

## Mortality trends and setbacks: global convergence or divergence?

Anthony J McMichael, Martin McKee, Vladimir Shkolnikov, Tapani Valkonen

**Health trends over much of the past century have been generally, and notably, positive throughout the world. In several regions, however, life expectancy has declined over the past 1–2 decades. This trend suggests that the expectation that emerged in the 1960s and 1970s of worldwide gains and convergence in population health status is not guaranteed by a general deterministic process. National populations can now be clearly grouped into those that have achieved rapid gains in life expectancy; those whose gains are slower or are perhaps plateauing; and those in which the trends have reversed. Over the past two centuries, outside times of war and famine, such reversals have been rare. Exploration of these varied population health trends elucidates better the close relation between population health and the processes of economic, social, and technological change. Such analysis has shown that the health status of human populations should be a guiding criterion in the debate on sustainable development.**

Throughout the world, health trends in the 20th century were generally positive and average life expectancy doubled. Death rates continue to decline in many, including all developed, countries.<sup>1</sup> However, in some regions—against an earlier general expectation—life expectancy has declined.

Many demographers have, over the past quarter century, forecast a worldwide convergence of nations towards low mortality and fertility, with resultant higher life expectancy.<sup>2–4</sup> This view prevailed in the 1970s and early 1980s when the population projections of the UN Population Division assumed a 2.5 year gain in life expectancy at birth every 5 calendar years for countries with life expectancy below 62 years, after which the gain would decrease to about 2 years.<sup>5,6</sup> This general expectation of convergence arose from systematic analyses of 20th-century mortality data from many developed countries, first available in the 1960s. The analyses suggested a recurring population health transition process, consisting of falling death rates from infectious diseases (especially in childhood), resulting in a greater proportion surviving to old age and a rise in chronic (or degenerative) diseases that were difficult to treat or prevent. Hence, the logical expectation was for a generalised rapid progress in high-mortality countries, via reduced young-age mortality, and slower progress or stagnation in countries that already had low mortality.

Beyond the broad health gains clearly attributable to social modernisation, infrastructural investment, environmental improvements, and safer water and food, medical interventions have also contributed significantly to saving lives. Despite a transient threat from rising coronary heart disease deaths during the third quarter of last century, the mortality decline continued in developed countries after the 1960s. These long-term positive trends

also seemed resilient to political and economic shocks, including the great depression of 1929–33.

Before the 1980s, outside times of war and famine (as in China in 1959–61<sup>7</sup>), the only well documented sustained national reversals in mortality decline were those that took place during the 1830s to 1850s in industrialising Europe and the USA.<sup>8,9</sup> Not surprisingly, therefore, demographers in the 1970s regarded future national mortality reversals to be unlikely. Indeed, the life expectancy gap between richer and poorer countries has subsequently generally lessened. Nevertheless, reversals have occurred in many countries in recent decades (table 1).<sup>10</sup> In addition to the well known setbacks in sub-Saharan Africa, central and eastern Europe, and the former Soviet Union countries, life expectancy has declined in North Korea, the Bahamas, Haiti, Fiji, and Iraq.<sup>11</sup>

In the Soviet Union, large gains in life expectancy in the immediate post-World War II period gave way, by 1965, to stagnation and subsequent decline, punctuated by a short-lived improvement in the late 1980s associated with a wide-ranging antialcohol campaign.<sup>12</sup> Although not then known, adult deaths were increasing in the Soviet Union throughout the 1970s, albeit offset by falls in infant deaths.<sup>13,14</sup> Stagnation appeared later in the Soviet satellites in central and eastern Europe in the 1980s, although these countries and the three ex-Soviet Baltic States are now improving. However, the situation continues to deteriorate in most other former Soviet states.

