Time trends in mortality from heart failure and atherosclerotic cardiovascular disease in people with and without diabetes: a multi-national population-based study

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Summary

Background Contemporary trends in cardiovascular disease (CVD) cause-specific mortality by diabetes status are inadequately described. We examined trends by diabetes status in coronary heart disease (CHD), cerebrovascular disease, and heart failure mortality, and mortality rate ratios (people with diabetes versus those without diabetes) across nine high-income jurisdictions.

Methods We assembled CVD cause-specific mortality data from nine administrative datasets (Europe [n=5], Australia [n=1], Canada [n=2], and South Korea [n=1]), spanning 2000–23. Using Poisson regression, we estimated mortality rates by diabetes status and mortality rate ratios.

Findings There were 2·92 million CVD deaths over 1·30 billion person-years of follow-up. In all jurisdictions and in both people with and without diabetes, the total CVD and CHD mortality rates fell across the observed time period. The 5-year percent changes in CHD mortality ranged from –11·5% to –32·3%. Reductions in heart failure mortality were smaller than those for CHD mortality (except in Scotland) and smaller than those for cerebrovascular mortality (except in Scotland and Denmark). Heart failure mortality increased in Ontario, Canada. The excess CHD mortality associated with diabetes (mortality rate ratio ~2·0) fell in three of nine jurisdictions and was stable or uncertain in the remainder. No jurisdiction had a fall in excess heart failure mortality associated with diabetes.

Interpretation Declines in heart failure mortality in both people with and without diabetes were less marked than were declines in CHD and cerebrovascular disease mortality in most jurisdictions. Heart failure mortality rate ratios have not decreased. A greater focus on reducing heart failure mortality in people with and without diabetes might be required.

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Introduction

Cardiovascular disease (CVD) incidence and mortality have declined in many high-income countries in recent decades; however, CVD remains a substantial burden, especially in people with diabetes.[1,2] Further, the rate of decline in CVD mortality rates has slowed in some regions (eg, in the USA since 2011).[3] In many low-income and middle-income countries (LMICs), CVD mortality rates have only slightly decreased, or have increased.[2]

Atherosclerotic CVD (ASCVD) is a key risk factor for heart failure. Improvements in ASCVD risk factors have reduced the incidence of ASCVD;[4] however, declining ASCVD incidence reduces heart failure prevalence, whereas declining ASCVD mortality probably increases heart failure prevalence.

Heart failure mortality rates vary by region and over time. From 1987 to 2008, there was a 40% reduction in age-standardised heart failure mortality rates in seven European countries.[5] Conversely, in the USA, age-adjusted heart failure mortality increased by 146% from 1970 to 2022.[6] This increase occurred in an era when many new randomised controlled trials on heart failure therapy were being published, including on β-blockers, angiotensin-converting enzyme inhibitors, and mineralocorticoid receptor antagonists. In this changing landscape of cardiovascular therapeutics, a clearer understanding of the contemporary trends in CVD cause-specific mortality is paramount.

Therefore, we assembled data from nine whole-of-jurisdiction administrative datasets that have recorded CVD causes of death by diabetes status. We aimed to examine trends in death due to coronary heart disease (CHD), cerebrovascular disease, and heart failure in people with and without diabetes over time, by age, sex,

Research in context

Evidence before this study

We searched PubMed for articles reporting whole population trends in cardiovascular cause-specific mortality in individuals with diabetes from Jan 1, 1990, to July 8, 2025. The terms "mortality trends", "cardiovascular", "heart failure", "ischaemic heart disease", "coronary heart disease", and "diabetes mellitus" were used, without language restrictions. In most high-income settings, mortality from atherosclerotic cardiovascular disease has declined over the past few decades, although some studies suggest this decline has slowed. Conversely, trends in heart failure mortality vary by region and over time.

Added value of this study

To the best of our knowledge, this is the first multi-country analysis of trends in contemporary cardiovascular cause-specific mortality in people with diagnosed diabetes, compared with people without diagnosed diabetes. In four of seven jurisdictions with heart failure data available, declines in heart failure mortality were less marked than declines in mortality due to atherosclerotic cardiovascular disease in people with and without diabetes. In one jurisdiction, heart failure mortality increased. In all of the jurisdictions studied, heart failure mortality rate ratios by diabetes status did not decrease.

Implications of all the available evidence

Effective approaches to reducing heart failure mortality in people with and without diabetes might be required; this could include appropriate targeting of existing cardioprotective therapies towards those at high risk of heart failure death.

and jurisdiction. We also assessed cardiac death, a composite of CHD and heart failure death, and total CVD death, a composite of all CVD causes of death (including CHD, cerebrovascular disease, heart failure, and other CVD).

