

## Measuring the Population Burden of Fatal and Nonfatal Injury

Suzanne Polinder\*, Juanita A. Haagsma, Ronan A. Lyons, Belinda J. Gabbe, Shanthi Ameratunga, Colin Cryer, Sarah Derrett, James E. Harrison, Maria Segui-Gomez, and Ed F. van Beek

\* Correspondence to Dr. Suzanne Polinder, Department of Public Health, Erasmus MC University Medical Center Rotterdam, P.O. Box 1738, 3000 DR Rotterdam, The Netherlands (e-mail: s.polinder@erasmusmc.nl).

Accepted for publication August 23, 2011.

The value of measuring the population burden of fatal and nonfatal injury is well established. Population health metrics are important for assessing health status and health-related quality of life after injury and for integrating mortality, disability, and quality-of-life consequences. A frequently used population health metric is the disability-adjusted life-year. This metric was launched in 1996 in the original Global Burden of Disease and Injury study and has been widely adopted by countries and health development agencies alike to identify the relative magnitude of different health problems. Apart from its obvious advantages and wide adherence, a number of challenges are encountered when the disability-adjusted life-year is applied to injuries. Validation of disability-adjusted life-year estimates for injury has been largely absent. This paper provides an overview of methods and existing knowledge regarding the population burden of injury measurement. The review of studies that measured burden of injury shows that estimates of the population burden remain uncertain because of a weak epidemiologic foundation; limited information on incidence, outcomes, and duration of disability; and a range of methodological problems, including definition and selection of incident and fatal cases, choices in selection of assessment instruments and timings of use for nonfatal injury outcomes, and the underlying concepts of valuation of disability. Recommendations are given for methodological refinements to improve the validity and comparability of future burden of injury studies.

disability evaluation; health status; quality of life; wounds and injuries

Abbreviations: DALY, disability-adjusted life-year; EQ-5D, EuroQoL-5 dimensions; HRQoL, health-related quality of life. ICD, *International Classification of Diseases*.

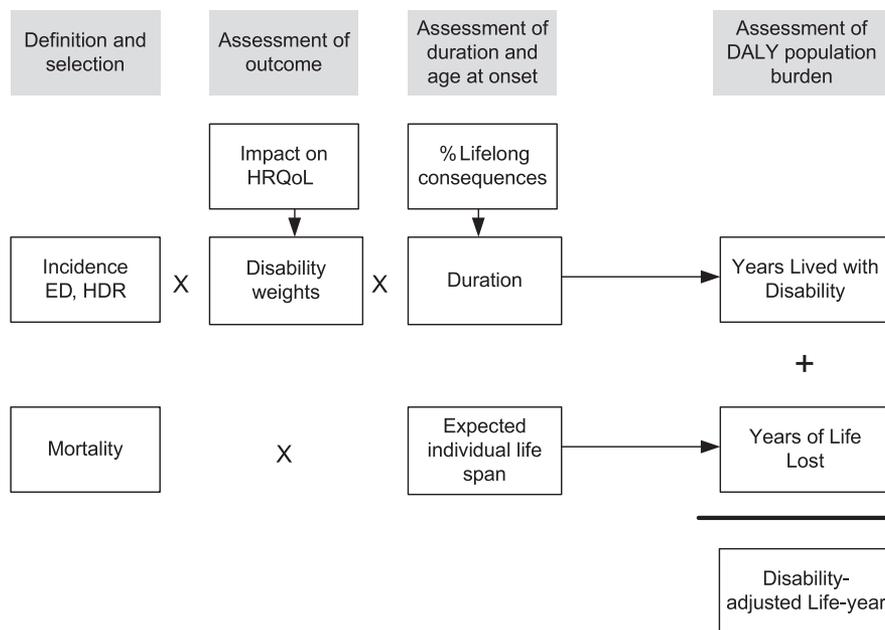
### INTRODUCTION

The value of epidemiologic analyses of the population burden of injuries was clearly demonstrated in the late 1940s by John Gordon, one of the pioneers of scientific approaches to the injury problem (1). Gordon suggested that gains in the prevention of injury could be made by approaching injury in the same manner as the prevention of other mass diseases, and he advocated the use of data to quantify the injury problem, establish causative factors, guide development of preventive measures, and enable periodic evaluation of the effectiveness of instituted prevention programs (1). Since then, a variety of metrics have been developed and used to quantify the impact of injuries on a population's health (2).

For many decades, injury epidemiologists relied largely on mortality figures (3). However, Segui-Gomez and MacKenzie

(2) convincingly argued that documenting the burden of injury should extend beyond counting deaths. Their paper provided an overview of the evolution of metrics assessing the burden of 1) fatal injuries, 2) nonfatal injuries, and 3) integrated measures of fatal and nonfatal consequences of injuries. These authors stressed the importance of metrics to assess health and health-related quality of life (HRQoL) specifically after injury and to integrate mortality, disability, and quality-of-life consequences.

A frequently used measure for integrating the fatal and nonfatal consequences of diseases and injuries, only touched upon in the aforementioned review (2), is the disability-adjusted life-year (DALY) (4, 5). The DALY quantifies the burden of disease by aggregating mortality and morbidity-related disability into a single figure (6, 7). Chandran et al. (8) found that the standardized rate of DALYs in low- and middle-income



**Figure 1.** Conceptual framework for assessment and valuation of fatal and nonfatal injury outcomes. DALY, disability-adjusted life-year; ED, emergency department; HDR, hospital discharge register; HRQoL, health-related quality of life.

countries was more than triple the rate in high-income countries, whereas the difference in mortality rates was only 2-fold.

Despite inherent advantages and wide acceptance (5, 9), the DALY approach, as applied in the Global Burden of Disease study, has several important methodological limitations (10–12) that may affect estimates of the burden of injury. In addition, there is a considerable lack of attention to validating the burden of injury estimates produced by the DALY metric and the Global Burden of Disease approach (13).

Given the influence of burden of disease estimates on priority setting and resource allocation (14, 15), it is important that valid methods be used to estimate injury burden. This review focuses on the specific methodological choices necessary to calculate injury-related DALYs. The purpose is to provide an overview of state-of-the-art methods and existing knowledge regarding the integrated consequences of fatal and nonfatal injuries at the population level. It describes the DALY concept, reviews studies that have calculated DALYs for injury patients, discusses problems in applying DALYs within the injury field, and recommends future methodological refinements.