In the 1980s, the spread of premature mortality from HIV/AIDS, particularly in sub-Saharan Africa, created a major setback (panel). Globally, HIV/AIDS now causes the fourth largest number of deaths per year, and is the leading contributor, alongside lower respiratory infections, to the global burden of disease.<sup>17</sup> Several other serious infectious diseases, including tuberculosis and malaria, have also rebounded in many populations over the past two decades, particularly (but not only) in sub-Saharan Africa. For similar reasons, exacerbated by aid embargoes, life expectancy has declined in Haiti.<sup>18</sup>

These examples underscore how newly arising combinations of social, economic, and political conditions, and altered relations with the microbiological world, can cause reversals in death rates. That is, gains in longevity could be less smooth and less certain than earlier notions of global convergence suggested. The impediments to convergence include: persistence of health gradients both within and among countries, reflecting

*Lancet* 2004; **363**: 1155–59

National Centre for Epidemiology and Population Health, The Australian National University, Canberra, ACT, Australia 0200 (Prof A J McMichael PhD); London School of Hygiene and Tropical Medicine, London, UK (Prof M McKee MD); Max Planck Institute for Demographic Research, Rostock, Germany (V Shkolnikov PhD); Department of Sociology, University of Helsinki, Finland (Prof T Valkonen PhD)

Correspondence to: Prof Anthony McMichael (e-mail: tony.mcmichael@anu.edu.au)

deleterious socioeconomic and political conditions, often with unequal access to health-care;<sup>19</sup> increases in various infectious diseases, especially those associated with poverty, such as tuberculosis and HIV/AIDS; the growing toll—especially in poorer countries—of injury, impaired mental health, and death from violence, conflict, and war;<sup>20</sup> and the health risks consequent on large-scale environmental changes caused by human pressures.<sup>21</sup>

### Trends in life expectancy

The figure shows three groupings of national life expectancy trends over the past half-century, with data from the UN World Population Prospects, 2002.<sup>22</sup> The three groupings are those suggested by Caselli and colleagues,<sup>23</sup> and refer to national populations that have undergone, respectively, rapid gains in life expectancy; slower, perhaps plateauing gains; and frank reversals. The countries shown are representative of each of those three contrasting trends. Chile, Mexico and Tunisia have improved rapidly, and are converging on developed countries (figure). Although life expectancy has increased in Senegal and Mali, the absolute levels remain low. France resembles other rich developed countries, with life expectancy increasing since 1950, albeit progressively less steeply. Japan starts from very low life expectancy, and

	1960–2001	1980–2001	1990–2001
Botswana	8	19	18
Zimbabwe	6	16	17
Zambia	5	13	12
Rwanda	2	6	NA
South Africa	2	10	15
Uganda	1	5	4
Ukraine	1	1	2
Lesotho	NA	10	15
Namibia	NA	9	14
Swaziland	NA	7	12
Kenya	NA	9	11
Malawi	NA	6	7
Congo, Democratic Republic	NA	4	7
Tanzania	NA	6	6
Azerbaijan	NA	3	6
Central African Republic	NA	3	5
Kazakhstan	NA	4	5
Cameroon	NA	1	5
North Korea	NA	6	5
Côte d'Ivoire	NA	3	4
Mali	NA	1	4
Russian Federation*	3	2	4
Belarus	NA	3	3
Burundi	NA	5	2
Mozambique	NA	2	1
Liberia	NA	4	NA
Djibouti	NA	NA	3
Nigeria	NA	NA	3
Ethiopia	NA	NA	3
Bahamas, The	NA	NA	2
Kyrgyz Republic	NA	NA	2
Tajikistan	NA	NA	2
Dominican Republic	NA	NA	2
Fiji	NA	NA	2
Uzbekistan	NA	NA	2
Burkina Faso	NA	NA	1
Turkmenistan	NA	NA	1
Ghana	NA	NA	1
Honduras	NA	NA	1
Moldova	NA	NA	1
Haiti	NA	NA	1
Togo	NA	NA	1

NA=not available: data unavailable for some countries, some of which were not then independent. Source: reference 10. \*Equivalent to Russia, today; was part of the USSR before 1992. Data source: reference 10.

Table 1: Countries where life expectancy at birth (both sexes) was lower in 2001 than in 1960, 1980, or 1990 (figures are years of life expectancy lost during specified period)

### HIV/AIDS in Africa

In 2002 just over three-quarters of the world's total burden of disabling disease and premature mortality from HIV/AIDS was in Africa. Systematic mortality statistics are generally unavailable in sub-Saharan Africa, so estimates are based on household surveys or census questions about recent deaths, orphanhood, child survival, and verbal autopsy questions.

