Review of Estimates of the Global Burden of Injury and Illness Due to Occupational Exposures

Timothy Driscoll, MB BS, PhD,[1,2]* **Jukka Takala,** PhD,[3] **Kyle Steenland,** PhD,[4]
Carlos Corvalan, PhD,[5] and **Marilyn Fingerhut,** PhD[6]

Background *Over the last decade, there have been several attempts to estimate the global burden of ill health due to work activity. The most recent of these is the Comparative Risk Assessment (CRA) project of the World Health Organization.*
Methods *Published estimates of global burden of injury and disease due to occupational factors were summarized, compared, and contrasted with the aim of putting the CRA estimates into context, identifying the most reliable and appropriate estimate for total burden due to occupational risks, and making recommendations regarding future work.*
Results *The best estimate of global work-related deaths of workers is approximately two million per year, with disease responsible for the vast majority of these, but even this is likely to be a considerable underestimate of the true number of deaths because of shortcomings in the available data.*
Conclusions *The CRA estimates of burden due to individual risk factors appear appropriate for the limited number of exposures and conditions included, but are a major underestimate of the overall number of work-related deaths at a global level due to exclusion of risk factors because of data limitations. Improvements in global estimates are likely to come from the use of different methodologies and improvements in the availability and use of local data.* Am. J. Ind. Med. 48:491–502, 2005. © 2005 Wiley-Liss, Inc.

KEY WORDS: occupation; work; deaths; DALYs; global burden

[1]School of Public Health, University of Sydney, New South Wales, Australia
[2]ELMATOM Pty Ltd, Sydney, Australia
[3]ILO, InFocus Programme SafeWork, International Labour Office, ILO,Geneva, Switzerland
[4]Rollins School of Public Health, Emory University, Atlanta, Georgia
[5]Occupational and Environmental Health Unit, Protection of the Human Environment, World Health Organization, Geneva, Switzerland
[6]National Institute for Occupational Safety and Health, Washington, District of Columbia
The views expressed in this article are those of the authors and do not reflect the position of the World Health Organization.
Funded by: WHO.
*Correspondence to: Timothy Driscoll, MB BS, PhD School of Public Health, University of Sydney, New South Wales 2006, Australia. E-mail: timd@health.usyd.edu.au

INTRODUCTION

Estimates of health burden at a population level, whether using a state, national, or global focus, have several important potential benefits. They attract the attention of policy makers and the community by showing the size of the problem. They also provide guidance to policy makers on how to expend limited resources by identifying the major disorders and the exposures resulting in the largest burden.

Over the last decade there has been much research focussed on estimating the global burden of ill health due to various health disorders and due to specific exposures [Leigh et al., 1996; Murray and Lopez, 1996, 1997; Takala, 1999, 2002; Ezzati et al., 2002, 2004; Crowcroft et al., 2003]. Some of this work has included exposures and outcomes related to

work activity. The estimated burden due to work has varied considerably between studies, raising concerns regarding which estimate is the most reliable and/or appropriate to use, and the reasons for the variation. The Comparative Risk Assessment (CRA) project of the World Health Organization (WHO), considered in detail in other studies in this series, provides the most recent of these estimates, although it explicitly excluded some important occupationally related conditions [Ezzati et al., 2002, 2004; Nelson et al., 2005]. This article considers the role these estimates play in global health and safety, the issues and general principles associated with developing such estimates, and the differences and similarities of the methodologies used in the main approaches used to date. The aim is to put the CRA estimates into context, identify the most reliable and appropriate estimate, and to make recommendations regarding future work. The focus of this article is on deaths, for which most information is available, but the principles are relevant to non-fatal disorders. The article begins with a consideration of some general issues that affect estimates of burden due to work and the approaches taken to develop the various estimates. Next, the methodology and results for each of the main estimates are briefly described, compared, and contrasted. Finally, suggestions for further work are provided.

PROBLEMS IN ESTIMATING OCCUPATIONAL BURDEN

Most cases of work-related disease or injury cannot be easily counted. Reasons for this include definitional, identification, and recording issues.

Definition of Work-Relatedness

Work-relatedness is not always a straightforward concept. A reasonable general definition of work-relatedness is an injury or disease that results from a work exposure. This definition requires an assessment of what is meant by work and work exposure, and the required connection between exposure and the disease or injury of interest.

It is commonly clear whether or not someone is employed, but persons in informal work arrangements (e.g., family members on a family-owned farm, children helping out in a family shop, and "unemployed" persons collecting discarded cans for recycling), which are very common in developing countries, must also be considered to be working. The person does not necessarily need to be at work at the time of the harmful exposure. Nor does the disorder need to become manifest while the person is working—for example, many diseases of long latency will not present with symptoms for many years or decades after the causative exposure, by which time the persons may have retired or had several other jobs. The person does not even need to be employed, because persons who are not working (bystan-

ders) can also suffer ill health as a result of work exposures. Distinctions have sometimes been made on the basis of the degree of contribution of work, or whether work "caused" the disorder or just exacerbated it. The key feature of a work-related disorder is that work exposures lead directly to the development of the condition, or to the significant exacerbation of a pre-existing condition.

The context of the work activity is commonly used as the basis for inclusion or exclusion of cases, especially injury cases. For example, work-related injuries of workers are commonly separated into three groups—injuries that occur in traffic incidents on public roads in the course of work (work-road injuries), other injuries that occur in the course of work (workplace injuries), and injuries that occur whilst travelling to or from work (commuting injuries). Workplace and work-road injuries are commonly combined into a single measure of work-related injuries of workers (working injuries).

