# Alternative projections of mortality and disability by cause 1990–2020: Global Burden of Disease Study

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## Summary

**Background** Plausible projections of future mortality and disability are a useful aid in decisions on priorities for health research, capital investment, and training. Rates and patterns of ill health are determined by factors such as socioeconomic development, educational attainment, technological developments, and their dispersion among populations, as well as exposure to hazards such as tobacco. As part of the Global Burden of Disease Study (GBD), we developed three scenarios of future mortality and disability for different age-sex groups, causes, and regions.

**Methods** We used the most important disease and injury trends since 1950 in nine cause-of-death clusters. Regression equations for mortality rates for each cluster by region were developed from gross domestic product per person (in international dollars), average number of years of education, time (in years, as a surrogate for technological change), and smoking intensity, which shows the cumulative effects based on data for 47 countries in 1950–90. Optimistic, pessimistic, and baseline projections of the independent variables were made. We related mortality from detailed causes to mortality from a cause cluster to project more detailed causes. Based on projected numbers of deaths by cause, years of life lived with disability (YLDs) were projected from different relation models of YLDs to years of life lost (YLLs). Population projections were prepared from World Bank projections of fertility and the projected mortality rates.

**Findings** Life expectancy at birth for women was projected to increase in all three scenarios; in established market economies to about 90 years by 2020. Far smaller gains in male life expectancy were projected than in females; in formerly socialist economies of Europe, male life expectancy may not increase at all. Worldwide mortality from communicable maternal, perinatal, and nutritional disorders was expected to decline in the baseline scenario from 17·2 million deaths in 1990 to 10·3 million in 2020. We projected that non-communicable disease mortality will increase from 28·1 million deaths in 1990 to 49·7 million in 2020. Deaths from injury may increase from 5·1 million to 8·4 million. Leading causes of disability-adjusted life years (DALYs) predicted by the baseline model were (in descending order): ischaemic heart disease, unipolar major depression, road-traffic accidents, cerebrovascular disease, chronic obstructive pulmonary disease, lower respiratory infections, tuberculosis, war injuries, diarrhoeal diseases, and HIV. Tobacco-attributable mortality is projected to increase from 3·0 million deaths in 1990 to 8·4 million deaths in 2020.

**Interpretation** Health trends in the next 25 years will be determined mainly by the ageing of the world's population, the decline in age-specific mortality rates from communicable, maternal, perinatal, and nutritional disorders, the spread of HIV, and the increase in tobacco-related mortality and disability. Projections, by their nature, are highly uncertain, but we found some robust results with implications for health policy.


*Lancet* 1997; **349:** 1498–1504

## Introduction

Future health scenarios that are likely, or probable, or merely possible can have an important role in shaping public-health policy. Studies on health projections[1–3] provide an indication of the strong interest shown by scientific and public-health communities in the definition and quantification of scenarios of future health. There have, however, been few comprehensive efforts to project health scenarios for a population[4] and none for the entire world or for major regions. In this paper, the last of four on the Global Burden of Disease Study (GBD) (see *Lancet* 1997; **349:** 1269–76; 1347–52; and 1436–42) we describe how we created three scenarios of future mortality and disability by cause, which may have important public policy implications.

Our scenarios were based on future health status as a function of projected changes in key socioeconomic variables, which influence health states. Uncertainties in the projections arise from the validity of these relational models, assumptions about their invariance over time, and, of course, uncertainty about the future rates and distribution of factors that currently influence health and survival. Despite these uncertainties, several robust projections—due largely to demographic change and the future effects of current smoking patterns—emerge from our analysis. Further detail on the methods used to estimate causes of death, to develop epidemiological profiles of each disabling sequela, to assess the burden attributable to major risk factors, and to project the burden of premature mortality and disability has been published.[5]

## Methods

### *Projection methods*

We used 12 separate analytical or computational steps to construct a baseline scenario, and optimistic and pessimistic scenarios. Separate projection models for both sexes and seven age-groups—0–4, 5–14, 15–29, 30–44, 45–59, 60–69, and 70