Mortality has increased most in young adults. The probability of death in males aged 15–55 years in Zimbabwe increased from 0.15 in the mid-1980s to 0.5 in the late 1990s; a similar doubling or tripling in premature mortality took place in Uganda and Zambia.<sup>15</sup> Adult mortality also rose substantially everywhere in East and Central Africa, but much less in West Africa. Demographic and health surveys detected substantial increases in child mortality in countries with the highest prevalence of HIV.

The general factors facilitating a rapid spread of HIV/AIDS and a huge burden of human losses in the region are poverty, lack of education, wars and spread of violence, widespread multiple partnership practices, gender inequalities, and fragility of medical care systems.<sup>16</sup>

finishes with the world's highest. Denmark starts with a very high life expectancy and then has a very slow increase during the 1960s–90s. Finally, Poland and Russia after strong increases in the 1950s and early 1960s, stagnate (Poland) or decline (Russia). The immediate causes of Denmark's poor performance are similar to some of those acting in eastern Europe, with increasing deaths attributable to tobacco and alcohol.<sup>24</sup>

The hectic swings in mortality seen in Russia are mirrored in its ex-Soviet neighbours and are driven mostly by changes in deaths from heart disease, injuries, and violence, with a large decline in male life expectancy from 65 to 58 years during the early 1990s. The complex reasons for these mortality reversals include social upheaval, heavy alcohol consumption, and institutional inadequacy in a population weakened by decades of failures of communism<sup>25</sup>—further exacerbated by the Soviet health-care system's inability to keep pace with developments in developed countries.<sup>26</sup>

In Zimbabwe and Botswana, life expectancy has fallen by 1–2 decades, to below the levels of 1950–55 (figure). Uganda, however, has begun to recover from the ravages of HIV/AIDS. In war-affected countries (eg, Rwanda, Angola) the falls have been even greater; whereas elsewhere economic and social disruptions (eg, Zimbabwe and Kenya) have impaired child health, growth, and survival. UN population data also show falls in life expectancy in several West African countries that are not obviously attributable to HIV/AIDS,<sup>22</sup> including Burkina Faso, Sierra Leone, Côte d'Ivoire, and Liberia (the last three have had serious conflicts). Life expectancy in North Korea declined substantially during the 1990s, reflecting widespread famine and political mismanagement.

In eastern Europe and sub-Saharan Africa these mortality increases have been concentrated in young and middle-aged adults, whereas traditionally vulnerable children and elderly people have been less affected. This finding implicates behavioural and psychosocial factors in adulthood.

### Differences within countries

The above analysis has examined inter-country differences. Increasing within-population mortality differentials have also emerged in many developed and

developing countries. A central target of WHO's Health for All strategy for Europe, from 1985, was to reduce differences in health status within countries by at least 25% by improving the health of disadvantaged groups. However, socioeconomic gradients in mortality have increased in most developed countries that provide data—at least in a relative, if not always in an absolute, sense.<sup>27</sup> In England and Wales, for example, the difference in male life expectancy between the highest and lowest socioeconomic class increased from 5.5 years in the mid-1970s to 9.5 years in the mid-1990s.<sup>28</sup> Socioeconomic differences also increased in the USA, France, and in all Scandinavian countries.<sup>29,30</sup>

This widening survival differential has largely related to the faster decline in cardiovascular disease mortality in upper socioeconomic strata than in lower socioeconomic groups. The less favourable mortality trends in disadvantaged groups, in some countries, have particularly reflected alcohol-related and smoking-related causes, suicides, and unintentional injuries. In the USA, the white-black life expectancy gap increased during the 1980s, largely because of increased deaths in black males from HIV infection and homicide, although it narrowed slightly before stabilising in the late 1990s.<sup>31</sup>