## THE DALY CONCEPT

Two major types of “summary measures of population health” are quality-adjusted life-years and DALYs (7, 14). Gold et al. (7) provide an overview of the similarities and differences between quality-adjusted life-years and DALYs. Quality-adjusted life-years provide the denominator in cost-effectiveness analyses (7, 16), whereas DALYs quantify the burden of disease and disability in populations. The focus of this review is on DALYs in relation to the burden of injury.

The DALY concept was developed by Murray and Lopez et al. and was subsequently used in the 1996 Global Burden of Disease study (5, 9, 17). The DALY measures the burden of disease (total health loss at the population level) into a single index by summarizing 1) years of life lost and 2) years lived with disability (6, 7). Years of life lost represents loss through premature mortality and is calculated by multiplying the number of fatal cases by the expected individual life span (number of future years the fatal injury victim would have been expected to live had he or she not died of injury). Years lived with disability represents the healthy time lost while living with a disability and is calculated by multiplying the number of cases (estimated from incidence data), a disability weight, and duration to recovery or death (Figure 1).

Ideally, DALY estimates are based on clearly defined, representative incidence data that were linked to appropriate disability weights and empirical information on the proportion of incident cases with lifelong consequences. In practice, the process is usually more complex. Lack of data on incidence and outcomes (e.g., long-term consequences) means that estimates are often patchy and inconsistent because of variations in type and quality. Modeling is used to address these and other deficiencies.

A denominator is needed to interpret the DALY. Ideally, the person-time lived by the population of a country would be used as a denominator for national estimates, particularly when the appropriate incidence data relate to several years (e.g., a 5-year period); a person-time denominator covers the exposure group in terms of the quantity of time the population has spent at risk of sustaining an injury. However, in practice, the denominator most commonly used is the population size inflated by the number of years to which the incidence data relate.

Aggregating mortality and morbidity enables comparisons between distinct diseases, between population subgroups, and among residents of different countries or regions (8, 18). A conceptual advantage of the DALY is that the public health effect of diseases and injuries can be compared in a transparent, systematic way.

However, a number of difficulties arise when the DALY concept is applied in the injury field. DALY calculations require sound epidemiologic data on both injury incidence and outcome, the latter in terms of nature, degree, and duration of disability and mortality, as well as judgment on the quantification of that disability to modify quality of life, a concept often referred to as “preference,” “value,” or even “utility.” Injuries are challenging for burden-of-disease methodology because they are characterized by heterogeneous health outcomes and duration. Injuries can affect any body region, are caused by multiple mechanisms (e.g., fall, fire, chemical substance), and lead to multiple types of injuries (e.g., fracture, strains, burns) and outcomes (from minor disability of short duration to severe, lifelong disability).

Epidemiologic data on a wide variety of injuries, and their short-term and long-term consequences, are therefore needed. However, Segui-Gomez and MacKenzie (2) noted that the use of epidemiologic data for the measurement of disability and HRQoL after nonfatal injury is a relatively new research area characterized by substantial variation in applied outcome measures and lack of consensus on preferred research methods. They also reported that few studies to date had used a preference-based measure enabling integration of mortality and disability into a single score necessary for DALY calculations.

## REVIEW OF DALY STUDIES MEASURING THE POPULATION BURDEN OF INJURY

To provide an overview of empirical burden-of-injury studies, we undertook a literature review of English-language studies published in peer-reviewed journals between January 1995 and February 2011. We conducted an initial search in PubMed, Embase, and Web of Science. Studies that calculated the combined impact of fatal and nonfatal consequences of injury (i.e., DALY) or the disability component of the DALY (i.e., years lived with disability) were included. Studies on “all-injury” and studies of specific injury groups (e.g., osteoporotic fractures) were evaluated, including studies from high-, middle-, and low-income countries. General burden-of-disease studies, investigating the complete disease spectrum (e.g., Mathers et al. (19), Murray and Lopez (20), and Vos and Begg (21)) were excluded.

The search terms we used were “wounds and injuries,” “burden of disease,” “disability adjusted life year,” “disability-adjusted life year,” “DALY,” “quality adjusted life years,” “disabled persons/statistics & numerical data health status measure,” “health status,” “morbidity,” and “mortality.” Keywords were matched to database-specific indexing terms. Furthermore, the reference lists of the included papers were checked. Relevant papers were selected by screening the titles (first step), abstracts (second step), and entire articles (third step) retrieved through the database searches by 2 independent researchers (S. P. and J. A. H.).

Overall, there were 9 published burden-of-injury studies of general injury populations (Table 1) (8, 18, 22–28) and 7 studies that calculated the burden of specific injuries (Table 2) (29–35). Variations in the methodologies included differences in 1) definition and selection of incident cases and their classification, 2) methods to assess injury outcome and valuation of health states, and 3) inclusion or exclusion of the mortality component in the calculations.

The definition and selection of injury cases varied widely. For example, one study included the broad spectrum of general practitioner-treated, emergency department-treated, and hospitalized cases (23); 4 studies included emergency department-treated and hospitalized cases (18, 22, 24, 25); and the remaining studies ( $n = 4$ ) included hospitalized patients only (Table 1). All studies on specific injuries were based on hospitalized patients (Table 2). However, for an injury type that almost always requires hospitalization (e.g., hip fracture), it is less of a study limitation to restrict cases to hospital admissions.

The severity of patients’ injuries in the studies varied substantially. For example, McClure and Douglas (25) included cases with non-life-threatening injury, whereas the Holtslag et al. study (27) was restricted to severely injured patients admitted to a trauma center with an Injury Severity Score of  $>15$ . While most studies measured the combined nonfatal and fatal consequences of injury, 4 did not include a mortality component (23, 24, 29, 30).

Assessment of injury outcome and valuation of health states also differed. In most studies, incident cases were multiplied by existing disability weights based on expert-panel opinions regarding the nature, duration, and health status value of injury consequences (mostly the Global Burden of Disease study weights). Alternatively, 4 studies used disability weights derived from cohorts of injured patients collected by using a self-administered HRQoL questionnaire (24, 25, 27, 30). By using preference-based questionnaires (EuroQol-5 dimensions (EQ-5D) or Health Consequences of Injury Questionnaire), HRQoL at follow-up could be calculated and subsequently converted into disability weights ( $1 - \text{HRQoL}$ ). Burden-of-disease studies of multiple causes, including injuries, were excluded from this review, but most of them used the expert-derived Global Burden of Disease disability weights (19, 36–39).

