IEA
International Epidemiological Association

International Journal of Epidemiology, 2019, 1815–1823
doi: 10.1093/ije/dyz143
Advance Access Publication Date: 5 August 2019
Original article

Cardiovascular Disease

Is the long-term decline in cardiovascular-disease mortality in high-income countries over? Evidence from national vital statistics

Alan D Lopez* and Tim Adair

Melbourne School of Population and Global Health, The University of Melbourne, Carlton, Victoria, Australia

*Corresponding author. Melbourne School of Population and Global Health, The University of Melbourne, Level 5, 207 Bouverie St, Carlton 3053, VIC, Australia. E-mail: alan.lopez@unimelb.edu.au

Editorial decision 5 June 2019; Accepted 1 July 2019

Abstract

Background: The substantial decline in cardiovascular-disease (CVD) mortality in high-income countries has underpinned their increasing longevity over the past half-century. However, recent evidence suggests this long-term decline may have stagnated, and even reversed in younger populations. We assess recent CVD-mortality trends in high-income populations and discuss the findings in relation to trends in risk factors.
Methods: We used vital statistics since 2000 for 23 high-income countries published in the World Health Organization Mortality Database. Age-standardized CVD death rates by sex for all ages, and at ages 35–74 years, were calculated and smoothed using LOWESS regression. Findings were contrasted with the Global Burden of Disease (GBD) Study.
Results: The rate of decline in CVD mortality has slowed considerably in most countries in recent years for both males and females, particularly at ages 35–74 years. Based on the latest year of data, the decline in the CVD-mortality rate at ages 35–74 years was <2% (about half the annual average since 2000) for at least one sex in more than half the countries. In North America (US males and females, Canada females), the CVD-mortality rate even increased in the most recent year. The GBD Study estimates, after correcting for misdiagnoses, suggest an even more alarming reversal, with CVD death rates rising in seven countries for at least one sex in 2017. The rate of decline and initial level of CVD mortality appear largely unrelated.
Conclusions: A significant slowdown in CVD-mortality decline is now apparent across high-income countries with diverse epidemiological environments. High and increasing obesity levels, limited potential future gains from further reducing already low smoking prevalence, especially in English-speaking countries, and persistent inequalities in mortality risk pose significant challenges for public policy to promote better cardiovascular health.

Key words: Medical subject headings, cardiovascular diseases, mortality, cause of death, heart diseases, stroke

Key Messages

- There has been a substantial slowdown in the rate of decline of cardiovascular-disease (CVD) mortality in many high-income countries in recent years.
- This is most apparent at ages 35–74 years, where CVD-mortality rates have increased in the USA (males and females) and Canada (females).
- High and increasing obesity, among other risk factors, jeopardize further CVD-mortality declines in many countries.

Background

Cardiovascular diseases (CVDs) collectively are the leading cause of death globally, and also the leading cause of premature deaths, as assessed by the Global Burden of Disease (GBD) Study.[1] In high-income countries, trends in life expectancy and premature mortality over the past 60 years have been driven largely by adverse, or favourable, trends in CVDs.[2] Beginning in the 1970s, reducing mortality from major vascular diseases such as ischaemic heart disease (IHD) and stroke has been and continues to be a primary focus of public-health efforts in these populations, but less so in many lower- and middle-income countries, where higher tobacco consumption among men, as well as poor blood pressure, lipid and sugar control, and the progressive adoption of Western diets and lifestyles, have led to significantly elevated CVD risks.[1,3] Increasing recognition of the likely substantial and global implications of widespread population exposure to key CVD risk factors has led to the inclusion of CVD-mortality outcome measures among the Sustainable Development Goals, with the explicit target of reducing premature CVD mortality by one-third by 2030.[4]

In high-income countries, the very substantial decline in CVD mortality over the past half-century has been a major, yet often unheralded, global public-health achievement. Following a period of relatively slow declines and, in some countries, increases in CVD mortality following World War II, from the 1970s, CVD mortality in several high-income countries began to decline, with levels typically falling by 40–80%—far in excess of declines in cancer mortality.[5–8] This has been attributed variously to the success of public policy and regulation to reduce exposure to a range of risk factors, including high prevalence of tobacco smoking and excess alcohol consumption, high blood pressure and high cholesterol, poor diet and insufficient exercise, as well as to improved medical management through screening, emergency care and treatment.[9–15] These declines in vascular disease mortality have been the primary reason for the impressive gains in life expectancy in countries such as Australia, the USA and the UK over the past 50 years.[2]

However, recent evidence from national vital-statistics systems in these countries suggests that the long-term decline in CVD and specifically heart-disease mortality may be stagnating, with rates even rising in some populations, particularly at ages <75 years.[11,16–18] Indeed, the advent of recent and prevalent hazards to population health, most importantly the high and increasing levels of obesity observed in some countries, have been identified, in the USA at least, as a primary cause of the recent modest increments in life expectancy, with the potential to offset the benefits of any further declines in smoking prevalence on life expectancy.[19,20] Indeed, some commentators have suggested that trends in obesity might well lead to an intergenerational decline in life expectancy in countries such as the USA.[21]

Given this context, we provide a detailed assessment of recent CVD-mortality trends in 23 high-income populations and identify countries that have experienced a substantial slowdown in the rate of decline in, or increases in, CVD mortality in recent years. We discuss the findings in relation to trends in risk factors, including obesity and smoking, and inequalities in mortality risk, and conclude with some reflections of possible implications for longevity.