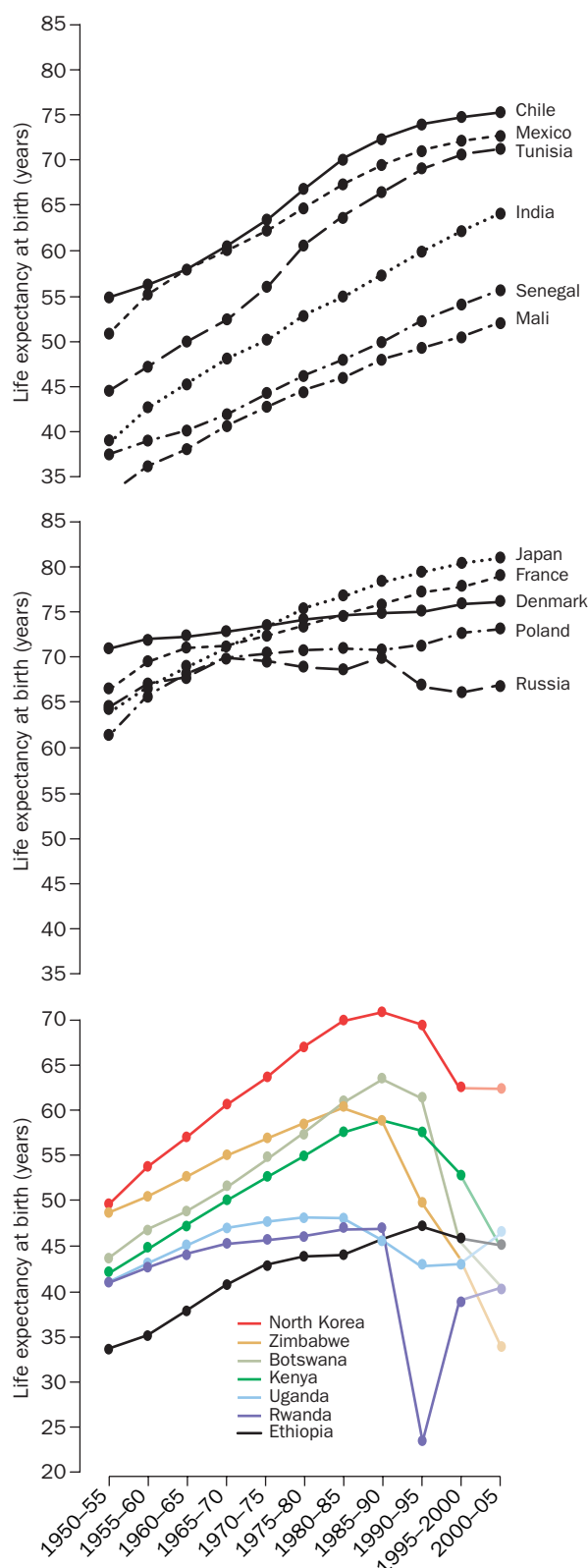
Death rates have previously been widely reported as being higher in single, divorced, and widowed people than in those who are married. In the 1980s–90s this difference widened further in many developed countries; especially at older ages, and in women. In the Netherlands and Denmark the death rate in women aged 65–74 years without a marital partner has increased since 1980.<sup>29</sup> These trends are poorly understood.

Developing countries also have inequalities. The largest studies involve analysis of childhood mortality data from nine countries from World Bank data<sup>32</sup> and from 40 countries from the Demographic and Health Surveys (DHS).<sup>33</sup> Mortality is consistently higher in poorer than in richer families. There are also detailed studies within some countries.<sup>34</sup> Although China, excluding the 1959–61 famine episode,<sup>7</sup> made substantial health gains after 1950, rapid socioeconomic changes have created inequalities in wealth, education, employment, and health care.<sup>35</sup> In African countries, child mortality is high in rural regions and urban slums with poor sanitation and no electricity. In Nairobi, mortality in children aged younger than 5 years in urban slums is 2.5-fold higher than in other urban districts and 1.5-fold higher than the national average (table 2).<sup>36</sup>

### Technological solutions?

Technological progress will not necessarily narrow these gaps. Such progress has brought great benefits, but has also brought various unintended consequences. For example, the between country gap in life expectancy caused by unequal access to health-care advances has widened. The discovery of insulin in 1921 transformed type 1 diabetes from a rapidly fatal childhood disease to a survivable disorder—but only for those with access to treatment. Other new treatments have meant that more people die with, rather than from, AIDS and many cancers. Meanwhile, we face a continuing evolutionary struggle with microorganisms as they become resistant to new antibiotics.