Our review also identified a variety of approaches used to measure duration of disability. Five studies used the Global Burden of Disease study methodology, which multiplied predefined proportions of lifelong disability determined by experts by life expectancies from standard life tables (8, 18, 22, 34, 35). Four studies used expert-derived assumptions of utility loss after the second and subsequent years (30–33). The burden-of-injury studies undertaken to date have focused on a variety of primary outcomes, and each of these studies used different case definitions and methodological approaches.

The results of the review show that the epidemiologic foundation of current burden-of-injury calculations is weak and that published estimates of the combined burden of fatal and nonfatal injury are limited. The combined estimated burden of fatal and nonfatal injury remains subject to bias and imprecision because of several methodological problems. These problems relate to the definition and selection

**Table 1.** Overview of Published Burden-of-Disease Studies of Generic Injury Populations, 1995–2010

First Author, Year (Reference No.)	Definition and Selection of Incident Cases			Assessment and Valuation of Nonfatal Outcome		DALY Components	
	Case Definition of Injury	Source Data	Anatomical Classification	Disability Weight	Measurement Duration Disability	Included DALY Components	Main Burden-of-Disease Findings
Chandran, 2010 (8)	Fatal and nonfatal unintentional injury	GBD 2004 study data	ICD coding	GBD	GBD % LL, standard GBD life table	Temporary and permanent YLD and YLL	Large variation between low- and high-income countries: 2.4 vs. 0.7 DALY/1,000 persons
Concha-Barrientos, 2005 (26)	Fatal and nonfatal occupational injury	ILO, PAHO	NA	GBD	NA	YLD and YLL	Worldwide occupational injuries result in 10.5 million DALYs
Ditsuwan, 2011 (28)	Fatal and nonfatal traffic injury	SPICE, HDR, IS, HWS	ICD coding	Thai DWs	% and severity LL based on recent Thai study	Temporary and permanent YLD and YLL	For men and women, 17.8 and 3.9 DALY/1,000 persons, respectively
Haagsma, 2008 (23)	Nonfatal unintentional injury treated by ED, admitted to hospital	GP, ED, HDR	EUROCCOST	New DDW	Based on % unrecovered patients after 2 years	Temporary and permanent YLD	116,000 YLD due to unintentional injury (7.1/1,000 persons)
Haagsma, 2009 (24)	Nonfatal unintentional injury, ED and admitted to hospital	ED, HDR	EUROCCOST	EQ-5D HRQoL, and APM	Only first year after injury	Temporary and permanent YLD	54,000 (EQ-5D approach) vs. 16,000 (APM) YLD
Holtslag, 2008 (27)	Major trauma, ISS >15 and admitted to trauma center	HTR, CND	ICD-10	EQ-5D HRQoL	Residual life expectancy × loss of ability after 15 months	Lifelong duration YLD and YLL	Major trauma causes 10 DALY/1,000 persons
McClure, 1996 (25)	Non-life-threatening injury	ED, MD, MCR	ICD-9	HCIQ, HRQL	Unrecovered after 6 months = LL	Short-term, lifelong YLD and YLL	Minor injuries responsible for the greater part of burden of injury
Polinder, 2007 (22)	Nonfatal and fatal injury in adults, ED and/or admitted to hospital	MD WHO, HDR, ED	EUROCCOST	GBD	GBD % LL, and DWs and standard GBD life table	Temporary and permanent YLD and YLL	Large variation between countries: 12–25 DALY/1,000 persons
Polinder, 2010 (18)	Nonfatal and fatal injury, age 0–24 years, ED and/or admitted to hospital	MD WHO, HDR, ED	EUROCCOST	GBD and new DDW	GBD % LL, and DWs and standard GBD life table	Temporary and permanent YLD and YLL	Large variation between countries: 14–58 DALY/1,000 children

Abbreviations: APM, annual profile method; CND, collection of nonfatal deaths; DALY, disability-adjusted life-year; DDW, Dutch disability weights; DW, disability weight; ED, emergency department; EQ-5D, EuroQol 5 dimensions; EUROCCOST, European Cost of Injury study; GBD, Global Burden of Disease study; GP, general practitioner; HCIQ, Health Consequences of Injury Questionnaire; HDR, hospital discharge registers; HRQoL, health-related quality of life; HTR, hospital trauma registration; HWS, Health and Welfare Survey data 2005; ICD, *International Classification of Diseases*; ILO, International Labor Organization; IS, Injury Surveillance data; ISS, injury surveillance system; LL, lifelong disability; MCR, medical care registrations; MD WHO, mortality data World Health Organization; NA, not applicable; PAHO, Pan American Health Organization; SPICE, SPICE cause of death study in Thailand; YLD, years lived with disability; YLL, years of life lost.

**Table 2.** Overview of Published Burden-of-Disease Studies of Specific Injury Patients, 1995–2010

First Author, Year (Reference No.)	Definition and Selection of Incident Cases		Assessment and Valuation of Nonfatal Outcome		DALY Components	
	Case Definition of Injury	Source Data	Disability Weight	Measurement Duration Disability	Included DALY Components	Main Burden-of-Disease Findings
Ahmadi-Abhari, 2007 (35)	Hip fractures	IMSAI, MD	GBD, NOF weights	GBD % LL, and DWs and standard GBD life table	Permanent YLD and YLL (temporary YLD sensitivity analysis)	Hip fractures resulted in 1.9 DALY/1,000 persons in Iran
Borgström, 2007 (33)	Osteoporotic fractures	PBS, NED, MD	EQ-5D HRQoL	LL 0.05 utility loss each year	Temporary and permanent YLD and YLL	15,930 DALY due to osteoporotic fractures in Sweden (1.7 DALY/1,000 persons)
Johnell, 2004 (32)	Hip fractures	GBD, NED	GBD	10% decrease in utility loss each year	YLD (durations from external data) and YLL	Worldwide hip fractures result in 1.75 million DALYs
Johnell, 2006 (31)	Osteoporotic fractures, age >50 years	GBD, NED	GBD	10% decrease in utility loss each year	YLD (durations from external data) and YLL	Worldwide osteoporotic fractures result in 5.8 million DALYs
Kanis, 2001 (30)	Osteoporotic fractures with threshold for BMD	EVOS/ EPOS	EQ-5D HRQoL	10% decrease in utility loss each year	Temporary (2 years) and permanent YLD	YLD due to osteoporotic fractures in women increased from 0.3 (50–54 years) to 4.1 per 1,000 (age 85–89 years)
Kanis, 2004 (29)	Vertebral fractures associated with low BMD, age >50 years	NBS	Utility loss data US OF	Second year calculated utility loss	Short-term and long-term disutility	Vertebral fractures result in high utility loss
Rahimi-Movaghar, 2010 (34)	Spinal cord injury, all ages	PBS, NED, MD	GBD	GBD % LL, and DWs and standard GBD life table	Permanent YLD and YLL	Spinal cord injury resulted in 0.7 DALY /1,000 persons in Iran