Methods

Study design and participants

This study used data from a subset of countries participating in an international diabetes consortium (GLOBODIAB).[7] This consortium has assembled aggregated data on all-cause and cause-specific mortality in people with and without diabetes from over 20 whole-of-jurisdiction administrative data sources. These data sources include health-care administrative databases, research databases, and health insurance databases worldwide. The initial eligibility criteria for inclusion in the consortium have been previously described.[7] This analysis included data sources that had ongoing enrolment of new cases of diabetes and cause-specific mortality data in people with and without diabetes.

Nine jurisdictions were included: Australia, two provinces of Canada (Alberta and Ontario), Denmark, Finland, France, Lithuania, Scotland, and South Korea. We collected data on population size, prevalent diabetes counts, death counts by underlying cause of death, and person-years of follow-up, by diabetes status, sex, and 10-year age groups (<40 years, 40–49 years, 50–59 years, 60–69 years, 70–79 years, 80–89 years, and ≥90 years), for each calendar year from 2000 to 2023 or a subset thereof. Follow-up time started when the person was first recorded in the given database and stopped when they were no longer recorded in the database (censored) or they died.

In Australia and Scotland, diabetes status was determined from the clinical diagnosis documented by health-care professionals, or International Classification of Diseases, 10th revision (ICD-10) codes. For the other jurisdictions, more complex algorithms were used to define diabetes (appendix p 4). People with known gestational diabetes (except for France), secondary diabetes (eg, drug-induced, exocrine pancreatic insufficiency, or genetic causes), and maturity-onset diabetes of the young (a primary genetic cause of diabetes) were excluded.

This study was approved by the Human Ethics Committees of Alfred Health and the University of Melbourne, Australia.

Procedures and statistical analysis

Death was determined by linkage to death registries. All countries included in this study have mandatory death registration systems with high completeness and quality as per the WHO Mortality Database.[8] Underlying causes of death were classified according to ICD-10 codes, and were grouped into CHD, cerebrovascular disease, heart failure, cardiac death (composite of CHD and heart failure), and total CVD (appendix p 4). CVD was defined as all CVD coded in ICD-10 codes I00–I99.

Two authors (DJM and LC) independently assessed the risk of bias in each data source using a modified Newcastle-Ottawa Scale (appendix pp 5–6). Disagreements were resolved by discussion with a third author (JES). The quality of the data was classified as low (score of zero to three), medium (four to six), or high (seven to nine).

We modelled mortality rates for the three underlying CVD causes of death, as well as cardiac death (CHD and heart failure death) and total CVD death, using age and calendar time as continuous variables. Data were tabulated into calendar time (single year) and age-group (10-year intervals), with each interval assigned the midpoint value of each age-group and calendar time interval. We used rate models with a Poisson likelihood to estimate mortality rates. We fitted age–period–cohort models using cubic splines for age, period (calendar

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See Online for appendix

time), and cohort (period minus age). Knots for the splines were placed at evenly spaced quantiles of the events at the three variables in the model.

For each data source and sex, we used the estimated rates from the age–period–cohort models[9] to calculate age-standardised and sex-standardised mortality rates using direct standardisation (to the pooled consortium diabetes population). Standardised rates were restricted to ages 40–90 years due to small numbers of deaths in the younger age groups and the availability of data for people older than 90 years. We fitted age–period models with smooth age effects and a linear effect of calendar time for each data source, to provide estimates of the mean change over the time period. Using this model, five-year changes in CVD cause-specific mortality rates were calculated for the total population and by sex. We calculated 95% CIs for rates based on standard errors of the parameter estimates.

For each underlying cause of death, we calculated the mortality rate ratio (MRR) of people with diabetes compared with people without diabetes. We fitted Poisson models for mortality rates with spline effects of age and calendar time, binary effects of sex and diabetes status, and an interaction term between diabetes status and calendar time. These models were used to estimate the MRR from the observed data, for each underlying cause of death, by jurisdiction and calendar time. We also fit a set of models that were parameterised in the same way, except with a linear effect of calendar time to provide an overall summary of the 5-year percent change in MRR by cause of death for each jurisdiction. For Finland and Lithuania, data on cause-specific mortality due to heart failure were excluded. In 2010, heart failure coding changed in Finland such that, in preference to heart failure, other CVD were coded as the cause of death. In Lithuania, heart failure is treated as a complication of other CVD; thus, the mortality numbers for heart failure were small.