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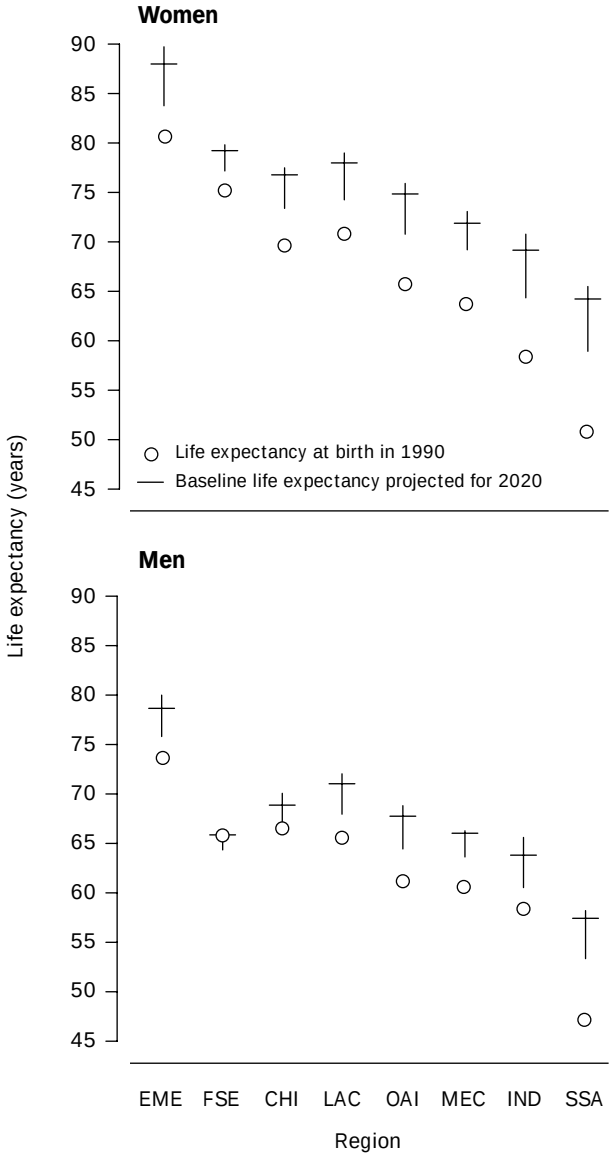


Figure 1: **Life expectancy at birth in 1990 and in baseline, optimistic, and pessimistic scenarios in 2020**

Abbreviations for regions are: EME=established market economies; FSE=formerly socialist economies of Europe; IND=India; CHN=China; OAI=other Asia and islands; SSA=sub-Saharan Africa; LAC=Latin America and the Caribbean; MEC=the middle eastern crescent. Vertical bars indicate upper and lower limits of life expectancy projected for 2020 defined by optimistic and pessimistic scenarios.

years or older—were developed to produce parsimonious equations for nine cause-of-death clusters: all group 1 (communicable, maternal, perinatal, and nutritional disorders); malignant neoplasms, cardiovascular diseases, digestive diseases, chronic respiratory diseases, and other group 2 (non-communicable) disorders; road-traffic accidents, other unintentional injuries, and intentional injuries (group 3 disorders). We used these nine cause groups to find total mortality in each age-sex group.

We developed regression equations from a dataset based on vital registration data from 47 countries for the years 1950–90. We used four independent variables in the analysis: income per person, average years of schooling per adult, smoking intensity, and time. Income per person, measured in international dollars (adjusted for differences in purchasing power not covered by official exchange rates), was the general proxy for many indices of development.[6] Research has shown consistently that education also influences health status.[7,8] Level of education was measured as the average number of years of schooling for the population older than 25 (data available for 98 countries since 1950).[9] For smoking intensity we used Peto and colleagues' method[10] to calculate observed lung-cancer rates minus non-smoker lung-cancer rates for each age-sex group to measure cumulative tobacco exposure. The fourth independent variable, time, was used to cover the impact of technological change on health status.

Our regression equations took the form:

$$LnM_{a,k,i}=C_{a,k,i}+\beta_1 LnY+\beta_2 LnHC+\beta_3 T,$$

where $C_{a,k,i}$ is a constant term; $M_{a,k,i}$ is the mortality rate for age-group a, sex k, and cause i; and Y, HC, and T denote gross domestic product per person, human capital and time, respectively. For cancers, cardiovascular diseases, and chronic respiratory disorders for age-groups older than 30 years, smoking intensity was added to this equation. The detailed econometric analysis that underlies our results is reported elsewhere.[11]

In general, these equations explained most of the variance in group 1 mortality and much of variance in group 2 morality, but explained little of the variance in intentional injuries (and road-traffic accidents for children). The $R^2$ for many cause clusters was generally lower for men and women aged 70 or older than for other age-groups, which probably reflects inaccurate coding of causes of death or the narrower range of variation in mortality rates between countries for this age-group. The $R^2$ for cardiovasucular diseases among women ranged from 48% to 69% between the ages of 15 and 69, whereas for men in the same age-groups, the $R^2$ ranged from 12% to 63%.

For causes that had $R^2$ of less than 10%, we chose not to use the parsimonious regression equations, and mortality rates specific for age and sex were assumed to stay constant. For intentional injuries in all age-sex groups, constant rates for 1990–2020 were assumed.

Predictions for 1990 based on these equations were compared with the GBD estimates of mortality rates by cause in 1990. A series of specific scalars for age, sex, cause, and region were calculated, which were the observed death rate divided by the predicted death rate. To make projections, these scalars were assumed to remain constant from 1990 to 2020. A consequence of the large scalars for group 1 disorders in regions such as sub-Saharan Africa was that we may have overestimated the future group 1 mortality.