Abbreviations: BMD, bone mineral density; DALY, disability-adjusted life-year; DW, disability weight; EQ-5D, EuroQol 5 dimensions; EVOS/EPOS, European Prospective Osteoporosis Study; GBD, Global Burden of Disease study; HRQoL, health-related quality of life; IMSAI, Iranian Multicenter Study on Accidental Injuries; LL, lifelong disability; MD, mortality data; NBS, nation bureau of statistics; NED, national epidemiologic data; NOF, National Osteoporotic Foundation; PBS, population-based study; US OF, United States Osteoporotic Fractures; YLD, years lived with disability; YLL, years of life lost.

of incident cases, assessment of nonfatal injury outcome and duration, valuation of HRQoL, and the mortality component of the burden of injury (Figure 1). Progress toward addressing these challenges is discussed in the following sections.

## DEFINITION AND SELECTION OF INCIDENT CASES

The definition and selection of incident cases in burden-of-injury calculations remain challenging and without standard solutions. Many epidemiology papers describe injuries without including a theoretical or operational definition of injury (40). A widely used definition is the following: “an injury is the physical damage that results when a human body is suddenly or briefly subjected to intolerable levels of energy. It can be a bodily lesion resulting from acute exposure to energy in amounts that exceed the threshold of physiological tolerance, or it can be an impairment of function resulting from a lack of one or more vital elements (i.e. air, water, warmth), as in drowning, strangulation or freezing. The time between exposure to the energy and the appearance of the injury is short” (41, p. 5).

Injuries typically regarded as trivial are included in this definition but are often excluded from studies. Researchers should make explicit the lower threshold of severity (40). Incidence data for an operational definition of injuries exceeding set threshold limits (e.g., injuries that limit usual activities by at least half a day) may be obtained from population surveys or many administrative sources of data, but there are limitations with both sources of data types (42).

Population surveys would seem to be an ideal source of incidence data but suffer from a series of problems, and generally they do not provide an unbiased estimate of injury incidence. Surveys tend to have response rate and information biases, capturing information on recalled injuries grouped into “lay” diagnoses such as “cuts, sprains, and broken bones” and lacking information on detailed diagnoses (41). Recall bias is a problem. For example, a 72% decline in reported incidence over a 12-month recall period in community surveys in Ghana and a 38% underestimate from self-reports in a US study of hip fractures have been reported (43, 44).

Operational definitions for estimating the incidence of fatal or nonfatal injuries are therefore usually based on available administrative data, such as mortality records, hospital discharge registers, emergency department systems, general practitioner records, imaging databases, emergency medical services systems, and data recorded by police or fire services for particular circumstances of injuries (45). However, this approach also has its limitations (46). The structure of health care provision and physical and financial barriers to access can effect estimation of injury incidence when such sources are used (6, 47). Whether, where, and how care for an injury is sought is a complex issue, with 43 pathway decision points being identified in the acute injury health care flow diagram designed to help understand variations in incidence data in different settings (48). Nonclinical factors also influence the likelihood of a given emergency department–attended injured person having been treated as an inpatient, affecting international comparisons of injury incidence and burden because of large disparities in access to health services (47, 49).

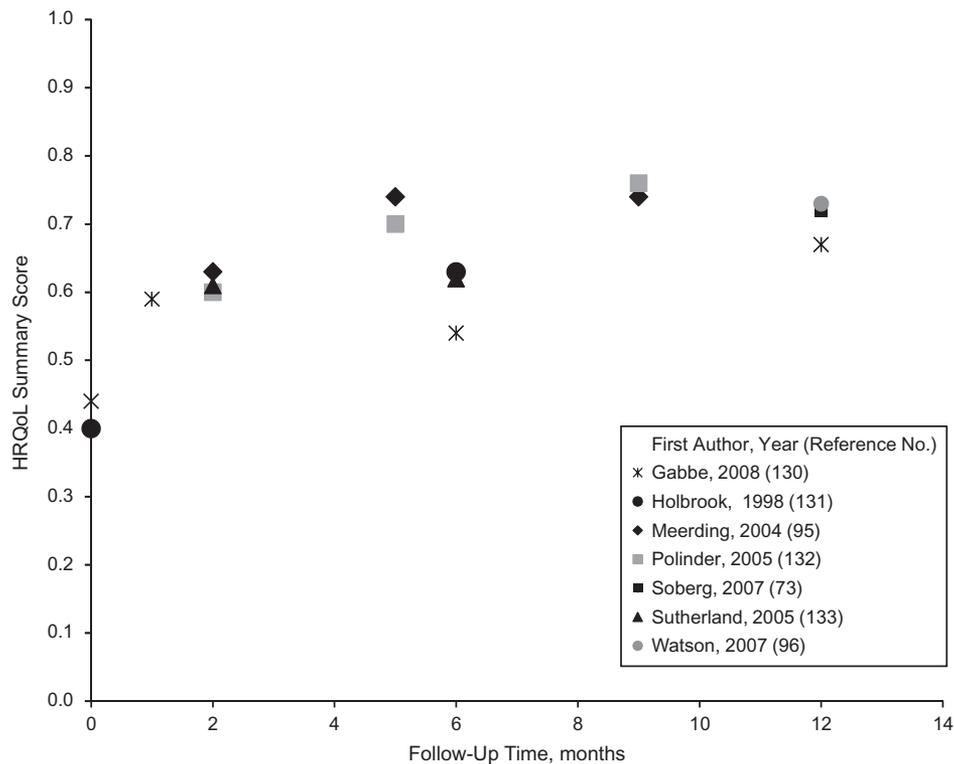
Administrative data sources, such as hospital discharge registers, often have coded nature-of-injury and external-cause fields from the *International Classification of Diseases*, Ninth Revision (ICD-9) and *International Statistical Classification of Diseases and Related Health Problems*, Tenth Revision (ICD-10). Most nature-of-injury codes are to be found in injury-specific chapters in the *International Classification of Diseases*. However, some obvious injuries are not included in the ICD-10 injury chapters, such as some eye and ear injuries, stress fractures, and fetal injury (50, 51). There is also a debate as to whether chronic sprains and back pain should be included as injuries, but they are usually excluded (52). A further way in which injuries have been operationally defined is in terms of mechanism: the external-cause code. Australian and New Zealand studies also report external-cause codes to be present in 15%–27% of hospital discharge register records without an accompanying nature-of-injury code (46, 53).