During analysis, a question arose as to whether any changes in physician practice regarding CVD coding on death certificates could explain the observed trends. We were able to access repeat analyses in the datasets from Australia, Ontario (Canada), Denmark, and Scotland. Therefore, in these datasets, we examined the other causes for deaths where the underlying cause was CHD, heart failure, or diabetes.

To understand the context in which the observed trends occurred, we summarised concurrent trends in cardiovascular risk factors (eg, smoking, lipids, and blood pressure) and life expectancy in the eight included countries.

Since all the databases are very large, we developed an algorithm for classifying trends that did not rely on statistical significance, but on the magnitude of the estimated change. This way, small but statistically significant changes could be labelled as stable. Changes in mortality rates and MRRs were classified as stable, uncertain trend, or meaningful (increasing or decreasing; appendix p 9). We chose a null interval for rate changes of –5% to +5% per 5 years. If the CI for the rate change was entirely outside the null interval (could include –5% or +5%), the estimate was labelled as meaningful (increasing or decreasing). If the CI was entirely within the null interval (could include –5% or +5%), the estimate was labelled as stable. All other cases were labelled as an uncertain trend (appendix p 9).

	Origin of data	Type of data	Years	Person-years in people with diabetes	Number of total CVD deaths in people with diabetes	Diabetes definition
Australia	National Diabetes Services Scheme linked to the National Death Index, and the General Record of Incidence of Mortality	Registry	2005–21	13 109 925	105 484	Clinical diagnosis
Alberta (Canada)	Population-level health-care administrative database in Alberta	Administrative	2005–20	3 913 521	35 051	Algorithm
Ontario (Canada)	Population-level health-care administrative database in Ontario	Administrative	2013–18	6 347 991	49 184	Algorithm
Denmark	National Patient Register, National Prescription Registry, and the National Health Service Register	Registry	2002–19	3 915 758	43 423	Algorithm
Finland	FinDM (Diabetes in Finland) research database	Registry	2000–23	9 178 177	152 850	Algorithm
France	Système National de Données de Santé (French national health data system)	Administrative	2013–20	23 527 395	166 013	Algorithm
Lithuania	National Compulsory Health Insurance Fund Information System	Administrative	2014–21	1 100 474	29 837	Clinical diagnosis (ICD-10 codes) and glucose-lowering medications
Scotland	Scottish Diabetes Research Network—national diabetes dataset 2021	Registry	2006–20	4 134 759	47 732	Clinical diagnosis (Read codes)
South Korea	National Health Insurance Service—national sample cohort	Health insurance	2007–19	1 215 616	6284	Glucose-lowering medications and clinical diagnosis (ICD-10 codes)

CVD=cardiovascular disease. ICD-10=International Classification of Diseases, 10th edition.

Table: **Summary characteristics of the included data sources**

For changes in mortality rates and MRRs, a threshold of 5% per 5 years was chosen, as it is comparable to the relative percent declines in cardiovascular mortality in recent decades. As per the 2023 World Heart Report, from 1990 to 2019, the age-standardised cardiovascular mortality rate declined by 32% over 29 years,[10] which approximates to 5% per 5 years. For MRRs, the relative risk of vascular mortality by diabetes status in the US National Health and Nutrition Examination Surveys cohort declined by 4·8–10·0% between adjacent, approximately 5-year-long time periods from 1995 to 2015;[11] thus, 5% per 5 years was chosen.

We performed sensitivity analyses with alternative thresholds of 3% and 7% (appendix pp 14–17). 3% and 7% represented a plausible range of variation around 5%, exploring the effect of slightly more conservative or optimistic assumptions. We used Stata software (version 17.0) for statistical analyses.

Role of the funding source

The funders of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report.

Results

Mortality data for people with and without diabetes were available for nine jurisdictions (table; appendix pp 7–8). Data were included from a variety of sources: four of nine were administrative data, four of nine were registries, and one was whole-of-nation health insurance data (table). All data were of high quality (quality scores of seven to nine), except for one jurisdiction's data with a