Recording Cases of Work-related Disorders

Direct information on the number and type of cases of work-related disorders usually comes from government agencies. In developed countries, the most reliable sources for work-related injury are usually workers' compensation databases. The strengths of such databases include that they usually have standardized systems for confirming cases and recording case information. The systems also have several important weaknesses—they usually only cover employees, they may exclude particular industry sectors explicitly (e.g., military personnel) or implicitly (e.g., a large number of agricultural workers are self-employed), and most importantly, they cover disease very poorly because the connection between occupational exposure and disease at an individual level is so hard to establish [Macaskill and Driscoll, 1998].

Other sources of direct information on case numbers are occupational disease registers. These appear to have had some success for specific disorders in the United Kingdom [McDonald et al., 2000] and Australia [Leigh and Driscoll, 2003], but in general they function primarily as sentinel event systems or provide a broad indication of numbers and trends, and only cover a very limited group of disorders.

The aforementioned shortcomings are relevant to data systems in developed countries. The situation for developing countries is typically much worse, with fewer resources available to establish and operate systems, and less-established networks for identifying and reporting cases.

APPROACHES TO ESTIMATING THE NUMBER OF WORK-RELATED CASES

This section considers various approaches that have been used to estimate the burden of work-related disorders, with emphasis on the number of cases, as opposed to the total

burden as measured by disability adjusted life years (DALYs) (discussed in more detail later).

INJURY DEATHS

Counting injury cases should, in theory, be straightforward. The connection between the work exposure and the injury is usually clear and there is no latency involved (this connection is less obvious for injury disorders that develop after cumulative exposure, such as back injuries related to vibration in powered equipment, and upper limb injuries related to repetitive movements). Routine data systems in most developed countries and some developing countries probably give reasonable coverage of severe and fatal injuries for the employees and industry sectors that they do cover (although some underenumeration can be expected, even for deaths [Driscoll et al., 2003; Concha-Barrientos et al., 2005]). Cases recorded by available data systems and reported to the World Health Organization or the International Labor Organization have been used as the basis for estimating the global number of work-related injury and disease cases.

The main problem arises because of the lack of accurate data for many countries, with the resulting requirement to extrapolate from subsets of the workforce or from other countries (considered below). There are also differences in inclusion criteria of injury cases, with some studies or data sources including work-road deaths, some including commuting deaths, and some combining disease data and injury data, and the extent to which these various inclusions occur is often not clear.

Extrapolation of Rates Between Sections of the Workforce

A key problem with relying on reported cases in routine data systems is that they only relate to the proportion of the workforce covered by the data system. However, if the number of workers covered by the system is known, reasonably valid injury rates can be determined for these workers. The number of injuries for the entire workforce can then be estimated by applying the calculated rates for the included workers to the total workforce. This approach has been used in several estimates, and is based on the assumption that the injury rate in the included workforce is similar to the injury rate in the workforce that is not included. In most situations, there will be little or no information to confirm or refute this assumption. However, several factors suggest that rates from routine data sources probably underestimate, and are unlikely to overestimate, injury rates in workforces not so covered. Many people in occupations or industries with high rates of serious and fatal injury (e.g., forestry, fishing, agriculture, and transport [Stout et al., 1996; Driscoll et al., 2001; Feyer et al., 2001]) are self-employed persons who are usually not covered by the routine compensation systems. Even if the routine system is not based on workers' compensation, these industries with high injury rates are commonly not well covered by data systems due to poor reporting and differing system priorities and focus. The effect of this can be decreased to some extent by extrapolating rates on an industry-specific basis, but this is not always possible and may still result in underestimation. In addition, many workers, especially in less-developed countries, are employed in informal or precarious capacities that are inconsistently included in official labor force estimates [Giuffrida et al., 2002]. Therefore, extrapolation of known rates for part of the workforce to the whole workforce is a reasonable approach, but one which is likely to result in an underestimation. The same general issues regarding extrapolation of rates apply to diseases, but to a greater extent, because there is more uncertainty surrounding the known rates, and probably more variation in the causative exposures.

Extrapolation of Rates Between Countries

The same extrapolation approach can be used to estimate work-related injury and disease numbers for countries or regions (a "region" in this context describes a group of countries in the same geographical area) that do not have valid data, by using rates from other countries. However, the concerns just mentioned for extrapolation within a country are magnified when rates from one country or region are extrapolated to the population of another country or region. Variations in employment patterns between countries can be expected. This means that even if the rates within a given at-risk group (e.g., industry or occupation) are the same in the two countries, extrapolation can lead to considerably biased estimates of the overall rates of injury or disease. This makes extrapolating rates on an industry-specific basis particularly important, if possible.

DISEASE DEATHS

Disease deaths present a major theoretical problem, because they are multi-factorial, making it impossible to know if an individual case is attributable to occupation or not. This necessitates an epidemiologic approach, specifically the population attributable risk (PAR) approach. The PAR is the proportion (often expressed as a percentage) of all cases of a particular condition that is due to a particular exposure (or group of exposures). By applying this proportion to the total number of deaths from a particular condition (obtained from the routine health data systems that in most countries reasonably reliably record the cause of death for all persons), the number of deaths from that condition due to that exposure can be estimated. The PAR is dependent only on the relative

risk of developing the condition due to the exposure, and the proportion of the population that has that exposure. Relative risk information is commonly available only from a limited number of epidemiological studies, for exposed versus non-exposed groups, in a limited number of (usually) developed countries. These relative risks must be considered universal in order to make any global estimates, although they are in fact specific to the exposure levels in the studies from which they are derived. Biological differences and co-exposures may influence the absolute exposure-risk relationship between populations, and differing distribution of co-exposures may mean a relative risk measured in a workforce in one circumstance may not be applicable to a different workforce in a different country or region. However, it is reasonable to assume that in many circumstances the relative risk is essentially constant between populations that have similar exposures. If information on a specific country's exposure prevalence is available, then a PAR specific to that country can be estimated. Since the PAR is dependent on the exposure characteristics, the PAR for a particular risk factor may vary considerably between different regions, countries, and time periods.

