of a comprehensive occupational health data collection system in the United States has led to reliance on piecemeal data sets produced by systems not designed for surveillance. These systems filter out work-related health problems at each step."[79]

Limitations of Burden Statistics

The methodology for determining DALYs and ARs (defined in Table 2) can lead to uneven treatment of different risk factors or may not provide a complete picture of occupational or other environmental risks.[84–86] The definition of DALYs combines information on morbidity and mortality with value choices such as disability weighting, age weighting, and discounting.[84–86] These value choices may lead to an inaccurate portrayal of the true burden of occupational disease and injury because of differential valuation of effects on young workers and failure to account for long-term effects in older workers and retirees.

The standard definitions of attributable fraction of disease, resulting from an exposure, capture only excess cases and not all cases that are etiologically linked by the exposures in question.[87] The extent to which cases are attributable to exposure is time-dependent, with only those cases occurring by some time after exposure being counted as attributable.[87,88] More recent efforts to assess occupational burden have used adjustment by occupational turnover to account for turnover in jobs with exposure to occupational carcinogens or to selected respirable particulates (silica, asbestos, and dust).[89] This approach may allow for a more accurate estimate of the proportion of a population exposed to occupational hazards and may result in better attribution of putative occupational cases if there is a long period between exposure and diagnosis/reporting.

Estimating the population distribution of exposure to various occupational risk factors also is a major challenge.[10] Recent efforts have used the concept of "economically active" populations to characterize the fraction of the population exposed to occupational hazards.[89] This approach allows for a comprehensive accounting of persons who may be exposed to occupational hazards.

The burden of occupational disease and injury is not distributed equally over the population, but rather generally occurs in various sectors or occupations characterized by occupational-specific exposure and risk. For example, although healthcare workers globally are 0.6% of the population, they experience an appreciable proportion of disease from bloodborne pathogens acquired through "sharps" contacts.[11] Worldwide, it has been estimated that approximately 40% of hepatitis C virus and hepatitis B virus infections and 2.5% of HIV infections are attributable to occupational exposure to sharps and needles.[11]

Nature of Occupational Disease

The methods for estimating the proportion of deaths and diseases attributable to occupational exposures are limited by the fact that many diseases have multiple potential causes, including lifestyle factors and a long latency period, that makes it difficult to establish whether the disease is work-related.[79] Moreover, many primary care providers are not trained in occupational medicine and may not recognize a disease as being occupationally related. Therefore, underreporting is likely.[80] There are many issues that make the collection and attribution of occupational disease data difficult. In addition to the multifactorial nature, other factors include difficulty in defining diagnostic criteria, difficulty in relating disease to exposure at the individual level, and difficulty identifying subtle changes in physical function.[90]

Need for an Integrated Approach

It is important for occupational safety and health practitioners to be able to effectively characterize the burden of occupational injury and disease and to have that information accepted and used in the allocation of public- and private-sector resources. There is a need for an integrated approach that brings together investment and activity in two aspects of characterizing burden of occupational injury and disease. These aspects include efforts to 1) obtain and analyze the full range of surveillance and cost data related to occupational exposures and outcomes and 2) identify the extent to which occupational morbidity and mortality is avoidable.

Obtaining and Analyzing Surveillance and Cost Data

To clearly characterize the magnitude and burden of occupational morbidity and mortality, it will be necessary to increase the availability of data and information on which to make those assessments.[91–95] This will require better reporting of the occupational relationship of death, injuries, and illnesses. Clearly, these represent three very different sets of surveillance issues.[96–98] For instance, occupational injury and injury mortality surveillance are much more advanced compared with occupational disease surveillance. Portrayal of burden will also involve more epidemiologic research to provide further evidence of occupational causality and more research to disentangle complex interactions among socioeconomic factors, personal factors, and job-related factors. This is particularly true for multifactorial diseases. There is also a need for better and more current data on hazard exposure and prevalence and cost of illness.[14,95,98–100] Of particular importance is the need to link work history to individual medical records, which may be more feasible with the wide use of electronic health record systems.[80,101] Also, there is a need to assess costs that may be shifted from workers' compensation to Medicare and personal insurance.[48,54] Reville et al have provided guidance on using limited administrative data (such as the Health and Retirement Survey; the Survey of Income and Program Participation; and the National Longitudinal Study of Youth, 1979) to explore earnings and employment consequences of workplace injuries.[102]

Identifying the Extent to Which Occupational Morbidity and Mortality Are Avoidable

