CHAPTER 1

Measures of Health and Disease in Populations

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In its 1948 charter, the World Health Organization (WHO) defined health as "a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity." Although this is an important ideological conceptualization, for most practical purposes, objectives of health programs are more readily defined in terms of prevention or treatment of disease. Disease has been defined in many ways and for a variety of reasons; distinctions may be made between disease, sickness, and illness. For purposes of defining and measuring disease burden, a general definition will be used in this text: *Disease* is anything that a person experiences that causes, literally, "dis-ease"—that is, anything that leads to discomfort, pain, distress, disability of any kind, or death constitutes disease. It may be due to any cause, including injuries or psychiatric conditions.

It is also important to be able to diagnose and classify specific diseases to the extent that such classification aids in determining which health intervention programs would be most useful. Thus, defining disease, understanding the pathogenesis of the disease process, and knowing which underlying risk factors lead to this process are critical for understanding and classifying causes so as to determine the most effective prevention and treatment strategies for reducing the effects of a disease or risk factor. Just as the purpose of diagnosis of a disease in an individual patient is to provide the right treatment, so the major purpose of working through a burden of disease analysis in a population is to provide the basis for the most effective mix of health and social program interventions.

Developments in the measurement of population health status and disease burden over the past two decades include the increasing use of summary, composite measures of health that combine the mortality and morbidity effects of diseases into a single indicator; the availability of results of Global Burden of Disease (GBD) studies, which make use of such summary indicators; and developments in the measurement of disability and risk factors. The more traditional approaches to measuring health are widely available in other public health textbooks and will be used for illustrative and comparative purposes here.

This chapter is divided into five sections. The first section explains the reasons for and approaches to measuring disease burden in populations, describes the need for using quantitative indicators, highlights the importance of using data for decision making in health, and lists a variety of major health indicators currently in widespread use. The second section critically reviews methods for developing and using composite measures that combine the mortality and morbidity from diseases in populations at national and regional levels. It explores the potential utility of these measures and discusses their limitations

and implications. The third section demonstrates the application of these methods for measurement of health status and assessment of global health trends. It reviews current estimates and forecasts trends in selected countries and regions, as well as examines the global burden of disease. The fourth section reviews important underlying risk factors of disease and discusses recent efforts to measure the prevalence of major risk factors and to determine their contributions to regional and global disease burdens. The final section provides conclusions for the chapter.

Reasons for and Approaches to Measuring Health and Disease

Rationale

The many reasons for obtaining health-related information all hinge on the need for data to guide efforts toward reducing the consequences of disease and enhancing the benefits of good health. These include the need to identify which interventions will have the greatest beneficial effect, to identify emerging trends and anticipate future needs, to assist in determining priorities for expenditures, to provide information for education to the public, and to help in setting health research agendas. The primary information requirement is for understanding and assessing the health status of a population and its changes over time. In recent years, practitioners have emphasized the importance of making evidence-based decisions in health care. There is little reason to doubt that evidence is better than intuition, but realizing its full benefits depends upon recognizing and acting upon the evidence. This chapter examines evidence—the facts of health and disease—and demonstrates how to assemble this evidence so that it can assist in better decision making concerning health and welfare.

A well-documented example of the relationship between decision making and data can be seen in a classic health systems project in Tanzania (**EXHIBIT 1-1**). This

EXHIBIT 1-1 Using Evidence to Improve a Health System: An Example from Africa

The **Tanzania Essential Health Interventions Project** (TEHIP), a joint venture of the Tanzanian Health Ministry, the International Development Research Centre (IDRC), and the Canadian International Development Agency, starting in 1996 was conducted in two rural districts—Morogoro and Rufiji—with a combined population of approximately 700,000. The annual health spending in Tanzania was about $8 per capita. In Morogoro and Rufiji, TEHIP added resources on the condition that they be spent rationally; in other words, the amount of money spent on interventions should reflect the burden of disease. TEHIP conducted burden of disease analysis for the two districts and established a demographic surveillance system (DSS). The routine data from the DSS provided information for the district teams to support resource allocation based on disease burden. The organization found that the amount that the local health authorities spent on addressing each disease bore little relation to the actual burden of disease. Although childhood problems (e.g., pneumonia, diarrhea, malnutrition, measles) constituted 28% of the disease burden, only 13% of the budget was devoted to addressing them. Other conditions, meanwhile, attracted more than their fair share of resources. For example, 22% of the budget was targeted to tuberculosis, even though it accounted for less than 4% of years of life lost.

TEHIP promoted the use of burden of disease analysis, district accounts, and other mapping tools for more rational decision making in the districts. It also brought management tools and community voice techniques to the district teams. The result was better ability of district-level healthcare workers and managers to control and allocate resources and processes related to healthcare provision. The district teams decided to spend more on neglected diseases for which cost-effective treatments or preventive measures were available. The extra $1 per capita was enough to allow the district health authorities to align their spending to reflect the real disease burden. For example, sexually transmitted diseases received 3% of the budget prior to TEHIP's intervention; that percentage changed to 9.5% after the realignment. Malaria accounted for 30% of the years of life lost because of death and debilitating illness; the budget for malaria prevention and treatment programs increased from 5% of total spending in 1996 to 25% in 1998.

The results of TEHIP were documented as changes in health outcomes. In Rufiji, for example, infant mortality fell by 40% in 5 years. In fact, just between 1999 and 2000, infant mortality fell from 100 deaths per 1,000 live births to 72 deaths per 1,000 live births, while the proportion of children dying before their fifth birthdays dropped by 14%, from 140 per 1,000 to 120 per 1,000. The success of TEHIP and its approach led to replication and further innovation in not only Tanzania but also many other low- and middle-income countries (LMICs), including Burkina Faso, Ghana, and Nigeria.

For additional information on the TEHIP success story, visit the websites identified in the following sources.

Data from https://www.odi.org/sites/odi.org.uk/files/odi-assets/publications-opinion-files/7814.pdf; https://www.idrc.ca/en/article/tanzanias-healthcare-breakthrough; https://www.researchgate.net/publication/268341357_Tanzania_Essential_Health_Interventions_Project_An_Overview_of_TEHIP_Interventions_Tanzania_Ministry_Of_Health_TANZANIA_ESSENTIAL_HEALTH_INTERVENTIONS_PROJECT_TEHIP_Interventions_-An_Overview

case illustrates how able people with good intentions had been making decisions routinely, only to find that using established methods to collect evidence on the burden of disease changed the nature and effectiveness of their own decisions. A major reason for the effective use of the evidence was that it was collected locally and put forward in a form helpful to decision makers.

Measuring Health and Disease

The relative importance (burden) of different diseases in a population depends on their frequency (incidence or prevalence), severity (the mortality and extent of serious morbidity), consequences (health, social, economic), and the specific people affected (gender, age, social and economic position).

Counting Disease

The first task in measuring disease in a population is to count its occurrence. Counting disease frequency can be done in several ways, and it is important to understand what these different methods of counting actually mean. The most useful way depends on the nature of the disease and the purpose for which it is being counted. There are three commonly used measures of disease occurrence: cumulative incidence, incidence density, and prevalence.

Cumulative incidence, or *incidence proportion*, is the number or proportion of new cases of disease that occur in a population at risk for developing the disease during a specified period of time. For this measure to have meaning, three components are necessary: a definition of the onset of the event, a defined population, and a particular period of time. The critical point is *new cases* of disease—the disease must develop in a person who did not have the disease previously. The numerator is the number of new cases of disease (the event), and the denominator is the number of people at risk for developing the disease. Everyone included in the denominator must have the potential to become part of the group that is counted in the numerator. For example, to calculate the incidence of prostate cancer, the denominator must include only men, because women are not at risk for prostate cancer. The third component is the period of time. Any time unit can be used as long as all those counted in the denominator are followed for a period comparable with those who are counted as new cases in the numerator. The most commonly used time denominator is one year.

Incidence density, which is often simply called *incidence rate*, is the occurrence of new cases of disease per unit of person-time. This metric directly incorporates time into the denominator and is generally the most useful measure of disease frequency; it is often expressed as new events per person-year or per 1,000 person-years. Incidence is a measure of events (in this case, the transition from a nondiseased state to a diseased state) and can be considered a measure of risk. This risk can be looked at in any population group, defined by age, sex, place, time, sociodemographic characteristics, occupation, or exposure to a toxin or any other suspected causal factor.

Prevalence is a measure of present status rather than of newly occurring disease. It measures the proportion of people who have the defined disease at a specific point of time. Thus, it is a composite measure made up of two factors—the incidence of the disease that has occurred in the past and its continuation to the present or to some specified point in time. That is, prevalence equals the incidence rate of the disease multiplied by the average duration of the disease. For most chronic diseases, prevalence rates are more commonly available than are incidence rates.

Severity of Disease

To understand the burden of disease in a population, it is important to consider not only the frequency of the disease but also its severity, as indicated by the morbidity and premature mortality that it causes. *Premature mortality* is defined as death before the expected age of death had the disease not occurred. *Morbidity* is a statement of the extent of disability that a person suffers as a consequence of the disease over time and can be measured by a number of indicators, as discussed later in this chapter.

Mortality

Traditionally, mortality has been the most important indicator of the health status of a population. John Grant developed the first known systematic collection of data on mortality with the *Bills of Mortality* in the early 1600s in London. He described the age pattern of deaths, categorized them by cause as understood at the time, and demonstrated variations from place to place and from year to year. Mortality rates according to age, sex, place, and cause continue to be central information about a population's health status and a crucial input for understanding and measuring the burden of disease. Considerable literature exists on the use of mortality to indicate health status and its application to national and subnational levels (Murray & Chen, 1992).

The fact of death by age, sex, and place is required by law in most countries through death registration, and in many countries the cause of death through death

certification is required as well. Both provide essential information about the health status of a population. Nevertheless, in many low-income countries, the fact of death, let alone its cause, is still not reliably available.

In high-income countries, vital statistics (i.e., the registration of births and deaths by age, sex, and place) are routinely collected and highly reliable. In most middle-income countries, the reliability and completeness of these data have been steadily improving and often are fairly satisfactory. In contrast, the collection of vital statistics remains grossly incomplete in many low-income countries. An analysis of death registration in the course of the Global Burden of Disease study showed that vital registration data together with sample registration systems still do not cover 100% of global mortality. Survey data and indirect demographic techniques are needed to provide information on levels of child and adult mortality to paint a complete picture of global mortality (GBD 2015 Mortality and Causes of Death Collaborators, 2016). Nevertheless, even in low-income countries, increasing use of survey methods is delivering useful estimates of the mortality rates for the population younger than age 5 years and other populations.

Obtaining information about cause of death remains difficult even in many middle-income countries; a lot of information depends on special surveys or studies of select populations. Verbal autopsies (VAs) have been used increasingly for judging the likely cause of death, especially for children younger than age 5. This method comprises structured questions administered by trained interviewers with family members after a death; the information is then reviewed by physicians (or computers) to assign a cause of death using algorithms. VAs are useful for assessing some causes of death such as neonatal tetanus and severe diarrhea, but their sensitivity and specificity may be limited for diseases whose symptoms are variable and nonspecific, such as malaria (Anker et al., 1999; Thatte, Kalter, Baqui, Williams, & Darmstadt, 2009). Recently, automated systems for analyzing VA data have been developed and are being tested.

Age-specific mortality profiles are a prerequisite for a burden of disease analysis. Although extensive work has been done to document and analyze child mortality in low- and middle-income countries (LMICs), less has been done for adult mortality (Hill, 2003). LMICs have higher rates of age-specific adult mortality than do high-income nations (GBD 2015 Mortality and Causes of Death Collaborators, 2016; Lopez et al., 2002; Murray & Chen, 1992). Indeed, mortality rates are higher for both women and men in LMICs at every age when compared with the high-income world. In Africa, the enormous increase in deaths of young and middle-aged women and men from acquired immunoeficiency syndrome (AIDS) has had a profound impact on mortality and survival (**EXHIBIT 1-2**).

Traditional indicators of mortality have been the standard for assessing population health status. Neonatal mortality rates (NMR; deaths of live-born infants before 28 days of age per 1,000 live births), infant mortality rates (IMR; deaths of live-born infants before 12 months of age per 1,000 live births), and child mortality (deaths of children younger than 5 years of age) are considered sensitive indicators of the overall health of nations. The United Nations Children's Fund (UNICEF) publishes an annual global report that includes a ranking of nations based on these indicators (UNICEF, 2015). These indicators have the added advantage of having been studied for their relationships with other indicators of the social and economic development of nations. For example, a clear relation exists between the gross national product (GNP) per capita, which is an indicator of national wealth, and child mortality. In general, the higher the level of economic development, the lower the rate of child mortality. However, there are exceptions, and they need to be examined carefully. For example, Sri Lanka and the Indian state of Kerala are both low-income regions that have traditionally had low child mortality rates. These examples demonstrate that the relationship between mortality and poverty is complex and needs in-depth investigation.

There are major deficiencies in cause-specific mortality data in low- and most middle- income countries. In keeping with demographic and epidemiologic transitions, the pattern of cause-specific mortality changes at different levels of total mortality, with a general trend of decreasing infectious and parasitic disease cause-specific mortality with declining total mortality. Indeed, mortality from these communicable causes has been a major reason for the historical difference between high- and low-mortality populations (Murray & Chen, 1992).

The cause of death certification system based on WHO's *International Classification of Diseases* (ICD) has been used widely in many countries for many years (WHO, 2016). Despite the existence of this standardized process for categorizing deaths, variations in the reliability of these data occur because of variations in the training and expertise of the people who are coding causes of death, as well as the supervision and feedback provided. Nevertheless, there have been steady improvements in many countries, including automation of data collection and analysis, and these kinds of data provide some of the best information available on major causes of mortality.

EXHIBIT 1-2 Trends of the HIV/AIDS Epidemic

Globally, AIDS is the leading infectious cause of death among 15- to 49-year-olds (Global Burden of Disease Risk Factors Collaborators et al., 2015). Untreated disease caused by the human immunodeficiency virus (HIV) has a case fatality rate that approaches 100% (WHO, 2003). Unknown more than 30 years ago, the HIV/AIDS epidemic has killed more than 35 million people.

At the end of 2016, an estimated 36.7 million people were living with HIV/AIDS, with 69.5% of those individuals living in sub-Saharan Africa (WHO, 2017) . The prevalence of new HIV infections has increased by 60% in eastern Europe and Central Asia (**TABLE 1-1**) (UNAIDS, 2017; WHO, 2017).

HIV/AIDS is the tenth leading cause of disability-adjusted life years, accounting for 2.7% of this global burden. In terms of mortality, it is the eleventh leading cause of death among people of all ages, accounting for 2.1% of all deaths (Global Burden of Disease Risk Factors Collaborators et al., 2015). Nearly 42% of the 1 million global deaths from HIV/AIDS have occurred in East and Southern Africa (**FIGURE 1-1**) (UNAIDS, 2017).

TABLE 1-1 Global Summary of HIV and AIDS Epidemic

Number of people living with HIV	**Total**	**36.7 million**	**(30.8–42.9 million)**
	Adults	34.5 million	(28.8.4–40.2 million)
	Women	17.8 million	(15.4–20.3 million)
	Children	2.1 million	(1.7–2.6 million)
Number newly infected with HIV	**Total**	**1.8 million**	**(1.6–2.1 million)**
	Adults	1.7 million	(1.4–1.9 million)
	Children	160,000	(100,000–220,000)
AIDS deaths	**Total**	**1.0 million**	**(830,000–1.2 million)**
	Adults	890,000	(740,000– 1.1 million)
	Children	120,000	(79,000–160,000)

Reproduced from Joint United Nations programme on HIV/AIDS (UNAIDS). (2017). *UNAIDS Data 2017*. Geneva, Switzerland: Author. Retrieved from http://www.unaids.org/sites/default/files/media_asset/20170720_Data_book_2017_en.pdf

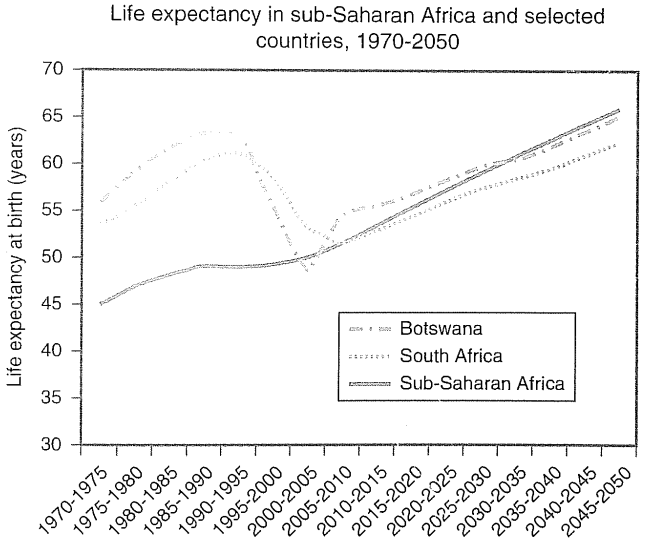


FIGURE 1-1 Trends in life expectancies and the HIV/AIDS epidemic.

Courtesy of Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat. (2008). *World population prospects: The 2008 revision*. Retrieved from www.un.org/esa/population/publications/wpp2008/wpp2008_highlights.pdf

Reproduced from Joint United Nations programme on HIV/AIDS (UNAIDS). (2017). *UNAIDS Data 2017*. Geneva, Switzerland: Author. Retrieved from http://www.unaids.org/sites/default/files/media_asset/20170720_Data_book_2017_en.pdf; World Health Organization (WHO). (2017). *Global health observatory (GHO) data – HIV/AIDS*. Geneva, Switzerland: Author. Retrieved from http://www.who.int/gho/hiv/en/

Mortality can be expressed in two important quantitative measures: (1) *mortality rate* (MR) and (2) *case fatality ratio* (CFR). The MR, a form of incidence rate, is expressed as the number of deaths in a defined population in a defined time period. The numerator can be total deaths, age- or sex-specific deaths, or cause-specific deaths; the denominator is the number of persons at risk of dying in the stated category as defined earlier for incidence. Demographers use the notation XqY for the probability of dying in the Y years following age X at the then prevailing age-specific mortality rates for the population. Thus, 5q0 is the probability of death of newborns by age 5 years (see Table 1-2 later in this chapter), and 30q15 is the probability of death in young adults from age 15 to 45. The CFR is the proportion of those persons with a given disease who die of that disease (at any time, unless specified). The MR is equal to the CFR multiplied by the incidence rate of the disease in the population.