For income per person and average years of schooling, baseline, pessimistic, and optimistic projections were generated from World Bank forecasts for 1995–2004 and the empirical record 1950–90.[5] Projections of smoking intensity were based on the observed relation between the number of cigarettes

| Disorder | Ranking | | Change in ranking |
|---|---|---|---|
| | 1990 | 2020 (baseline model) | |
| **Within top 15** | | | |
| Ischaemic heart disease | 1 | 1 | 0 |
| Cerebrovascular disease | 2 | 2 | 0 |
| Lower respiratory infections | 3 | 4 | ↓1 |
| Diarrhoeal diseases | 4 | 11 | ↓7 |
| Perinatal disorders | 5 | 16 | ↓11 |
| Chronic obstructive pulmonary disease | 6 | 3 | ↑3 |
| Tuberculosis | 7 | 7 | 0 |
| Measles | 8 | 27 | ↓19 |
| Road-traffic accidents | 9 | 6 | ↑3 |
| Trachea, bronchus, and lung cancers | 10 | 5 | ↓5 |
| Malaria | 11 | 29 | ↓18 |
| Self-inflicted injuries | 12 | 10 | ↑2 |
| Cirrhosis of the liver | 13 | 12 | ↑1 |
| Stomach cancer | 14 | 8 | ↑6 |
| Diabetes mellitus | 15 | 19 | ↓4 |
| **Outside top 15** | | | |
| Violence | 16 | 14 | ↓2 |
| War injuries | 20 | 15 | ↑5 |
| Liver cancer | 21 | 13 | ↑8 |
| HIV | 30 | 9 | ↑21 |

Table 1: **Changes in ranking for most important causes of death from 1990 to 2020 in baseline scenario**

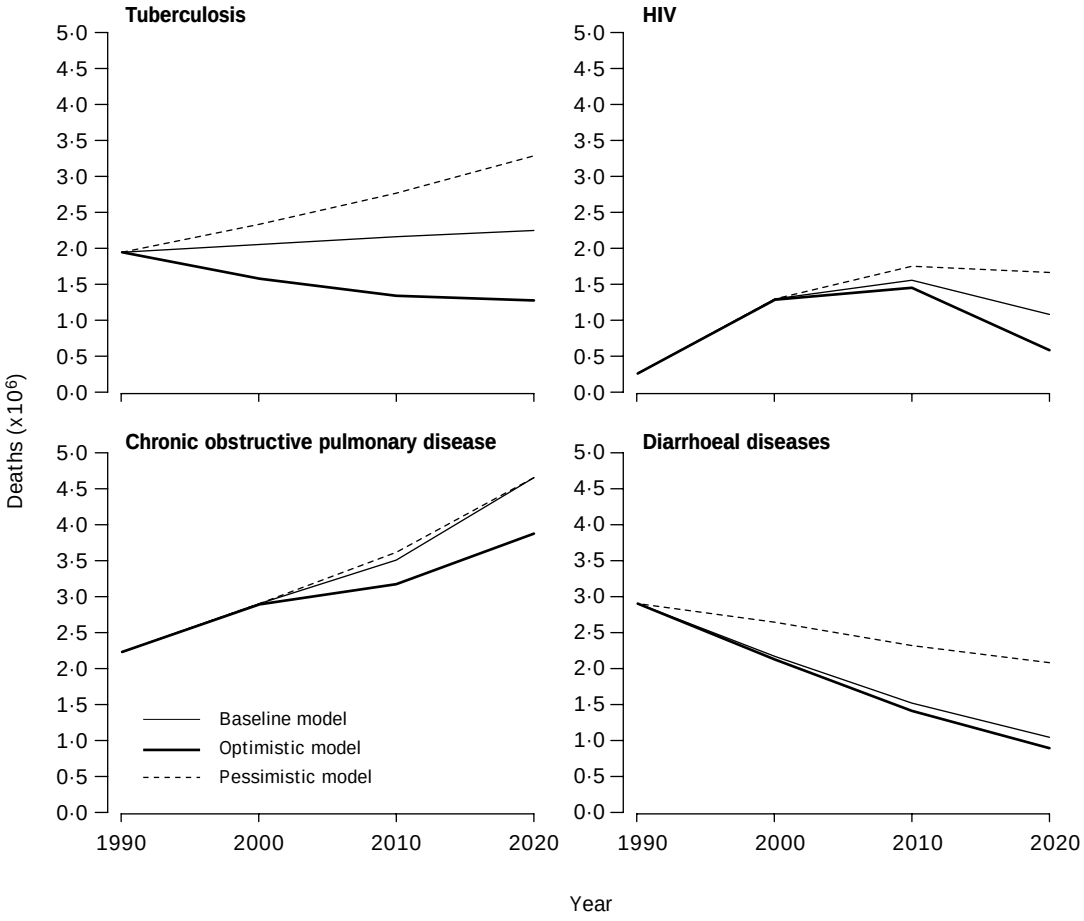


Figure 2: **Projected increase in mortality from 1990–2020 for tuberculosis, HIV, chronic obstructive pulmonary disease, and diarrhoeal diseases in baseline, optimistic, and pessimistic scenarios**

consumed per adult in the UK from 1900 to 1990 and calculated smoking intensity 30 years later. Estimates for per-person cigarette consumption for men and women for each region were used with this relation to estimate sex-specific future smoking intensity. Since the future course of the smoking intensity variable is largely determined by current smoking patterns, we did not generate projections for the optimistic and pessimistic scenarios.

To generate projections of specific disorders within the nine cause clusters, the relation between the age-sex-specific mortality rate from a disorder and the age-sex-specific mortality rate from the cause cluster to which the disorder belonged were used.[5,12,13] The variables that defined these relations were estimated from a restricted dataset of ICD-9 data from only 67 countries from about 1990.