The PAR enables one to estimate the proportion of cases of disease which would not have occurred in the absence of exposure, based on a counter-factual assumption about what the rate in the exposed would have been had that group not be exposed. The advantages of this approach include that it can take into account local exposures and workforce distribution, and local general health outcome (usually deaths) data. Deaths data is most commonly used because it is likely to be the most reliable local health data. However, there are several disadvantages. The relative risk is dependent on the exposure characteristics of the workforce(s) in which it is measured. These characteristics are often not known to any level of detail. Also, the detailed exposure characteristics of the local population are even less likely to be known. Typically, only general workforce data, based on industry and sometimes occupation, are available.

Exposure prevalence can sometimes be estimated by applying job-exposure information from one area to general employment data from another. For diseases with long latencies, exposure prevalence should be based on persons who have ever been exposed, rather than only those who are currently exposed. The CRA project applied a factor of four to the currently exposed prevalence to derive an estimate of the persons ever exposed for diseases of long latency (see [Nelson et al., 2005]). However, this factor itself was based on several assumptions, particularly related to workforce turnover and disease latency.

An additional problem is that information on exposure intensity is often not available and, if required, will have to be extrapolated from a third data source. Exposure intensity is mainly of importance when estimating future burden (for which exposure intensities would usually be expected to be lower) or when making estimates for countries with widely different exposure intensities and for which different, exposure-specific, relative risks will be used (although, as mentioned earlier, in practice these are often not available).

The end result of the PAR approach may then be the application of a relative risk obtained from one exposure circumstance to the prevalence of a different exposure circumstance.

Morbidity Versus Mortality

Most global estimates have relied on mortality data rather than morbidity data, since the latter are often lacking. However, the use of morbidity data is important, because a number of occupational injuries and diseases are not fatal. The PAR approach can still be used for multi-factorial diseases to estimate the number of incident (morbidity) cases attributable to occupation rather than the number of deaths, but this first requires an estimation of the total number of incident cases. In the absence of existing data on incidence, this can be done using case-fatality ratios. It is difficult to compare the relative burden of non-fatal incident occupational cases across diseases because the PAR and the number of cases for each disease will not really enable a meaningful comparison.

DALYs are an attempt to solve this comparison problem. DALYs are a weighted estimate of the number of years lived with disability. The weighting refers to the severity of the disability. The DALY thus represents the gap between the current situation, and an ideal situation where everyone achieves an agreed standard life expectancy in perfect health. More detail is provided in the introductory article to this series [Nelson et al., 2005] and elsewhere [Murray and Acharya, 1997; Ezzati et al., 2004].

SPECIFIC STUDIES PRODUCING NATIONAL ESTIMATES OF BURDEN DUE TO WORK

National estimates of work-related injury and/or disease have been attempted in many developed countries, including Australia, Canada, Finland, New Zealand, and the United States. Most have counted the number of injury deaths using Coroner's data and used an attributable risk approach to estimate the number of disease deaths. In terms of injury, all included workplace deaths, most included work-road deaths and some included commuting deaths. The distinction between disorders caused by occupational exposures, as opposed to disorders exacerbated by them, was rarely addressed explicitly. The majority of these studies are summarized in Table I.

Although the absolute numbers are not of relevance to a global estimation, it is of interest to note that work-related disease deaths as a percentage of all work-related deaths was

TABLE I. Summary of Work-Related Injury and Disease Death Estimates From the Main Studies Providing National Estimates

Country	Years covered	Injuries[a]	Disease[a]	Total[1]	Percent disease[b]	Reference
Australia	1982–1984	426	—	—	—	Harrison et al. [1989]
Australia	1989–1992	447	—	—	—	Driscoll et al. [2001]
Australia	1992	—	2,290	—	—	Morrell et al. [1998]
Australia	1992	393	2,290	2,683	85	Combining Driscoll et al. [2001]; Morrell et al. [1998]
Canada	1989	869	4,195	5,064	83	Kraut [1994]
Finland	1996	82	1,728	1,810	96	Nurminen and Karjalainen [2001]
New Zealand	1999	91	886	977	91	Driscoll et al. [2004]
United States	1992	6,529	60,290	66,819	90	Leigh et al. [1997]
United States	1997	6,238	49,016	55,254	89	Steenland et al. [2003]

[a]Deaths per year.
[b]Number of work-related disease deaths as a percentage of total work-related deaths.

similar in all the estimates, ranging from 83%–96%. The commuting data are not presented in Table I, but for those countries where these data were available, commuting deaths comprised 14% (New Zealand-[Feyer et al., 2001; Langley et al., 2003; Driscoll et al., 2004]) to 26% (Australia-[Driscoll et al., 2001]) of all injury deaths.

SPECIFIC STUDIES PRODUCING GLOBAL ESTIMATES

This section summarizes the methodology and results of the main global estimates of work-related injury and disease published in the last decade. Tables II–V provide comparisons of the approaches used and the results reported.

Preliminary World Health Organization Estimates of Occupational Burden

In preparation for the original WHO global burden project to estimate burden of disease and injury due to many factors, Leigh et al. [1996, 1999] estimated the global burden of fatal injury and disease using data published up to 1994. They estimated there were 141,813 injury deaths and 583,700–704,200 disease deaths each year (centered on 1990). For injuries, they used data on compensable fatal injury deaths as reported from a limited group of countries. Where data were not available, rates from similar countries were applied to available employment data. This extrapolation was done at a national level, rather than using industry-specific rates. A different approach was used for India, for which a local survey and an extrapolation using Malaysian rates were used to produce the final estimate. For occupational disease, information was obtained from single reports or studies. Rates were estimated for countries without adequate data on occupational disease by applying overall disease rates from appropriate national or averaged data of countries or groups of countries closest in geography and economic development to employment data from the relevant country. A range rather than a single number was estimated for some countries.