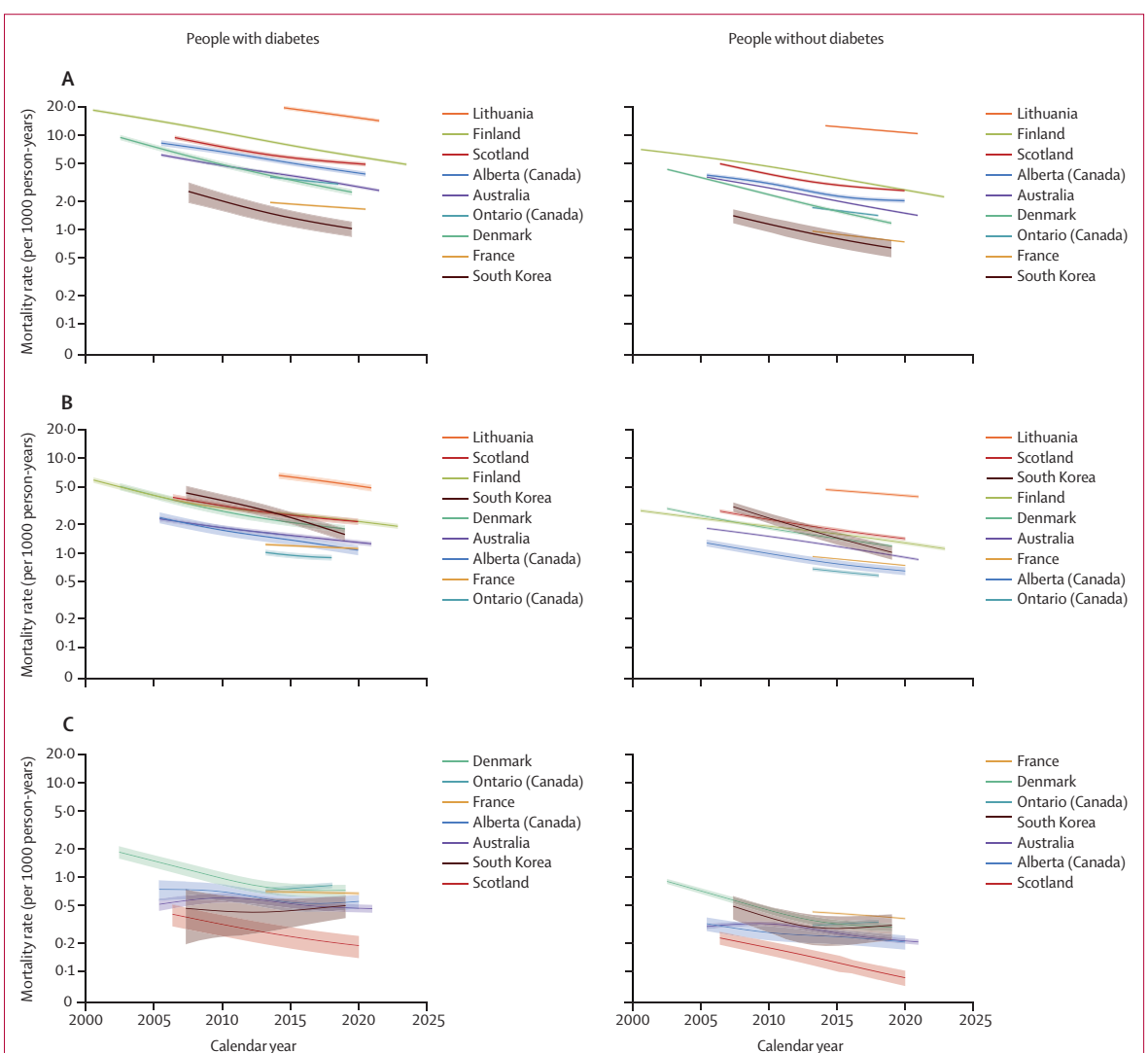

Figure 1: **Trends in age and sex-standardised mortality rates by jurisdiction and diabetes status**
Coronary heart disease (A), cerebrovascular disease (B), and heart failure (C). Shading represents 95% CIs. Jurisdictions in the key are ordered by the magnitude of the corresponding mortality rates.

medium quality score of six (appendix pp 5–6). Eight of the nine databases captured more than 80% of their national or subnational populations, except for data from South Korea, which came from a random, representative sample of a nationwide, universal health-care system.[12]

There were 2·92 million CVD deaths over 1·30 billion person-years of follow-up, with 635 860 of these deaths occurring in people with diabetes and 2·29 million of these deaths occurring in people without diabetes.

Figure 1 shows the trends in age-standardised mortality rates for CHD, cerebrovascular disease, and heart failure in people with and without diabetes (appendix pp 10–11, 32–41). 5-year percent changes in these mortality rates are shown (figure 2).