Overall, modern medical care has become much more complex, and beyond the resources of some countries. Health professionals need new skills, tools, and managerial skills to help patients navigate the complex health-care system. In some countries, previous health gains have receded as health-care systems collapse under



**Life expectancy trends in three groups of selected countries from 1950–55 to 1995–2000 (estimates for current quinquennium are also shown)**

(Upper) Countries that have achieved rapid gains in life expectancy.

(Middle) Countries achieving slower, perhaps plateauing, gains.

(Lower) Countries where there have been frank reversals in life expectancy.

Source: UN World Population Prospects, 2002.<sup>22</sup> See also reference 23.

	Neonatal mortality rate	Post-neonatal mortality rate	Infant mortality	Child mortality	Under-5 mortality
<b>Survey region</b>					
Nairobi slums	30.4	60.9	91.3	65.2	150.6
<b>KDH Survey</b>					
National	28.4	45.3	73.7	40.8	111.5
Rural	30.3	45.7	75.9	40.1	113.0
Other urban	16.9	39.8	56.6	28.9	83.9
Nairobi	21.8	16.9	38.7	23.8	61.5

Source: reference 36.

**Table 2: Infant and child death rates, per 1000, by residential area for 5 years preceding the Nairobi Cross-sectional Slums Survey, 2000, and Kenyan Demographic and Health (KDH) Survey, 1998**

economic pressures. In some former Soviet Union countries, with effective programmes against infectious disease, various infectious diseases that had been almost eradicated have returned, whereas death rates from treatable conditions such as diabetes and hypertension have increased.<sup>37</sup>

Elsewhere, economic progress has had other unplanned health consequences. The combination of motorised transport, automated workplace and domestic activity, and increased availability of calorie-rich food is causing a global epidemic of obesity and type 2 diabetes. As the smoking-related epidemic attenuates in the industrialised world, it is rising elsewhere as the international tobacco industry nurtures new markets.

Today's high-density urban living, rapid long-distance travel and trade, intensified food production, land clearance, liberalised sexual behaviours, intravenous drug use, and medical technologies such as transfusion and transplantation have created new ecological opportunities for microbes. For example, the international trade in used car tyres has disseminated mosquito species that can spread dengue fever.<sup>38</sup> The identification of many new and re-emerging infectious agents in the past quarter-century indicates that infectious disease persists as a substantial problem.

### Transient aberrations or continuing divergence?

Are these divergences in population health mere transient aberrations? Or might a worldwide convergence of health indices be less achievable than previously thought? Part of the answer might lie in the fact that, at global and regional scales, major changes are occurring to social and environmental living conditions. These unprecedented global changes will both enhance and impair population health. For example, the global spread of mass schooling, in combination with radios and television, facilitates a shared potentially health-promoting literacy. Meanwhile, other global changes, including some of the consequences of deregulated trading regimens, might exacerbate health disparities between rich and poor.<sup>21</sup> Indeed, there is an escalating risk of conflict as freshwater supplies diminish, regional agricultural yields are affected by climate change and land degradation, and, more generally, the rich-poor gap widens.

These setbacks in national mortality, properly understood, should afford us insights into how to achieve a sustainable and more equitable world, supportive of long-term good health.

Changes in culture, social structure, technologies, and environmental conditions have been shaping population patterns of health for a long time. Today, reinforced by

urbanisation, our ways of eating, working, moving, satisfying addictive urges, and being entertained are being transformed rapidly. They have immediate consequences for health, some beneficial, some detrimental. Meanwhile, our increasing effect on Earth's climate system, stocks of biodiversity, arable land, freshwater supplies, fisheries, and the global cycles of elemental nitrogen, sulphur, and phosphorus are impairing the biosphere's capacity to sustain healthy human life.<sup>39</sup> These processes will affect wellbeing and health, especially in susceptible populations, over coming decades. These factors raise a central question: Can we leave a positive, health-supportive, social and environmental legacy to oncoming generations?