Adjusted World Health Organization Estimates of Occupational Burden

The results of the Leigh and co-workers' study [Leigh et al., 1996, 1999] were included in the formal Global Burden of Disease project. Adjustments were made to take into account differences in methodology in the approach used by Leigh and coworkers compared to the standard Global Burden of Disease methodology, producing a final estimate of 1,129,000 deaths from injury and disease. The authors stated that this probably underestimated the impact of occupation for most developing countries [Murray and Lopez, 1996].

International Labor Organization Global Estimates of Fatal Occupational Accidents

Takala [1998, 1999] estimated 335,000 deaths from "occupational accidents" in 1996. This estimate was obtained by applying reported fatal injury rates for each country to the total employed labor force for that country (as described earlier). Where rates were not available for a country, rates from "similar or comparable" countries were applied to employment data for the particular country. National death rates were applied rather than industry-specific rates. Deaths data came from various years between 1985 and 1995. Data from some countries included reported/recorded commuting deaths and/or disease deaths, but most did not. The extent to which work-road fatalities were included in the data is unclear. Another 158,000 commuting deaths were estimated

TABLE II. Methodology of Studies Providing Global Estimates of Work-Related Injury and/or Disease

Reference	Years covered	Source of outcome data	Approach	Age-range	Comment
Leigh et al. [1996, 1999]	Latest available data up to 1994; centered on 1990	Injury: compulsory accident reporting and workers' compensation schemes Disease: specific reports or studies Denominator: ILO and World Bank	Injury: counts where reported; extrapolation of rates from similar countries to available employment data from the relevant country Disease: number/rates where available; extrapolation of rates from similar countries to available employment data from the relevant country	No specific range, but probably 15+	No allowance for combined injury and disease reporting
Murray and Lopez [1996]	1990	Same as Leigh et al. [1996, 1999]	Same as Leigh et al. [1996, 1999], with some adjustments to maximize validity of comparisons with other exposures		Based on Leigh et al. [1996, 1999]
Takala [1999, 2000]	1996	Injury: accident reporting schemes in each country Disease: based on denominator data Denominator: ILO, United Nations, GBD	Injury: reported rates, applied to total working population Disease: extrapolation of Finnish data showing ratio of fatal "occupational accidents" to fatal "occupational diseases" of 51:49		"Work-related diseases" were seen as additional to "occupational diseases," with the results based on a Danish estimate of 10% of these deaths being work-related
Takala [2000]	1998	Injury: accident reporting schemes in each country Disease: GBD, 1996 Denominator: ILO, United Nations, GBD	Injury: Reported rates, applied to total working population. Disease: PARs from United States	"Working age"	
Hamalainen et al. [2004]; Takala [2002]	2000	Global Burden of Disease 1996	Injury: reported rates, applied to total working population Disease: PARs from Finland, applied to age-sex groups	"Working age"[a]	
CRA; Concha-Barrientos et al. [2004]; Nelson et al. [2005]	2000	Global Burden of Disease 2000	Injury: Direct application of rates from countries with available data and extrapolation of these to other countries that did not have adequate data Disease: PARs based on relative risks from literature; direct application of absolute risks from literature	15–85 years	Only included a limited number of diseases

[a]15–70 years for communicable disease and digestive systems disease; 15–75 years for circulatory system disease; 15 years and above for other diseases.

496

TABLE III. Work-Related Injury Death Estimates From the Main Studies Providing Global Estimates

Reference	Working	Commuting	Total	Comment
Leigh et al. [1996, 1999]	141,813	—	—	Probably includes some, but not all, commuting deaths
Takala [1999, 2000]	334,870	158,000	493,000	Commuting data estimated on the basis of ratios of working to commuting deaths in Finland
Hamalainen et al. [2004]; Takala [2002]	354,753	—	—	Probably includes a small number of commuting deaths
CRA, Concha-Barrientos et al. [2004]; Nelson et al. [2005]	312,000	—	—	Excludes commuting

to have occurred, based on a ratio of workplace and work-road deaths to commuting deaths of 68%: 32% from a Finnish study.

The number of disease deaths was indirectly estimated on the basis of the number of injuries. Finnish data provided a ratio of fatal injuries to fatal disease of 51%: 49%. Using this result and the above estimate of 335,000 injury deaths, Takala [1999] estimated there were 325,000 disease deaths. This gave a total of 660,000 work-related deaths due to workplace injury, work-road injury and disease, or 818,000 if commuting injury is included. He also mentioned an estimate of an additional 626,000 deaths from ''work-related'' diseases (defined as ''only partially work-related'') based on 10% of all such conditions. This would give a final estimate of 1,286,000 working injury and disease deaths, or 1,444,000 deaths if commuting is included.

Initial International Labor Organization Global Estimates of Occupational Deaths Due to Injury and Disease

Takala [2000] used the same estimates of working injury deaths as in his 1999 study, but used an attributable risk approach to estimate disease deaths. Using the same PARs as a 1997 United States study [Leigh et al., 1997] and applying

these to the world population of working age, Takala estimated 992,445 deaths from occupational disease.