For total CVD, CHD, cerebrovascular disease, heart failure, and cardiac (CHD and heart failure) death (figure 2), declines in mortality over the study period were observed in people with and without diabetes, except for heart failure mortality in people with and without diabetes in Ontario (Canada), where it increased, heart failure mortality in people with diabetes in France (stable), heart failure mortality in people with diabetes in South Korea

	CVD	CHD	Cerebrovascular disease	Heart failure	Cardiac
Australia					
Diabetes	−17·2 (−17·7 to −16·7)	−23·0 (−23·7 to −22·3)	−16·9 (−18·0 to −15·7)	−7·2 (−9·4 to −5·0)	−21·2 (−21·9 to −20·5)
No diabetes	−18·6 (−18·8 to −18·4)	−25·0 (−25·4 to −24·7)	−20·4 (−20·9 to −19·9)	−12·6 (−13·6 to −11·6)	−23·6 (−23·9 to −23·3)
Alberta (Canada)					
Diabetes	−18·4 (−19·4 to −17·5)	−22·7 (−23·9 to −21·5)	−22·7 (−24·9 to −20·4)	−12·0 (−15·9 to −8·0)	−21·6 (−22·8 to −20·5)
No diabetes	−15·6 (−16·3 to −15·0)	−20·6 (−21·5 to −19·7)	−19·9 (−21·4 to −18·3)	−12·4 (−15·2 to −9·5)	−19·8 (−20·6 to −18·9)
Ontario (Canada)					
Diabetes	−8·3 (−10·7 to −5·9)	−15·1 (−18·4 to −11·7)	−11·1 (−17·4 to −4·4)	15·7 (6·9 to 25·2)	−9·7 (−12·8 to −6·4)
No diabetes	−12·2 (−13·7 to −10·6)	−17·4 (−19·7 to −15·0)	−11·6 (−15·5 to −7·6)	13·4 (7·0 to 20·3)	−12·2 (−14·4 to −9·9)
Denmark					
Diabetes	−24·2 (−24·9 to −23·5)	−32·3 (−33·3 to −31·3)	−25·7 (−27·1 to −24·3)	−25·3 (−27·6 to −23·0)	−31·1 (−32·0 to −30·2)
No diabetes	−23·2 (−23·5 to −22·9)	−31·8 (−32·3 to −31·4)	−23·0 (−23·6 to −22·4)	−29·6 (−30·7 to −28·6)	−31·4 (−31·9 to −31·0)
Finland					
Diabetes	−18·8 (−19·1 to −18·5)	−25·2 (−25·6 to −24·8)	−19·5 (−20·2 to −18·8)	..	..
No diabetes	−16·3 (−16·5 to −16·1)	−22·4 (−22·7 to −22·1)	−17·8 (−18·2 to −17·4)	..	..
France					
Diabetes	−9·3 (−10·2 to −8·3)	−11·5 (−13·2 to −9·8)	−7·1 (−9·2 to −4·9)	−2·2 (−5·0 to 0·7)	−8·7 (−10·2 to −7·3)
No diabetes	−14·0 (−14·4 to −13·6)	−17·6 (−18·5 to −16·7)	−13·1 (−14·1 to −12·2)	−7·8 (−9·1 to −6·6)	−13·9 (−14·7 to −13·2)
Lithuania					
Diabetes	−13·3 (−15·5 to −11·1)	−19·3 (−21·8 to −16·8)	−19·3 (−23·3 to −15·0)	..	..
No diabetes	−8·3 (−9·3 to −7·2)	−14·0 (−15·2 to −12·8)	−12·0 (−14·0 to −10·0)	..	..
Scotland					
Diabetes	−15·1 (−16·0 to −14·2)	−20·5 (−21·7 to −19·4)	−19·5 (−21·2 to −17·7)	−24·4 (−29·4 to −19·1)	−20·7 (−21·8 to −19·6)
No diabetes	−17·2 (−17·6 to −16·7)	−21·7 (−22·3 to −21·1)	−22·1 (−22·9 to −21·4)	−30·5 (−32·9 to −28·0)	−22·1 (−22·7 to −21·5)
South Korea					
Diabetes	−25·4 (−28·0 to −22·8)	−31·0 (−35·6 to −26·0)	−35·0 (−38·3 to −31·4)	4·1 (−8·5 to 18·4)	−24·0 (−28·5 to −19·2)
No diabetes	−27·2 (−29·3 to −25·1)	−25·5 (−29·7 to −21·0)	−36·0 (−38·7 to −33·1)	−16·7 (−24·7 to −7·8)	−23·6 (−27·3 to −19·6)

Figure 2: **5-year percent change (95% CIs) in cause-specific mortality rates by jurisdiction and diabetes status**
Colouring of cells is as per their value interpretation using a 5% threshold (green=decreasing trend, red=increasing trend, blue=stable, yellow=uncertain trend). Total CVD is a composite of CHD, cerebrovascular disease, heart failure, and other CVD death. Cardiac death is a composite of CHD and heart failure death. CVD=cardiovascular disease. CHD=coronary heart disease.