The distinction between the proportion of deaths attributable to a cause (number of deaths due to the cause divided by total number of deaths in a given population in a given time period) as compared to the probability of death from the cause (disease-specific MR) is important to understand. For example, the probability of death (and disability) from noncommunicable causes (indeed, from virtually all causes) is higher in low- and middle-income regions than in the high-income world. However, the proportion of deaths and disability attributable to these chronic causes is smaller in LMICs than in wealthier countries because of the much larger toll taken by infectious and nutritional causes. With increasing economic development, the risk of death and disability from chronic disease does not increase; rather, the proportion of deaths attributable to chronic disease increases as the proportion of deaths attributable to communicable and nutritional disease declines.

Demographic and Epidemiologic Transitions

The demographic transition describes the changes in birth and death rates that historically have accompanied the shift from a traditional society to a modern society; it is detailed in other chapters. With modernization, sharp declines in mortality have been followed by a reduction in fertility, albeit one that commonly lags behind the change in the death rate by years or decades. The term *transition* refers to the shift away from a stable population in which very high birth rates are balanced by very high death rates to a stable population in which low birth rates are balanced with low death rates. In between these extremes, as a society undergoes modernization, there is a lag between falling mortality, especially in the under-5 age group, and the drop in birth rates that leads to explosive population growth. Thereafter birth rates fall and a new stage is reached in which birth and death rates are low and balance resumes. The result is a striking change in the age structure of the population, with a decreased proportion of children and an aging population. These changes in the population age distributions are reflected in the shift from a wide-based pyramid, reflecting larger numbers in the younger age groups, to a structure with a narrow base, nearly rectangular configuration, and nearly equal percentages in each age group.

In 1971, Omran described the underlying reasons for the demographic transition and used the term *epidemiologic transition* to explain the changing causal factors of disease that accounted for the dramatic drop in under-5 mortality, which was largely due to reduction in malnutrition and communicable diseases. Although high rates of maternal mortality are characteristic of the low- and middle-income world, reductions in maternal mortality occur in a different time frame from those in under-5 mortality. Reductions in maternal mortality require a better-developed infrastructure, including ready availability of surgical and blood transfusion capacity plus improved communication and transportation systems. Thus, drops in maternal mortality occur much further along the road toward economic development, and changes occur only after shifts in the child mortality have been seen.

Major changes in the patterns and causes of injury are also likely to occur with modernization. For example, road traffic injuries tend to increase as countries go through the stage of development in which there is a great increase in vehicles and in the speeds at which they are operated before improved roads, appropriate laws and regulations, and law enforcement are in place (Crooper & Kopits, 2003; WHO, 2015). There may also be important shifts in the nature of violence and the people toward whom it is directed, related to crime patterns, civil unrest, ethnic conflicts, and intrafamily tensions (WHO, 2002b). The profound impact of the HIV/AIDS epidemic was discussed earlier in Exhibit 1-2.

Other Health-Related Metrics

In addition to basic measures of mortality, morbidity, and life expectation that are central for population health status assessment, a variety of important health-related indicators are useful for specific purposes. Many are discussed more fully in other chapters of this text; they are summarized in **TABLE 1-2**. Those related to the Sustainable Development Goals (SDGs) are discussed in **EXHIBIT 1-3**.

TABLE 1-2 Health-Related Metrics

Type	Indicator	Definition/Interpretation
Demographic indicators: reproductive health	Maternal death	Death of a woman while pregnant or up to 42 days post-delivery from any cause except accident
	Maternal mortality ratio	Maternal deaths per number of pregnancies (maternal deaths per 100,000 live births)
	Maternal mortality rate	Maternal deaths per number of women of reproductive age (maternal deaths per 100,000 women aged 15–49)
	Lifetime risk of maternal mortality	Cumulative loss of human life due to maternal death over the female life course
	Total fertility rate	Average number of children a woman would bear if she lived to the end of her reproductive period
	Life expectation at birth	Average number of years a newborn would live if his or her life were lived under the mortality conditions for the place and year in question
Anthropometric indicators: nutrition	Weight for age	Underweight
	Height for age	Stunting
	Weight for height	Wasting
	Mid-upper arm circumference	Wasting
Mortality (death) indicators	Mortality rate	Number of deaths in a specified time period/number of persons at risk of dying during that period
	Infant mortality rate	Number of deaths of live born infants before 12 months of age per 1,000 live births
	Under-5 mortality rate	Number of deaths of children younger than age 5 per 1,000 live births averaged over the last 5 years
	5q0	Probability of death of a newborn by age 5
	Neonatal mortality rate	Number of deaths of live-born infants before 28 days of age per 1,000 live births
	Stillbirth rate	Number of babies born with no signs of life at or after 28 weeks' gestation per 1,000 births
	Perinatal mortality rate	Number of fetal deaths (28 or more weeks of gestation) + postnatal deaths (first week) per 1,000 live births
Disease frequency	Endemic	Usual occurrence of a given disease in a defined population
	Epidemic	Occurrence of a given disease in a defined population clearly in excess relative to its usual occurrence
	Pandemic	A worldwide epidemic involving large numbers

EXHIBIT 1-3 Sustainable Development Goals

On September 25, 2015, UN member states adopted 17 *Sustainable Development Goals* (SDGs) as part of the post–Millennium Development Goals (MDGs) development agenda. The SDGs build on the goals identified under MDGs and broaden the scope to include new areas of focus—for example, climate change, economic inequality, innovation, sustainable consumption, and peace and justice—to improve overall well-being and life of current and future generations through sustainable means.

The 17 SDGs were divided into 169 quantifiable targets that are measured by 230 indicators. Of these, 21 targets and 39 indicators are directly related to health. The health-related indicators include a variety of indicator types: incidence rates, prevalence "rates," mortality rates, mortality ratios, birth rates, and proportion of target populations receiving an intervention.

Appendix 1 provides examples of some of the health-related SDG indicators.

Morbidity and Disability

Measures of mortality have been the principal indicators of population health status for generations. Their relative ease of observation, availability of data, and history of use make mortality information useful for assessing and monitoring the health status of populations. However, the key limitation with mortality-based indicators is that they "note the dead and ignore the living" (Kaplan & Anderson, 1996). Measurements of morbidity, by comparison, are more problematic because there is not a clearly defined endpoint such as death provides. In addition, several components of disability need to be assessed, and there may be a substantial subjective aspect to grading the extent or severity of a condition.

The *International Classification of Impairments, Disabilities, and Handicaps* (ICIDH) was developed in the 1970s to classify nonfatal health outcomes as an extension of WHO's ICD system (WHO, 1980). It was developed to more fully describe the impact of a given disease on an individual and on society, and to account for that disease's heterogeneity of clinical expression and evolution in different individuals and societies. ICIDH categories included *impairment* (loss or abnormality of psychological, physiological, or anatomic structure or function), *disability* (restriction or lack of ability to perform an activity considered normal), and *handicap* (disadvantage from a disability or impairment for a given individual based on the inability to fulfill a normal role as defined by age, sex, or sociocultural factors). These distinctions clarified more than just processes—they helped define the contribution of medical services, rehabilitation facilities, and social welfare to the reduction of disability.

In 2002, WHO built on the ICIDH to develop the *International Classification of Functioning, Disability, and Health*, commonly known as ICF (WHO, 2002c). In this system, health-related domains are classified from the perspectives of the body, of the individual, and of society by means of two lists: a list of body functions and structures, and a list of domains of activity and participation. Because an individual's functioning and disability occur within a context, the ICF also includes a list of environmental factors that provide a description of that context. The ICF has become WHO's framework for measuring health and disability at both individual and population levels. It was officially endorsed by all 191 WHO member states in the Fifty-Fourth World Health Assembly on May 22, 2001 (resolution WHA 54.21). Unlike its predecessor, which was endorsed for field trial purposes only, the ICF was endorsed for use in member states as the international standard to describe and measure health and disability.

Using such classifications, indicators of disability—such as *impairment-free*, *disability-free*, and *handicap-free* life expectancies—have been developed. These, in turn, have been used to estimate health-adjusted life expectancies using severity and preference weights for time spent in states of less than perfect health.

Hospital inpatient discharge records—when they are based on good clinical evidence and coded by staff well trained in coding procedures—can provide high-quality data on the major causes of morbidity serious enough to require hospitalization. They also can provide good cause-of-death data for hospitalized persons, and some sense of the outcome status of those with serious conditions. Hospital data are generally improving in quality, especially in middle-income countries and in selected sentinel (usually tertiary care) teaching hospitals in low-income countries. Such information is inevitably biased because of the highly skewed distribution of those using such hospitals, but in many situations it is possible to have a good understanding of those biases and make appropriate adjustments to draw useful conclusions.

Generally, outpatient records in most of the world are highly deficient in terms of diagnosis; indeed,

they often identify only the patient's chief complaint and the treatment dispensed. The main value of most such records is limited to establishing the fact of using a facility. There are usually strong biases in terms of those patients who use outpatient facilities because of access factors (distance and cost of use), nature and severity of the disease problem, and opportunity for using alternative services.

Visits to healthcare facilities, functional disability (a measure of activity that is less than the norm), and time spent away from work (absenteeism, work days lost) have all been used to assess the magnitude of morbidity from various conditions. A commonly used approach to evaluating morbidity in a population has been the assessment of the impact on social roles or functional performance, such as days missed from work or spent in bed (Kaplan & Anderson, 1996). A considerable body of literature focuses on the wide variety of instruments used to measure such functional capacity, especially in the clinical medical literature, that are not directly useful for population-based morbidity assessment.

Data about morbidity are often based on self-perceived assessments, and are frequently gleaned from survey-based interview information. The perception of morbidity and its reporting, the observation of morbidity and its impact, and other factors are responsible for the wide variations between reported and measured prevalence of conditions (Murray & Chen, 1992). This has resulted in an underestimation of the presence and impact of morbidity in both LMICs as compared with high-income nations. This situation also underscores the variations in morbidity data, which are often interpreted as indicating that wealthy individuals and low-mortality populations report higher rates of morbidity (*Global Burden of Disease and Risk Factors*, 2006; Woolf et al., 2015).

Measurement of health-related quality of life has also been discussed in the medical literature for decades. *Health-related quality of life* refers to how well an individual functions in daily life and his or her perception of well-being. Various domains of quality have been defined, such as health perception, functional status, and opportunity, and several instruments have been developed to evaluate them. Both disease-specific and general instruments exist, with such tools abounding in fields dealing with patients having chronic disabled states, such as psychiatry, neurology, and counseling. These scales are often dependent on self-reported information, although some incorporate observational data as well. However, concerns have been raised about their reliability and validity. These measures are not discussed further in this text, because they have been primarily used in clinical assessments of individuals, rather than larger populations.

Measuring Disability

If all the various forms of disability—physical, functional, mental, and social—are to be compared with mortality, they must be measured in an equivalent manner for use in health assessments. To do so, measurement of disability must quantify the duration and severity (extent) of this complex phenomenon. A defined process is needed that rates the severity of disability as compared with mortality, measures the duration of time spent in a disabled state, and converts various forms of disability into a common scale. General measures of disability without regard to cause (often carried out by special household surveys) are useful to determine the proportion of the population that is "disabled" and unable to carry out normal activities, but are not much help for quantifying the extent of disability.

In general, three components of disability need to be assessed. The first component is the *case disability ratio* (CDR)—the proportion of those diagnosed with the disease who have disability. For most diseases that are diagnosed clinically, the CDR will be 1.00 because, by the definition of disease given earlier, patients will have signs or symptoms. In contrast, when the diagnosis is based on, for example, infection rather than disease (such as tuberculosis) or on a genetic marker rather than the physical manifestation (such as sickle cell trait), the CDR is likely to be less than 1.00.

The second component of disability is its *extent or severity*—how incapacitated the person is as a result of the disease. The extent of disability is expressed on a scale, such as from 0 (indicating no disability) to 1.00 (equivalent to death). The assessment of severity can be quite subjective, particularly because so many different types and dimensions of disability exist. A number of methods have been introduced in an effort to achieve comparability and obtain consistency (Murray, Salomon, Mathers, & Lopez, 2002).

Measurement of individual preferences for different health states to determine relative severity of disability has been done by a variety of methods (Kaplan & Anderson, 1996; Murray et al., 2002; Torrance, 1986). Factors that influence the assessment of such preferences include the type of respondent, the type of instrument used to measure the response, and the time from entry into the disabled state. Individuals who are in a particular state, healthy individuals, healthcare providers, caretakers, and family members have all

been interviewed in studies. Adaptation, conditioning, development of special skills, and vocational training can all change the response of individuals over time within a particular health state, thereby affecting the value of that state to the individual. As a consequence, the valuation is time dependent—for example, the value placed on a year of life by a paraplegic soon after entering that health state would be different from that obtained after several years of adjustment to that state (Murray & Lopez, 1994).

Instruments used to extract such preferences involve visual and interview techniques (*Global Burden of Disease and Risk Factors*, 2006; Torrance, 1986). Two alternative scenarios are often presented to the subject and the point of indifference sought (as in standard gamble techniques). Despite much work in this area, there is no consensus or accepted standard method for such elicitation. Severity of disability scales have been developed by group consensus using community surveys (Kaplan & Anderson, 1996), a mixture of community and expert groups (Ghana Health Assessment Team, 1981), experts only (World Bank, 1993), and population surveys (Global Burden of Disease Risk Factors Collaborators et al., 2015; Murray et al., 2002; Salomon et al., 2012). These scales usually compare perfect health states to death on a scale of 0 to 1 (**TABLE 1-3**).

In the first Global Burden of Disease 1990 study, the disability severity estimates were based on expert opinion. Twenty-two indicator conditions were selected and used to construct seven disability classes (Table 1-3). Outcomes from all other health conditions were categorized within these seven classes (with special categories

TABLE 1-3 Examples of Disability Classification Systems

Ghana Health Assessment Team, 1981		
Class	**Severity**	**Equivalent to (Maximum)**
1	0	Normal health
2	0.01–0.25	Loss of one limb's function
3	0.26–0.50	Loss of two limbs' function
4	0.51–0.75	Loss of three limbs' function
5	0.76–0.99	Loss of four limbs' function
6	1	Equivalent to death

Global Burden of Disease Study, 2013*	
Category	**Disability Weight for Unique Health States**
Infectious disease	Acute episode, mild: 0.006 (0.002–0.012) Acute episode, moderate: 0.051 (0.032–0.074) Diarrhea, mild: 0.074 (0.049–0.104) Ear pain: 0.013 (0.007–0.024)
Cancer	Diagnosis and primary treatment: 0.288 (0.193–0.399) Metastatic: 0.451 (0.307–0.600)
Cardiovascular and circulatory disease	Acute myocardial infarction (MI), days 1–2: 0.432 (0.288–0.579) Acute MI, days 3–28: 0.074 (0.049–0.105) Heart failure, mild: 0.041 (0.026–0.062)
Diabetes and digestive and genitourinary disease	Diabetic foot: 0.020 (0.010–0.034) Gastric bleeding: 0.325 (0.209–0.462) Infertility, primary: 0.008 (0.003–0.015)

Chronic respiratory disease	Asthma, controlled: 0.015 (0.007–0.026) Chronic obstructive pulmonary disease (COPD) and other chronic respiratory diseases, mild: 0.019 (0.011–0.033) COPD and other chronic respiratory diseases, severe: 0.408 (0.273–0.556)
Neurologic disorders	Dementia, mild: 0.069 (0.046–0.099) Multiple sclerosis, moderate: 0.463 (0.313–0.613) Parkinson's disease, severe: 0.575 (0.396–0.730)
Mental, behavioral, and substance use disorders	Alcohol use disorder, very mild: 0.123 (0.082–0.177) Anxiety disorders, moderate: 0.133 (0.091–0.186) Anorexia nervosa: 0.224 (0.150–0.312)
Hearing and vision loss	Hearing loss, mild: 0.010 (0.004–0.019) Hearing loss, profound, with ringing: 0.277 (0.182–0.387) Distance vision, severe impairment: 0.184 (0.125–0.258)
Musculoskeletal disorders	Low back pain, moderate: 0.054 (0.035–0.079) Neck pain, severe: 0.229 (0.153–0.317) Gout, acute: 0.295 (0.196–0.409)
Injury	Burns, lower airway, with or without treatment: 0.376 (0.240–0.524) Crush injury, short or long term, with or without treatment: 0.132 (0.089–0.189) Concussion: 0.110 (0.074–0.158)
Other	Abdominopelvic problem, mild: 0.011 (0.005–0.021) Anemia, moderate: 0.052 (0.034–0.076) Hypothyroidism: 0.019 (0.010–0.032)

* Health states included in this table are only examples. The full list of 235 unique health states and their disability weights are available in Salomon et al., 2015.
Data from Salomon, J. A., Haagsma, J. A., Davis, A., de Noordhout, C. M., Polinder, S., Havelaar, A. H., et al. (2015). Disability weights for the Global Burden of Disease 2013 study. *Lancet Global Health, 3*(11), e712-723. doi: 10.1016/S2214-109X(15)00069-8

for treated and untreated groups). This approach was revised for the 2010 iteration of the study, for which the process included empirical studies comprising simple paired questions, and survey of the general public through household surveys in countries such as Bangladesh, Indonesia, Peru, Tanzania, and the United States, as well as a web-based survey in English, Spanish, and Mandarin. The result was a categorization that included 220 health states (Salomon et al., 2012). Generally, for most conditions a reasonable degree of consensus can be reached within broad categories (e.g., 25% disabled as compared with 50%), but efforts to reach much finer distinctions have proved equivocal. The need to seek out more refined scales for purposes of health program decision making ought to be a national or local decision.