Recent International Labor Organization Global Estimates of Occupational Deaths Due to Injury and Disease

In his most recent estimates, Takala [2002] (also working with Hamalainen and other colleagues) again used the attributable risk approach to estimate occupational disease deaths, but this time applied on a regional rather than a global basis. Attributable fractions were taken from the Finnish study by Nurminen and Karjalainen [2001], with some minor modifications to take account of particular conditions and regions. These PARs were applied to overall disease death estimates by age and sex for the year 2000 from the Global Burden of Disease project [Murray and Lopez, 1996]. This resulted in an estimate of 1.9 million deaths from occupational disease. The main reason this estimate was so much higher than previous disease estimates was that it included communicable diseases such as schistosomiasis, malaria, and viral and bacterial infections (320,000 estimated deaths), two and a half times more cardiovascular disease deaths and 50% more cancer deaths, although only half as

TABLE IV. Work-Related Disease Death Estimates From Main Studies Providing Global Estimates

Reference	Communicable	Malignancy	Respiratory	Circulatory	Neuropsych	Digestive	Genito-urinary	Total
Leigh et al. [1996, 1999][a]	—	—	—	—	—	—	—	583,700–704,200
Takala [1999][b]	—	—	—	—	—	—	—	325,000
Takala [1999][c]	—	—	—	—	—	—	—	951,000
Takala [2000]	—	456,240	311,000	200,025	12,080	—	13,100	992,445
Hamalainen et al. [2004]; Takala [2002]	320,471	609,678	146,175	519,255	20,341	22,566	8,478	1,646,965
CRA; Concha-Barrientos et al. [2004]; Nelson et al. [2005]	—	152,000	386,000	—	—	—	—	538,000

[a]There was no information on deaths from specific diseases.
[b]Based on the injury estimate, and extrapolation of Finnish data showing ratio of fatal "occupational accidents" to fatal "occupational diseases" of 51:49.
[c]Based on the same estimate identified in footnote b, plus an estimate for "work-related" disease deaths (defined by the author as "diseases that are only partly work-related") from Denmark of 10% of all deaths from the particular conditions.

TABLE V. Total Work-Related Death Estimates From Studies Providing Global Estimates

Reference	Injury	Disease	Total	Percentage of disease[a]
Leigh et al. [1996, 1999]	141,813	583,700–704,200	725,513–846,013	81–83
Murray and Lopez [1996]			1,129,000	
Takala [1999][b]	334,870	325,000	659,870	49
Takala [1999][c]	334,870	951,000	1,285,870	74
Takala [2000]	334,870	992,445	1,327,315	75
Hamalainen et al. [2004]; Takala [2002]	354,753	1,646,965	2,001,718	82
CRA; Concha-Barrientos et al. [2004]; Nelson et al. [2005]	312,000	538,000	850,000	63

[a]Number of work-related disease deaths as a percentage of total work-related deaths.
[b]Based on the injury estimate, and extrapolation of Finnish data showing ratio of fatal "occupational accidents" to fatal "occupational diseases" of 51:49. If estimated commuting deaths are included, the injury total is 463,000, and the injury and disease total 818,000.
[c]Based on the same estimate identified in footnote b, plus an estimate for "work-related" disease deaths (defined by the author as "diseases that are only partly work-related") from Denmark of 10% of all deaths from the particular conditions. If estimated commuting deaths are included, the injury total is 463,000, and the injury and disease total 1,444,000.

many respiratory deaths were included compared to Takala's 2000 estimates [Takala, 2000]. There were also a higher number of cancers because older workers were included and some of the PARs were different to those used previously.

The study included an estimate for the number of injury deaths (355,000). This estimate was based on data on the number of injury deaths obtained directly from countries where available. Rates from selected countries were used for each region, and account taken of underinclusion of sections of the workforce in official statistics from which the original data were obtained.

Lower and upper limits for the overall estimates were provided, but the range was fairly small for all diseases except communicable disease. The final range of the estimate was 1,920,086–2,328,934 deaths [Takala, 2002; Hamalainen et al., 2004].

World Health Organization Comparative Risk Assessment Project to Estimate Global Burden of Disease Due to Many Risk Factors

The most recent estimate of global occupational deaths comes from the CRA project. This work was conducted as part of the World Health Organization's Global Burden of Disease project, in which comparable global risk and exposure data were put into a common model to estimate the burden of ill health arising from 26 risk factors grouped into 7 major categories [Ezzati et al., 2004]. Five occupational risk factors were included—all other occupational risks had to be excluded due to inadequate available data. The specific occupational risk factors included were occupational carcinogens, airborne exposures, noise, ergonomic stressors, and

exposures leading to injury. The occupational results are summarized in a companion article by Nelson et al. [2005] and reported in more detail in the occupational chapter in the WHO CRA publication [Concha-Barrientos et al., 2004] and individual articles included in this issue. Only occupational carcinogens, airborne exposures, and risk factors for injury contributed to the estimated annual 850,000 deaths from occupational exposures. Injuries (312,000) were estimated by using rates from countries with available data and extrapolating these to other countries that did not have adequate data. The rates included work-road deaths but not commuting deaths. Most disease deaths were estimated using a PAR approach. Relative risk was estimated from relevant epidemiological studies, and exposure prevalence and intensity were estimated from a combination of national or regional employment data and exposure data extrapolated from specific countries or regions. Deaths from mesothelioma, asbestosis, silicosis, and coal workers' pneumoconiosis were estimated by applying absolute mortality rates from the literature to estimates of cumulative exposure.

COMPARISON OF ESTIMATES

Injury

Occupational injury estimates vary from about 140,000 [Leigh et al., 1996, 1999] to nearly 500,000 [Takala, 1999]. If commuting deaths are excluded (to the extent the data allow), the range is from 140,000 [Leigh et al., 1996, 1999] to 355,000 [Takala, 2002; Hamalainen et al., 2004]. The methodology used to derive all of the larger estimates was similar and appears sounder than the lower estimates because it was based more directly on national rates. The main

problems with the estimates are a widespread lack of data, the "contamination" of injury data by the inclusion of some diseases cases in some countries, and the inconsistent inclusion of homicides, suicides, and commuting deaths. The WHO CRA estimate of 312,000 is close to the other larger estimates. The study suggests that this figure underestimates the true number of deaths by about 80,000 deaths, because of undercounting in developing countries [Concha-Barrientos et al., 2005]. It is likely that additional underestimation arose from the more indirect approach that was used.