(uncertain), and cerebrovascular disease mortality in people with diabetes in Ontario (Canada) and France (uncertain). In four of the seven jurisdictions with heart failure mortality data available, among people with and without diabetes, the magnitude of the declines in heart failure mortality was less than the magnitude of the declines in CHD and cerebrovascular disease mortality (Australia, Alberta [Canada], France, and South Korea). In Ontario (Canada), heart failure mortality increased.

Modelled mortality rates for CHD, cerebrovascular disease, and heart failure were broadly similar across the sexes and ages (appendix p 12).

Figure 3 shows trends in MRRs for people with diabetes versus people without diabetes, by jurisdiction, for CHD, cerebrovascular disease, and heart failure. 5-year percent changes in these MRRs are shown (figure 4). People with diabetes had approximately twice the risk of CHD death compared with people without diabetes. The MRRs for all specific cardiovascular causes of deaths decreased, or were stable or uncertain, in the included jurisdictions. For total CVD, the MRR decreased in Lithuania; was stable in Australia, Denmark, France, and Scotland; and was uncertain in both Canadian provinces, Finland, and South Korea. The MRR for CHD decreased in Finland, Lithuania, and South Korea; was stable in Australia, Denmark, and Scotland; and was uncertain in both Canadian provinces and France. For cerebrovascular disease, the MRR decreased in Lithuania, was stable in Australia, Finland, and Scotland; and uncertain in the remaining jurisdictions. For heart failure, the MRR trend was uncertain in all jurisdictions and did not meaningfully decrease.

MRRs were broadly similar across the sexes and ages (appendix pp 12–13).

Mortality rates and MRRs were also measured using 3% and 7% thresholds instead of a 5% threshold for interpretation (appendix pp 14–17).

The trends in the other contributory causes of death accompanying deaths where CHD, heart failure, and diabetes were the underlying causes of death in Australia, Denmark, Ontario (Canada), and Scotland are shown in the appendix (pp 18–29). In these four jurisdictions, the proportion of CHD deaths with heart failure listed as a contributory cause of death was relatively stable across the study period. Conversely, the proportion of deaths due to diabetes with CHD and cerebrovascular disease listed as contributory causes of deaths declined over the study period. In Ontario (Canada), the proportion of heart failure deaths with CHD or diabetes listed as a contributory cause of death declined over the study period. Australia, Denmark, and Scotland had too few heart failure deaths with CHD or diabetes as associated causes of death to draw meaningful conclusions regarding trends.

The trends in cardiovascular risk factors and life expectancy that have accompanied the above trends in mortality rates and MRRs are shown in the appendix (pp 30–31). Cardiovascular risk factors (eg, smoking, lipids, and blood pressure) improved in most of the included countries.

Discussion

CHD, cerebrovascular disease, cardiac, and total CVD mortality have declined in most of the nine jurisdictions studied, in both people with and without diabetes. In four of the seven jurisdictions where heart failure mortality data were available, the declines in heart failure mortality were less than the declines in mortality from other CVD, and in one jurisdiction, heart failure mortality increased. The MRR for CHD declined in three jurisdictions, whereas the MRR for cerebrovascular disease declined in one jurisdiction. In the other