The third component of disability is its *duration*. The duration is generally counted from onset of the disability until cure, recovery, or death. Sometimes there is continuing permanent disability after the acute phase is completed; in such a scenario, the duration would be the remaining life expectation from the time of onset of disease.

Data for Decisions

In the collection and assessment of information, the level of precision required should be guided by the purpose for collecting the information and depend on the decisions to be taken. Even rough estimates may be helpful; though disconcerting to some, the time and cost of efforts to realize further precision need to be justified by the increased precision's potential impact on decision making. LMICs, with their scarce resources, need timely and appropriate information to plan and implement health interventions that maximize the health of their populations. Methods, indicators, and assessments of disease must support and contribute to this primary purpose of health systems.

Decisions concerning deployment of interventions against diseases and underlying risk factors ideally should be taken such that maximum healthy life per resource expenditure is obtained in an equitable, fair, and just fashion. The ultimate reason for obtaining health data is to have the information to guide such decision making.

Summary Measures of Population Health

This section focuses on the major approaches used for developing composite measures of population health status that summarize mortality and morbidity occurring in a population through the use of a single number. It discusses the rationale for composite measures, reviews the origins of each major approach, examines methodological differences among these approaches, and outlines the advantages and limitations of each.

Rationale for Composite Measures

Rationing of healthcare resources is a fact of life everywhere; choices about the best use of funds for health must inevitably be made (Hyder, Rotllant, & Morrow, 1998; WHO, 2000). The global scarcity of resources for health care is a challenge for every country, rich and poor (Evans, Hall, & Warford, 1981; Figgis & Walters, 2015–2017; World Bank, 1993), but the realities in LMICs paint the choices in much starker terms. It is even more important for LMICs to choose carefully how to optimize health expenditures so as to obtain the most health in the most equitable fashion from these expenditures. Important tools under development to assist in making better choices for health spending are based on measures of the effectiveness of health interventions in improving health status in relation to their cost.

In most sectors, decisions on resource allocation are based on perceived value for money. The health sector, however, has had no coherent basis for determining the comparative value of different health outcomes (from different health programs). To make decisions about whether to put money into programs that reduce mortality in children, as compared with those programs that reduce disabling conditions in adults, a common denominator is needed. In recent decades, work has been carried out to develop composite indicators combining morbidity and mortality into a single measure that may serve as a common denominator for comparing different health outcomes. A common unit of measure for these different health outcomes is *time lost from healthy life*.

The most important reason for attempting to capture the complex mix of incommensurable consequences resulting from disease within a single number is the need to weigh the benefits of health interventions against their costs. Costs of health programs are expressed in a unidimensional measure, such as U.S. dollars; therefore, the benefits to be achieved from their expenditure should be expressed in the same manner. *Healthy lifetime* is a unidimensional measure that can be used to compress health benefits and losses into a single time dimension. An explicit, objective, quantitative approach should enable better budgetary decisions and permit resource allocation in the health sector to be undertaken in a more effective and equitable fashion.

Note that a composite indicator is simply a tool to be used to assist decision makers in resource allocation. Like any tool, it can be misused. Conclusions that are reached on the basis of these indicators must be carefully examined. Not only do problems arise in trying to put so many dimensions together, which inevitably may lead to distortions, but serious issues also emerge concerning the reliability and validity of the information on which these indicators are based. Thus, all the problems associated with determining causes of death, counting the number of cases of disease, and assessing the extent of disability from a condition will lead to uncertainties when these factors are added and multiplied together. The development of a single indicator consisting of a specific number implies deceptive stability about something that may actually be composed of fragile data. Continuing vigilance in how these data are obtained, compiled, and used is critical, and those responsible for using the tool must have a clear technical understanding of what lies behind the numbers and which underlying assumptions and limitations are associated with these approaches. Despite all of these caveats, alternative approaches to improved decision making leave even more to be desired.

Uses of Composite Indicators

Measures of health status that combine mortality and morbidity facilitate comparisons both within and across populations. They can be used to estimate the quantitative health benefits from interventions and serve as tools to assist in the allocation of resources. The development of such measures entails two major processes: the measurement of healthy life, including losses of time from premature mortality and disability; and the valuing of life, which incorporates issues of duration, age, extent of future life, productivity, dependency, and equity (Morrow & Bryant, 1995). The purpose of developing such measures and the need for refining them become clear if the following objectives are to be achieved:

- The use of such methods at the country level for evaluating the impact of diseases
- Their use in the allocation of resources within the health sector
- The generation of more relevant and useful data for policy makers

Understanding Summary Measures

Precursors of composite indicators have been discussed in the literature for decades and generally were developed to assist with prioritization of health issues. Usually these metrics were based on the measurement of losses of time, losses of productive time, income forgone, or other costs incurred as a result of diseases. The earlier indicators generally focused on economic losses and estimated time loss due to disease and converted these losses into a dollar value. Thus, these measures are more economic measures than disease burden measures.

Two types of composite summary measures have been developed: *health gap measures* (healthy life lost), such as healthy life years (HeaLYs) or disability-adjusted life years (DALYs), and *health expectancies*, such as disability-free life expectancy (DFLE) or health-adjusted life expectancy (HALE). Both types use healthy lifetime lost through disability and death as a common measure of the impact of mortality and nonfatal health outcomes. These two types of measures are complementary and can be studied using survivorship curves, as discussed by Murray and Lopez (1994) (**FIGURE 1-2**).

In Figure 1-2 (Murray et al., 2002), the darker line is the survivorship curve based on a standard hypothetical life table population that demonstrates the proportion (y-axis) of an initial birth cohort that remains alive at any age (x-axis). The area A + B is the total life expectancy at birth of this cohort. A part of this life is spent in full health (area A); the lighter line is the survivor curve of those persons in full health. Thus, area A represents time lived in full health, whereas area B is time lived in suboptimal health (with disability). Area C represents time lost due to mortality. The area of the complete rectangle (A + B + C) represents the ideal survivorship curve—the theoretical maximum of healthy life for a cohort who lived in full health until a maximum age when all died.

Health expectancies are summary measures that estimate expectancy of life in a defined state of health. Examples include DFLE, active life expectancy, and HALE. These indicators extend the concept of life expectancy to expectations of various states of health, not just of life per se. Health expectancies assign lower weights to life lived in less than full health on a scale of 0 to 1, in which full health is rated 1. In Figure 1-2, health expectancy is given by the following equation:

$$\text{Health expectancy} = A + f(B)$$

where f is some function that assigns weights to years lived in suboptimal health.

Health gaps are summary measures that estimate the difference between actual population health and some specified norm or goal. In Figure 1-2, that difference is indicated by area C (loss due to mortality) plus some function of area B—that is, survivorship with disability:

$$\text{Health gap (healthy life lost)} = C + g(B)$$

where g is some function that assigns weights to health states lived during time B. Weights range between 0, meaning no disability (full health), and 1, meaning complete disability (equivalent to death). Note that this measure is equivalent to healthy life lost based on the natural history of disease in a population as discussed in the section "Healthy Life Year" later in this chapter.

Although some believe that health expectancies such as the HALE indicator are more readily understood (because they are conceptual extensions of the

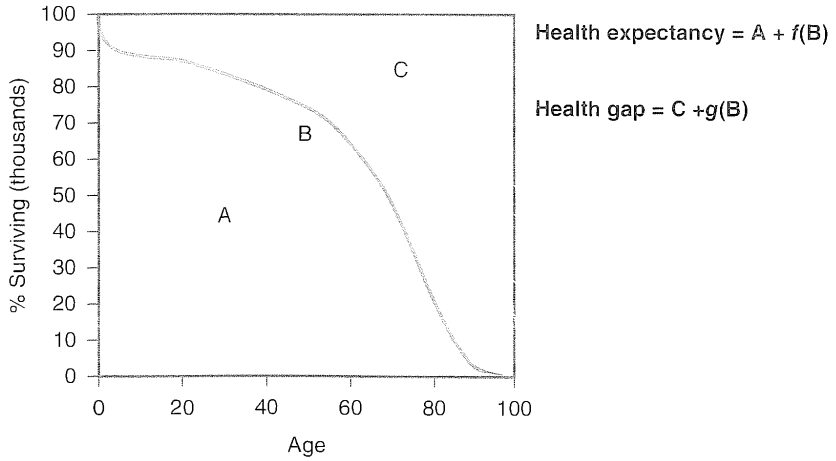


FIGURE 1-2 Survivorship curve of a hypothetical population showing health gaps and health expectancies.

Modified from Murray, C. J. L., et al. (2002). *Summary measures of population health*. Geneva, Switzerland: World Health Organization.

widely used life expectancy measure), health gap measures have important advantages for the purposes of health policy, planning, and resource allocation decisions. Both HeaLYs and DALYs are developed on the basis of disability and death attributable to a specific disease in an individual person. In their construction, great care is taken to ensure that there is *categorical attribution* using the ICD, so that each event (death or disability) is mutually exclusive and collectively exhaustive. With these measures, therefore, summing deaths and disabilities from each disease provides the total amount of death and disability for the population (a property termed *additive decomposition*). Health gap measures have this property, whereas health expectancies do not (Murray et al., 2002).

Composite Indicators

A number of composite summary indicators for burden of disease assessment have been developed. We will focus on four of these indicators: three of the health gap type (the healthy life year, the disability-adjusted life year, and the quality-adjusted life year) and one of the health expectancy type (HALE). In addition to measures of morbidity and mortality per se, these composite indicators may incorporate certain social value choices either explicitly or implicitly: the choice of life expectancy tables, valuing future life as compared with present life, valuing life lived at different ages, valuing social or economic productivity, and valuing equity in relation to cost-effectiveness. These social value choices are discussed later in this chapter (see the section "Valuing Life: Social Value Issues"), but because some social value choices are integral to the calculations of some composite indicators, they are briefly mentioned in this section.

Healthy Life Year

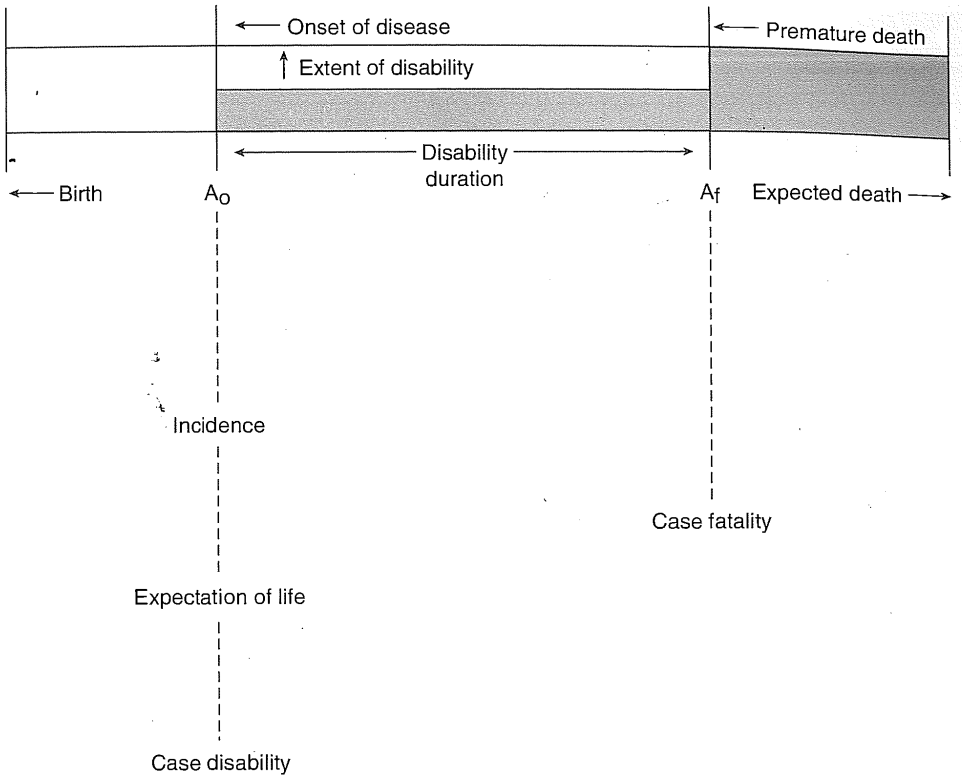
The healthy life year (HeaLY) is a composite measure that combines the amount of healthy life lost due to morbidity with that lost due to death—that is, loss of life expected had the disease not occurred (Hyder et al., 1998). We discuss the HeaLY first because it is conceptually straightforward, serves as a prototype for other health gap indicators, and was the first of the composite measures to be used as a tool in national health planning (Ghana Health Assessment Team, 1981).

Measuring the loss of healthy life from disability is more challenging than measuring the comparable loss from death, and many approaches have been used (Murray & Lopez, 1994). To incorporate loss from disability in a composite measure, such a loss must have comparable dimensions to that for life lost due to death. The HeaLY includes three components for disability: case disability ratio (comparable to the case fatality ratio), extent of disability, and duration of disability. The CDR and duration of disability can be determined objectively, but assessment of the extent of disability, which usually ranges from 0 (no disability) to 1 (equivalent to death), has a substantial subjective element (Morrow & Bryant, 1995).

The healthy life approach focuses on knowledge of the pathogenesis and natural history of disease (Last, Spasoff, & Harris, 2000) as the conceptual framework for assessing morbidity and mortality and for interpreting the effects of various interventions (**FIGURE 1-3**).

The onset of disease usually will be dated from the start of symptoms or signs, as determined by the individual afflicted, a family member, or a medical practitioner, or as the result of a lab test. Several different patterns of disease evolution are possible, of course. **FIGURE 1-4** illustrates healthy life lost from disability and premature death due to typical cases of cirrhosis, polio, and multiple sclerosis, respectively, in terms of onset, extent and duration of disability, and termination. The conclusion of the disease process depends on the natural history of the disease as modified by possible interventions. The possible outcomes include clinical recovery (the complete disappearance of clinical signs and symptoms), progression to another disease state (such as chronic hepatitis progressing to cirrhosis), and death. The last outcome includes death directly caused by the disease as well as death indirectly brought on by the disease as a result of disability.

The definitions of variables and formulas to calculate HeaLYs are provided later in this section and summarized in **TABLE 1-4**. Each disease will have a distribution of ages at which onset or death may occur, but for most diseases the average age will provide a satisfactory approximation for a population. In view of the limitations of data, this is the starting assumption for the application of the HeaLY method in LMICs. Nevertheless, as with other choices in this method, if sensitivity testing indicates that the average age is not satisfactory, then estimates may be based on age distributions. Similarly, if the natural history of a disease or response to interventions is different in different age groups, then the disease can be specifically classified by age (e.g., neonatal tetanus as compared with adult tetanus, and childhood pneumonia as compared with adult pneumonia). In recurrent diseases or diseases with multiple episodes (e.g., diarrhea), age at onset denotes the average age at first episode.



Note: A_o = average age at onset; A_f = average age at death; ▨ = healthy life lost.

FIGURE 1-3 The HeaLY model: Loss of healthy life from disability and death.

The expectation of life in HeaLYs were based on normative expectations of what should occur under usual circumstances at the time of that work. Women in Japan, who had the highest global expectation of life, approximated this norm with an expectation of life at birth of 82.5 years for females (Model Life Table West, level 26) (Coale, Demeny, & Vaughan, 1983; Coale & Guo, 1989).

The definition of disease ("dis-ease") makes the value of the case disability ratio 1 by default for most disease states, because all cases are disabled (to varying degrees and duration) if those persons have been labeled as diseased. For some conditions (e.g., sickle cell trait or HIV positivity) and risk factors, however, cases may not be considered diseased by definition, but the condition nonetheless needs to be assessed.

The duration of disability can be either temporary or permanent (lifelong). If the disability is temporary, then Dt is the duration of that disability until recovery (see Table 1-4). If the disability is permanent and the disease does not affect life expectation, then Dt is the expectation of life at age of onset of disease [Dt = E(Ao)]. If the disability is permanent and the disease reduces life expectation, then Dt is the expectation of life at age of onset reduced by the difference between ages of fatality and onset [Dt = E(Ao) − (Af − Ao)]. A disability severity scale needs to be used to estimate extent (severity) of the disability (see Table 1-4).

The HeaLYs lost from death and from disability are added and expressed as the total years of life lost per 1,000 population per year. The loss is attributed to the year in which disease onset occurs and includes the stream of life lost from disability and death at any time after onset, even if these events happen many years later. This method offers a prospective view of the event (disease onset) and its natural history (or as modified by interventions) over time.

An important benefit of the HeaLY formulation is that the effects of different kinds of interventions can be readily explored to determine their expected gains in terms of healthy life. The HeaLY spreadsheet (available upon request from the authors) incorporates these concerns; it also includes options for considering the proportion of the population that will be covered by an intervention and allows for different levels of coverage for different segments of the population for each intervention.