The concept of attributable risk is often interpreted as the fraction of disease that can be eliminated if exposure is totally removed. Generally, effective interventions can rarely achieve anything near complete exposure removal, may have untoward side effects, and may affect the size of the population at risk.[103] Nonetheless, much of occupational morbidity and mortality is avoidable if exposures are controlled. For example, the World Health Organization estimates, based on several observational studies, that a 74% reduction in occupational back pain incidence would be obtained from implementation of a full ergonomics program.[11] The World Bank has estimated that up to two thirds of occupationally determined loss of DALYs could be prevented by occupational safety and health programs.[104] Occupational safety and health professionals have long established a hierarchy of controls that progress downward from substitution, through engineering controls, to use of personal protective equipment.[105–107] Clearly, there is strong evidence for the efficacy of controlling occupational hazards, but this has not been described comprehensively in terms of attributable risks, preventive fractions, or other means of comparison.[48] One approach toward this end, described by Park et al,[108] involved assessing years of potential life lost among uranium miners (approximately 86 months for 10 years of underground mining) and comparing it with gains in life expectancy from common medical interventions.[109]

"For example: quitting smoking in 35-year old men is estimated to add 10 months of life from averted heart disease in populations at average risk, or 28 months in populations at high risk; annual fecal occult blood test plus tri-annual x-ray or colonoscopy in 50-year olds adds 2.8 months; chemotherapy in patients with extensive small cell carcinoma of the lung adds about 7 months; implantation of pace-makers in survivors of cardiac arrest with recurrent arrhythmias adds 36–46 months; bone marrow transplant (compared with chemotherapy) in patients with relapse non-Hodgkins lymphoma adds 72 months. The loss of potential years of life from working 10 years in Colorado uranium mines generally greatly exceeds gains resulting from a variety of major medical interventions and preventive strategies, including quitting smoking."[108]

There is an absence of cost-effectiveness statistics for many types of occupational safety and health interventions; therefore, decision-makers have limited information on which to make evidence-based decisions.[110] There is a need to characterize the effectiveness, feasibility, and impact of occupational interventions.[111–113] One area where this type of discussion has occurred involved the development of the Community Guide to Preventive Services: Systematic Reviews and Evidence-Based Recommendations.[114–116] This is a broad effort to develop and disseminate evidence-based public health recommendations for practitioners and decision-makers. To date, some perceive that occupational safety and health has been underemphasized in this process, although as many as 30 to 40 of 171 existing Task Force on Community Preventive Services' findings may be applicable to worksites, albeit focusing on workplace health promotion for the most part. Some of the gaps may be the result of the lack of information about attributable risk and preventive fractions; this is likely to be truer for workplace safety than for worksite health promotion. One positive step would be to address occupational interventions such as those that were identified as topics for consideration in the first volume but not included. These include allergic and irritant dermatitis, asthma and COPD, fertility and pregnancy abnormalities, hearing loss, infectious disease, pneumoconiosis, and low back disorders and injuries.[116] Additional candidates for consideration might arise from the growing body of literature indicating an important role of psychosocial factors at work leading to disease.[22–24,117,118] This particularly has been observed for job strain and cardiovascular disease.[22,23]

Conclusions

As the need increases for stronger evidence on which to base policy choices, it is important for the occupational safety and health community to be able to portray the extensive burden of occupational injury and disease and have that information accepted and used in allocation of public and private sector resources. To achieve this, policymakers, practitioners, and investigators need to champion heightened surveillance, further epidemiologic assessment of causality and the use of comprehensive information in comparative burden assessments. Extensive underreporting, long latencies, and multifactorial influences obfuscate the characterization of the entire burden of occupational disease and injury.

Employers are primarily responsible for providing a safe and healthy workplace, and thus there is a multiplier effect from public investments in occupational safety and health research, information, guidance, and regulation that impacts employers. The relatively small amounts of public funds invested in these efforts set targets and provide guidance for employers to invest in occupational safety and health controls and interventions. This approach has contributed to the reduction of occupational morbidity and mortality in the last 35 years.[119–130]

A hallmark of the occupational safety and health field is the long experience with developing and implementing controls that are effective.[119–130] As Hernberg has noted, ". . . work-related means preventable, and removing the work-related factor, if it is a so-called necessary factor, could reduce incidence of occupational injuries and disease."[131] Demonstrating how workplace interventions enhance public health will help policymakers direct resources appropriately toward where they will have the greatest impact.

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