Data and methods

We assessed CVD-mortality trends since 2000 for 23 high-income countries (see Table 1) encompassing a broad epidemiological spectrum. Only Portugal (no age-specific data available in the database for 2004–2006) and Iceland (because its small population makes interpretation of trends more difficult) were excluded.

The primary source of data for the analysis is the World Health Organization (WHO) Mortality Database.[22] This

Table 1. Countries included in the analysis

Australia	France	Japan	Spain
Austria	Germany	Netherlands	Sweden
Belgium	Greece	New Zealand	Switzerland
Canada	Ireland	Norway	United Kingdom
Denmark	Israel	Republic of Korea	USA
Finland	Italy	Singapore	

information was assembled from annual reports submitted to WHO by country statistical or health authorities of the number of deaths according to sex, age and cause. More recent data for New Zealand (2015) and Canada (2016) were not available in the WHO Mortality Database and were obtained from each country's national statistics office.[23,24] All country-years analysed were based on International Classification of Diseases Version 10 (ICD-10) codes, except the following, which used ICD Version 9 (ICD-9): Greece 2000–2013, Ireland 2000–2006, Singapore 2000–2011, Italy 2000–2002 and Austria 2000–2001. CVD mortality includes all deaths coded to ICD-9 codes B25–B30 and ICD-10 codes I00–I99 and is directly comparable between ICD-9 and ICD-10; further, given this broad cause grouping, it is highly unlikely that there would be significant misclassification of CVD deaths between the two ICD versions. We also compared trends across all countries for IHD (ICD-9: B27; ICD-10: I20–I25), cerebrovascular diseases (ICD-9: B29; ICD-10: I60–I69) and all other cardiovascular diseases. Population data to calculate rates were taken from the GBD Study.[25]

Our principal measures of CVD mortality were sex-specific age-standardized death rates per 100 000 population, standardized according to the GBD age standard and calculated for all available years of data from 2000.[5] We report on trends at all ages and, to identify the extent to which the deceleration in the rate of mortality decline is present among young and middle-aged adults, also at ages 35–74 years. To account for any stochastic variation in annual CVD mortality, the rates are smoothed over time using LOWESS regression using Stata 13.0.[26,27] Trends are also assessed over two distinct time periods—before and since 2010—to identify period differences in the rate of change of CVD mortality. We also compare the average annual percentage change in CVD mortality since 2010 with the level of CVD mortality in that year to assess whether subsequent patterns of mortality change might have been related to the initial level.

The WHO Mortality Database is not adjusted for any potential diagnostic errors, or differences in diagnostic practices and training across countries, and so potentially underestimates CVD mortality to the extent that such practices may lead to misdiagnoses of CVD deaths to other causes. In particular, previous studies have identified the widespread use of ICD 'garbage' codes for what are likely to be true cases of IHD, stroke and other CVDs as the underlying cause of death.[1,28,29] Whereas such diagnostic errors may seriously impede comparative mortality analyses across countries, they are much less likely to affect temporal changes within a country over the relatively short period of this analysis. The strength of using the WHO Mortality Database is that the data reflect the causes of death as certified by medical practitioners in countries and are not adjusted by redistribution algorithms, such as those used by the GBD Study, to achieve greater comparability of findings across countries. Further, restricting the analysis of deaths to ages 35–74 years should reduce the impact of any potential diagnostic inaccuracies that are likely to be more prevalent at older ages when multiple morbid conditions are often present at or around the time of death.[28]

We also used data from the GBD Study to assess whether the trends observed at ages 35–74 years based on data reported to WHO are also apparent after the adjustments for 'garbage' coding, primarily to assess the results reported by countries for plausibility given the potential for errors mentioned above.[1] This involves reallocating codes such as ill-defined causes, septicaemia, heart failure and certain other ICD codes that cannot, or should not, be certified as an underlying cause of death. These conditions are of limited value, even potentially misleading, for guiding public-health priorities and have been redistributed to other target causes based on various diagnostic algorithms, including statistical methods.[28] Common target causes for the redistribution of such 'garbage' codes include several major CVDs, due to their high proportion of deaths, and because deaths certified to such causes as senility have frequently been identified, upon more intensive clinical review, to be actual cases of vascular disease mortality.[28,29] As a result, CVD-mortality rates estimated in the GBD Study are likely to be higher than what is reported by countries to the WHO, although there is no a priori reason to expect that the trends will be markedly dissimilar. An advantage of the GBD Study is that it estimates CVD mortality for all countries up to and including 2017, compared with the WHO Mortality Database for which the most recent data refer to either 2015 or 2016. GBD estimates for years with no data in the WHO Mortality Database are essentially projections, although, given they are made for only 1–2 years at most, they are unlikely to exaggerate recent trends. The GBD estimates were also smoothed using LOWESS regression, to ensure consistency with the methods used for the WHO Mortality Database.