Large variations in the completeness of coding is a problem and has been reported in a study of 18 European countries (54). Individual-level record linkage is also often necessary to prevent erroneous counting of incident cases due to readmissions (55).

## ASSESSMENT OF NONFATAL INJURY OUTCOME AND DURATION

Measuring disability (i.e., diminished functioning and participation resulting from disease or injury (World Health Organization (56)) has become increasingly important in the field of injury and trauma. Over the past decades, case fatality rates of severe injury have rapidly decreased, at least in countries with advanced health systems (57–59). This puts a growing number of patients at risk of serious long-term disability (27, 60). The World Health Organization International Classification of Functioning, Disability and Health is a conceptual framework for measuring disability (56, 61). According to this classification, disability is an overall term that incorporates all consequences of decrements in the following 4 components: body structures (anatomic body parts), body functions (physiologic and psychological functions), activities (execution of tasks or actions by an individual), and participation (involvement in life situations) (56).

Instruments measuring HRQoL include components within the World Health Organization International Classification of Functioning, Disability and Health model. For example, they usually contain questions related to physical, psychological, and social functioning (62). Generic HRQoL measures include items that are not specific to particular diseases or conditions but are applicable to people with a range of conditions and also to the general population (11). Studies examining outcomes following particular types of injury, such as traumatic brain injury or spinal cord injury, usually contain disease-specific measures. When addressing the burden of nonfatal injury, HRQoL measures need to be selected that are applicable across the gamut of injury types, nature, and causes. Therefore, our focus is on generic measures of HRQoL. Widely used generic measures include the EQ-5D, 36-item



**Figure 2.** Reported health-related quality of life (HRQoL) summary scores over time ( $\leq 12$  months) for general injury populations. Adapted from Polinder et al. (69).

Short-Form Health Survey (SF-36), the Functional Capacity Index, and the Health Utilities Index (63–66), although many more exist (67).

Utility-based measures are a subgroup of HRQoL measures. They can be differentiated by their ability to summarize HRQoL in a single index “score” using a multiattribute utility instrument (68). These summary scores are an indication of the “preference” given for living life in that particular HRQoL state.

A recent systematic review showed that, between 1995 and 2010, 24 different HRQoL instruments were used in general injury populations (69). Figure 2 provides an overview of the included studies that reported utility scores over time in the 12 months following injury for patients aged 15 years or older. Overall, HRQoL improves in the first year after injury, although the large variation in HRQoL instruments, study populations, and time points at which HRQoL was assessed impedes comparison of scores between studies. When different instruments are used, it is important to note that they may assess different dimensions of health, which may lead to different utilities for the same health state (70).

To reduce the heterogeneity of applied methods, a working group of Eurosafe (the European Association for Injury Prevention and Safety Promotion) has published guidelines for conducting follow-up studies after injury. Largely in agreement with other experts, this group recommended that a measure to quantify the burden of injuries be generic

(to enable comparisons with other diseases); include all dimensions relevant to injury consequences as defined by the International Classification of Functioning, Disability and Health; and be responsive to changes over time in patients’ health and well-being. On the basis of data to 2005, the group recommended use of a combination of the EQ-5D and the Health Utilities Index as a common core of measures at 1, 2, 4, and 12 months after injury in studies of injury-related disability. This combination was considered to cover all relevant health dimensions and to be suitable for “all injury” populations and for all age ranges except the youngest (71). A recent review found an increasing number of injury outcome studies using one of the recommended utility measures, the EQ-5D, in the last 5 years (72).

Information on long-term residual disability is also required to measure the burden of injuries, and severe injuries in particular. Proportions of residual disabilities can be assessed with long-term follow-up studies, but few follow-up studies extend beyond 1 year after injury (69), and residual disability at 1 year is often assumed to be lifelong. Some studies have reported residual disability at longer follow-up periods, such as 2 years (73, 74), 6 years (75), or even 12 years (76) after injury, but without making comparisons with earlier time points. A detailed understanding of the duration of disability is lacking. Few studies have sought to clarify the long-term course of recovery for patients with severe injury, but a number have indicated further improvements in functioning

and HRQoL after the first year (60, 77). To avoid possible overestimations of the burden of nonfatal injury, data from cohort studies with multiple assessments during follow-up (e.g., 1, 2, 5, 10, and 20 years after injury) are needed.

### VALUING HRQoL AFTER INJURY

Calculation of the disability component of the burden of injury for DALYs also requires a set of “disability weights” that value HRQoL after injury on a scale from 0 (equivalent to death) to 1 (perfect health) (17). These values are commonly based on the “preferences” of a panel of judges for pairs of hypothetical health states, expressing the relative undesirability of the health states compared (78, 79).

Several sets of disease-specific disability weights have been constructed, such as the Global Burden of Disease study disability weights (5) and the Dutch disability weights (80). Few sets have been produced because the process is complex and costly. Using the same set of disability weights has advantages in terms of comparability. However, diseases and injuries rated less severe by experts in a high-income country might be rated more burdensome by people in resource-poor settings. Studies comparing health-state valuations among residents of several countries showed that ranking of health states is similar across countries (81, 82), although further research is needed to improve understanding of the effect of cultural differences on disability weights.