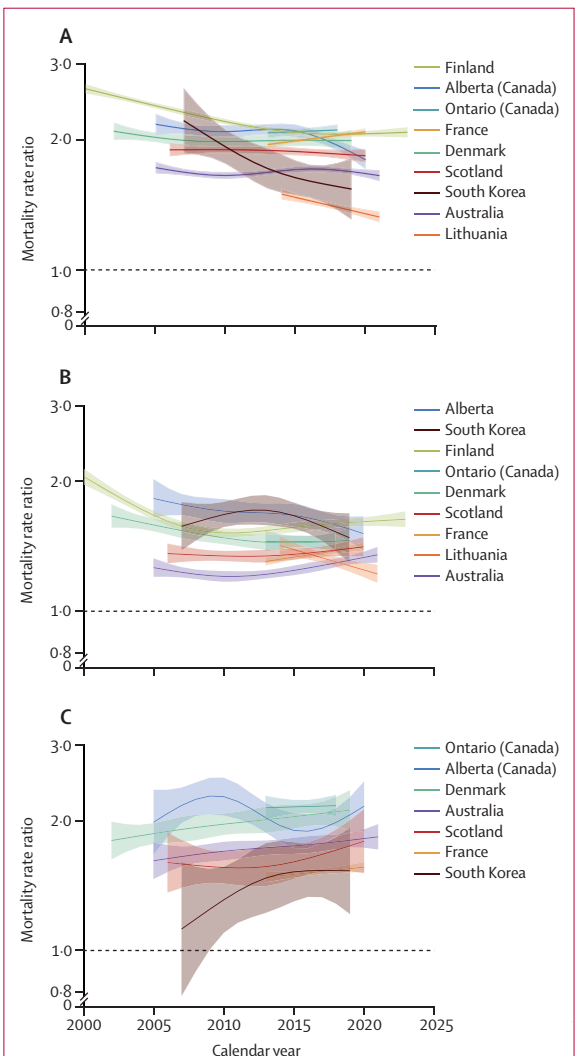

Figure 3: **Trends in mortality rate ratios (people with diabetes versus people without diabetes) by jurisdiction and cause of death**
Coronary heart disease (A), cerebrovascular disease (B), and heart failure (C). Shading represents 95% CIs. Jurisdictions in the key are ordered by the magnitude of the corresponding mortality rate ratios.

	CVD	CHD	Cerebrovascular disease	Heart failure	Cardiac
Australia	−0·8 (−1·5 to −0·1)	−0·1 (−1·0 to 0·9)	2·7 (1·2 to 4·2)	2·6 (−0·1 to 5·4)	0·3 (−0·6 to 1·2)
Alberta (Canada)	−5·0 (−6·3 to −3·6)	−4·3 (−6·1 to −2·5)	−4·7 (−8·0 to −1·4)	−2·3 (−7·6 to 3·2)	−4·1 (−5·8 to −2·3)
Ontario (Canada)	3·3 (0·1 to 6·6)	1·5 (−3·3 to 6·6)	−0·1 (−8·3 to 8·8)	1·1 (−8·4 to 11·5)	1·7 (−2·6 to 6·2)
Denmark	−1·5 (−2·5 to −0·5)	−1·0 (−2·6 to 0·6)	−3·6 (−5·6 to −1·7)	6·5 (2·9 to 10·2)	0·3 (−1·1 to 1·8)
Finland	−4·8 (−5·2 to −4·3)	−5·5 (−6·1 to −5·0)	−3·1 (−4·0 to −2·1)	..	..
France	3·4 (2·2 to 4·6)	4·9 (2·6 to 7·3)	5·7 (3·1 to 8·5)	3·9 (0·6 to 7·3)	3·4 (1·6 to 5·3)
Lithuania	−7·6 (−10·1 to −5·1)	−8·3 (−11·3 to −5·1)	−10·2 (−15·1 to −5·0)	..	..
Scotland	0·2 (−1·0 to 1·4)	−0·5 (−2·1 to 1·1)	1·5 (−0·9 to 3·9)	3·9 (−3·7 to 12·1)	−0·4 (−1·9 to 1·2)
South Korea	−3·1 (−7·2 to 1·3)	−13·6 (−20·9 to −5·5)	−2·4 (−8·7 to 4·5)	18·0 (0·6 to 38·5)	−7·3 (−14·2 to 0·1)

Figure 4: **5-year percent change (95% CIs) in cause-specific mortality rate ratios by jurisdiction**
Mortality rate ratios represent the mortality rate in people with diabetes, divided by the mortality rate in people without diabetes. Colouring of cells is as per their value interpretation using a 5% threshold (green=decreasing trend, red=increasing trend, blue=stable, yellow=uncertain trend). Total CVD is a composite of CHD, cerebrovascular disease, heart failure, and other CVD death. Cardiac death is a composite of CHD and heart failure death. CVD=cardiovascular disease. CHD=coronary heart disease.

jurisdictions, the MRRs for CHD and cerebrovascular disease were stable or the trend was uncertain. The MRR for heart failure was stable or the trend was uncertain in all seven jurisdictions with heart failure data available.

If a threshold other than 5% was selected to designate meaning for changes in rates and MRRs, our conclusions would have differed. This 5% threshold was chosen to compare our results with previous meaningful declines in cardiovascular mortality.[10] The method for interpretation used in this study, modelled on non-inferiority, was chosen to avoid relying only on statistical significance, given its limitations. However, best practice would be to interpret the point estimates and CIs themselves without using thresholds for interpretation.