Results

Figure 1 shows trends in smoothed CVD age-standardized death rates for all ages, measured by the average annual percentage change before, and since, 2010 (for all available years of data from 2000 onwards). To place these trends in perspective, the annual percentage change for the most recent available year of data is also shown. In the most recent year, CVD death rates for females appear to have increased slightly in the USA, were steady in Italy and declined only marginally (by <2%) in Belgium, the Netherlands and

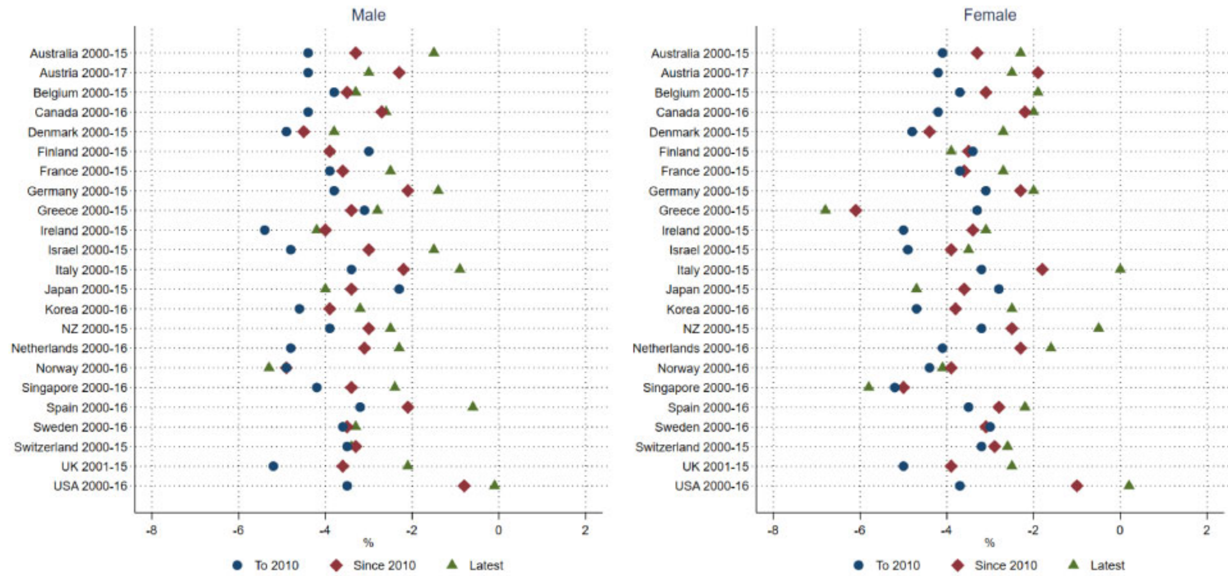

Figure 1. Cardiovascular-disease age-standardized death rates (all ages), annual % change (average to 2010, average since 2010, latest year), LOWESS-smoothed, males and females, WHO Mortality Database.

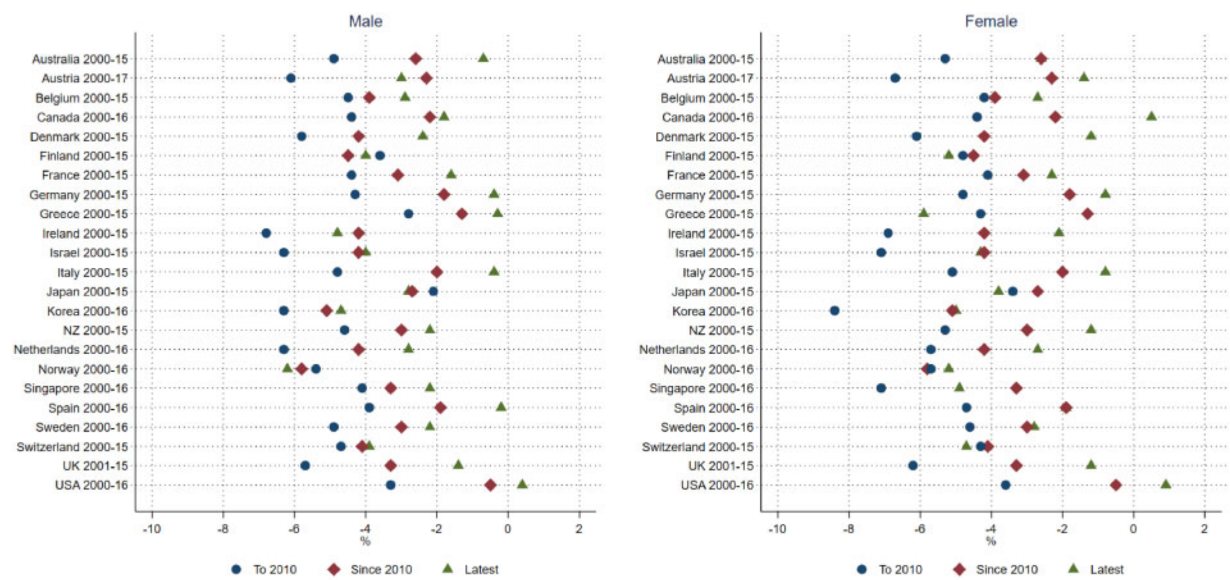

Figure 2. Cardiovascular-disease age-standardized death rates (35–74 years), annual % change (average to 2010, average since 2010, latest year), LOWESS-smoothed, males and females, WHO Mortality Database.