In summary, the best estimate of the annual number of fatal injury deaths of workers is about 350,000. This includes workplace and work-road deaths, but largely excludes commuting deaths, for which there are no soundly-based estimates. There are no global or regional estimates of bystander injury deaths.

Disease

Disease estimates vary from 325,000 [Takala, 1999, 1998] to 1.6 million [Takala, 2002; Hamalainen et al., 2004]. A variety of methodologies have been used because of the major shortcomings in available data, even in developed countries, for most exposure-disease relationships. The most recent estimate from Takala [2002] and Hamalainen et al. [2004] seems the most comprehensive and the methodology on which it is based appears reasonable. The WHO CRA project probably used a better method for estimating disease deaths because it used region-specific attributable fractions, taking into account exposure prevalence and, to a limited extent, exposure intensity. However, these regional exposure estimates were partially based on non-regional data, and the CRA project only included a very limited number of conditions. In particular, communicable and circulatory diseases were excluded. The inclusion of only three malignancies (lung cancer, leukemia, and malignant mesothelioma) in the CRA project probably explains the vast difference between the CRA and the most recent other estimates.

In contrast, the recent estimate from Takala [2002] and Hamalainen et al. [2004] for non-malignant respiratory disease was less than 50% that of the CRA, and also less than 50% of his previous estimate. The difference presumably arises because of the different attributable fractions used—the earlier estimate of Takala [2002] was based on United States' attributable fractions [Leigh et al., 1997], whereas the more recent estimates were based on Finnish attributable fractions [Nurminen and Karjalainen, 2001].

Taking into account the inclusions and exclusions and methodologies of the different studies considered above, the best estimate of the annual number of occupational disease deaths of workers is about 1.6 million, based on the most recent ILO study. There are no estimates at national, regional, or global level of disease deaths of non-workers arising from occupational exposures.

Total Deaths

Combining the injury and disease results, the best estimate of the annual number of deaths of workers arising from occupational exposures is about two million, comprised of about 350,000 injury deaths and about 1.65 million disease deaths. This estimate does not include injury deaths of commuters and relates to the beginning of the 21st century (2000 to 2005). The CRA estimate of 850,000 deaths each year is a major underestimate of the total, as noted by the CRA authors due to exclusion of many occupational risk factors, but the CRA effort probably makes only a small underestimate for the limited range of occupational risk factors and outcomes that were included in the project. There are no estimates of total deaths of non-workers due to occupational exposures.

The number of work-related disease deaths as a proportion or percentage of all work-related deaths was considerably lower in the global estimates than in the country-specific estimates (Tables I, IV), with a range of 49%–82% for global estimates, compared to 83%–96% in national estimates. It is probably reasonable to accept the national estimates as being more accurate than the global estimates, given the larger data uncertainties involved at a global level. This suggests that the global analyses are either underestimating disease deaths or over-estimating injury deaths, with the former more likely, and that the larger, more recent global estimates are more accurate than the earlier estimates.

DALYs

This comparison has not focused on DALYs because these are only available from the two studies related to the Global Burden of Disease project [Murray and Lopez, 1996, 1997; Concha-Barrientos et al., 2004; Nelson et al., 2005]. The absolute number of DALYs is probably of less importance than the percentage of all DALYs due to occupational exposures. This was estimated to be 2.7% in 1990 [Murray and Lopez, 1996, 1997] and in the CRA project to be about 1.7% in 2000. Note that these DALY estimates include non-fatal conditions, which have not been considered in the earlier discussion. The above analysis makes it clear that the CRA is a major underestimate of the extent of work-related mortality because of the limitations in the number of risk factors and outcomes that could be included. The 1990 Global Burden of Disease study also appears to have been a significant underestimate of the true burden of occupational injury and disease, based on the methodology used and the authors' comments, as mentioned earlier. Although the analysis only considered mortality, it is very likely that morbidity is also underestimated significantly. The above "best estimate" of about two million deaths (not including commuters) each year from work-related injury and disease is approximately twice the 1990 Global Burden of Disease

estimate of 1.1 million and the 2000 CRA estimate of 850,000. Therefore, the true extent of the global burden of disease resulting from occupational risk factors is likely to have been considerably more than 2.7% in 1990 and 1.7% in 2000, and probably should be increased at least by a factor of two. However, the true burden is difficult to assess.

SOURCES OF BIAS

These estimates are subject to many potential biases, involving exposure assessment, risk measures, outcome assessment, and population at risk. All the significant relevant biases are likely to result in an underestimation of injury and disease cases.

Where absolute measures of exposure are used in these estimates, developed countries are usually the primary source of exposure information for developing countries. However, for the same work task or process, exposures can be expected to be higher in developing countries than in developed countries. Therefore, this approach is likely to underestimate exposures in developed countries, leading to an underestimate of risk and hence to an underestimate of the resulting burden.