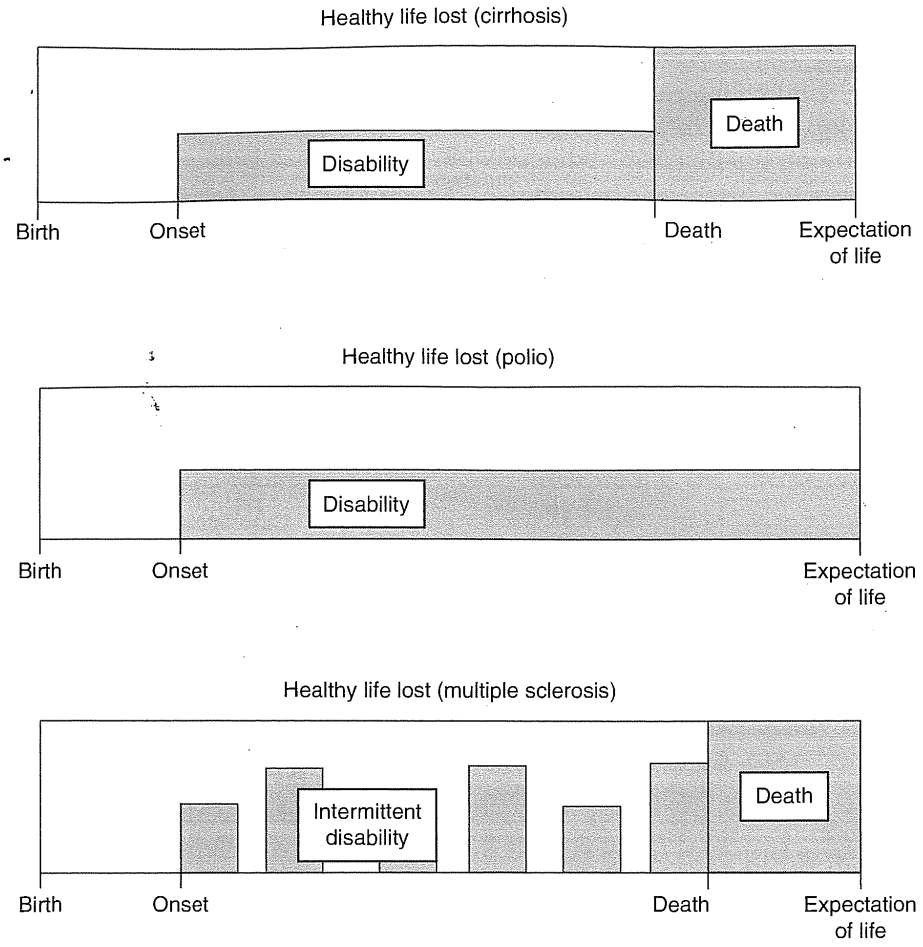


FIGURE 1-4 Different patterns of healthy life lost.

Reproduced from Hyder A., Rollant G., and Morrow R. H. (1998). Measuring the burden of disease: Healthy life-years. *American Journal of Public Health, 88*(2), 196–202. Figure 1, p. 197.

Disability-Adjusted Life Year

The disability-adjusted life year (DALY) is a health gap population summary measure that combines time lost due to disability with that lost due to death (life that would have been expected had the disease not occurred), in a manner similar to the HeaLY measure. It first appeared in the World Development Report of 1993 and has become the most widely used composite measure of population health (Global Burden of Disease Risk Factors Collaborators, 2016; Global Burden of Disease Risk Factors Collaborators et al., 2015; Jamison et al., 2006; Lim et al., 2012; Lopez et al., 2002; Murray & Lopez, 1994; Murray et al., 2002).

DALYs are calculated as two separate components for the measurement of life lost due to disease, and they may also directly include three social value choices. The two components are (1) years of life lost (YLL), referring to the loss of healthy life from death, and (2) years of life lived with disability (YLD), referring to the loss of healthy life from disability. Thus

$$\text{DALY} = \text{YLL} + \text{YLD}$$

The social value choices that may be included in DALYs are (1) life expectation values, (2) discount rates for future life, and (3) weighting for life lived at different ages, as discussed later.

Since the GBD 2010 study (Lozano et al., 2012), age weighting is no longer a default value choice for the DALY. Instead, users have the option to calculate these values with or without age weighting, as well as with or without discounting. The following three options could be applied: (1) use both age weights and discounting, (2) use either age weights or discounting, and (3) use neither age weights nor discounting.

The calculation for YLL in a population uses the age distribution of all deaths by cause in one year multiplied by life expectation at each age to estimate the loss of life for each disease that would have been expected if not for that disease. The expectation of life can be obtained either from a model life table (Coale & Guo, 1989) or based on the best achievable low levels of mortality such as those found in Japan; thus the DALY, as does the HeaLY, directly incorporates this social value choice.

TABLE 1-4 Variables for Estimating Healthy Life Years (HeaLYs)

Symbol	Explanation	Expression
I	Incidence rate per 1,000 population per year	/1,000/year
Ao	Average age at onset	years
Af	Average age at death	years
E(Ao)	Expectation of life at age of onset	years
E(Af)	Expectation of life at age of death	years
CFR	Case fatality ratio: proportion of those developing the disease who die from the disease	0.00–1.00
CDR	Case disability ratio: proportion of those developing the disease who have disability from the disease	0.00–1.00
De	Extent of disability (from none to complete disability equivalent to death)	0.00–1.00
Dt	Duration of disability in years	years
	Disability can be either permanent or temporary: ▪ If temporary, then Dt = duration of that disability (i.e., until recovery or death) ▪ If permanent and disease does not affect life expectation, then Dt = E(Ao) ▪ If permanent and the disease does reduce life expectation, then Dt = Af − Ao	
HeaLY	Healthy life years lost per 1,000 population per year: $I \times \{[CFR \times \{E(Ao) - [Af - Ao]\}] + [CDR \times De \times Dt]\}$	HeaLYs per 1,000 per year

For disability, the DALY uses estimates of incidence, duration, and severity to calculate the time lived with disability (YLD) for each disease. The YLD component equals the number of incident cases in the period multiplied by the average duration of disease multiplied by a weight factor for the degree of severity (extent) of the disease. A description of the severity scale used in one version of DALY was given earlier in this chapter, in the section on measurement of disability (see Table 1-4).

The second social value choice, which was directly incorporated in the original version of DALY, is the discount rate of 3% per annum. This social time preference has been used for most estimates; recently, DALY results discounted at 0% have also become available.

The third social value choice concerns weighting life lived at different ages. Earlier DALYs were age weighted according to an arbitrary exponential curve designed to give the most value to life lived as a young adult (Hyder et al., 1998; World Bank, 1993). Weighting by age was the most controversial component of the DALYs when they appeared and caused great dissent from other health professionals (see the section "Valuing Life Lived at Different Ages" later in this chapter). Recent DALY listings from GBD studies also include results with no age weighting (all years equally valued). It has been argued that age weighting

of DALYs does not affect final results, but this depends on the purpose for making the estimates and has been challenged (Anand & Hanson, 1997; Barendregt, Bonneux, & Van der Maas, 1996; Barker & Green 1996; Hyder et al., 1998).

An important difference between the HeaLY and the DALY is the fact that the starting point for the HeaLY is the onset of disease; that is, the loss of healthy life is based on the natural history of the disease (as modified by interventions), illustrated in Figures 1-2 and 1-3. This is true for the YLD component of the DALY, but the YLL is based on mortality in the current year. In a steady state, there is no difference in these perspectives. However, when incidence is changing—such as with HIV in many parts of the globe—the DALY approach can potentially understate the true situation (Hyder & Morrow, 1999).

The calculation for DALYs can be expressed in the form of an integral that was first published in the World Bank literature (Murray & Lopez, 1994). This single equation incorporating all technical and value choices had the advantage of standardization to ensure comparability of the multiple calculations undertaken in the GBD studies, and greatly facilitated the actual computations. Nevertheless, for national and local priority setting, it may be preferable to use an indicator constructed such that the social value choices can be adjusted to suit national and local preferences (Bobadilla, 1998; Hyder et al., 1998; Morrow & Bryant, 1995). Recent DALY formulations allow for this possibility; indeed, it is useful to think of DALYs as a family of related measures using terminology specifying the following formulation: DALY (r, K) uses a discount rate of r and age weighting indexed to K. Other parameters can be added in a similar fashion (Jamison et al., 2006).

HeaLYs and DALYs are both "health gap" measures and can be considered part of the same family of measures. In fact, DALYS exactly equal HeaLYs when the following conditions are met: (1) the condition in question is in steady state or equilibrium (that is, the incidence, CFR, and disability variables remain constant during the time intervals under consideration); (2) age weighting is not applied ($K = 0$); and (3) the same measures of disability (weights) are used.

Quality-Adjusted Life Year

The quality-adjusted life year (QALY) was introduced in 1976 to provide a guiding principle for selecting among alternative tertiary healthcare interventions (Zeckhauser & Shepard, 1976). The idea was to develop a single measure of quality of life that would enable investigators to compare expected outcomes from different interventions—a measure that valued possible health states both for their quality of life and for their duration.

The central notion behind the QALY is that a year of life spent in one health state may be preferred to a year spent in another health state. This generic measure sums time spent in different health states using weights on a scale of 0.00 (dead) to 1.00 (perfectly healthy) for each health state; it is the arithmetic product of duration of life and a measure of quality of life (health state weight). For example, 5 years of perfect health = 5 QALYs; 2 years in a state measured as 0.5 of perfect health followed by 5 years of perfect health = 6 QALYs.

The QALY was originally developed as a differentiating indicator for individual choices among tertiary healthcare procedures, not as a measure of disease burden in a population. It was used to assess individual preferences for different health outcomes from alternative interventions (Morrow & Bryant, 1995). The QALY, too, comprises a large family of measures. Since its introduction, a wide variety of QALY measures have been developed, along with a voluminous literature on alternative methods incorporating a range of disability domains and a diversity of methods to assign weights to generate QALYs (Kaplan & Anderson, 1996; Nord, 1993). The most widely used measure is the EQ-5D (European Quality of Life with Five Domains and three levels of quality for each domain; www.euroqol.org).

Perhaps the most important use of QALYs has been as a common denominator to measure utility in cost-utility analysis (and effectiveness in cost-effectiveness analysis) to assist in resource allocation among alternative health interventions by ranking interventions in terms of cost per QALY (Kaplan & Anderson, 1996; Nord, 1992; Torrance, 1986). An early and widely publicized attempt to make the best use of healthcare resources by maximizing QALYs per dollar expended was the well-intentioned but rather unfortunate effort undertaken in Oregon in the early 1990s (**EXHIBIT 1-4**).

In the United Kingdom, as part of its 1997 National Health Service (NHS) reforms, the National Institute for Clinical Excellence (NICE; www.nice.org.uk) was created to advise public health officials about the effectiveness and cost-effectiveness of various health interventions. In an explicit attempt to introduce economic considerations in addition to medical judgments for the allocation of resources, NICE has produced a large collection of studies on the cost per QALY produced by the interventions it appraises. Some of these appraisals have been the source of considerable controversy. If a treatment is considered cost-effective for a group of patients,

EXHIBIT 1-4 Oregon: Historical Application of the QALY for Allocation of Resources

An early and well-known attempt to apply the QALY approach for allocation of health resources occurred in the state of Oregon (Blumstein, 1997). In 1988, Oregon faced a budgetary shortfall for its Medicaid program, and coverage for organ transplants was denied. In an effort to prioritize its health services, Oregon undertook a bold attempt to explicitly ration health services. A coalition including consumers, healthcare providers, insurers, business, and labor representatives launched a broad and courageous healthcare reform. It began with a series of "experiments" in which the decision-making process was based on a cost-effectiveness approach using quality of well-being (QWB—essentially a QALY) for comparing the outcomes of treatment options among people.

The initial list, published in 1990, consisted of 1600 condition/treatment pairs drawn up as follows:

Cost-effectiveness ratio = cost of services / (health gain × duration)
Cost of services = charges for treatment including all services and drugs
Quality of well-being (QWB) = sum of QWB weight (W) × each QWB state × probability that symptoms of that QWB state would occur
Health gain = QWB with treatment − QWB without treatment

From the beginning, there was great opposition to the very notion of rationing; consequent denial of services to those who had conditions that did not make the list contributed to the rancor. There were also unfortunate technical blunders in the generation of the first list. For example, treatment for thumb sucking was ranked higher than hospitalization for starvation, and treatment for crooked teeth higher than early treatment for Hodgkin's disease. Such inconsistencies, together with objections raised by groups advocating for the disabled, gave rise to alternative approaches for establishing rankings.

Although enormous public effort went into the reform and much was accomplished, the explicit cost-effectiveness approach with QALYs as the outcome measure was eventually dropped (Blumstein, 1997; Eddy, 1991; Morrow & Bryant, 1995; Nord, 1993).

NICE will recommend its use throughout the NHS; if not, it will recommend against its use in the NHS. The use of these cost-effectiveness studies as an aid to decision making is intended to increase the total healthcare benefits gained from the money spent by the NHS.

The QALY as originally used is essentially equivalent to the YLD of the DALY; in fact, it would be exactly the same as the YLD when the following conditions are met: (1) there is no discounting ($r = 0$); (2) there is no age weighting ($K = 0$); and (3) the same disability weights are used. More recently (as used in some cost-effectiveness studies), QALYs have incorporated life expectation as well.

Health-Adjusted Life Expectancies

Several types of health expectancies exist in the literature. During the 1990s, *disability-free life expectancy* (DFLE) and related measures were calculated for many countries (Robine, 1994; Mathers et al., 2001). However, these measures incorporate a dichotomous weighting scheme in which time spent in any health state categorized as disabled is assigned, arbitrarily, a weight of zero (equivalent to death). Thus, DFLE is not sensitive to differences in the severity distribution of disability in populations. In contrast, *disability-adjusted life expectancy* (DALE) adds up expectation of life for different health states with adjustment for severity weights. In 2001, WHO replaced the DALE terminology with *health-adjusted life expectancy* (HALE); the latter term will be used throughout the remainder of this text.

The HALE is a composite summary measure of population health status that belongs to the family of health expectancies; it summarizes the expected number of years to be lived in what might be termed the equivalent of "full health." WHO has used it as the measure of the average level of health of the populations of member states for annual reporting on population health for a few years (WHO, 2000).

Health expectancy indices combine the mortality experience of a population with the disability experience. The HALE is calculated using the prevalence of disability at each age so as to divide the years of life expected at each age (according to a life table cohort) into years with and without disability. Mortality is captured by using a life table method, while the disability component is expressed by additions of prevalence of various disabilities within the life table. This indicator allows an assessment of the proportion of life spent in disabled states. When compared with the total expectation of life, it translates into a measure of the total disability burden in a population.

Comparison of the various methods and specific indicators is available in the literature (Robine, 1994). Alternative methods are given in WHO's *National Burden of Disease Studies* manual (Mathers et al., 2001a). As originally designed, the HALE does not relate to

TABLE 1-5 Comparisons of Original Versions of Composite Summary Measures of Population Health

	Quality-Adjusted Life Years	Healthy Life Years	Disability-Adjusted Life Years	Health-Adjusted Life Expectancy
Origin	North America, 1976	Ghana Ministry of Health, 1981	World Bank development report, 1993	World Health Organization report, 2000
Purpose	Assess individual preferences for various outcomes from complex interventions	Assist in resource allocation decisions	Compare disease burdens in many different populations	Compare national disease burdens
Level of use	Personal decisions	National- and district-level decisions	Broad policy decisions	Global comparisons
Data	Tertiary hospital data and personal interviews	National and local data from multiple sources; expert review	Global data and expert opinion	Global data and expert opinion
Original discipline base	Economists, clinicians	Epidemiologists, clinicians, national planners	Economists, statisticians	Demographers, economists, statisticians
Social values that may be incorporated	Generally not included	Future life discounted	Age weighting (not mandatory), future life discounted	Not relevant

Reproduced from North America, 1976; Ghana Ministry of Health, 1981; World Bank Development Report, 1993; World Health Organization Report, 2000.

specific diseases, but rather to the average extent of disability among that proportion of each age group that is disabled. The lack of correlation between a condition or disease entity and the measure made it less valuable for resource allocation and cost-effectiveness calculations.

Summary

TABLE 1-5 summarizes these summary measures (original versions) in terms of origins, purposes, level of use, sources of data, and disciplinary background of originators.

Valuing Life: Social Value Issues

The very idea of valuing some lives more than others is jarring, yet these notions are regularly reflected in our actions. The value of life is often implicit in the way resource allocation decisions are made; therefore, as much as possible such decisions should be explicit, open, and transparent. Many thoughtful people have serious reservations about assigning a single number to such a complex multidimensional phenomenon as health. But what is the alternative for use as a measure of utility or effectiveness in economic analyses? Outcome measures must be expressed as a unidimensional measure to be comparable to unidimensional monetary expenditure units for costs. (However, decisions about allocation should not be made on a mechanical basis; other factors, including the effect on equity, may need to be considered in decisions in addition to the goal of maximizing healthy life per unit expenditure.)

To construct composite measures of population health, important social value choices must be made. Choices about which expectation for life should be used and about valuing life lived at different ages, valuing future life as compared with the present, valuing life in terms of economic and social productivity, and valuing equity in relation to efficiency—all raise major ethical concerns.

Expectation of Life

Years of life lost due to death and to chronic disability are based on life expected had the disease not occurred. To estimate the expectation of life in a population, a choice must be made between using a local, national, or model life table. This choice should be determined by the purpose of the study. For example, for assisting in national and local decision making, it may be more suitable to use national life tables based on the mortality and fertility of the population in question than to use model life tables. Conversely, a model life table might be selected to reflect the best health state possible in the world, as this selection may allow a fair comparison with other countries. For example, from a global perspective it would be unfair to use national life tables to compare gains that could be achieved from a particular intervention in Ghana with those in the United Kingdom, even if both costs and lives saved were the same in each country. The reason is that those lives saved in Ghana would have a lower life expectancy than those in the United Kingdom, resulting in less healthy life saved for the same expenditure. From the global viewpoint in this example, the priority would be to fund the intervention in the United Kingdom because it would produce more healthy life per expenditure than for Ghana.

Valuing Life Lived at Different Ages

Age weighting refers to the valuing of a year of life according to the age at which it is lived. This practice immediately raises questions about the basis for valuing human life. Does a day of one person's life have the same value as a day of anyone else's life? Does the value vary with age, economic productivity, or social status? Should life itself be valued separately from what is done with that life?

The Ghana Health Assessment Team (1981) judged that all human life was intrinsically valuable and that a given duration of any life was equal in value to that of any other life. The valuing of a year of life equally, irrespective of age, has been considered egalitarian (Busschbach, Hesing, & de Charro, 1993; Morrow & Bryant, 1995). This choice was incorporated into the development of the HeaLY approach: A year of life lived at any age is equally valued.