New Zealand. For men, they were unchanged in the USA and declined only marginally (by <2%) in Australia, Germany, Israel, Italy and Spain. The average annual rate of decline of CVD mortality in the USA since 2010 has been about 1% for both males and females, compared with about 3.5% over the previous decade. Average annual declines in CVD mortality between 2000 and 2010 were at least 3% in every country (and only slightly less so in Japan), averaging 4.1% for males and 3.9% for females, compared with 3.2% (males and females) since 2010 (Supplementary Table A.1, available as Supplementary data at *IJE* online). The largest average annual declines in CVD mortality over the decade to 2010 were observed in Ireland (5.4% males, 5.0% females), the UK (5.2% males, 5.0% females), Denmark males (4.9%), Norway males (4.9%) and Singapore females (5.2%). With relatively few exceptions, there is a clear gradient in the pace of change in CVD mortality over the past 18 years or so, being fastest before 2010, less rapid since then and slowest for the most recent year for which data are available.

This pattern of slowing CVD-mortality declines is even more evident at ages 35–74 years. Figure 2 reveals more countries with increases, or at most small declines, for the most recent year; USA (males and females) and Canada (females) recorded increases in CVD mortality according to their most recent year of data. In several other countries, the rate of decline for both sexes has slowed to <2%—Germany, Italy, Spain and the UK—and for at least one sex in others (males: Australia, Canada, France and Greece; females: Austria, Denmark and New Zealand). In general, mortality declines over the decade to 2010 were greater at ages 35–74 years than for all ages, being largest in Korea, where the annual rate of mortality decline was as high as 8.4 and 6.3%, for females and males, respectively, or falling by 58 and 48%, respectively, over the decade to 2010 (Supplementary Table A.2, available as Supplementary data at *IJE* online). Much lower rates of CVD-mortality decline between 2000 and 2010 were observed in Japan and the USA, despite the fact that the level of CVD mortality in the USA for the latest year was still roughly double that of Japan. Closer examination of the data revealed there were no discernible trends by age within the broad 35–74 years age category. Analysis for more specific causes shows that the decline in other cardiovascular-disease mortality at ages 35–74 years has been slower than for IHD and cerebrovascular diseases (Supplementary Table A.3, available as Supplementary data at *IJE* online).

The dramatic reversal in the long-term decline in cardiovascular-disease mortality in recent years is clear from Figure 3, which shows trends for those countries where the deceleration in the rates of decline has been most acute or where rates may even have begun to increase. Three points in particular emerge from the figure; first, the deceleration in the rate of decline of CVD mortality is a generalized phenomenon, occurring in countries with such diverse CVD epidemiological environments as Australia, Denmark, Germany, Italy, Spain, the USA and the UK; second, by and large, the trend is apparent, and similar, for both males and females; and, third, the momentum of change is remarkably strong and consistent, suggesting that it is highly likely that all of these countries will see increases in CVD-mortality rates within the next year or two, as has already been the case in the USA since 2014, and for Canadian women. The USA was also the first country where the rate of decline in CVD mortality fell below 2% per annum (2011).

Moreover, the rate of decline in CVD mortality at ages 35–74 years since 2010 does not appear to be related to the initial level of CVD mortality in 2010 (Figure 4). Both relatively slow and relatively quick CVD-mortality declines have occurred in countries across a wide range of initial mortality levels, including countries where rates were already comparatively low.

For almost all countries where the decline in the age-standardized CVD death rate at ages 35–74 years in the