The regression results for specific disorders were used only when the relation was reasonably strong, shown by an $R^2$ greater than 0·25 and an X-coefficient with $p<0·001$. Otherwise, the proportionate distribution of the remaining cause cluster was assumed to stay constant.

We used the cause-cluster regression estimates and alternative assumptions for selected causes, the projections of the independent variables, and the equations for specific disorders to project mortality rates by cause for eight regions and 14 age-sex groups from the base year 1990 to 1995, 2000, 2005, 2010, 2015, and 2020. To screen for data-entry errors or mistakes in the computer code, we examined graphs of each of these age-specific rates from 1990 to 2020 (10 976 graphs in total). Any errors were corrected. A final set of projected specific rates by age, sex, cause, and region was then generated.

Alternative projections of incidence and mortality from the HIV epidemic are well documented.[14–20] For the purpose of the GBD, we used the projections prepared by the Global Programme on AIDS for WHO, with some modifications.[21] The predictions suggested that, by 2020, there will be essentially few or no new cases of HIV in any region. Based on infectious-disease modelling,[22,23] this was too optimistic for our baseline scenario. The Global Programme on AIDS' projections were, therefore, modified, and for the baseline scenario, we assumed that the number of incident cases per year would stabilise once incidence fell to half of the peak incidence. The equilibrium incidence was assumed to be 75% of peak incidence for the pessimistic projections and 20% for the optimistic projections.

Because of the powerful interaction between tuberculosis and HIV infection in regions such as sub-Saharan Africa, we predicted that about a third of HIV-positive individuals will die from tuberculosis in high-prevalence regions.[24] The pace of decline in tuberculosis death rates was modified to reflect the projected regional HIV seroprevalence.

Based on projected death numbers for each model, years of life lost (YLLs) were calculated by the GBD method.[5] To project disability-adjusted life years (DALYs) it was also necessary to project years lived with disability (YLDs). We divided causes of death and disability into three categories, each of which had a different method to project YLDs: for those causes in which the age-sex-specific ratio of YLDs to YLLs, as estimated in the 1990 GBD results, was less than ten in all regions, YLDs were estimated with the assumption that these ratios for age, sex, and region would be constant from 1990 to 2020; for selected disabling disorders that are likely to decline the epidemiological transition, rates of change in the age-specific YLD rates were indexed on the group 1 death rate; and specific YLD rates for age and sex for the remaining causes, such as bipolar disorder, unipolar major depression, drug dependence, schizophrenia, alcohol dependence, Alzheimer's disease and other dementias, Parkinson's disease, multiple sclerosis, post-traumatic stress

| Disorder group | Projected DALYs | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | EME | FSE | IND | CHN | OAI | SSA | LAC | MEC | Developed | Developing | World |
| **Group 1** | | | | | | | | | | | |
| Total group 1 | 5·2 | 3·0 | 24·4 | 4·3 | 16·5 | 39·8 | 12·6 | 19·9 | 4·3 | 22·2 | 20·1 |
| Infectious and parasitic diseases | 2·9 | 1·0 | 17·3 | 1·4 | 9·7 | 28·5 | 7·4 | 8·4 | 2·1 | 14·3 | 12·9 |
| Respiratory infections | 1·2 | 0·8 | 3·2 | 1·1 | 2·8 | 5·4 | 1·5 | 4·6 | 1·0 | 3·4 | 3·2 |
| Maternal disorders | 0·0 | 0·1 | 0·3 | 0·1 | 0·3 | 0·6 | 0·2 | 0·4 | 0·1 | 0·3 | 0·3 |
| Perinatal disorders | 0·7 | 0·7 | 2·4 | 0·9 | 2·2 | 3·7 | 2·3 | 4·6 | 0·7 | 2·7 | 2·5 |
| Nutritional disorders | 0·4 | 0·3 | 1·2 | 0·9 | 1·4 | 1·5 | 1·1 | 1·9 | 0·4 | 1·3 | 1·2 |
| **Group 2** | | | | | | | | | | | |
| Total group 2 | 84·7 | 79·7 | 56·5 | 79·3 | 66·3 | 31·9 | 68·1 | 59·6 | 82·7 | 56·7 | 59·7 |
| Malignant neoplasms | 17·3 | 16·1 | 7·1 | 18·7 | 11·6 | 4·5 | 8·5 | 5·3 | 16·8 | 9·0 | 9·9 |
| Other neoplasms | 0·6 | 0·3 | 0·1 | 0·3 | 0·2 | 0·2 | 0·4 | 0·2 | 0·5 | 0·2 | 0·2 |
| Diabetes mellitus | 2·1 | 0·7 | 0·8 | 0·4 | 0·9 | 0·2 | 1·6 | 1·0 | 1·5 | 0·7 | 0·8 |
| Endocrine disorders | 0·9 | 0·2 | 0·0 | 0·2 | 0·2 | 0·4 | 1·0 | 0·6 | 0·6 | 0·4 | 0·4 |
| Neuropsychiatric disorders | 25·4 | 16·4 | 12·6 | 15·4 | 17·4 | 8·5 | 21·6 | 14·9 | 21·8 | 13·7 | 14·7 |
| Sense organ disorders | 0·1 | 0·1 | 2·7 | 1·7 | 2·3 | 1·3 | 1·2 | 1·3 | 0·1 | 1·8 | 1·6 |
| Cardiovascular disorders | 19·4 | 26·1 | 18·4 | 16·3 | 15·6 | 6·0 | 13·2 | 17·7 | 22·0 | 13·8 | 14·7 |
| Respiratory disorders | 5·3 | 8·1 | 6·4 | 16·3 | 4·3 | 4·5 | 6·3 | 6·6 | 6·4 | 7·4 | 7·3 |
| Digestive disorders | 5·2 | 3·9 | 2·5 | 3·5 | 6·5 | 1·8 | 4·6 | 3·7 | 4·7 | 3·4 | 3·5 |
| Genitourinary disorders | 1·2 | 1·1 | 0·8 | 1·1 | 1·3 | 0·9 | 1·3 | 2·1 | 1·2 | 1·1 | 1·2 |
| Skin disorders | 0·1 | 0·1 | 0·0 | 0·1 | 0·1 | 0·3 | 0·1 | 0·1 | 0·1 | 0·1 | 0·1 |
| Musculoskeletal disorders | 5·0 | 4·5 | 1·1 | 2·6 | 2·6 | 0·8 | 5·5 | 1·2 | 4·8 | 1·9 | 2·2 |
| Congenital anomalies | 0·9 | 1·2 | 3·2 | 1·9 | 1·8 | 2·2 | 1·7 | 3·3 | 1·0 | 2·4 | 2·2 |
| Oral disorders | 1·0 | 0·8 | 0·8 | 0·7 | 1·5 | 0·3 | 1·3 | 1·8 | 0·9 | 0·9 | 0·9 |
| **Group 3** | | | | | | | | | | | |
| Total group 3 | 10·1 | 17·4 | 19·1 | 16·4 | 17·2 | 28·3 | 19·3 | 20·5 | 13·0 | 21·1 | 20·1 |
| Unintentional injuries | 6·9 | 11·6 | 16·4 | 11·0 | 13·6 | 15·4 | 13·2 | 9·8 | 8·8 | 13·6 | 13·0 |
| Intentional injuries | 3·2 | 5·7 | 2·8 | 5·4 | 3·6 | 12·9 | 6·2 | 10·7 | 4·2 | 7·5 | 7·1 |