The original 1990 DALY formulation assigned an exponential function to provide a value chosen so that life lived as a dependent (e.g., infants, children, the elderly) was given less value than life lived during the productive years. With this approach, the intrinsic value of life increased from zero at birth to a maximum at age 25 and declined thereafter, so that a day of life of a 50-year-old was worth about 25% less than that of a 25-year-old. Paradoxically, the age weighting used in the original DALY formulation led to higher valuation of life lived before age 15 than did the HeaLY formulation, in which life lived at all ages has equal value (Barendregt et al., 1996; Hyder et al., 1998). Current formulations of the DALY leave age weighting as an option, and such weighting is not used with the HALE.

Age-related valuing has been justified by studies showing that individuals value their own life lived at different ages differently. Such values have been reported in the literature, and classic studies have reported that they are consistent across respondents of different ages (Busschbach et al., 1993). In addition, studies from many countries reveal a preference for saving younger lives as compared with older ones (Murray & Lopez, 1994). Nevertheless, it was not clear how much of the differential valuing of life at different ages is related to an underlying appreciation that economic and social productivity varies at different ages. If it is decided at the local or national level that healthy life should be valued according to economic and social productivity, then an alternative to age weighting might be to explicitly add a productivity factor or subtract for the societal costs of dependents, such as education (see the section "Valuing Life for Its Economic and Social Productivity").

Valuing Future Life Compared with Present Life: Discounting

Discounting is the process for determining the present value of future events. *Social time preference* takes into account the phenomenon that people value events at present more highly than those in the future (independent of inflation and of uncertainty). For investments in other sectors, time preference is normally taken into account by discounting future returns and costs by some appropriate discount rate. Thus, the discount rate can be considered the inverse of an interest rate. The main issue concerning discounting in relation to summary measures is whether discounting life itself is appropriate. There seems to be little question about the usefulness of discounting the future value of what is produced by healthy life, but should the life itself be discounted (Morrow & Bryant, 1995)?

Discounting has been applied in the health sector because both the losses from a disease and the benefits from a health intervention often occur in the future. An intervention today may not produce immediate benefits (such as in immunization), or it may result in benefits being sustained over a long time (such as in supplementary nutrition). The costs for these activities must be borne now, but the benefits are realized in the future and are less valuable than if they could

occur now. This is equivalent to investing money now so as to obtain more in the future. Thus, a HeaLY now has greater intrinsic value to an individual or community than one in the future (Gold, 1996; Weinstein, Siegel, Gold, Kamlet, & Russell, 1996).

The rate at which society is supposed to discount benefits, termed the social discount rate (SDR), is a numeric reflection of societal values regarding intertemporal allocation of current resources. There is no consensus about the most appropriate choice of a discount rate in health, but most agree that it should be lower than that used in the private commercial sector. Historically, the 1993 World Development Report and the first GBD studies used a discount rate of 3% per year (more recent iterations of the GBD studies do not use discounting in the default calculations, but instead have it as an optional parameter that can be set by the user); in lieu of other information, this rate has been adopted in many international public health cost-effectiveness studies. Nevertheless, the impact of using a range of discount rates, including zero, should be explored with each study.

Valuing Life for Its Economic and Social Productivity

Whether and how to value economic and social productivity for purposes of healthcare decision making is highly contentious; to a large extent, the age weighting incorporated in the original DALY formulation was considered by many to be a proxy for productivity. Such valuations should be considered separately, made explicit, and very much dependent on the purpose of the valuations. In general, productivity may be attributed to adults aged 15 to 64, and persons in these age groups could be given a higher value. Persons younger than age 15 and older than age 65 may be considered as dependents and given a lower value. Many variations for differential valuing are possible, including type of employment. People at different socioeconomic levels in a society are expected to have different capacities for productivity—yet, to value life according to income levels or social class would not seem fair and generally would not be acceptable. In LMICs, the value of marginal wages for subsistence agriculture is negligible, but the value of the workers' lives certainly is not.

A fundamental question is whether to consider adding a productivity component to the summary measures. Health issues do not readily conform to the requirements of market economics; information is inadequate, and misinformation is rife on the part of the providers as well as the public. Externalities from good health are generally large; demand for costly services is largely determined by the healthcare providers rather than by the consumers, and competitive market forces have not worked well for those in greatest need. In the private sector, demand for services is clearly related to productivity and willingness (and ability) to pay. However, if left to market forces alone, inequitable distribution would be inevitable.

Economic arguments have been put forward for valuing life according to productivity, but counter-claims have been made that human life cannot and should not be expressed in economic terms for decision-making purposes. Nevertheless, efforts to avoid such expression result in implicit valuation of life. More than 30 years ago, Barnum (1987) argued for adding productivity to the valuing of human life, stating that it has been ignored in health policy, is readily quantifiable, and does not ignore the welfare of children because the whole population is dependent on adult productivity for quality and sustenance. Such an economic appraisal of human life is often based on the net transfer of resources from the "producers" to the "consumers" and the consequent interdependence of people. In relation to this issue, in the *Report of the Commission on Macroeconomics and Health* (WHO, 2001), a DALY was stated to be worth at least an average annual income per head, although the basis for such a valuation was not adequately justified. More work on explicit valuations of human life and what that life produces is needed, and will certainly affect health-related cost-effectiveness decisions.

Valuing Equity in Relation to Efficiency

A child born in Malawi or Uganda will likely live only half (approximately) as long as one born in Sweden or Singapore; many babies born in Niger or Sierra Leone will not live to see their fifth birthday. These inequalities are unfair and harmful and, therefore, qualify as inequities. In terms of social justice, equity has to do with a fair distribution of benefits from social and economic development. However, the term *equity* is used in different conceptual senses: equal access to health services for all (opportunity equality), equal resources expended for each individual (supply equality), equal resources expended on each case of a particular condition (equality of resource use to meet biological need), equal healthy life gained per dollar expended (cost-effectiveness), care according to willingness to pay (economic-demand equality), care according to biological or socioeconomic need, and equal health states for all.

Decisions based on cost-effectiveness (e.g., cost per HeaLY), therefore, may not accord well with concerns about equity. These calculations are generally indifferent to equity; they are designed to steer interventions to what is efficient, whatever the differential need may be. To meet the requirements of equity,

health system planners need to go beyond ensuring equality of access to health care and require a balance so that health system responses are in accord with equity as well as efficiency.

Provided that health information is available according to socioeconomic and vulnerable groups, use of these summary indicators as tools for determining equity by calculating healthy life per dollar to be gained by all socioeconomic and vulnerable groups could readily be undertaken. It would be important to assess the impact of specific health decisions to ensure that they enhance equity. Summary measures such as HeaLYs and DALYs can be used to guide allocation of resources to ensure equitable distribution of those resources to reach those most in need. Cost-effectiveness by itself does not provide adequate guidance; equity should also be an associated criterion to govern the distribution of societal benefits.

Data for Composite Measures

Types of Data

The data needs for estimating the burden of disease in a region or country are extensive, and obtaining even reasonable estimates in LMICs has been a source of concern (Anand & Hanson, 1997; Barker & Green, 1996; Bobadilla, 1998; Murray et al., 2002). Brief descriptions of the types of data required follow. Note that any available data need to be carefully reviewed and optimally utilized.

Demographic Data. Population data are integral to burden of disease estimations and are needed both as denominators and for consistency checks. In a national setting, a recent census is useful for providing population counts by age, sex, and geographic location. Particularly helpful, when there is inadequate death registration, is to have a one-year post-census follow-up on a sample of enumeration areas to obtain robust age, sex, and place mortality. The age and sex distribution of the population is critical, and often is a major factor that determines the nature of the disease burden. A good vital registration system is a key asset that will provide both birth and death numbers. Underreporting, age misreporting, and other biases in data may have to be addressed (using standard demographic methods) prior to use of these data in burden of disease estimation.

Mortality. Mortality data are required for any burden of disease analysis. Specifically, age, sex, and place mortality rates greatly assist the analysis by defining the contribution of mortality to the pattern of disease burden. They also serve as an essential framework that constrains estimates obtained from a variety of special studies that fill important information gaps but may be incomplete or biased in the populations covered. Reporting errors, such as underreporting of deaths and failure to report age at death, need to be carefully examined. In particular, information must be evaluated for deficiencies in the under-5 group and older age groups. For the youngest ages, the probabilities of deaths in the first year (1q0) and in the next four years (4q1) provide better estimates of the risk of death than do overall mortality rates. Methods such as the Brass method for indirect estimates of mortality provide useful ways to assess age-specific mortality data for potential errors (Hill, 2001).

For burden of disease studies, cause of death data are required for all ages (except stillbirths, which are not included—a limitation of composite measures), but reliable cause of death records are often not available in LMICs, especially for deaths that do not occur in healthcare facilities. Even if available, the classification system used may be outdated and not based on the ICD, and the reliability of coding may vary by the type and location of the hospital. Young-adult deaths may be better recorded than deaths of infants and the elderly. Especially in low-income countries, it can be helpful to cross-check death records with other information, using postmortem interviews and hospital registers to assist in defining causes of death or to extrapolate from other data or other regions to assist in making estimates.

Morbidity. Meaningful data on disability are even more difficult to find and interpret than mortality data. Often morbidity information is institution-based or restricted to one or two sources, such as hospital inpatient and clinic outpatient records. The representativeness of small studies and the range and types of morbidity covered in any survey need careful evaluation. National disability surveys or regional studies conducted for the evaluation of disabled people may be available; such research is useful in providing some estimate of the prevalence of serious disabilities and their age and sex distribution. However, linkage between disability and disease is often not available, and attributing one type of disability to specific causes is difficult. For example, because many conditions can lead to blindness—for example, diabetes, hypertension, injuries, trachoma, and cataracts—the attribution of proportions of blindness in a population to its cause can be problematic. Information on the duration of disability may be found in specialized studies and the experience of institutions. The severity of disability will have to be rated on a scale; the various methods used in the literature were described earlier in this chapter.

Variables

The types of data just described need to be processed in the form of specific disease-based estimates. The key variables are defined in Table 1-4. The *incidence* rate (usually expressed per 1,000 general population per year) is central to the natural history of disease concept. Although incidence is a basic epidemiologic indicator, it is usually not found in routine data collection systems. Special studies, prospective surveys, or calculations based on the prevalence (which is more commonly available than the incidence) and knowledge of the average duration of the disease can be helpful in developing this measure.

The case fatality rate is the proportion of those developing the disease who die from it at any time. It is expressed as a decimal value between 0 (for nonfatal conditions) and 1 (for universally lethal conditions). The *case disability ratio* (analogous to the CFR) is the proportion of those diagnosed with a disease who have signs or symptoms, and is usually 1 (as discussed earlier). *Age* is required in various formats. Age at onset is when disease onset occurs in a population; age at fatality denotes the age at death as a result of the disease. The *expectation of life* at age of onset is the years of life expected at that age had the disease not occurred. Similarly, expectation of life at fatality is the years of life expected at that age had the death not occurred.

Checking Data

Data used for generation of indicators need to be evaluated for validity, reliability, and consistency, using defined qualitative and quantitative criteria. Large population-based studies may be given preference over smaller sample-based work if both are available and the quality of their data is comparable. Better conclusions may be possible by cross-checking different sources of data. Community-based studies, which may be representative of the population but have limited diagnostic validity, may be compared with hospital-based work, in which diagnosis may be valid but would come from a biased population sample. The following subsections profile simple types of checks for data quality.

Comparison of Total Numbers. Cross-checks should be done to compare total numbers. It is essential to check that the number of deaths in a year in a region is the same as the sum of all deaths from all causes in the same region. Similarly, program-based data can be compared with data from other sources to ensure better estimates of causes of death. The comparison of totals allows one to work within a frame of mortality and avoids double counting of one death. However, it does not assist in the distribution of deaths within that frame.

Relationship Between Variables. Checks based on the epidemiologic relationship between parameters refer to the application of simple, yet vital, relationships such as the following:

- Prevalence (point) = incidence × average duration of disease
- Cause-specific mortality rate = incidence × case fatality rate

These checks allow estimates from different sources to be compared for internal consistency. Such relationships can also be used to derive one of the estimates in the equations when the others are known.

Sensitivity Analysis. Sensitivity analysis is a useful tool to determine whether data that are more precise are required for the purposes of a particular decision. A one-way sensitivity analysis (Petiti, 1994) evaluates the effect of manipulating one variable at a time on the dependent variable. If the outcome is sensitive to one or more variables, their precision is more important in the estimation.

Disease Groups: Classification

Murray and Chen (1992) introduced a disease group system based on WHO's ICD classification system. Group I includes conditions characteristic of low-income countries: communicable diseases, maternal and prenatal conditions, and nutritional deficiencies. These conditions decline at rates faster than overall mortality rates as socioeconomic conditions improve; thus, group I contributes to a relatively small percentage of deaths in the high-income world. Group II, which consists of noncommunicable and chronic diseases, accounts for most loss of healthy life in high-income countries and proportionately increases with the epidemiologic transition in LMICs. Group III consists of injuries, both intentional and unintentional (including violence).

The distribution of the disease burden among these three groups is one indicator of the type of disease burden and the level of epidemiologic transition in a country. It is important to distinguish between the proportions of deaths attributed to these groups, as opposed to the risk of dying from the conditions in these groups. For example, the proportion of deaths attributable to group II causes increases from high- to low-mortality countries (or to an older age structure of the population); however, the risk of death from group II conditions is higher in high-mortality countries.

Implementing a Burden of Disease Study

Knowing how to conduct a burden of disease analysis is important for all countries. Generic steps for a national burden of disease study include the following:

- Assess demographic information, including a census with age, sex, geographic (urban/rural), and selected socioeconomic status information, and vital statistics with births and deaths.
- Collect cause-of-death information for all deaths in a year by age, sex, geographic location, and socioeconomic status as possible, according to the ICD system.
- Define disability by cause/disease, and develop a severity scale using expert and community input.
- Collate information by disease from all sources and assess these data's reliability and validity, using expert opinion when needed to define variables for a spreadsheet.
- Decide whether social value preferences such as age weighting, discounting, economic and social productivity, and expectation of life will be used and what their values will be.
- Estimate healthy life lost for each disease condition and by disease groups.
- Perform sensitivity analyses to check the robustness of results relative to critical variables and assumptions.
- Consider other variations, including assessment of losses by risk factors; regional, age, and sex breakdowns; and future projections.
- Review the policy implications for overall mortality and morbidity in the country and by cause; feed data into cost-effectiveness analysis and further research.
- Include other modifications as appropriate to the country setting.

To use summary measures to assist in health planning and resource allocation decisions, additional steps include the following:

- Estimate the effectiveness (gains of healthy life) of each intervention under consideration in terms of expected coverage and reductions in incidence and/or case fatality or case disability ratios.
- Work out the costs of the proposed interventions.
- Develop cost-effectiveness ratios to plan which combination of interventions targeted to which groups will provide a maximum return of healthy life per expenditure for the funds allocated to health.
- Review expected gains of healthy life according to age, sex, geographic area, and socioeconomic and vulnerable groups to ensure that all are better off (or at least none is worse off) and adjust as necessary.

Another very important consideration in this process is time. The conduct and analysis of such studies must be timely to assure its appropriate use by policy makers and useful for resource allocation decisions. The precision and comprehensive nature of the study must be balanced by the need for timely results.

The steps described previously may be carried out simultaneously or in some sequence, depending on the specific national situation. Modifications will likely be needed depending on the availability of data (**EXHIBIT 1-5**). An actual study requires careful planning on the part of those responsible for its conduct and may include many additional steps that are beyond the scope of this chapter. Even so, these generic steps summarize the essentials of applying the burden of disease methods to a country. Increasingly countries are obtaining, refining, and using these data on an ongoing fashion.

EXHIBIT 1-5 The Burden of Disease in United Arab Emirates, 2010

The United Arab Emirates (UAE) is one of the seven Gulf Cooperation Council (GCC) countries and consists of seven emirates: Abu Dhabi, Dubai, Sharjah, Ajman, Uum Al-Quwain, Fujairah, and Ras Al-Khaimah. An academic study was undertaken to estimate the burden of disease in UAE in 2010 and to develop a set of 2010 population estimates as well as a mortality and disability profile by age group and gender. This analysis was conducted for the UAE national and migrant populations. A burden of disease approach was used to calculate standard expected years of life lost (YLL). Data from the Global Burden of Disease 2010 study and vital registration data from the UAE's Ministry of Health were utilized for the study. Forty-five disease and injury conditions were included in the analysis. Disability estimates were calculated in terms of years of life lived with disability (YLD) using health data from the Emirate of Abu Dhabi; 150 conditions were included in the final analysis.

In 2010, the crude death rate per 1,000 population was 2.47 for UAE nationals and 1.00 for migrants. For all residents of the UAE, regardless of nationality, the leading causes of death were ischemic heart disease (14.5%), other circulatory system diseases (12.4%), motor vehicle crashes (11.3%), malignant neoplasm (6.5%), and other respiratory tract infections (5.5%). For UAE nationals, the crude death rate was estimated at 2.84 for males and 2.08 for females; for migrants, the crude death rate was estimated at 0.99 for males and 1.01 for females. Age-specific mortality rates (ASMRs) for most age groups were lower in migrant males compared to males who were UAE nationals, except for the age groups of 10–14 and 25–29 years.

(continues)

EXHIBIT 1-5 The Burden of Disease in United Arab Emirates, 2010 *(continued)*

The rates were also lower in migrant females compared to nationals, except for migrant females in the age groups of 30–39, 45–49, and 55–64 years.

A total of 291,834 YLL was lost in 2010 due to premature mortality; nationals accounted for 27% of this total and migrants for 73%. YLL lost for migrants (males: 48,514; females: 28,986) were greater than that for nationals (males: 169,864; females: 44,470), reflecting the population imbalance in the UAE wherein migrants vastly outnumber migrants. The leading causes of premature mortality for migrants were motor vehicle crashes, ischemic heart disease, and other circulatory system diseases. Drowning, falls, fires, and unintentional poisoning were some of the important causes of injuries among migrant children between 5 and 14 years of age. Occupational injuries were also an important cause of premature deaths among migrant males between 15 and 44 years.