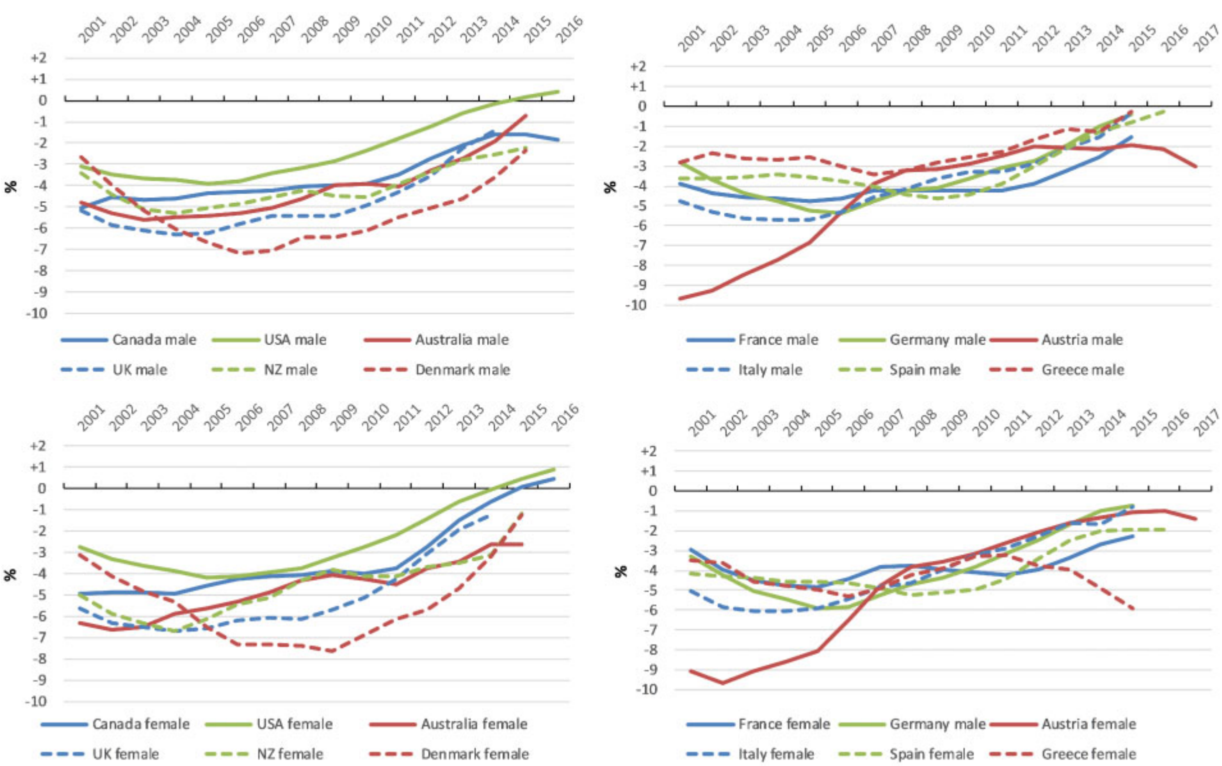

Figure 3. Annual % change in cardiovascular-disease age-standardized death rates (35–74 years), LOWESS-smoothed, selected countries, 2000–2017, males and females, WHO Mortality Database.

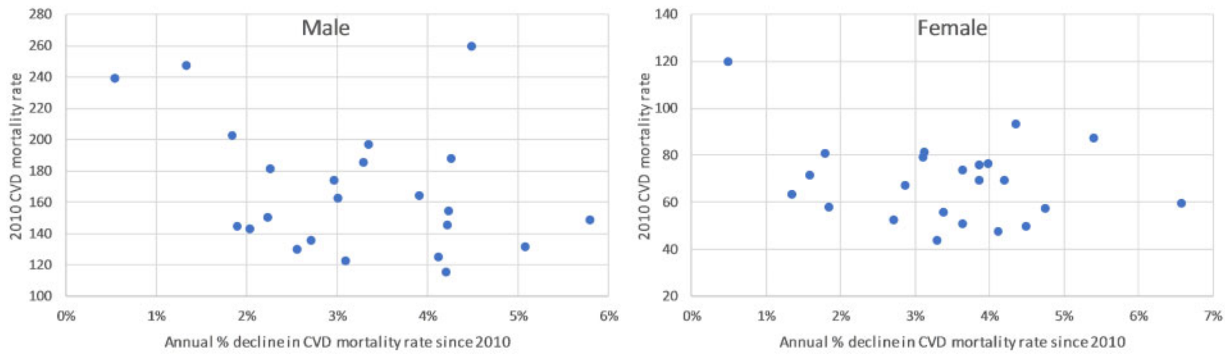

Figure 4. Cardiovascular-disease age-standardized death rate (35–74 years) in 2010 (per 100 000) vs average annual % decline since 2010, LOWESS-smoothed, males and females, WHO Mortality Database.

most recent year was >2%, based on the WHO Mortality Database, the GBD estimates (also LOWESS-smoothed) suggest a less optimistic trend, namely that the rate in 2017 was declining by <2%. Further details can be found in Supplementary Figure A.1, available as Supplementary data at *IJE* online. The only countries where the rate of decline in 2017 based on the GBD estimates was >2% were Korea and Singapore (males and females), Ireland, Italy, Sweden and Switzerland (males) and Israel (females). Indeed, the GBD estimates suggest that CVD mortality *increased* from 2016 to 2017 for seven countries, including Australia, Germany, the USA and the UK (males and females), Greece and New Zealand (males) and the Netherlands (females).