*Abbreviations for regions as in figure 1. Developed=established market economies and formerly socialist economies of Europe. Developing=all other regions.

Table 2: **Percentage distribution of projected DALYs for specific two causes**

disorder, panic disorder, obsessive-compulsive disorder, rheumatoid arthritis, osteoarthritis, benign prostatic hypertrophy, dental caries, periodontal diease, edentulism, and glaucoma were assumed to remain constant from 1990 to 2020.

Population projections for each region were developed from World Bank projections of fertility and the estimations in our mortality projection scenarios.

The projected rates of YLLs and YLDs that incorporated the projections of HIV and modifications for tuberculosis were applied to these projected populations to generate projected numbers of deaths, YLLs, YLDs, and DALYs for each of the three scenarios.

## Results

Life expectancy at birth (figure 1) for women in all three scenarios was projected to increase in all regions, with the largest gains expected in sub-Saharan Africa, India, and other Asia and islands. Life expectancy for women in established market economies may reach close to 90 years—this is especially plausible since Asian women in the USA already have a life expectancy at birth of over 86 years.[25] The smallest gain for women is projected for formerly socialist economies of Europe. Comparison of women's and men's projected life expectancy highlights the much lower life expectancy in men in 1990 in all regions except India, and the far smaller gains projected in all regions for men than women. The much smaller improvements in male mortality are due largely to the greater impact of tobacco use in men. Only in men in formerly socialist economies of Europe is there no improvement in life expectancy projected between 1990 and 2020, although, since life expectancy dropped in 1995 in parts of the region such as Russia by as much as 5 years,[23] some gain between 1995 and 2020 is implied.

Worldwide annual mortality from communicable maternal, perinatal, and nutritional disorders (group 1) is predicted to decline from 17·2 million in 1990 to 10·3 million in 2020 in the baseline model (8·2 million in the optimistic and 16·9 million in the pessimistic scenarios). Conversely, a very large increase in deaths from non-communicable diseases (group 2) is expected, with a rise in annual mortality from an estimated 28·1 million deaths in 1990 to 49·7 million (48·0 and 53·0) in 2020. The projected increase in group 2 deaths is expected to be larger for males (91%) than for females (61%), consistent with the increase observed in industrialised countries during epidemiological transition. Deaths from injuries (group 3) are also projected to increase dramatically from 5·1 million in 1990 to 8·4 million (8·2 and 8·4) in 2020. Increases in the absolute number of deaths due to group 3 causes are largely determined by the projected changes in population size and age structure, and, in particular, by an increase in the number of men in the 15–29 years age-group, in which the risk of death from injury is highest.