Overall, the estimated YLD lost was 373,051; nationals accounted for 37% of YLD losses, and the losses were distributed equally among males and females. The top five conditions causing disability among nationals were low back and neck pain (26%), other musculoskeletal diseases (8.3%), injuries (7%), and diabetes (5.3%). Noncommunicable diseases and injuries were responsible for the top 20 causes of YLDs among both nationals and migrants.

FIGURE 1-5 shows the main causes of death in the UAE, and **TABLE 1-6** reviews the top conditions responsible for disease burden in the UAE.

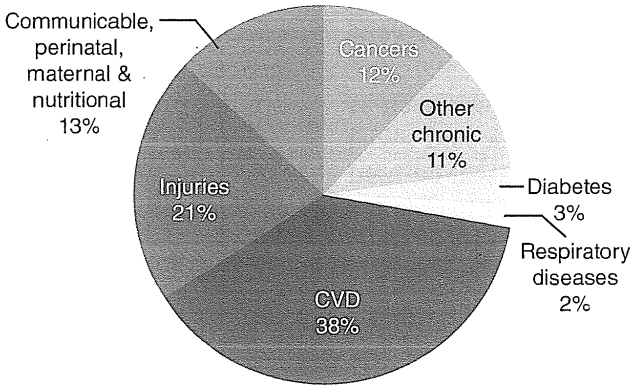


FIGURE 1-5 Deaths in the United Arab Emirates by cause, 2008.

Reprinted from World Health Organization, Noncommunicable Diseases Country Profiles 2011, page 196, Copyright 2011.

TABLE 1-6 Burden of Disease, United Arab Emirates, 2010

	Premature Mortality Only	Disability (YLD) Only	Disability-Adjusted Life Years (DALY)
Rank	Disease	Disease	Disease
1	Motor vehicle crashes	Low back and neck pain	Injuries
2	Ischemic heart disease	Other musculoskeletal disorders	Diseases of the musculoskeletal
3	Other circulatory disease	Injury requiring urgent care	Diseases of the circulatory system
4	Congenital anomalies	Fracture of sternum, rib, or bone	Diseases of the respiratory system
5	Perinatal conditions	Diabetes	Endocrine, nutritional, and metabolic diseases, and immunity disorders
6	Other respiratory tract diseases	Chronic obstructive pulmonary disease	Neoplasm
7	Other malignant neoplasm	Open wounds, superficial injuries	Congenital anomalies
8	Cerebrovascular disease	Fracture of patella, tibia, fibula	Perinatal conditions
9	Suicide	Other neurologic disorders	Diseases of the nervous system
10	Diabetes mellitus	Eczema	Diseases of the digestive system

Data from Allen, K. (2010). A national burden of disease study for the United Arab Emirates (UAE): Quantifying mortality and morbidity differentials between nationals and migrants, 2010.

Data from Allen, K. (2010). A national burden of disease study for the United Arab Emirates (UAE): Quantifying mortality and morbidity differentials between nationals and migrants, 2010.

Comparisons and Trends in Disease Burden

This section reviews a number of country-based and historical burden of disease studies to compare and assess trends in disease burden from place to place and over time.

National Disease Burden Assessments

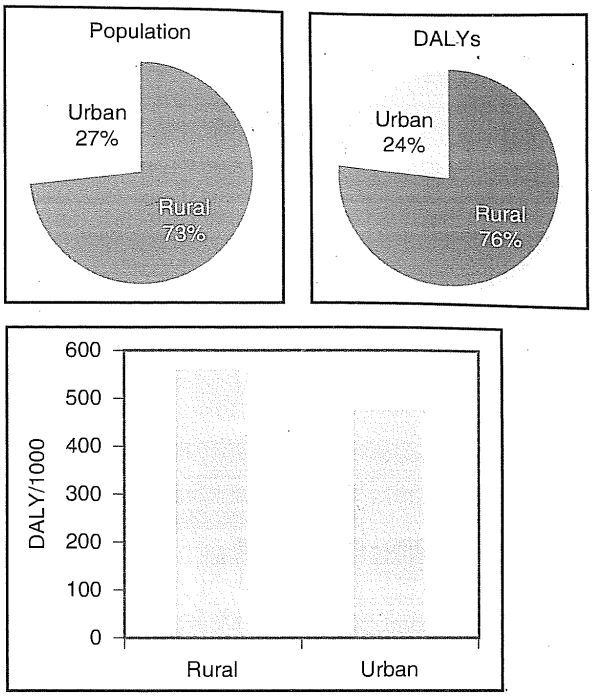
Comparing the burden of disease across populations, time, and place is an important aspect of national burden of disease studies. This subsection uses examples from burden of disease studies over the past two decades to illustrate how disaggregated data can help in understanding the distribution of ill health in a country.

The Andhra Pradesh Burden of Disease Study, 2001

The regional distribution (urban/rural, state, district) of the disease burden is important to explore in a national burden of disease study. Andhra Pradesh, a state in India, was the focus of one of the most meticulous burden of disease studies, conducted between 1994 and 2001. It had a population of 76 million in 2001, 27% of whom lived in urban areas (20.8 million people); a 1:3 ratio of urban-to-rural disease burden in terms of DALYs lost was identified (Mahapatra, 2001). The burden of disease rates were 19% higher in rural areas than in urban areas, as measured by DALYs lost per 1,000 population (**FIGURE 1-6**).

The Burden of Disease and Injury in New Zealand, 2013

According to the latest burden of disease estimates from New Zealand, there has been a reduction in DALYs by 1.2% per year after adjusting for population changes and age structures. The main burden of disease is due to losses from noncommunicable diseases (88%), followed by injuries (8%), and communicable diseases (4%). Approximately 52% of the DALYs are due to nonfatal outcomes. Aging of the population and longer life expectancy is an area of focus for New Zealand to develop and implement preventive and management programs. Coronary heart disease in males and back pain among females are main causes of health loss (Tobias, 2016) (**FIGURE 1-7**).



Note: Total DALYs lost in Andhra Pradesh = 5 million.

FIGURE 1-6 Burden of disease in Andhra Pradesh, 2001, by region.

Data from Mahapatra, P. (2001). *Estimating national burden of disease: The burden of disease in Andhra Pradesh 1990s.* Hyderabad: Institute of Health Systems.

Burden of Disease Estimates for South Africa, 2000

HIV/AIDS is ravaging Africa; thus, the impact of HIV/AIDS on the burden of disease in African countries can be significant. In South Africa, 30% of the 15 million DALYs lost in 2000 were attributed to HIV/AIDS (**FIGURE 1-8**) (Bradshaw et al., 2003); for a population of 45 million, this means 0.33 DALY lost per capita. Such data are important for national decision making.

The Burden of Disease and Injury in Australia, 2003

In 2003, 2.63 million DALYs lost were attributed to the disease and injury burden in Australia, with 62% of this burden caused by noncommunicable diseases such as cancers and cardiovascular diseases and mental and neurologic disorders. Approximately 49% of the disease burden was caused by deaths from various diseases and injuries, while 51% was due to nonfatal disease and injury outcomes. The top three causes of fatal outcomes were cancers (32.0%), cardiovascular disease (29.0%), and injuries (11.0%); the leading causes of nonfatal outcomes were mental disorders (24%) and neurologic and sense disorders (19%) (Begg et al., 2007) (**FIGURE 1-9**).

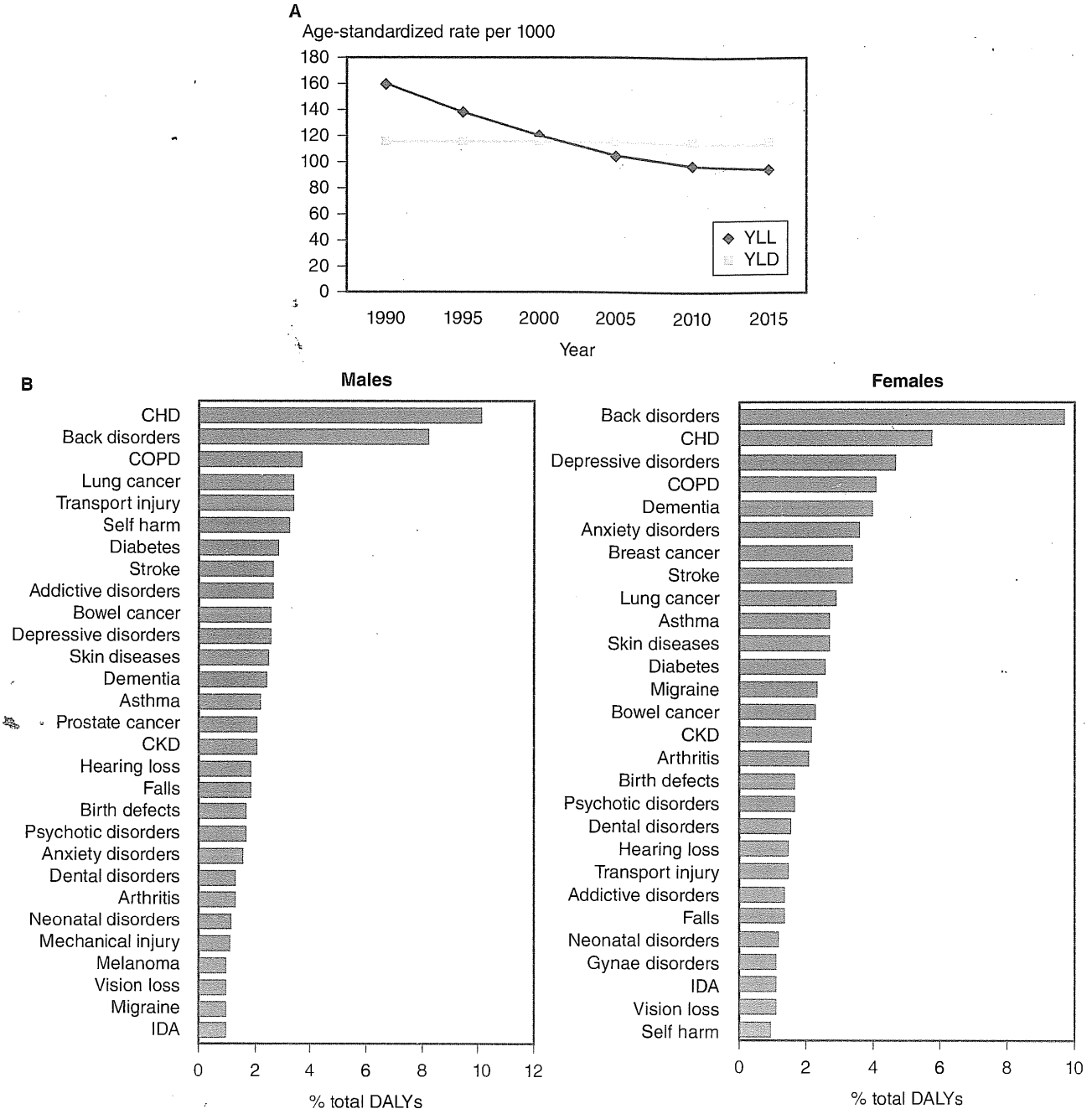
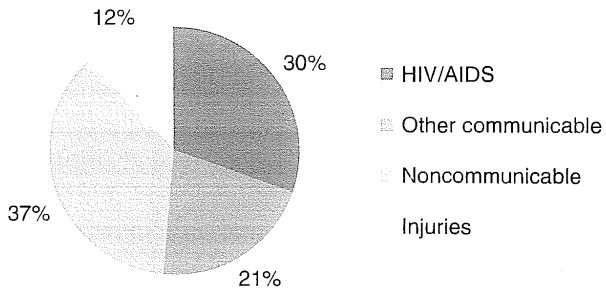


FIGURE 1-7 (a) All-cause YLL and YLD age-standardized rates per 1,000, whole population, 1990–2013, in New Zealand. (b) Contribution of leading major specific conditions to health loss (% total DALYs), by gender, 2013, in New Zealand.

(a) New Zealand Ministry of Health. (2016). *Health loss in New Zealand, 1990–2013.* (b) New Zealand Ministry of Health. (2016). *Health loss in New Zealand, 1990–2013.*



Note: Total DALYs lost in South Africa for 2000 = 15 million.

FIGURE 1-8 Burden of disease in South Africa, 2000, by disease groups.

Data from Burden of Disease Research Unit. (2003). *Initial burden of disease estimates for South Africa, 2000.* South Africa: South African Medical Research Council.

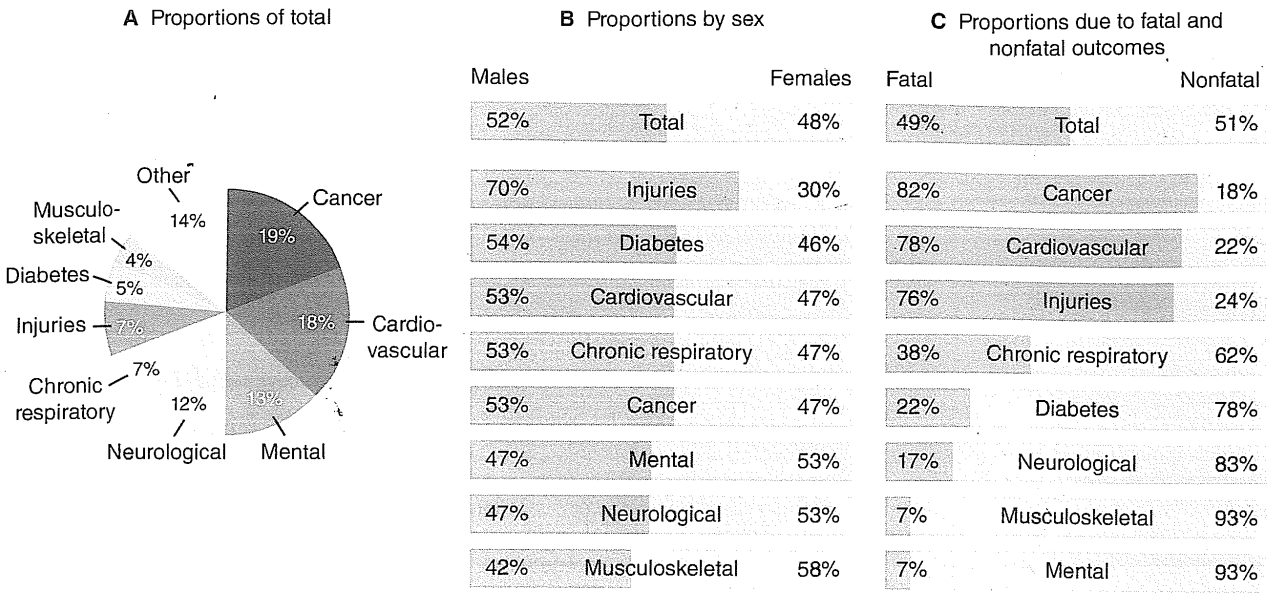


FIGURE 1-9 Burden (DALYs) by broad cause group expressed as (a) proportions of total, (b) proportions by sex, and (c) proportions due to fatal and nonfatal outcomes, Australia, 2003.

The Burden of Disease Attributable to 11 Risk Factors in Hubei Province, China, 2016

Health losses caused by 11 risk factors—namely, smoking, secondhand smoke, alcohol use, diet low in vegetables, diet low in fruits, diet high in sodium, low physical activity, high body mass index, high fasting plasma glucose, high total cholesterol, and high blood pressure—were estimated using multiple data sources in China. They included data related to population demographics, mortality, DALYs, and distribution of exposure to risk factors. Approximately 53% of all deaths were caused by these 11 risk factors, with the mortality rate being 330 per 100,000 people. The DALY rate for the 11 risk factors was 9624 per 100,000 people and accounted for 36% of all DALYs. The leading risk factor for death and DALYs was high blood pressure, which accounted for 15% of all deaths and 9% of total DALYs (**FIGURE 1-10**).

WHO Estimates of Global Burden of Disease

WHO has categorized its member states by income levels into high-, middle-, and low-income nations. The population of the world in 2015 totaled slightly more than 7.3 billion people, with 84% residing in LMICs (**FIGURE 1-11**). As may be expected, approximately 88% of the global burden is found in LMICs, reflecting the double challenge faced by the majority of people in the world: They are relatively poor and they are unhealthy. This relationship between ill health and poverty has long been recognized as complex and has been the object of much research and inquiry.

Burden of Disease by Disease Groups

Another way to disaggregate data is to explore the disease burden based on three disease groups: group I (communicable, infectious, maternal, and perinatal), group II (noncommunicable, chronic), and group III (injuries and violence). There is great variation in the portions allocated to these groups; for example, group I conditions may be responsible for anywhere from 12% to 70% of the burden of disease. When the countries are stratified by gross national income (GNI) per capita as a measure of development, an important trend can be seen from historical data (**TABLE 1-7**): As income rises, the proportion of the burden attributable to group I conditions decreases, while the share attributable to group II conditions increases. This effect is progressive, although countries such Turkmenistan (a middle-income country) still retain a high group I burden. This finding is consistent with the theory of epidemiologic transition, which predicts a change in a country's disease profile with economic development.