Discussion

For many high-income countries, the vital statistics reported annually to the WHO indicate that CVD-mortality declines in recent years have either slowed dramatically or, in some cases, have reversed. These trends are particularly apparent at ages <75 years. The GBD estimates, which adjust, using standardized methods, for poor-quality cause-of-death data and in addition provide estimates that are at least 1–2 years more recent than the WHO Mortality Database, suggest an even more dramatic reversal. They estimate that, for most high-income countries, CVD-mortality rates have either increased or are now declining by <2% per year. This remarkable development follows declines in CVD mortality of around 40% in some countries over the previous decade from 2000 to 2010, and longer-term declines roughly twice that level over the past 50 years in many more, contributing significantly to the large increases in longevity observed since 1970. Although the pace of decline observed over much of the past half-century may not necessarily have been sustainable, the speed and extent of the reversal of this long-term trend across a number of countries with quite different epidemiological environments should raise concerns about whether the long-term decline in CVD mortality in high-income countries is coming to an end. The change in CVD mortality in recent years also appears to be largely unrelated to the level of mortality attained in countries, suggesting that a feasible floor in CVD-mortality levels is not yet apparent, supported by the fact that these reversals have occurred in countries that have not attained the low levels of mortality achieved by Japan.

Examination of trends in risk factors such as tobacco smoking, obesity, high cholesterol, high blood pressure and diabetes, as well as access to health care, can provide insight into causes of recent CVD-mortality change. Previous analysis of CVD-mortality trends has found they are primarily influenced by period rather than cohort factors.[8] A possible explanation for recent mortality trends is that, in many countries, tobacco-smoking prevalence had already fallen to such a low level that additional (absolute) declines could only be comparatively minor and hence would have had a smaller impact on CVD mortality. In Australia, Canada, New Zealand, the USA and the UK, where CVD mortality is either increasing or decreasing only slowly, smoking prevalence measured by the summary exposure value (SEV) (a measure of risk-factor exposure adjusted for severity) is among the lowest among high-income countries.[30] However, of these countries, the USA, the UK and Canada have actually all experienced faster-than-average absolute falls in smoking since 2000 and, because this period is sufficiently long to account for the potential lag effect of smoking on CVD mortality, their recent mortality declines could be expected to be larger than what has occurred. Although already low smoking prevalence is possibly a factor underlying the slowdown in recent CVD-mortality declines in some countries, evidence suggests it is not a universal explanation.

Among other explanations are rising levels of obesity and poor dietary habits. Obesity levels for both males and females in these countries with low smoking prevalence are the highest among all high-income countries.[31] The recent moderation of CVD-mortality trends in these countries suggests that obesity, or at least poor diet, might well have offset the risk reductions attributable to their low levels of smoking, given the clear increase in CVD-mortality risks with increasing obesity.[32] For the USA, at least, this claim is consistent with recent findings on the impact of obesity on reducing life expectancy.[19] More generally, there is some evidence to suggest that the mortality risk from CVD among the extreme obese is similar to that for smoking and, in a cross-country analysis, it has been reported that high body mass index levels prevented further cardiometabolic mortality declines, although the effect was comparatively modest.[13,14,32]

Obesity, of course, is likely to be only a partial explanation; Italy and France, where the deceleration in CVD mortality in recent years is among the most notable (certainly at ages 35–74 years), each has below-average obesity levels but higher smoking prevalence among both men and women. Other factors such as declining population exposure to high blood pressure and high cholesterol have undoubtedly contributed to the long-term CVD-mortality declines, but evidence on recent changes in these exposures in high-income countries suggests that their contribution may have been small and inconsistent.[13,14,30] More broadly, the GBD comparative analysis of cardiovascular-disease mortality attributable to different risk factors does not suggest that any one risk factor has made a significantly larger contribution to CVD-mortality increases in recent years, notwithstanding the uncertainty arising from the availability and quality of data, nor is it clear from national-level analyses that changes in specific risk-factor exposure can be readily related to the timing of important reversals in mortality.[14,30] Closer analysis of trends by specific cause shows slower declines in other cardiovascular diseases than IHD and cerebrovascular diseases, possibly because this is a residual category that is not clearly defined, and hence has a range of many conditions with different aetiologies. It could therefore be expected that there is a less clear trend for this (relatively minor) set of conditions than for the other two causes.

Analyses have shown that further CVD-mortality reductions can occur by narrowing inequalities in CVD risk factors and improving access across the population to treatment.[15] However, such inequalities persist in some of the countries in this study, particularly in those with the slowest recent declines.[33–38] This is consistent with widening area-level inequalities in CVD-mortality rates in Australia and the UK, whereas, in the USA, counties with higher initial heart-disease-mortality risk and located outside major metropolitan areas were more likely to experience heart-disease-mortality rate increases from 2010 to 2015.[18,39,40] Also of concern are increasing income inequalities, evident in the USA and Australia, which have been found to increase country-level CVD-mortality risk, controlling for socio-economic factors.[41,42] Although reducing inequalities in risk factors, secondary prevention and treatment should be a policy priority, the political, fiscal and structural changes in policy required to do so are unlikely to be affected quickly enough to counter any impact that these inequalities are likely to have on CVD-mortality rates in the short term.