Table 3 illustrates the methodological choices underlying current disability weights, including who valued the health states, how the health state was depicted, which valuation method was used, and the number of injury-related health states and disability weights determined for frequently occurring injuries (78, 79). Panels of judges may consist of patients, patient proxies, health experts, or general population representatives. To date, most panels have been formed in developed countries.

Choices are also required concerning the “ideal” method for deriving the valuations; usually the visual analog scale, time trade-off, or person trade-off has been used. The person trade-off and time trade-off methods require a respondent to sacrifice (hypothetically) something valuable as part of the process of assessing the relative undesirability of health states (trade-off feature). Consequently, the preferences elicited with the visual analog scale give less information about the relative desirability of a health state than those elicited by time trade-off and person trade-off; therefore, the visual analog scale is regarded as less appropriate for generating disability weights (83).

Correspondence between injury incidence data descriptors and the injuries for which disability weights have been derived is needed. This linkage is particularly complicated in the field of injury because incidence data covering a wide range of injury diagnoses are scarce (84). When incidence data are available, many of the required disability weights are often lacking because the existing set does not cover the complete spectrum of diagnoses. For example, the Global Burden of Disease study and subsequent studies used DALY methodology-derived disability weights for 33 groups of injuries (19, 85–89). Ideally, disability weights should be

available for each logical grouping of a nature of injury classification (84). Furthermore, each disability weight should represent a group of injuries that is homogenous for outcome and for diagnostic grouping.

The approach based on empirical data of patient cohorts, as applied by McClure and Douglas (25) and Holtzlag et al. (27), meets these requirements. With this approach, disability weights are derived from the HRQoL follow-up data on individual patients, which can be grouped by nature of injury to avoid heterogeneity within groups. However, there are limitations. Some seriously injured groups (e.g., patients with severe brain injury), those with preexisting cognitive impairment, and young children often cannot complete the necessary instruments for development of disability weights. While proxy respondents have been used to cope with this problem, evidence is growing that proxy reporting of HRQoL differs from patient responses (90–93), potentially leading to bias. Further research into the validity of proxy responses to HRQoL instruments in injured populations is therefore required, including measurement of the agreement between proxy and patient responses over time.

When the disability weight approach based on a multi-attribute utility instrument is used, as applied by McClure and Douglas (25) and Holtzlag et al. (27), understanding the health of injured populations prior to injury is important for valid estimates of the burden attributable to injury. Many researchers have compared the health or disability status of injured participants with that of the general population (94, 95), while others have advocated comparison with preinjury status (96, 97). When the injured have a postinjury status (usually poorer) different from their preinjury status, or from that of the general population, the difference is usually interpreted as being due to the injury.

Comparison with population norms assumes that the injured are not different from the general population. However, some previous studies suggest higher preinjury morbidity in participants who sustain an injury than in those who do not (98, 99), which would lead to an overestimate of burden due to injury if relying on population norms. In contrast, other studies have found better recalled preinjury HRQoL compared with the general population (96, 97, 100). The higher preinjury HRQoL could arise through response shift, whereby the injury event itself prompts an internal recalibration of HRQoL, or the injured population may simply be healthier than the general population before injury. If the injured population is healthier, use of population norms would underestimate injury burden.

Overall, there is no clear consensus, and there is the potential for error in burden estimates using both approaches. Ideally, large prospective cohort studies of the HRQoL of the general population could be undertaken, from which injured subgroups are identified as they experience injury events, as described by Pons-Villanueva et al. (99). However, the cost of these studies is likely to be prohibitive in many settings, limiting the availability of prospectively collected HRQoL information on preinjury health status. Pending availability of unbiased preinjury HRQoL data, evaluation of preinjury recalled HRQoL among studies of injury burden (96), supplemented by estimates based on population norms (97), is perhaps the most sensible approach.

**Table 3.** Overview of Existing Sets of Disability Weights

First Author, Year (Reference No.)	Name of the Set of Disability Weights	Panel of Judges	Health State Description	Valuation Method	No. of Injury-related Health States	Disability Weights
Murray, 1996 <sup>a</sup> (86)	GBD	Health experts (n = 10)	Disease specific	<1% PTO	41	Hf: 0.372-LL 0.272 (5%)
				>99% VAS <sup>b</sup>		Sbi: 0.431-LL 0.350 (15%) Sci: LL 0.725 (100%)
Stouthard, 2000 (80)	DDW	Health experts (n = 34)	Disease specific + generic (EQ-5D)	Approximately 10% PTO	9	Hf: LL 0.13
				100% VAS <sup>b</sup>		Sbi: mild LL 0.37, moderate LL 0.73, severe LL 0.74 Sci: LL paraplegia 0.57, tetraplegia 0.84
Haagsma, 2008 (23)	Haagsma et al.	Population (n = 143)	Disease specific + generic (EQ-5D)	100% VAS	45	Hf: 0.124
				100% TTO		Sbi: moderate 0.193, severe 0.540, severe LL 0.429 Sci: paraplegia 0.563, LL 0.656, quadriplegia 0.713, LL 0.719
Haagsma, 2009 (134)	INTEGRIS	Population	Generic (EQ-5D)	100% TTO	87	Hf: 0.423 LL 0.172 (52%)
						Sbi: 0.241 LL 0.323 (15%) Sci: LL 0.676 (100%)
Yoon, 2007 (135)	Korea DW	Health experts (n = 30)	Disease specific	9% PTO	Not available	Not available
Lai, 2009 (136)	Estonia DW	Health experts (n = 25)	Not available	9% PTO	Not available	Not available
				91% VAS <sup>b</sup>		
				9% PTO		
				91% VAS <sup>b</sup>		

Abbreviations: DDW, Dutch disability weights; DW, disability weight; EQ-5D, EuroQol 5 dimensions; GBD, Global Burden of Disease; Hf, disability weight for hip fracture; INTEGRIS, integration of European injury statistics; LL, lifelong disability; PTO, person trade-off; Sbi, disability weight for skull brain injury; Sci, spinal cord injury; TTO, time trade-off; VAS, Visual Analogue Scale.

<sup>a</sup> A new set of weights is being constructed for the GBD 2010 project.

<sup>b</sup> Assessment of these sets of DWs consists of a 2-step procedure. First, a group of indicator conditions is selected, which are valued by a panel of judges using the PTO. Subsequently, the nonindicator conditions are assigned a DW using an interpolation exercise (VAS).