Global Assessments of Disease Burden

Information regarding health and disease for all countries of the world can be collated to provide a picture of global health status. In addition, global health assessments may be completed as a separate activity, and these data can then be disaggregated into regional

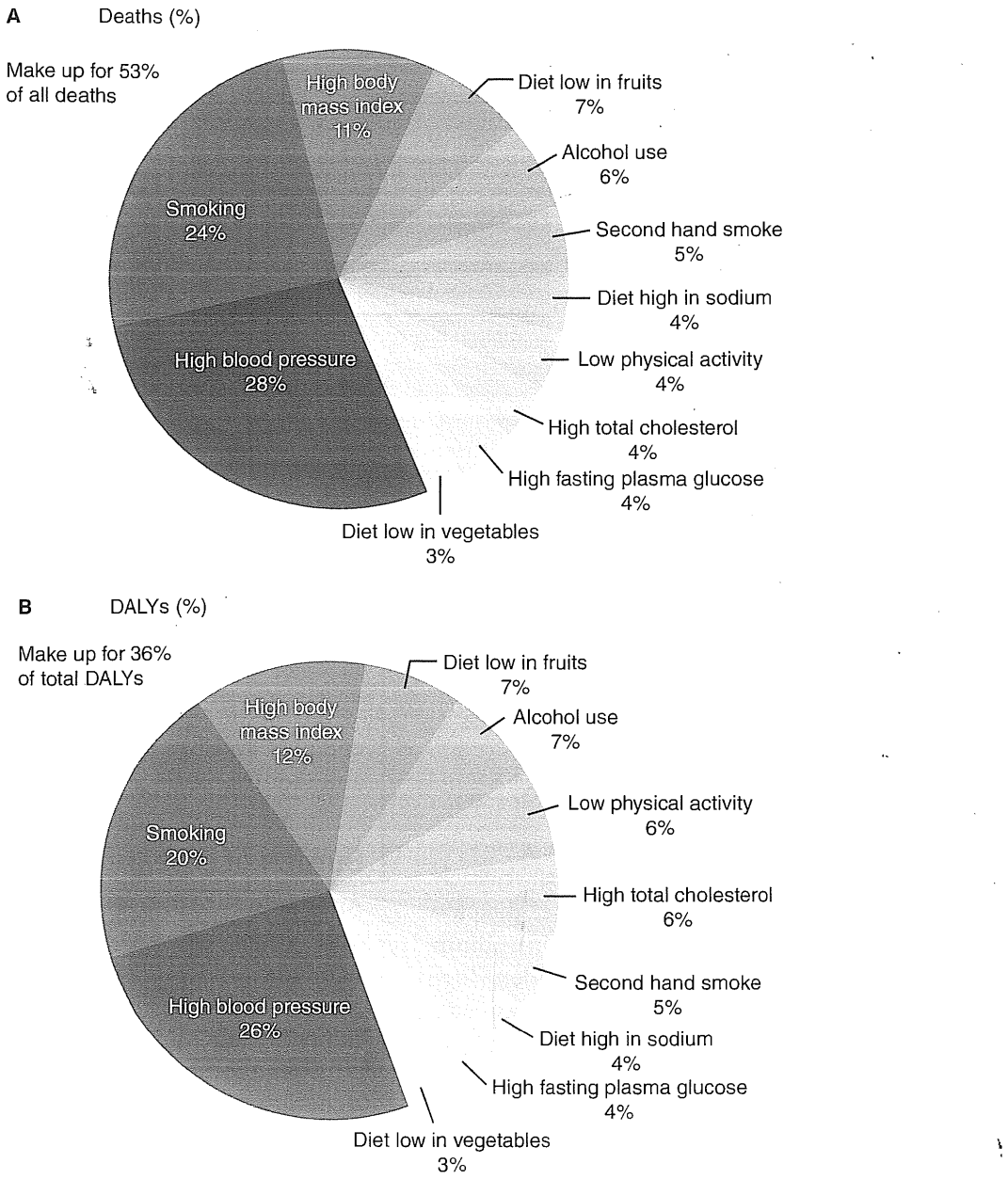


FIGURE 1-10 Burden of disease attributed to 11 risk factors in Hubei Province, China, 2013.

Data from Cui F, Zhang L, Yu C, Hu S, Zhang Y. (2016). Estimation of the disease burden attributable to 11 risk factors in Hubei Province, China: A comparative risk assessment. *International Journal of Environmental Research and Public Health, 13*(10), 944.

information. Global assessments serve to highlight major challenges facing the world community, and trends in such assessments indicate progress, if any, in improving the health of people worldwide. Such information is critical to the work of organizations such as WHO and UNICEF in their efforts to combat ill health and disease worldwide. This section highlights results of some of these global exercises for assessment of the disease burden and projections for the future.

The Global Burden of Disease Study

The 2015 Global Burden of Disease study constructed estimates of mortality, disability, and DALYs by cause for regions of the world. Demographic estimates of deaths in 2015 by age and sex form the basis of this work. It provides all-cause and cause-specific estimates for 195 countries for 249 causes from the year 1990 to 2015. The results were based on a variety of sources, including vital registrations systems, special studies, surveys, and expert opinion. This section summarizes some of the 2015 GDB data.

Mortality. Globally, in 2015, an estimated 55.8 million deaths occurred, 55% of whom were males. Approximately 20% of global deaths in 2015 were due to group I causes (communicable, maternal, neonatal, and

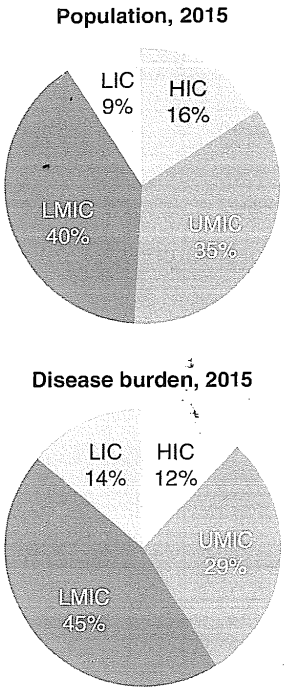


FIGURE 1-11 Global burden of disease, 2015, by income level of countries.

Data from World Health Organization. (2015). *Global burden of disease estimates*. http://www.who.int/healthinfo/global_burden_disease/en/

nutritional diseases), 71% were due to noncommunicable diseases, and 9% were due to injuries. Ischemic heart disease, cerebrovascular disease, and chronic obstructive pulmonary disease were the top three causes of death. Road traffic injuries, self-harm, falls, interpersonal violence, and drowning were the top five causes of injury-related deaths in 2015. Approximately 5.8 million deaths occurred in children younger than 5 years of age globally, with more than 80% of these fatalities being caused by group I causes. Of those under-5 deaths, 79% occurred in the African and Southeast Asia regions. An inordinate share of the mortality burden at the beginning of this century was found in LMICs, even among adults.

TABLE 1-8 shows the differences in the 10 leading causes of deaths in 2015 for high- and low-income countries. The presence of perinatal conditions, tuberculosis, HIV/AIDS, and malaria in the low-income world is indicative of the high impact of these conditions on premature mortality. These conditions are absent from the top 10 causes in the high-income countries, reflecting the success in combating these infectious conditions in the modern era. It is important to note that noncommunicable diseases such as cerebrovascular diseases and ischemic heart disease had already become prominent causes of premature deaths in the low-income world in 2015.

TABLE 1-7 Historical Distribution of Disease Burden Within Countries

Country	Disease Burden in Disease Categories (of 100%) Group I	Group II	Group III
Low-Income Nations (GNI per capita: $1,045 or less)*			
Benin	60	30	10
Guinea	65	26	9
Haiti	40	45	15
Mozambique	64	27	9
Lower Middle-Income Nations (GNI per capita: $1,046–$4,125)			
Bangladesh	32	59	9
Cambodia	33	54	13
Egypt	21	72	7
Uzbekistan	26	64	10
Upper Middle-Income Nations (GNI per capita: $4,126–$12,736)			
Colombia	13	67	20
Mauritius	9	84	7
Mexico	13	75	13
Turkmenistan	24	65	11

Note: Disease classification system: Group I: Communicable, infectious, maternal, and perinatal; Group II: Noncommunicable and chronic; Group III: Injuries and accidents.
* Gross national income (GNI) per capita calculated using the World Bank Atlas method.
Data from WHO and World Bank, 2015.

Disability. The GBD study 2015 update also provides an evaluation of the contributions made by specific conditions to disability in the world. Leading causes of disability in 2015 worldwide are shown in

TABLE 1-8 Leading Causes of Deaths in High-Income and Low-Income Countries, 2015

High-Income Countries		Low-Income Countries	
Rank	**Cause**	**Rank**	**Cause**
1	Ischemic heart disease	1	Lower respiratory infections
2	Cerebrovascular disease	2	HIV/AIDS
3	Alzheimer's and other dementias	3	Diarrheal diseases
4	Lung cancer	4	Malaria
5	Lower respiratory tract infection	5	Cerebrovascular disease
6	Chronic obstructive pulmonary disease	6	Ischemic heart disease
7	Colorectal cancers	7	Tuberculosis
8	Chronic kidney disease	8	Congenital defects
9	Diabetes	9	Neonatal preterm birth complications
10	Breast cancer	10	Neonatal encephalopathy

Data from GBD, 2015 (Based on the World Bank income categories).

TABLE 1-9. Neuropsychiatric and behavioral conditions, musculoskeletal disorders, and diabetes dominate the causes of disability, accounting for 5 of the top 10 conditions. However, a diverse spectrum of conditions, such as iron-deficiency anemia, skin diseases, and oral disorders, also appear on the list. A unique contribution of the GBD work has been its placement of nonfatal health outcomes in the center of international health policy in recent years. The important, and yet often ignored, effects of these conditions are obvious once disability is counted in these estimates of disease burden.

Disease Burden. Based on the estimation of deaths and disability presented in the preceding subsection, the global disease burden for 2015 was estimated using DALYs. Leading causes of the global burden in 2015 (**TABLE 1-10**) indicate how those conditions affect the global disease burden. The top 10 list is a mixture of communicable and perinatal conditions, noncommunicable diseases, and road traffic injuries. This situation highlights the challenge facing the global health community as it simultaneously continues to fight infectious diseases, seeks to improve the response to chronic conditions, and prepares to meet the increasing impact of injuries.

Age and Disease Distributions. **FIGURE 1-12** illustrates the distribution of the global burden in 2015 by disease groups and demonstrates the growing relative impact of chronic diseases (group II) over infectious conditions (group I). **FIGURE 1-13** provides comparable figures for loss of healthy life in seven major regions of the world. Note that communicable diseases still represent a considerable portion of the disease burden in 2015, especially in sub-Saharan Africa.

As the figures demonstrate, various subregions within middle- and low-income countries are at different stages of the epidemiologic transition. The influx of chronic diseases has added another layer of problems in some areas, while the burden of communicable diseases has not yet been eradicated. This "double burden" poses a major challenge for the health systems in these nations. In addition, the scarcity of resources in many of these countries makes the situation even more critical, and it becomes imperative to define interventions that are cost-effective and able to reduce the burden of disease.

Other Ways Burden Can Be Measured

Mortality and morbidity alone have been used for decades for international comparisons of disease

TABLE 1-9 Leading Causes of Disability Losses Globally, 2015

Rank	Cause
1	Lower back and neck pain
2	Sense organ diseases
3	Depressive disorders
4	Iron-deficiency anemia
5	Skin diseases
6	Diabetes
7	Migraine
8	Other musculoskeletal disorders
9	Anxiety disorders
10	Oral disorders

Note: Disability losses are defined by years of life lived with disability (YLD). Ranking is based on YLD rates for all age groups, both sex and level 3 cause (http://ihmeuw.org/44lj).
Source: Institute for Health Metrics and Evaluation, 2015.
Data from GBD, 2015.

TABLE 1-10 Leading Cause of Global Burden of Disease, 2015

Rank	Cause
1	Ischemic heart disease
2	Cerebrovascular disease
3	Lower respiratory infections
4	Low back and neck pain
5	Neonatal preterm birth complications
6	Diarrheal diseases
7	Sense organ disease
8	Neonatal encephalopathy
9	Road traffic injuries
10	HIV/AIDS

Data from Institute for Health Metrics and Evaluation, 2015. Ranking based on DALYs rates for all age groups, both sex for 2015 and level 3 cause. Retrieved from http://ihmeuw.org/44lk.

burden. Mortality among children younger than 5 years is considered a sensitive indicator of the overall health of nations, but especially of the health of women and children. UNICEF publishes an annual *State of the World's Children* report (UNICEF, 2016) that includes a ranking of nations based on this indicator (**TABLE 1-11**).

Gross national income (GNI) per capita is an indicator of national wealth, and the relationship between these variables usually follows an expected sequence, such that the country with the lowest GNI per capita has the worst indicators of health. However, as Table 1-11 indicates, even countries that have relatively higher per capita income can have poor indicators of health service accessibility (e.g., proportion of newborns protected against tetanus). For example, the per capita GNI for Mongolia is higher than that for Nicaragua, yet both the countries rank 84th for under-5 mortality, with lower life expectancy in Mongolia compared to Nicaragua. Such examples demonstrate that the relationship between health and poverty is complex and needs in-depth investigation. When seeking to improve the health of nations, both absolute poverty and the disparities within societies

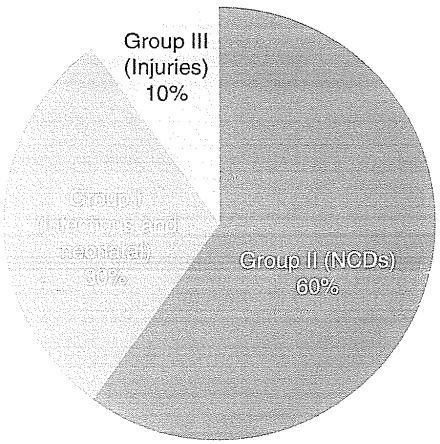


FIGURE 1-12 Global burden of disease 2015 by disease groups.
Data from GBD, 2015.

serve as impediments to empowerment of the poor and needy, especially women and children.

Projections

Forecasts of disease burden have been attempted with the intent of providing some basis for health planning. Making such projections is a challenging task

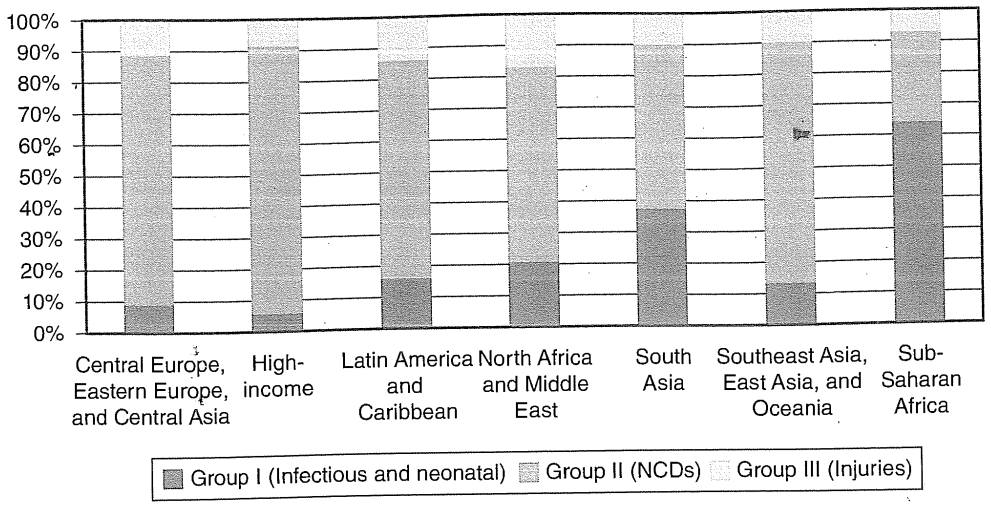


FIGURE 1-13 Proportion of disease burden by disease groups in selected regions, 2015.

Data from GBD, 2015.

TABLE 1-11 Health Status Indicators and National Income for Selected Low- and Middle-Income Countries

Country	Ranking by Child Mortality (<5 years)	Life Expectation at Birth, 2015 (years)	Stunted Children <5 Years (%)	Newborns Protected Against Tetanus *(%)	Gross National Income per Capita, 2014 (U.S. dollars)
Afghanistan	16	61	41	70	680
Angola	1	53	29	78	4,126 to 12,735
Bhutan	67	70	34	83	2,370
Guatemala	71	72	47	85	3,430
Mongolia	84	70	11	—	4,280
Nicaragua	84	75	23	81	1,870
Niger	10	62	43	81	410
Pakistan	22	66	45	75	1,400
Peru	99	75	15	85	6,360
Sierra Leone	5	51	38	85	700

* Modeling is done based on pregnant women who were given two doses or more of tetanus toxoid vaccine to calculate the percentage of births that can be considered as protected against tetanus.
Data from UNICEF, 2016.

that requires further data manipulations and the use of assumptions. These assumptions must predict changes in disease prevalence and incidence over time, the effects of interventions, and other factors. As a result, all projections are estimates with substantial variations that are highly dependent on the data used to derive them.

The GBD 2015 study was conducted to provide burden of disease estimates for more than 200 health conditions. These estimates are available based on gender, age groups, countries, and regions, allowing for comparisons across different years. Estimates are available since 1990, and the current

leading causes of disease burden are presented in Table 1-10.

The dominance of chronic diseases on this list is obvious, although respiratory conditions still appear to be important. Injuries from road traffic crashes are the ninth leading cause of the global disease burden and are expected to rise in prominence.

The growing importance of noncommunicable diseases is a global phenomenon, and these conditions' impact on low- and middle-income countries and regions needs to be assessed. However, there is a persistent burden of respiratory infections and diarrheal diseases in these regions. The situation in the low- and middle-income world is one where the "triple burden" of persistent communicable diseases, prevalent noncommunicable conditions, and increasing injuries will call for an appropriate response from public health officials.

Burden of Disease Attributed to Risk Factors

An analysis of risk factors that underlie many important disease conditions can help inform policy decisions concerning interventions directed toward health promotion and disease reduction. For example, smoking, alcohol, hypertension, and malnutrition are risk factors for a variety of diseases, and specific interventions have been developed that may reduce their prevalence. Risk factors include an array of human behaviors, nutritional deficiencies and excesses, substance abuse, and certain characteristics such as hypertension. Some factors are both an outcome and a risk factor (hypertension), some are challenging to measure (violence), and yet others (smoking and alcohol) lead to many possible disease outcomes. The linkage between an identified risk factor and the set of associated disease outcomes may be difficult to directly quantify, and the portion of specific disease prevalence attributable to any one factor may be problematic.