Another way to describe the projected changes in mortality is to examine the changes in the leading causes of death. Table 1 shows the predicted change in the ranking of various causes of death from 1990 to 2020 in the baseline projections. Diarrhoeal diseases, perinatal disorders, measles, and malaria are all projected to decline substantially in importance, whereas lung cancer, stomach cancer, war injuries, liver cancer, and HIV are predicted to move up five or more places by 2020. The range defined by the optimistic and pessimistic projections differs substantially by cause (figure 2). For example, the trend for deaths from tuberculosis rises in the pessimistic projection and falls in the optimistic projection, whereas for diarrhoeal diseases the trend is downwards in all models.

In 1990, an estimated 1·38 billion DALYs were lost due to disease and injury occurring in that year. The total number of DALYs in 2020 worldwide is expected to be similar at about 1·39 billion in the baseline model (1·30 billion and 1·69 billion in the optimistic and pessimistic models, respectively). The proportionate contribution from the three groups of disorders, however, is expected to change significantly (table 2). Therefore, in 2020, group 1 causes are projected to account for 20·1% (17·2,

| Rank | Worldwide | | | Developed regions | | | Developing regions | | |
|---|---|---|---|---|---|---|---|---|---|
| | Disease or injury | DALYs ($\times 10^6$) | Cum % | Disease or injury | DALYs ($\times 10^6$) | Cum % | Disease or injury | DALYs ($\times 10^6$) | Cum % |
| · · | **All causes** | 1388·8 | · · | **All causes** | 160·5 | · · | **All causes** | 1228·3 | · · |
| 1 | Ischaemic heart disease | 82·3 | 5·9 | Ischaemic heart disease | 18·0 | 11·2 | Unipolar major depression | 68·8 | 5·6 |
| 2 | Unipolar major depression | 78·7 | 11·6 | Cerebrovascular disease | 9·9 | 17·4 | Road-traffic accidents | 64·4 | 10·8 |
| 3 | Road-traffic accidents | 71·2 | 16·7 | Unipolar major depression | 9·8 | 23·5 | Ischaemic heart disease | 64·3 | 16·1 |
| 4 | Cerebrovascular disease | 61·4 | 21·1 | Trachea, bronchus, and lung cancers | 7·3 | 28·0 | Chronic obstructive pulmonary disease | 52·7 | 20·4 |
| 5 | Chronic obstructive pulmonary disease | 57·6 | 25·3 | Road-traffic accidents | 6·9 | 32·3 | Cerebrovascular disease | 51·5 | 24·6 |
| 6 | Lower respiratory infections | 42·7 | 28·4 | Alcohol use | 6·1 | 36·1 | Tuberculosis | 42·4 | 28·0 |
| 7 | Tuberculosis | 42·5 | 31·4 | Osteoarthritis | 5·6 | 39·5 | Lower respiratory infections | 41·1 | 31·4 |
| 8 | War injuries | 41·3 | 34·4 | Dementia and other degenerative and hereditary CNS disorders | 5·5 | 43·0 | War injuries | 40·2 | 34·6 |
| 9 | Diarrhoeal diseases | 37·1 | 37·1 | Chronic obstructive pulmonary disease | 4·9 | 46·0 | Diarrhoeal diseases | 37·0 | 37·6 |
| 10 | HIV | 36·3 | 39·7 | Self-inflicted injuries | 3·9 | 48·4 | HIV | 34·0 | 40·4 |

Table 3: **Ten projected leading causes of DALYs in 2020 according to baseline projection**

29·4) of DALYs worldwide, compared with 43·9% in 1990. The contribution from group 2 is projected to rise from 40·9% to 59·7% (61·4 and 53·6). The relative contribution from injuries is also expected to rise from 15·2% to 20·1% (21·4 and 17·0).

DALYs due to all group 1 disorders are expected to decrease substantially by 2020. This fall is expected for infectious and parasitic diseases, which accounted for 22·9% of DALYs worldwide in 1990; the proportion is expected to decrease to 12·9% (10·4 and 18·0) in 2020. DALYs due to maternal disorders are expected to fall from 2·2% to 0·3% (0·3 and 0·9) and those from respiratory infections to fall from 8·5% to 3·2% (3·0 and 4·8) of the worldwide total. Conversely, major increases in DALYs are expected for some of the leading non-communicable diseases. DALYs from cancers are expected to rise from 5·1% to 9·9% (10·5 and 18·0) of the worldwide total in 2020. The proportionate share of the global burden of disease due to neuropsychiatric disorders is projected to rise from 10·5% in 1990 to 14·7% (15·7 and 12·2) in 2020, and that due to cardiovascular diseases, to rise from 11·1% to 14·7% (15·4 and 13·7). Chronic respiratory infections are also likely to move to a higher rank, rising from 4·4% in 1990 to 7·3% (6·5 and 6·7) in 2020. Both unintentional and intentional injuries are projected to increase from 11·1% to 13·0% (13·8 and 11·3) and from 4·1% to 7·1% (7·6 and 5·7) of the worldwide total, respectively.