Our analysis, using routine vital-statistics data, suggests a more conservative reversal of the long-term decline in CVD mortality than do the adjusted trends from the GBD, but confirms its general pattern, timing and direction. Further insight into the variation of CVD-mortality decline within countries can be gained by analysis of individual cause-of-death data, linked with various socio-economic and geographic covariates. The implication for policy is that the effect of the successful public-health interventions applied over the past 50 years is diminishing and that CVD mortality has reached such low levels that further gains will be very difficult to achieve without much more targeted and strategic public-health measures, or in the absence of significant advances in medical management and health-care delivery. Given that CVDs remain a leading cause of death in high-income countries, the slowdown or reversal in their decline will likely have an important impact on the ability of countries to meet Sustainable Development Goal 3.4 and, more generally, on future longevity.[43] A resumption of CVD-mortality declines will require concerted and strategic efforts to reduce population exposure to risk factors even further, particularly obesity, as well as improvements in population access to high-quality treatment and care.

Supplementary Data

Supplementary data are available at *IJE* online.

Acknowledgements

The authors acknowledge that the World Health Organization is only responsible for provision of data in the WHO Mortality Database; the original data were submitted by country statistical or health authorities. This research received no specific grant from any funding agency.

Conflict of interest: None declared.

References

1. GBD 2017 Causes of Death Collaborators. Global, regional, and national age-sex-specific mortality for 282 causes of death in 195 countries and territories, 1980–2017: a systematic analysis for the Global Burden of Disease Study 2017. *Lancet* 2018;**392**: 1736–88.