Relationships such as those shown in **FIGURE 1-14** require careful assessment to determine the proportion of heart disease to be attributed to hypertension in relation to other interacting causal factors. The best way to determine the portion of disease that may be ascribed to hypertension is through randomized trials with careful assessment of disease outcomes over time: Results from studies that control hypertension have shown a reduction of death and disability from not only cardiac disease, but also from cerebrovascular and renal diseases.

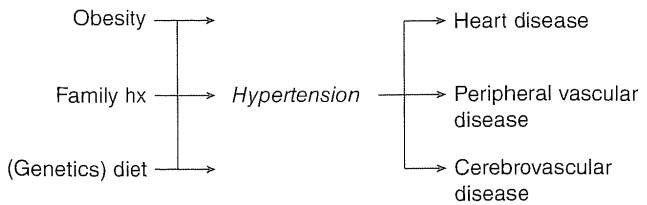


FIGURE 1-14 Flowchart of a "disease" and "risk factor" – Hypertension.

Because the most important purpose of risk factor analysis is to assist in decision making about the allocation of resources, the link between the various risk factors and potential interventions to reduce those risks should be clear. The effectiveness of interventions against risk factors ultimately should be judged by their ability to reduce the amount of healthy life lost attributed to the diseases that the risk factor affects. For the evaluation of an intervention that reduces hypertension, for example, the healthy life losses from the entire range of diseases that hypertension influences are required.

Although understanding the underlying factors that lead to disease and the complex interrelations in the web of causation has long been a major focus of epidemiology (Rothman, 2012), most analyses of the relationships of risk factors to specific diseases have been done in the context of individual risk factors in limited settings and with wide variations in the criteria for risk assessment. As a consequence, comparisons of risk factors as determinants of disease on a population health level are problematic.

The Burden of Selected Major Risk Factors

The model used in recent GBD studies for causal attribution of health outcomes is based on *counterfactual analysis* that focuses on risk factor compared to a counterfactual risk distribution (Ezzati et al., 2002). Within this analysis, the contribution of one risk factor, or a group of risk factors, to disease or mortality was estimated by comparing the current or future disease burden with the levels that would be expected under an alternative hypothetical scenario. This involves an evaluation of the effect that a risk factor has on a disease and its consequences, by setting the risk factor to its minimum while keeping all other factors constant. This method has the advantage of showing the potential gains by risk reduction from all levels of suboptimal exposure in a consistent way across risk factors (Ezzati et al., 2002).

The Comparative Risk Assessment (CRA) part of GBD 2015, for example, carried out a systematic evaluation of 79 risk factors divided into three main groups (referred to as "level 1")—behavioral, environmental

and occupational, and metabolic risks—relative to global and regional burdens of disease using a specific model for analysis (WHO, 2002a). Recently, the analysis was conducted from 1990 to 2015 for 17 level 2 risk factors (Global Burden of Disease Risk Factors Collaborators, 2016). As shown in part (a) of **FIGURE 1-15**, the five leading risks for mortality on a global level are dietary risks (19%), high systolic blood pressure (17%), tobacco smoke (11%), air pollution (10%), and high fasting plasma glucose (8%); together these account for 65% of global mortality. These five factors especially increase risks for heart disease, diabetes, and cancer and have major consequences for countries across all income groups. Part (b) of Figure 1-15

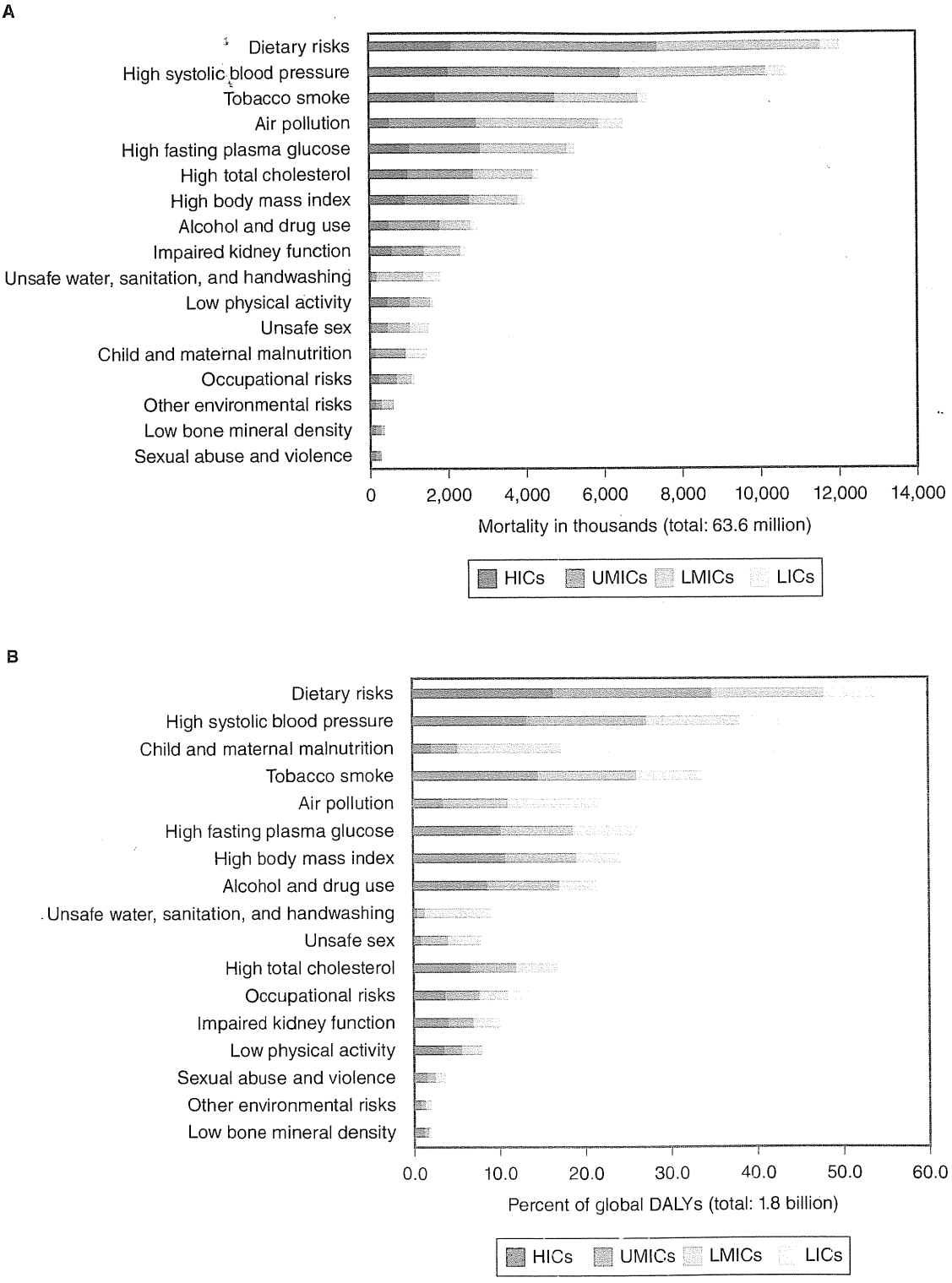


FIGURE 1-15 Mortality (a) and DALYs (b) due to 19 leading risk factors by country income level, 2015.

Data from GBD, 2015.

shows the main risks for burden of disease (DALYs) on a global level, with dietary risks (15%), high systolic blood pressure (12%), child and maternal malnutrition (9%), tobacco smoke (9%), and air pollution (9%) accounting for more than half of the global DALYs. These estimates show the contribution of behavioral and environmental risk factors toward development of group II diseases.

The recent reductions in environmental risk factors mostly stem from reductions in unsafe water, unsafe sanitation, poor hygiene, and household air pollution. In terms of behavioral risk factors, smoking is among five top risk factors contributing to DALYs at the regional level. Alcohol and drug abuse is largely a problem for men, contributing to 7% of burden of disease in 2015, but those mainly affected vary greatly by geographic region: This factor has its greatest impact on men in Southeast Asia, South Asia, and Central and Eastern European countries (Institute for Health Metrics and Evaluation, 2015).

Eight level 2 risk factors—dietary risks, high blood pressure, high total cholesterol, air pollution, tobacco, high fasting plasma glucose, high body mass index, and low physical activity—account for more than 90% of ischemic heart disease (the leading cause of death worldwide). Although these major risk factors are associated with high-income countries, more than 88% of the total global burden of disease that they cause occurs in LMICs (Institute for Health Metrics and Evaluation, 2015). Some risk factors may have few effects on the total global burden of disease, yet be very important locally within certain populations and regions. For example, iodine deficiency affects certain LMICs and results in substantial disability in those populations.

The demographic and epidemiologic transitions discussed earlier in this chapter affect shifts in these major risk factors by changing social, economic, and political trends and their complex interactions. Low-income countries continue to struggle against the high burdens of infectious diseases, malnutrition (including undernutrition and micronutrient deficiencies), and maternal and child health problems; at the same time, they must deal with the additional burdens of high levels of noncommunicable disease and injuries. WHO has estimated that if such types of risks did not exist, global life expectancy would be 10 years longer (Mathers, Stevens, & Mascarenhas, 2009).

Conclusion

The health of populations is the fundamental concern of global public health. The first step in the pursuit of population health improvement is the measurement of health and disease. Measurement is required to establish the magnitude of disease problems, define causal factors, explore potential solutions, and determine the impact of interventions. Measuring the impact of diseases on populations in terms of mortality and morbidity and their consequences is essential for planning effective ways to reduce the burden of illness and for setting priorities.

The burden of disease in populations has been gauged in many ways. Examples include measures of mortality, such as infant mortality rates; demographic measures, such as expectation of life at birth; and measures of morbidity, such as days away from work. However, for purposes of comparison among populations and for assisting in health planning and resource allocation, a common denominator combining these factors is needed. Summary measures of population health based on the amount of healthy life lost from disability and from death have been developed to serve that purpose. Composite indicators (such as HeaLYs and DALYs) use duration of time (years, weeks, days) to measure the loss of healthy life from disease and the gain from interventions. These metrics are evolving into important tools for assisting health-related decision making. Nevertheless, to avoid misuse of such indicators, it is critical for those using them to understand the underlying assumptions and limitations and to meet the rather formidable data requirements. These summary measures also could be used to examine the burden of disease among subpopulations defined by sociocultural economic attributes and especially on vulnerable groups. Thus, they could be used for ensuring that health-related decisions consider equity as well as cost-effective criteria.

Trends in disease burden provide important clues about the success of ongoing health programs and the need for development of new interventions. At the same time, they reflect non-health-related factors that are important to the production or maintenance of health in populations. Inter-country and inter-regional comparisons allow for measuring progress among nations; they can highlight inequalities in health status and examine these disparities in relation to social, economic, educational, and other factors.

Health systems across the world are greatly affected by ongoing changes in disease profiles and population dynamics. These systems must develop the capacity to respond to such changes effectively within the resources of each nation. Decisions must be based on evidence about the patterns of diseases, their risk factors, and the effectiveness of alternative interventions. Timely collection and analysis of appropriate, high-quality data to support such evidence are

a prerequisite for improving equitable global health development.

Acknowledgments

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Discussion Questions

1. How can data help achieve the main purpose of a health system in any country? Give examples.
2. What are the essential elements of a burden of disease assessment, and which types of data are the most challenging to obtain in a low-income country?
3. What are the relative strengths and weaknesses of summary measures such as HeaLYs and DALYs compared to more traditional indicators of disease burden such as infant or maternal mortality?
4. In your country or city, what would be the most appropriate set of indicators to assess the impact of chronic diseases on the population? Why?

Appendix 1

Some of the Health-Related SDG Indicators

Target 2.1: By 2030, end hunger and ensure access by all people, in particular the poor and people in vulnerable situations, including infants, to safe, nutritious, and sufficient food all year round

- 2.1.1 Prevalence of undernourishment

Target 2.2: By 2030, end all forms of malnutrition, including achieving, by 2025, the internationally agreed targets on stunting and wasting in children under 5 years of age, and address the nutritional needs of adolescent girls, pregnant and lactating women, and older persons

- 2.2.1 Prevalence of stunting
- 2.2.2 Prevalence of malnutrition

Target 3.1: By 2030, reduce the global maternal mortality ratio to less than 70 per 100,000 live births

- 3.1.1 Maternal mortality ratio
- 3.1.2 Proportion of births attended by skilled health personnel

Target 3.2: By 2030, end preventable deaths of newborns and children under 5 years of age, with all countries aiming to reduce neonatal mortality to at least as low as 12 per 1,000 live births and under-5 mortality to at least as low as 25 per 1,000 live births

- 3.2.1 Under-5 mortality rate
- 3.2.2 Neonatal mortality rate

Target 3.3: By 2030, end the epidemics of AIDS, tuberculosis, malaria, and neglected tropical diseases and combat hepatitis, water-borne diseases, and other communicable diseases

- 3.3.1 Number of new HIV infections per 1,000 uninfected population, by sex, age, and key populations
- 3.3.2 Tuberculosis incidence per 1,000 population
- 3.3.3 Malaria incidence per 1,000 population
- 3.3.4 Hepatitis B incidence per 100,000 population
- 3.3.5 Number of people requiring interventions against neglected tropical diseases

Target 3.4: By 2030, reduce by one third premature mortality from noncommunicable diseases through prevention and treatment and promote mental health and well-being

- 3.4.1 Mortality rate attributed to cardiovascular disease, cancer, diabetes, or chronic respiratory disease
- 3.4.2 Suicide mortality rate

Target 3.5: Strengthen the prevention and treatment of substance abuse, including narcotic drug abuse and harmful use of alcohol

- 3.5.1 Coverage of treatment interventions (pharmacological, psychosocial, and rehabilitation and aftercare services) for substance use disorders
- 3.5.2 Harmful use of alcohol, defined according to the national context as alcohol per capita consumption (aged 15 years and older) within a calendar year in liters of pure alcohol

Target 3.6: By 2020, halve the number of global deaths and injuries from road traffic accidents

- 3.6.1 Death rate due to road traffic injuries

Target 3.7: By 2030, ensure universal access to sexual and reproductive healthcare services, including for family planning, information and education, and the integration of reproductive health into national strategies and programs

- 3.7.1 Proportion of women of reproductive age (aged 15–49 years) who have their need for family planning satisfied with modern methods
- 3.7.2 Adolescent birth rate (aged 10–14 years; aged 15–19 years) per 1,000 women in that age group

Target 3.8 Achieve universal health coverage, including financial risk protection, access to quality essential healthcare services, and access to safe, effective, quality, and affordable essential medicines and vaccines for all

- 3.8.1 Coverage of essential health services
- 3.8.2 Number of people covered by health insurance or a public health system per 1,000 population

Target 3.9: By 2030, substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water, and soil pollution and contamination

- 3.9.1 Mortality rate attributed to household and ambient air pollution
- 3.9.2 Mortality rate attributed to unsafe water, unsafe sanitation and lack of hygiene (exposure to unsafe Water, Sanitation and Hygiene for All [WASH] services)
- 3.9.3 Mortality rate attributed to unintentional poisoning

Target 4.2: By 2030, ensure that all girls and boys have access to quality early childhood development, care, and pre-primary education so that they are ready for primary education

- 4.2.1 Proportion of children under 5 years of age who are developmentally on track in health, learning, and psychosocial well-being, by sex

Target 5.2: Eliminate all forms of violence against all women and girls in the public and private spheres, including trafficking and sexual and other types of exploitation

- 5.2.1 Proportion of ever-partnered women and girls aged 15 years and older subjected to physical, sexual, or psychological violence by a current or former intimate partner in the previous 12 months, by form of violence and by age
- 5.2.2 Proportion of women and girls aged 15 years and older subjected to sexual violence by persons other than an intimate partner in the previous 12 months, by age and place of occurrence

Target 5.6: Ensure universal access to sexual and reproductive health and reproductive rights

- 5.6.2 Number of countries with laws and regulations that guarantee women aged 15–49 years access to sexual and reproductive health care, information, and education

Target 6.1: By 2030, achieve universal and equitable access to safe and affordable drinking water for all

- 6.1.1 Proportion of population using safely managed drinking water services

Target 6.2: By 2030, achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations

- 6.2.1 Proportion of population using safely managed sanitation services, including a hand-washing facility with soap and water

Target 8.8 Protect labor rights and promote safe and secure working environments for all workers, including migrant workers, in particular women migrants, and those in precarious employment

- 8.8.1 Frequency rates of fatal and nonfatal occupational injuries, by sex and migrant status

Target 11.5: By 2030, significantly reduce the number of deaths and the number of people affected and substantially decrease the direct economic losses relative to global gross domestic product caused by disasters, including water-related disasters, with a focus on protecting the poor and people in vulnerable situations

- 11.5.1 Number of deaths, missing persons, and persons affected by disaster per 100,000 people

Target 11.7 By 2030, provide universal access to safe, inclusive, and accessible green and public spaces, in particular for women and children, older persons, and persons with disabilities

- 11.7.2 Proportion of persons who are victims of physical or sexual harassment, by sex, age, disability status, and place of occurrence, in the previous 12 months

Target 16.1: Significantly reduce all forms of violence and related death rates everywhere

- 16.1.1 Number of victims of intentional homicide per 100,000 population, by sex and age
- 16.1.2 Conflict-related deaths per 100,000 population, by sex, age, and cause
- 16.1.3 Proportion of population subjected to physical, psychological, or sexual violence in the previous 12 months
- 16.1.4 Proportion of population that feel safe walking alone around the area they live

Target 16.2 End abuse, exploitation, trafficking, and all forms of violence against and torture of children

- 16.2.1 Proportion of children aged 1–17 years who experienced any physical punishment and/or psychological aggression by caregivers in the past month
- 16.2.3 Proportion of young women and men aged 18–29 years who experienced sexual violence by age 18

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