Measures of absolute risk for injury mostly came from data systems based on workers' compensation claims or official reports of serious occupational incidents. Since these systems usually have limited coverage of many high-risk industries and occupations such as farming, fishing, forestry, and transport, injury rates from these systems are likely to underestimate overall injury rates. There is inconsistent inclusion of work-related homicide cases, which should be included in any estimate of fatal work-related injury. Also, work-related suicide is sometimes included in compensation data, but uncommonly included in most estimates. Bystander cases are not included in any of the global estimates, presumably because of a lack of appropriate data. Information on bystander injury deaths is available from a limited number of national studies. The number of workplace bystander deaths was about one-quarter of the number of workplace deaths of workers in Australia [Driscoll, 2003] and about 10% in New Zealand [Feyer et al., 2001]. In Australia the number of road bystander deaths (non-working persons killed in motor vehicle incidents on public roads in which the working vehicle was ''at fault'') (477) was similar to the number of work-road deaths (543) [Mitchell et al., 2004]. This gives some idea of the scope of the problem of bystander injury. There is no information available on the extent of bystander disease.

The difficulty recognizing or substantiating an exposure-disease association almost certainly leads to gross underestimation of work-related disease cases by routine reporting systems. Use of an attributable risk methodology can overcome this problem to some extent. However, this requires knowledge of a general connection between a specific ex-

posure and a specific outcome, exposure information, and risk data describing the exposure-risk relationship. One or more of these aspects are commonly not known, resulting in an underestimation of disease cases.

The population at risk is usually obtained from official labor sources. These often do not include workers in the informal sector or child workers. In addition, many estimates use an upper age limit for certain disorders. This may be appropriate for disorders with short latencies, such as most injuries and many communicable diseases, but it has also been used for some longer latency diseases, most notably circulatory disorders, and the appropriateness of this is arguable.

FURTHER WORK

It is important that estimates be as accurate as possible so that resources are most appropriately allocated. Competition between different health areas, each attempting to maximize the measured health burden in their area in order to attract maximal resources from a finite resource pool, can undermine the accuracy of individual estimates and comparison between health areas. This highlights the importance of comparisons based on similar assumptions and similar inclusion/exclusion criteria. The Global Burden of Disease project is an attempt to develop health burden estimates on such an equitable basis. However, such standardization can also restrict the methodologies available for analysis of a specific area, serving to decrease rather than increase the validity of the resulting estimates. This was particularly evident in the CRA analysis for occupational exposures. The attributable risk approach was used for most exposures in the CRA and was applied well for the limited number of carcinogens and cancer types, and the limited number of atmospheric exposures and resulting respiratory conditions, that were included, but the overall disease estimates were much too low because so many exposures and outcomes had to be excluded. Missing or poor data was the major underlying reason for exclusion, but this was because of the need to use the standardized approach, which did not facilitate the use of other approaches that could have better dealt with such data problems.

Another reason why standardized approaches might not always be appropriate is that when there is such uncertainty in the data, there is value in developing estimates using a variety of methods and assumptions in an attempt to ''triangulate'' results. It is unlikely that the same bias will affect estimates derived using different methodologies, so if the resulting estimates are similar, more confidence can be placed in the results. Conversely, if different approaches produce very different results, this indicates considerable problems with one or more of the approaches, providing a focus for examination of the potential baises, how they might be operating and how they might be overcome. Therefore,

future work could usefully focus on the development of varying methodologies and assumptions to arrive at regional or global estimates.

In terms of the approaches used to date, improvements in injury estimates are likely to come from more country-specific outcome data; clearer delineation of the type of cases included (particularly by excluding disease cases, separately identifying commuting cases, including homicide cases, and deciding whether to include or exclude suicide cases); better estimates of the true population at risk by including child workers and workers in the informal sector; and inclusion of bystanders.

Improvements in disease estimates will probably arise in the first instance from the use of better country or region-specific exposure data, allowing more appropriate PARs to be used, and improved relative risk estimates for cardiovascular, malignant, respiratory, and communicable diseases. Estimates of bystander deaths would also be an appropriate, but methodologically difficult, inclusion.

This analysis has focused on deaths rather than DALYs. DALYs have the advantage of incorporating information on disability as well as death, and so aim to provide a more complete estimate of community burden [Murray and Acharya, 1997]. However, DALYs are not intuitive, are subject to subjectivity in the weightings and have some other shortcomings [Anand and Hanson, 1997]. Most importantly, some of the available studies included only deaths. It should also be noted that information on global burden, whether measured by deaths or DALYs, has limitations because it does not provide information on the cost-effectiveness of various interventions. This information is required if prevention activity is to be targeted as appropriately as possible, but information on the number of deaths makes an important contribution to awareness raising, monitoring, and to initial prioritization of resources. Included in this issue are several articles evaluating the cost-effectiveness of occupational interventions.

CONCLUSION

In the last decade there have been several studies to estimate the number of deaths at a global level arising from work-related exposures. The more recent, larger estimates have used better methodology and are probably more accurate. The WHO CRA estimates appear appropriate for the limited number of occupational exposures and conditions included, but are a major underestimate of the overall number of work-related deaths at a global level. The best estimate of global work-related deaths is approximately two million per year, with disease responsible for the vast majority of these, but even this is likely to be a considerable underestimate of the true number of deaths because of shortcomings in the available data. No reliable global estimates of bystander deaths are available. Improvements in the estimates are likely to come from the use of different methodologies and improvements in the availability and use of local data.

ACKNOWLEDGMENTS

REFERENCES

Anand S, Hanson K. 1997. Disability-adjusted life years: A critical review. J Health Econ 16:685–702.

Concha-Barrientos M, Nelson D, Driscoll T, Steenland N, Punnett L, Fingerhut M, Prüss-Ustün A, Corvalan C, Leigh J, Punnett L, Tak S. 2004. Selected occupational risk factors. In: Ezzati M, Lopez A, Rodgers A, Murray C, editors. Comparative quantification of health risks: Global and regional burden of disease attributable to selected major risk factors. Geneva: World Health Organization. p 1651–1802.

Concha-Barrientos M, Nelson D, Fingerhut M, Driscoll T, Leigh J. 2005. The global burden due to occupational injury. Am J Ind Med 48:470–481 (this issue).