Table 3 shows the ten leading causes of DALYs for both sexes together for the developed and developing regions, and the world in the baseline scenario. Worldwide, the top three contributors to the burden of disease in 2020 are predicted to be ischaemic heart disease, followed by unipolar major depression and road-traffic accidents. Despite a 30-year decrease projected for total group 1 death and DALYs, four group 1 disorders are predicted to remain in the ten leading causes of DALYs in 2020: lower respiratory infections, tuberculosis, diarrhoea, and HIV. In the developing regions, these four causes are also the only group 1 disorders expected to remain in the ten leading causes of DALYs. In developed regions, osteoarthritis, dementia, and breast cancer are all expected to be in the ten leading causes of burden for women in 2020.

| Region* | Deaths$\times 10^6$ (% of worldwide total) | |
|---|---|---|
| | 1990 | 2020 |
| FME | 1·1 (36·7%) | 1·3 (15·5%) |
| FSE | 0·5 (16·7%) | 1·1 (13·1%) |
| IND | 0·1 (3·3%) | 1·5 (17·9%) |
| CHN | 0·8 (26·7%) | 2·2 (26·2%) |
| OAI | 0·2 (6·7%) | 0·7 (8·3%) |
| SSA | 0·1 (3·3%) | 0·3 (3·6%) |
| LAC | 0·1 (3·3%) | 0·4 (4·5%) |
| MEC | 0·1 (3·3%) | 0·8 (9·5%) |
| **World** | 3·0 | 8·4 |

*Abbreviations for regions as in figure 1.

Table 4: **Worldwide deaths attributable to tobacco use in 1990 and 2020**

By the same method as we used to estimate mortality attributable to tobacco in 1990,[5] we estimated mortality and disability attributable to tobacco in all three models. The number of deaths attributable to tobacco was projected to increase from 3·0 million in 1990 to 8·4 million (in the baseline scenario) in 2020 (table 4). In the developed regions, the number of deaths attributable to tobacco was projected to rise from 1·6 million in 1990 to 2·4 million in 2020. The largest increases in the epidemic of tobacco-related mortality will be in India, China, and other Asia and islands, where attributable deaths will increase from 1·1 million to 4·2 million by 2020. In terms of DALYs, the contribution of tobacco in the baseline model is projected to increase to nearly 9% of worldwide burden in 2020, by which time tobacco is projected to cause more deaths than any single disease worldwide.

Figure 3 shows the projected changes in population size by age for the world, developed, and developing regions used for our models.

## Discussion

In all three scenarios, substantial changes were predicted in regional patterns of mortality and disability. Some major themes are worth emphasising. The distribution of deaths by age will shift from younger to older ages. A major decline in the mortality and disability from communicable, maternal, perinatal, and nutritional disorders was predicted in all three scenarios, although the declines in the optimistic and baseline scenarios were much greater than in the pessimistic scenario. Deaths and DALYs due to group 2 disorders were projected to increase by 77% and 47%, respectively, in the baseline scenarios, and by similar amounts in the pessimistic and optimistic scenarios. The most striking increases in the burden of neuropsychiatric disorders were projected for other Asia and islands, the middle eastern crescent, sub-Saharan Africa, and India. The largest change in DALYs due to injuries is expected in sub-Saharan Africa.

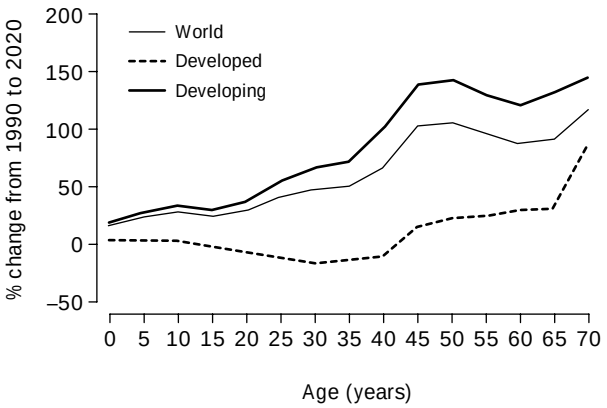


Figure 3: **Projected change in global population by age from 1990 to 2020**

Female life expectancy at birth was projected to increase in all regions—by 4·1 years in formerly socialist economies of Europe, and by 13·1 years in sub-Saharan Africa. Predicted gains in male life expectancy, by contrast, were much smaller, ranging from no change in formerly socialist economies of Europe to an increase of 10·2 years in sub-Saharan Africa. The gender gap in life expectancy was, therefore, also projected to increase in all regions. Even in established market economies, a low-mortality region, the male-female gap in life expectancy could well continue to widen, far beyond biological differences in life potential.

We attributed these dramatic trends to four main factors: ageing of the population, the spread of HIV, the rise of tobacco-related mortality and disability, and the decline in group 1 death rates. The average age of the world's population will increase, largely because of the demographic transition caused by declining fertility rates (figure 3). In the developed regions, the population aged 15–44 is predicted to decline, and the populations aged 45–64 and 65 and older will increase by about 26% and 71%, respectively. By contrast, in the developing world, the growth rate in the adult population will be dramatic. By 2020, the number of children and adolescents younger than 15 will increase by 25% but the number of adults aged 45–59 years will increase by 140%. Even if all age-specific death and disability rates were to remain constant, the differential rate of increase in different age-groups would lead to major changes in the burden of disease. If 1990 death and DALY rates were to remain constant but the expected changes in population age structure were to occur, the increase in group 2 burden expected in 2020 would be even larger than in our three scenarios. In other words, age-specific group 2 death and DALY rates are projected to decline (with a few exceptions, such as some adult male age-groups in India, China, and formerly socialist economies of Europe.