2. Klenk J, Keil U, Jaensch A, Christiansen MC, Nagel G. Changes in life expectancy 1950–2010: contributions from age- and disease-specific mortality in selected countries. *Popul Health Metr* 2016;**14**:20.
3. GBD 2017 Risk Factor Collaborators. Global, regional, and national comparative risk assessment of 84 behavioural, environmental and occupational, and metabolic risks or clusters of risks for 195 countries and territories, 1990–2017: a systematic analysis for the Global Burden of Disease Study 2017. *Lancet* 2018;**392**:1923–45.
4. World Health Organization. *World Health Statistics 2017: Monitoring Health for the SDGs, Sustainable Development Goals*. Geneva: World Health Organization, 2017.
5. GBD Mortality Collaborators. Global, regional, and national under-5 mortality, adult mortality, age-specific mortality, and life expectancy, 1970–2016: a systematic analysis for the Global Burden of Disease Study 2016. *Lancet* 2017;**390**:1084–150.
6. Mirzaei M, Truswell AS, Taylor R, Leeder SR. Coronary heart disease epidemics: not all the same. *Heart* 2009;**95**:740–46.
7. Levi F, Lucchini F, Negri E, La Vecchia C. Trends in mortality from cardiovascular and cerebrovascular diseases in Europe and other areas of the world. *Heart* 2002;**88**:119–24.
8. Ouellette N, Barbieri M, Wilmoth JR. Period-based mortality change: turning points in trends since 1950. *Popul Dev Rev* 2014;**40**:77–106.
9. Taylor R, Dobson A, Mirzaei M. Contribution of changes in risk factors to the decline of coronary heart disease mortality in Australia over three decades. *Eur J Cardiovasc Prev Rehabil* 2006;**13**:760–68.
10. Tobias M, Taylor R, Yeh LC, Huang K, Mann S, Sharpe N. Did it fall or was it pushed? The contribution of trends in established risk factors to the decline in premature coronary heart disease mortality in New Zealand. *Aust N Z J Public Health* 2008;**32**:117–25.
11. Mensah GA, Wei GS, Sorlie PD *et al*. Decline in cardiovascular mortality: possible causes and implications. *Circ Res* 2017;**120**:366–80.
12. Tunstall-Pedoe H, Vanuzzo D, Hobbs M *et al*. Estimation of contribution of changes in coronary care to improving survival, event rates, and coronary heart disease mortality across the WHO MONICA project populations. *Lancet* 2000;**355**:688–700.
13. Di Cesare M, Bennett JE, Best N, Stevens GA, Danaei G, Ezzati M. The contributions of risk factor trends to cardiometabolic mortality decline in 26 industrialized countries. *Int J Epidemiol* 2013;**42**:838–48.
14. Ezzati M, Obermeyer Z, Tzoulaki I, Mayosi BM, Elliott P, Leon DA. Contributions of risk factors and medical care to cardiovascular mortality trends. *Nat Rev Cardiol* 2015;**12**:508–30.
15. Ford ES, Capewell S. Proportion of the decline in cardiovascular mortality disease due to prevention versus treatment: public health versus clinical care. *Annu Rev Public Health* 2011;**32**:5–22.
16. O'Flaherty M, Allender S, Taylor R, Stevenson C, Peeters A, Capewell S. The decline in coronary heart disease mortality is slowing in young adults (Australia 1976–2006): a time trend analysis. *Int J Cardiol* 2012;**158**:193–98.
17. Sidney S, Quesenberry CP Jr, Jaffe MG *et al*. Recent trends in cardiovascular mortality in the United States and public health goals. *JAMA Cardiol* 2016;**1**:594.
18. Vaughan AS, Ritchey MD, Hannan J, Kramer MR, Casper M. Widespread recent increases in county-level heart disease mortality across age groups. *Ann Epidemiol* 2017;**27**:796–800.
19. Preston SH, Vierboom YC, Stokes A. The role of obesity in exceptionally slow US mortality improvement. *Proc Natl Acad Sci USA* 2018;**115**:957–61.
20. Stewart ST, Cutler DM, Rosen AB. Forecasting the effects of obesity and smoking on U.S. life expectancy. *N Engl J Med* 2009;**361**:2252–60.
21. Olshansky SJ, Passaro DJ, Hershow RC *et al*. A potential decline in life expectancy in the United States in the 21st century. *N Engl J Med* 2005;**352**:1138–45.
22. World Health Organization. *WHO Mortality Database*. Geneva: World Health Organization, 2018.
23. Ministry of Health New Zealand. *Mortality 2015: Data Tables*. Wellington: Ministry of Health, New Zealand, 2018.
24. Statistics Canada. *Table 13-10-0392-01: Deaths and Age-Specific Mortality Rates, by Selected Grouped Causes*. Ottawa: Statistics Canada, 2018.
25. GBD Population and Fertility Collaborators. Population and fertility by age and sex for 195 countries and territories, 1950–2017: a systematic analysis for the Global Burden of Disease Study 2017. *Lancet* 2018;**392**:1995–2051.
26. Cleveland WS. Robust locally weighted regression and smoothing scatterplots. *J Am Stat Assoc* 1979;**74**:829–36.
27. StataCorp LP. *Stata/IC 13.0*. College Station, TX: StataCorp LP, 2013.
28. Naghavi M, Makela S, Foreman K, O'Brien J, Pourmalek F, Lozano R. Algorithms for enhancing public health utility of national causes-of-death data. *Popul Health Metr* 2010;**8**:9.
29. Truelsen T, Krarup LH, Iversen HK *et al*. Causes of death data in the global burden of disease estimates for ischemic and hemorrhagic stroke. *Neuroepidemiology* 2015;**45**:152–60.
30. GBD Collaborative Network. *Global Burden of Disease Study 2017 (GBD 2017) Results*. Seattle: Global Burden of Disease Collaborative Network, 2018.
31. GBD Collaborative Network. *Global Burden of Disease Study 2015 (GBD 2015) Obesity and Overweight Prevalence 1980–2015*. Seattle: Institute for Health Metrics and Evaluation (IHME), 2017.
32. Prospective Studies Collaboration, Whitlock G, Lewington S *et al*. Body-mass index and cause-specific mortality in 900 000 adults: collaborative analyses of 57 prospective studies. *Lancet* 2009;**373**:1083–96.
33. Australian Institute of Health and Welfare. *Risk Factors to Health*. Canberra: Australian Institute of Health and Welfare, 2017.
34. Bilger M, Kruger EJ, Finkelstein EA. Measuring socioeconomic inequality in obesity: looking beyond the obesity threshold. *Health Econ* 2017;**26**:1052–66.
35. Centers for Disease Control and Prevention. *Cigarette Smoking and Tobacco Use among People of Low Socioeconomic Status*. Atlanta: Centers for Disease Control and Prevention, 2018.
36. Hiscock R, Bauld L, Amos A, Platt S. Smoking and socioeconomic status in England: the rise of the never smoker and the disadvantaged smoker. *J Public Health (Oxf)* 2012;**34**: 390–96.
37. Hawkins NM, Scholes S, Bajekal M *et al*. Community care in England: reducing socioeconomic inequalities in heart failure. *Circulation* 2012;**126**:1050–57.
38. Schroder SL, Richter M, Schroder J, Frantz S, Fink A. Socioeconomic inequalities in access to treatment for coronary

heart disease: a systematic review. *Int J Cardiol* 2016;**219**: 70–78.
39. Asaria P, Fortunato L, Fecht D *et al*. Trends and inequalities in cardiovascular disease mortality across 7932 English electoral wards, 1982–2006: Bayesian spatial analysis. *Int J Epidemiol* 2012;**41**:1737–49; discussion 50–2.
40. Australian Institute of Health and Welfare. *Indicators of Socioeconomic Inequalities in Cardiovascular Disease, Diabetes and Chronic Kidney Disease*. Canberra: Australian Institute of Health and Welfare, 2019.
41. Dewan P, Rorth R, Jhund PS *et al*. Income inequality and outcomes in heart failure: a global between-country analysis. *JACC Heart Fail* 2019;**7**:336–46.
42. The World Bank. *GINI Index (World Bank Estimate)*. Washington, DC: The World Bank, 2019.
43. NCD Countdown Collaborators. NCD countdown 2030: worldwide trends in non-communicable disease mortality and progress towards Sustainable Development Goal target 3.4. *Lancet* 2018;**392**:1072–88.