Economic growth has often been a powerful force for improved life expectancy, although it has depended on countering the accompanying adverse health effects at institutional and individual levels. Today, in countries of rapid economic growth (eg, India, China, Indonesia), the probability of mortality reversals or stagnation is increasing through spread of unhealthy behaviours such as smoking, high-energy diets environmental pollution, and growing economic inequality. Taking a longer view—and as history has repeatedly shown—the health and survival of local populations often declines when the carrying capacity of the local environment is exceeded, usually because of resource mismanagement.

Carrying capacity remains a contentious issue for human beings, compared with other animal species. Our cultural capacity (including trade and reshaping of environments) allows expansion of local environmental carrying capacity. Today, however, we increasingly augment the world's (human) carrying capacity by depleting stocks of natural capital (eg, soil fertility) and by overloading natural sinks (eg, atmospheric greenhouse gas accumulation). This is an unfamiliar dilemma—by contrast with the well known Malthusian spectre of local numbers exceeding food supplies, we are now actually weakening nature's life-support systems.

### Conclusion

Globally, life expectancy has been on a long uptrend. However, the emerging picture of variable mortality trends and regional setbacks indicates that future health gains are not guaranteed by any general deterministic process of convergence. Rather, there is an increased heterogeneity between countries, here summarised as those achieving rapid gains, those achieving slower or plateauing gains, and those having frank reversals.

From these varied population health trends, we can understand better the close relation between population health, the processes of economic, social, and technological change, and ecological constraints. From this change should emerge recognition that human wellbeing and health should be a central criterion of sustainable development.

#### Contributors

All the authors attended the international symposium on Determinants of Diverging Trends in Mortality, convened by the International Union for Scientific Study of Population in June, 2002, in Rostock, Germany. The symposium looked at recent, unexpected evidence of setbacks in life expectancy and of divergent mortality trends between and within countries. Subsequently, all authors contributed to the drafting of the paper, via a series of circulated revisions, and the shaping of the arguments. A J McMichael coordinated the drafting, and took primary responsibility for final preparation of the text.

#### Conflict of interest statement

None of the authors had any financial or personal relationships with other people or organisations that could inappropriately influence (bias) this work. The corresponding author (AJMcM) has full access to all the data

in the study and had final responsibility for the decision to submit for publication.

#### Acknowledgments

We thank the Max Planck Institute for Demographic Research in Rostock for funding and organising the seminar. We also thank the anonymous reviewers for their constructive criticisms.