## METHODOLOGICAL ISSUES RELATED TO CHILDREN AND THE ELDERLY

Assessment of injury outcome by nature and duration is further complicated by the methodological issues inherent to important specific age groups, such as children and the elderly. Pediatric injury warrants particular discussion given the potential for lifelong impact (101) and specific methodological issues challenging robust estimation of childhood injury burden (102). Recruitment of children for injury studies generates additional ethical considerations for researchers with respect to consent and data collection. Return to pre-injury function is less relevant for children than whether they have remained on (or returned to) the trajectory of growth and development they were on before injury.

Pediatric instruments sensitive to changes in cognitive, physical, and psychosocial development are necessary, but development of such instruments has lagged behind that of

adult HRQoL measures (103, 104), with the Pediatric Quality of Life Inventory (PedsQL) being one of the most widely used tools (102, 104). The challenge of eliciting standard HRQoL measures from preverbal children is clear, yet many studies involving older children and adolescents often rely on parent report. This approach ignores the reporting of a salient group of respondents whose perceptions of their health could differ in important ways from those of their parents (92, 105).

While studies have applied previously existing, panel-derived weights to estimate childhood injury burden (18), empirical data on postinjury disability in children for deriving disability weights are limited (69). Most have involved relatively small samples of injured children recruited at the child's interface with health care, ignoring the potential burden associated with less severe injuries. Common, specific exclusions used by studies include victims of child abuse, intentional self-harm injuries, children with chronic preexisting conditions, and children of nonnative-language-speaking

backgrounds. These exclusions limit the generalizability of study results. Overall, data on which to calculate robust population-based estimates of the burden of childhood injury are scant, affecting current perceptions of priorities and the informed public policy, preventive interventions, and health care services.

A similar special consideration group for injury burden estimates is the elderly. A disproportionate contribution to injury burden estimates is borne by the elderly given the prevalence of falls-related injury. Although studies of HRQoL following injury have included elderly patients, many have limited the age to less than 65 or 75 years (69), with few published elderly-specific studies of postinjury disability (106, 107). A key challenge for establishing injury-related burden in the elderly is differentiating the effect of injury from comorbidities, that is, the presence of preexisting disabilities other than injury (108). Most burden-of-disease studies have failed to consider comorbidity, and few studies have collected robust data about preinjury and postinjury comorbidity (98). A further challenge for establishing reliable estimates of disability weights relates to the logistical difficulties of collecting HRQoL information in a group where visual, hearing, and cognitive impairment can be prevalent (108).

The potential to introduce a “healthy well” responder bias is clear and may also be present in age- and gender-specific population norms of HRQoL because the latter are often drawn from community-dwelling populations. Thus, the risk of introducing selection biases is high in studies of injured people who have required hospitalization, as these populations are more likely to include institutionalized or frail people and those with declining health for reasons unrelated to the injury.

A further issue that arises for both young and old in burden-of-injuries studies is the use of age weighting, specifying the relative value of a year of healthy life lived at different ages. The DALY can incorporate nonuniform age weights that give less weight to years of life lived in early childhood and at older ages. The 1990 Global Burden of Disease study included an age-weighting factor in the calculation of DALYs that started with zero at birth, peaked at age 25 years, and then declined exponentially (86). This choice was based on a number of studies that maximized the value given to economically active years of life lost (5). Not all such studies agree that the youngest and oldest ages should be given less weight, nor do they agree on the relative magnitude of the differences (10, 109).

### **INCLUSION OF ALL RELEVANT NONFATAL CONSEQUENCES**

Traditionally, burden-of-injury studies have focused on the physical consequences of injury, whereas psychological consequences such as posttraumatic stress disorder, travel anxiety, and other maladaptive syndromes are not considered, even though numerous studies have shown that these syndromes occur relatively frequently among injury patients (110–113). A literature review showed that shortly after the injury, approximately 1 in 5 injury patients treated in the emergency department and 1 in 3 patients who were hospi-

talized suffered from posttraumatic stress disorder and that including posttraumatic stress disorder increased nonfatal burden estimates by more than 50% (114).

These findings emphasize the importance of including all relevant outcomes. However, doing so entails that, first, all possible health outcomes for a certain injury or disease be defined—immediate as well as long-term health outcomes and physical as well as psychological health outcomes. A recent paper developed a conceptual framework, the Injury List of All Deficits (LOAD) framework, for all consequences of the injury burden across individual, family, and societal domains, supported by empirical evidence (115). This framework can be used to map the effects of injury that may be expected when planning burden-of-injury studies. This would also serve as an interpretation aid when results from published studies are compared. A clearly defined structure, such as the construction of outcome trees, and decision rules as to which outcomes should be included or excluded, may help to identify otherwise-ignored long-term consequences and enhance assessment of injury burden.

### **THE MORTALITY COMPONENT IN BURDEN-OF-INJURY CALCULATIONS**

Calculation of the mortality component (years of life lost) of the DALY is also challenging. Counting deaths that occur soon after the injury incident is relatively straightforward and likely to be accurate (although it should be noted that only about one-half of deaths, globally, are recorded in vital registers). However, many injuries, particularly those to older, frail individuals, result in elevated mortality over quite a long period. For example, a review of cohort studies shows that hip fracture mortality remained unchanged between 1959 and 1998, with mortality being 11%–23% at 6 months and 22%–29% at 1 year (116). Attributing all such deaths to the injury is problematic because some deaths will be directly related to the injury, some will occur when the injury overwhelmed an already compromised host with multiple existing health conditions, and some are entirely unrelated. However, evidence exists that the injury-related mortality component is substantially underestimated. In England and Wales, there are some 60,000 hip fractures a year. On the basis of quoted survival figures, at least 13,000 attributed deaths would be expected; however, the total annual number of fall-related deaths for all ages is approximately 3,800 (47). Relative survival methods, widely used in cancer epidemiology, might have utility for assessment of late mortality after injury (117).