HIV, which 20 years ago was not a significant determinant of global mortality or disability, will become, soon after the year 2000, one of the ten leading causes of mortality and disability. According to the modified Global Programme on AIDS projections, HIV will cause 1·7 million deaths in 2006—in the optomistic scenario mortality peaks at 1·7 million deaths, and in the pessimistic model mortality peaks at 1·9 million deaths in 2012. In these projections, HIV will still cause 1·2 million (0·8 and 1·8 million) deaths and 2·6% (1·8 and 3·0) of all DALYs in 2020. Clearly, with a disease such as HIV, for which the incidence of new infections is declining in some populations and increasing in others, the various projections are extremely uncertain. The future course of HIV in Asia is probably the most uncertain. The HIV epidemic is an unprecedented reversal of human health progress.

Perhaps the most important determinant of human health trends is the increase in tobacco-related mortality and disability. As regions have developed, age-specific group 2 mortality rates have tended to decline; therefore a 15-year-old boy in sub-Saharan Africa has a higher risk of dying from a non-communicable disease than does a 15-year-old in the established market economies. The pervasive effects of tobacco, however, are the major factors that counter this decline in group 2 mortality. Tobacco-related deaths were projected to increase from 3·0 million in 1990 to 8·4 million in 2020. Tobacco use accounted for 2·6% of global DALYs in 1990 and was projected to account for 9·0% in 2020, which would make it the largest single health problem in 2020. National and international policy responses to this public-health challenge need to be intensified.

The final factor that influenced our projections was the expected decline in group 1 mortality, particularly in children and women of reproductive age. This forecast—which is contrary to the rise of new and re-emerging diseases—is based on the empirical record in the 47 countries for which reliable data were available in 1950–90. There was no convincing empirical evidence that, at the population level, the dramatic gains of the past four decades in reduction of group 1 mortality will not continue in the future. The prediction of a decline in group 1, which we forecast in all three scenarios was implicitly based on the presumption that socioeconomic development will decrease disease incidence and severity, and that research and development will guarantee the availability of antibiotics that are effective against resistant strains of major pathogens.

The baseline, optimistic, and pessimistic scenarios we designed offer three possible visions of future mortality and disability. There are, however, many other possible, albeit less probable, scenarios that could be envisaged, particularly for group 1 disorders. For example, new antibotics may not be discovered, and drug resistance may become so common for tuberculosis, malaria, pneumococcus, and other pathogens, that mortality rates could increase. Such a scenario is possible, but, we believe, not highly probable. In-vitro drug resistance of certain bacteria—for example, methicillin-resistant *Staphylococcus aureus*—has been recognised for many years. Because of many factors, however, including differences between in-vitro resistance and treatment failure, and the continued development of novel antibiotics, there has been no increase in mortality directly attributable to drug resistance in any population that had reliable data on mortality trends. Possible but improbable scenarios may still, however, be important for policy formulation. Societies should be willing to reduce the risks or consequences of unlikely, but real and potentially disastrous outcomes.

Any projection exercise is, by its nature, an exercise in conjecture with wide confidence intervals. Nevertheless, some features of our study introduce more uncertainty than others. First, the timing and magnitude of the peak in HIV incidence was based on estimates developed by the Global Programme on AIDS. Alternative projections with higher or lower peak incidences that occur sooner or

later are also credible. Second, death and YLD rates for intentional injuries were assumed to remain constant from 1990 to 2020, since we were unable to indentify significant relations between income, education, and time, based on the datasets available. The panel dataset, however, included some examples of countries, such as Hungary, where injury death rates have changed significantly over a short time. Injury death rates in a given region may, therefore, increase or decrease by 2020. For war injuries in particular, the assumption of constant rates combined with substantial adult-population growth gives projections that are highly uncertain. Third, there are specific relations between group 1 disorders and group 2 disorders, such as hepatitis B and liver cancer, and human papillomavirus and cervical cancer, that were not modelled directly. We predict that those group 2 disorders that are related to group 1 disorders may decrease at a faster rate than other group 2 disorders. As a result, our projections for such disorders may be overestimated. Finally, the entire set of YLD projections was based on either fixed-relational models or arbitrary assumptions about rates of decline.

Our results provide a comprehensive view of the future and may aid health planners in many different fields of public health. However, the strength of these projections it is also their major disadvantage. Focused, detailed projections of a specific disorder or injury in a given population are likely to be more reliable than the generic methods employed here, simply because more information about the disease or injury would usually be available to guide projections.

We recognise the uncertainties in our projections and we urge those who use them to exercise caution in their application. We emphasise that the projections are simply three visions of the future—the numerical consequences of the set of assumptions and methods used to generate these visions. Perhaps our method and assumptions will prove to be reasonable, perhaps not. In making the results available to the public-health community, we hope that the methods and assumptions will be challenged, rethought, and reapplied to enhance their usefulness.

There is a clear need for projections of this nature, and we are aware that the research reported here is, or should be, seen as the first step in an exhaustive effort to predict the future of health.

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