Crowcroft N, Stein C, Duclos P, Birmingham M. 2003. How best to estimate the global burden of pertussis? Lancet Infect Dis 3:413–418.

Driscoll T. 2003. The epidemiology of work-related fatal injury in Australia: University of Sydney.

Driscoll T, Mitchell R, Mandryk J, Healey S, Hendrie A, Hull B. 2001. Work-related fatalities in Australia, 1989 to 1992: An overview. J Occ Health Saf—Aust N Z 17:45–66.

Driscoll T, Mitchell R, Mandryk J, Healey S, Hendrie A, Hull B. 2003. Coverage of work-related fatalities in Australia by compensation and occupational health and safety agencies. Occup Environ Med 60:195–200.

Driscoll T, Mannetje A, Dryson E, Feyer A-M, Gander P, McCracken S, Pearce N, Wagstaffe M. 2004. The burden of occupational disease and injury in New Zealand. Wellington: NOHSAC.

Ezzati M, Lopez A, Rodgers A, VanDer Hoorn S, Murray C, Comparative Risk Assessment Collaborating Group. 2002. Selected major risk factors and global and regional burden of disease. Lancet 360:1347–1960.

Ezzati M, Lopez A, Rodgers A, Murray C. 2004. Comparative quantification of health risks: Global and regional burden of disease attributable to selected major risk factors Geneva: World Health Organization.

Feyer A-M, Langley J, Howard M, Horsburgh S, Wright C, Alsop J, Cryer C. 2001. The work-related fatal injury study: Numbers, rates and trends of work-related fatal injuries in New Zealand 1985–1994. NZ Med J 114:6–10.

Giuffrida A, Iunes R, Savedoff W. 2002. Occupational risks in Latin America and the Carribean: Economic and health dimensions. Health Policy Plan 17:235–246.

Hamalainen P, Takala J, Hellsten A, Saarela K. 2004. Global estimates of occupational accidents and work-related diseases Tampere: ILO.

Harrison J, Frommer M, Ruck E, Blyth F. 1989. Deaths as a result of work-related injury in Australia, 1982–1984. Med J Aust 150:118–125.

Kraut A. 1994. Estimates of the extent of morbidity and mortality due to occupational diseases in Canada. Am J Ind Med 25:267–278.

Langley J, Feyer A-M, McNoe B. 2003. Work-related fatal traffic injuries in New Zealand 1985–1998 Dunedin: Injury Prevention Research Unit, New Zealand Environmental and Occupational Health Research Centre.

Leigh J, Driscoll T. 2003. Malignant mesothelioma in Australia, 1945–2002. Int J Occup Environ Health 9:206–217.

Leigh J, Macaskill P, Corvalan C, Kuosma E, Mandryk J. 1996. Global burden of disease and injury due to occupational factors Geneva: Office of Global and Integrated Environmental Health, World Health Organisation.

Leigh J, Markowitz S, Fahs M, Shin C, Landrigan P. 1997. Occupational injury and illness in the United States. Arch Intern Med 157:1557–1568.

Leigh J, Macaskill P, Kuosma E, Mandryk J. 1999. Global burden of disease and injury due to occupational factors. Epidemiology 10:626–631.

Macaskill P, Driscoll T. 1998. National occupational injury statistics: What can the data tell us? In: Feyer A-M, Williamson A, editors. Occupational injury: Risk, prevention and intervention. London: Taylor and Francis. p 5–14.

McDonald J, Keynes H, Meredith S. 2000. Reported incidence of occupational asthma in the United Kingdom, 1989–97. Occup Environ Med 57:823–829.

Mitchell R, Driscoll T, Healey S. 2004. Work-related road fatalities in Australia. Accid Anal Prev 36:851–860.

Morrell S, Kerr C, Driscoll T, Taylor R, Salkeld G, Corbett S. 1998. Best estimate of the magnitude of mortality due to occupational exposure to hazardous substances. Occup Environ Med 55:634–641.

Murray C, Acharya A. 1997. Understanding DALYs. J Health Econ 16:703–730.

Murray C, Lopez A. 1996. The global burden of disease: A comprehensive assessment of mortality and disability from disease, injuries, and risk factors in 1990 and projected to 2020. 1st edn. Cambridge: Harvard University Press.

Murray C, Lopez A. 1997. Mortality by cause for eight regions of the world: Global Burden of Disease Study. Lancet 349:1269–1276.

Nelson D, Concha-Barrientos M, Driscoll T, Steenland N, Fingerhut M, Prüss-Üstün A, Corvalan C, Leigh J. 2005. The global burden of selected occupational disease and injury risks: Methodology and Summary. Am J Ind Med 48:400-418.

Nurminen M, Karjalainen A. 2001. Epidemiologic estimate of the proportion of fatalities related to occupational factors in Finland. Scand J Work Environ Health 27:161–213.

Steenland K, Burnett C, Lalich N, Ward E, Hurrell J. 2003. Dying for work: The magnitude of US mortality from selected causes of death associated with occupation. Am J Ind Med 43:461–482.

Stout N, Jenkins L, Pizatella T. 1996. Occupational injury mortality rates in the United States: Changes from 1980 to 1989. Am J Public Health 86:73–77.

Takala J. 1998. Global estimates of fatal occupational accidents. Sixteenth International Conference of Labour Statisticians Geneva: ILO, p 29–39.

Takala J. 1999. Global estimates of fatal occupational accidents. Epidemiology 10:640–646.

Takala J. 2000. Indicators of death, disability and disease at work. Safework. The Global programme on Safety, Health and the Environment. Asian-Pacific Newsletter.

Takala J. 2002. Introductory report: Decent work—safe work. XVIth World Congress on Safety and Health at Work Vienna: ILO.