A further issue is the low quality of mortality data in many countries and the absence or unavailability of data in others. Bhalla et al. (118) reviewed the availability and quality of cause-of-death data for estimating the global burden of injuries and found that recent death data, satisfying criteria for adequacy, were available for 83 countries, covering only 28% of the world's population. Only 20 countries had data that met a criterion for high-quality national death registration data because many had high proportions of deaths coded to unspecified or partially specified causes. The authors concluded that alternative sources of mortality data for less-resourced countries that experience the greatest burden of

**Table 4.** Current Challenges and Recommendations for Future Work

Research Need	Recommendations
Definition and selection of incident cases	Be explicit about the operational definition of injury adopted <sup>a</sup> . Conduct more studies that empirically test severity thresholds of “nontrivial injury” (e.g., Haagsma et al. (23), Polinder et al. (49)) <sup>a</sup> .
Assessment of nonfatal injury outcome and duration	Reach agreement on which framework to use for defining nonfatal injury outcome, for example, which quality-of-life dimensions to include. Ensure wide adoption of existing guidelines (Eurosafe) for a common core of measures (EQ-5D and HUI) and timing of assessments (1, 6, 12, and 24 months) to allow meta-analyses to produce better understanding of nonfatal injury outcomes (69, 71). Refine estimates of preinjury health status, ideally based on large, prospective cohort studies (e.g., Lyons et al. (55), Derrett et al. (137)). Analyze the long-term course of recovery and impact on life expectancy by cohort studies with multiple assessments during long-term follow-up. Use LOAD framework to map the effects of injury and interpretation aid when comparing study results (115).
Valuation of HRQoL after injury	Develop a comprehensive set of disability weights from internationally available empirical data with wide applicability (including consensus with other disease measurement). Each disability weight should represent injury groups that are fairly homogenous for outcome and for diagnostic grouping. Improve estimates of disability (weights) of “minor” and major injury (including effects on life expectancy among survivors). Consider cultural, societal, and economic context in burden estimates, including differences between high-income and low-income countries).
Specific groups and settings	Investigate and develop robust measures of disability for children, adolescents, and the elderly. Conduct further studies to determine the validity of using proxies to report HRQoL after injury, especially for populations such as children, the elderly, and the severely injured (e.g., traumatic brain injury).
Mortality	Refine estimates of longer-term premature mortality due to injury by longitudinal studies, record linkage, and use of relative survival methods <sup>a</sup> . Remove barriers and promote use of data linkage for research <sup>a</sup> . Improve poor-quality mortality data through capture-recapture methods.

Abbreviations: EQ-5D, EuroQol-5 dimensions; Eurosafe, European Association for Injury Prevention and Safety Promotion; HRQoL, health-related quality of life; HUI, Health Utility Index; LOAD, Injury List Of All Deficits.

<sup>a</sup> Although these issues are particularly relevant in the calculation of disability-adjusted life-years, they are also relevant (and need work) for all other injury-related epidemiologic work.

injuries are essential, such as data from demographic surveillance sites (119), mortuaries (120), national censuses (121), and surveys (122). Where poor-quality mortality data exist, it is sometimes possible to improve data through capture-recapture methods (123, 124) or record linkage.

Capture-recapture methods involve the use of 2 or more independent sources to derive the incidence of cases or population of interest and have been used previously in injury studies (125–127). However, capture-recapture methods assume that data sources span similar time periods, independence of the data sources, and equal probability of being “captured” by each of the included data sources (123, 124). These assumptions are rarely met in epidemiologic studies and within the injury field, specifically where interdependency between data sources is high (e.g., hospital discharge registers and vital registers).

Data linkage is increasing globally, with the availability of complex data management systems capable of linking multiple data sets in a secure environment while maintaining privacy and minimizing ethical concerns. Linked data provide an alternative method for improving the quality of injury reporting. Gabbe and Lyons (128) linked mortality data in

Wales, where 24% of unintentional deaths are coded with an unspecified ICD-10 code (X59) to hospital admission data. Some 84% of cases had a recent hospital admission, of which the cause of death was specified in 69%; the majority were due to falls. One way forward is to develop algorithms to redistribute unspecified codes by age group and region to measure the burden of injuries due to specific causes.

The poorly estimated impact of injuries on longer term mortality may lead to underestimates of injury-related DALYs. Injuries resulting in disability or the development of secondary health conditions may result in premature mortality. Most current adopted methodologies do not take this factor into account and may overestimate lifelong years lived with disability at the expense of underestimating years of life lost. Cameron et al. (129) carried out the Manitoba Injury Outcome Study by matching an inception cohort of injured patients from hospital discharge data with population register and mortality databases, and they reported an elevated mortality rate ratio (1.80, 95% confidence interval: 1.65, 1.98) over the following 10 years for the injured cohort. Including a matched, noninjured comparison group reduced the excess mortality rate by a third.

## CONCLUSIONS AND RECOMMENDATIONS

We have provided an overview of methods and existing knowledge regarding metrics to assess HRQoL after injury and for integrating mortality, disability, and quality-of-life consequences. This overview shows that the epidemiologic foundation of current burden-of-injury calculations is weak on most every dimension involved in the process. Thus, knowledge of the combined burden of fatal and nonfatal injury is limited. This possibly reflects the pressing need to use these metrics in the larger context of health priority setting but also the lack of consensus or strong evidence on how best to move forward. However, progress toward consensus on preferred methods and necessary advances is under way. This review proposes several solutions for methodological refinements in future studies measuring the population burden of injury (Table 4). Implementing these recommendations will lead to increased validity and comparability of future estimates of the population burden of injury. Ultimately, this should positively influence priority setting and resource allocation in injury prevention and trauma care and lead to improvements in the health of our populations.

## ACKNOWLEDGMENTS

Author affiliations: Department of Public Health, Erasmus Medical Center, Rotterdam, the Netherlands (Suzanne Polinder, Juanita A. Haagsma, Ed F. van Beeck); College of Medicine, Swansea University, Swansea, United Kingdom (Ronan A. Lyons); Department of Epidemiology and Preventive Medicine, Monash University, The Alfred Hospital, Melbourne, Victoria, Australia (Belinda J. Gabbe); Section of Epidemiology and Biostatistics, School of Population Health, University of Auckland, Auckland, New Zealand (Shanthi Ameratunga); Injury Prevention Research Unit, Department of Preventive and Social Medicine, University of Otago, Dunedin, New Zealand (Colin Cryer, Sarah Derrett); Research Centre for Injury Studies, Flinders University, Adelaide, South Australia, Australia (James E. Harrison); and European Center for Injury Prevention, Universidad de Navarra, Pamplona, Spain (Maria Segui-Gomez).

Conflict of interest: none declared.

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