#### References

- Tuljapurkar S, Li N, Boe C, et al. A universal pattern of mortality decline in the G7 countries. *Nature* 2000; **405**: 789–92
- Wilson C. On the scale of global demographic convergence 1950–2000. *Popul Dev Rev* 2001; **27**: 155–71.
- Abdel R, Omran. The epidemiological transition. *Millbank Mem Fund Q* 1971; **49**: 509–38.
- Preston SH. Mortality patterns in national populations. New York: Academic Press, 1976.
- United Nations. World population prospects as assessed in 1973. UN, NY, 1977: 10–11.
- United Nations. World population prospects as assessed in 1980. UN, NY, 1981: 3.
- Smil V. China's great famine: 40 years later. *Br Med J* 1999; **319**: 1619–21.
- Steckel RH. Industrialization and health in historical perspective. In: Leon DA, Walt G, eds. Poverty, inequality and health. Oxford: Oxford University Press, 2001: 37–57.
- Haines MR, Craig LA, Weiss T. Development, health nutrition and mortality: the case of the 'Antebellum puzzle' in the United States. Cambridge, MA: National Bureau of Economic Research, 2000.
- World Bank. World development indicators 2003. Washington DC: World Bank, 2003.
- Blacker J, Jones G, Ali M. Annual mortality rates and excess deaths of children under five in Iraq, 1991–98. *Popul Stud (Camb)* 2003; **57**: 217–26.
- Shkolnikov V, McKee M, Leon DA. Changes in life expectancy in Russia in the 1990s. *Lancet* 2001; **357**: 917–21.
- Shkolnikov V, Meslé F, Vallin J. Health crisis in Russia I: Recent trends in life expectancy and causes of death from 1970 to 1993. *Popul* 1996; **8**: 123–90.
- Goskomstat. The Demographic Yearbook of the Russian Federation 2002. Moscow, 2002: 105.
- UNAIDS. Report on the global HIV/AIDS epidemic. June 2000. UNAIDS/WHO.
- Butler CD. HIV and AIDS, poverty, and causation. *Lancet* 2000; **356**: 1445–46.
- WHO. The world health report. reducing risks, promoting healthy life. Geneva: World Health Organization, 2003: 186–94.
- Farmer P, Fawzi MCS, Nevil P. Unjust embargo of aid for Haiti. *Lancet* 2003; **361**: 420–22.
- Whitehead M, Dahgren G, Evans T. Equity and health sector reforms: can low-income countries escape the medical poverty trap? *Lancet* 2001; **358**: 833–36.
- WHO. World report on violence and health. Geneva: WHO, 2002: 9–11.
- McMichael AJ. Human frontiers, environments and disease: past patterns, uncertain futures. Cambridge: Cambridge University Press, 2001.
- UN World Population Prospects. 2002. Population Database. UN Population Division. URL <http://esa.un.org/unpp/index.asp?Panel=2> last visited in May, 2002.
- Caselli G, Meslé F, Vallin J. Epidemiologic transition theory exceptions. *Genus*, 2002; **9**: 9–51.
- Chenet L, Osler M, McKee M, Krasnik A. Changing life expectancy in the 1980s: why was Denmark different from Sweden? *J Epidemiol Comm Health* 1996; **50**: 404–07.
- Leon DA, Chenet L, Shkolnikov VM, et al. Huge variation in Russian mortality rates 1984–1994. Artefact or alcohol? *Lancet* 1997; **350**: 383–88.
- Andreev EM, Nolte E, Shkolnikov VM, et al. The evolving pattern of avoidable mortality in Russia. *Int J Epidemiol* 2003; **32**: 437–46.
- Mackenbach JP, Bos V, Andersen O, et al. Widening socioeconomic inequalities in mortality in six Western European countries. *Int J Epidemiol* 2003; **32**: 830–37.
- Hattersley L. Trends in life expectancy by social class: an update, 1999. *World Health Stat Q*; **2**: 17–24.
- Valkonen T. 2001. Trends in differential mortality in European countries. In: Vallin J, Meslé F, Valkonen T. Trends in mortality and differential mortality. Population Studies no 36. Strasbourg: Council of Europe Publishing: 185–328.
- Preston SH, Elo IT. Are educational differentials in adult mortality increasing in the United States? *J Aging Health* 1995; **7**: 476–96.
- Hoyert DL, Anderson RN. Age-adjusted death rates: Trend data based on the year 2000 standard population. *Natl Vital Stat Rep* 2001; **49**: 3.
- Wagstaff A. Socioeconomic inequalities in child mortality: comparisons across nine developing countries. *Bull World Health Organ* 2000; **78**: 19–29.
- Gwatkin DR. Reducing health inequalities in developing countries. In: Detels R, McEwen J, Beaglehole R, Tanaka H. Oxford Textbook of Public Health. Oxford: Oxford University Press, 2002. 1791–809.
- Victora CG, Wagstaff A, Schellenberg JA, et al. Applying an equity lens to child health and mortality: more of the same is not enough. *Lancet* 2003; **362**: 233–41.
- World Bank. Financing health care: issues and options for China. Washington, DC: World Bank, 1997.
- Ngom P. Infant and child mortality. In: Population and Health Dynamics in Nairobi's Informal Settlements. African Population and Health Research Center, Nairobi, 2002: 86–94.
- Telishevska M, Chenet L, McKee M. Towards an understanding of the high death rate among young people with diabetes in Ukraine. *Diab Med* 2001; **18**: 3–9.
- Knudsen AB. Global distribution and continuing spread of *Aedes albopictus*. *Parasitologia*. 1995; **37**: 91–97.
- Vitousek PM, Mooney HA, Lubchenco J, Melillo J. Human domination of Earth's ecosystems. *Science* 1997; **277**: 494–99.

Copyright of Lancet is the property of Lancet and its content may not be copied or emailed to multiple sites or posted to a listserv without the copyright holder's express written permission. However, users may print, download, or email articles for individual use.