Improvements in ASCVD mortality have occurred in the context of improvements in cardiovascular risk factors, pharmacotherapies, and procedural interventions for cardiovascular disease.[4] This improvement in CVD mortality occurs despite rising rates of obesity and type 2 diabetes. Worldwide, diabetes prevalence has risen rapidly; as of 2024, one in nine adults has diabetes.[13] Obesity prevalence has also increased globally, particularly in middle-income regions.[14]

It is noted that a substantial proportion of incident CVD is not associated with the standard modifiable risk factors—namely BMI, systolic blood pressure, non-high-density lipoprotein cholesterol, smoking, and diabetes.[15] Further, the magnitude of the association between these risk factors and CVD varies between low-income, middle-income, and high-income countries.[16] There is also substantial ethnicity-based variation in cardiovascular risk.[17]

Advances in pharmacotherapy include the introduction of sodium–glucose co-transporter-2 inhibitors and incretin mimetics, primarily glucagon-like peptide-1 receptor agonists. Given these medications were initially developed for people with diabetes, they might have partly contributed to the ASCVD MRR decline in some jurisdictions. However, given their relatively recent introduction in some countries and suboptimal uptake, the effect on ASCVD MRR is probably small.[18]

Although ASCVD mortality has declined, heart failure mortality has either declined to a lesser extent or increased in five of the seven jurisdictions with heart failure mortality data available. A US study suggested that heart failure mortality declined from 2000 to 2012 but increased from 2012 to 2014.[19] South Korea also reported increasing heart failure mortality from 1983 to 2019.[20]

This smaller decline, or increase, in heart failure mortality mirrors some studies of incidence and hospitalisation. The current study reports an increase in heart failure mortality in Ontario (Canada) from 2013 to 2018. Similarly, from 1995 to 2019, heart failure hospitalisation rates in Ontario (Canada) initially decreased, then stabilised in the 2010s.[21] However, some studies have found a disconnect between mortality and hospitalisation. For example, in France from 2002 to 2012, heart failure hospitalisation rates were unchanged, despite a substantial decrease in heart failure mortality.[22]

There are several possible explanations for the stalled decline or increase in heart failure mortality. It is possible that improved survival from CHD has allowed more people to develop heart failure.[23] Obesity has also increased in prevalence[14] and is a notable risk factor for heart failure. The advent of improved heart failure awareness and diagnostics could have increased rates of heart failure detection.[24] However, the additional cases detected by improved diagnostics are likely to be milder, with only a small effect on heart failure mortality rates.

Since heart failure mortality trends might be influenced by changes in coding practices,[25] the current study explored one important component of this; among all deaths with CHD as the underlying cause, the proportion that also included heart failure on the death certificate was stable over time. This finding suggests no change during the observation period in the likelihood that heart failure is perceived as a cause of death independent from CHD. Perhaps the number of heart failure deaths secondary to non-ischaemic causes has increased; this is supported by the Ontario (Canada) data, which show that the proportion of heart failure deaths with CHD or diabetes listed as a contributory cause has decreased over time. However, we did not separate heart failure by aetiology because aetiology cannot be reliably ascertained from ICD-10 codes, and the causal chains on death certificates are often incomplete.

For deaths occurring in people with diabetes and CHD, the underlying cause of death is more likely to be listed as diabetes, as compared with earlier years in Australia and the USA.[26] Similarly, the current study found that the proportion of diabetes deaths with CHD listed as a contributory cause decreased over time in Australia, Denmark, and Scotland, although it was relatively stable in Ontario (Canada). Deeming a death from CHD in a person with diabetes to be primarily related to diabetes is subjective. Although determining whether a CHD death in someone with diabetes should be attributed mainly to diabetes is subjective, this pattern could also be due to the diversification of the causes of death in people with diabetes.[23]

This study has limitations. First, our analysis is based on total diabetes, since many jurisdictions were unable to stratify by diabetes type. However, since well over 90% of people with diabetes in the older age groups that drive mortality data have type 2 diabetes, we might expect that these findings could apply to type 2 diabetes, although we cannot assume that they apply to type 1 diabetes. Second, all the included data were from high-income settings; CVD mortality is higher among people with diabetes in LMICs.[27] Third, France was unable to exclude gestational diabetes using their diabetes algorithm. Given women with gestational diabetes are probably a healthier population than the general population of people with type 1 and type 2 diabetes, in France, mortality rates for people with diabetes and MRRs might have been slightly underestimated. Fourth, we did not collect covariate data and therefore were unable to adjust for some factors, such as blood pressure, which influence cardiovascular mortality. Fifth, the time period of available data in some jurisdictions was limited. Sixth, coding practices in Finland and Lithuania required exclusion of heart failure mortality data during analysis. Seventh, the numbers of heart failure deaths were small in Scotland and South Korea, which might limit the power of these analyses. Eighth, deaths were coded based on ICD-10 codes, the use of which differs by clinician and region. Further, coding changes by WHO occurred during the observation period,[28] which might have been implemented differently by different countries.

This study also has key strengths. This is the first multi-country analysis of trends in contemporary CVD cause-specific mortality in people with diagnosed diabetes, compared with people without diabetes, and one of the largest studies of cardiovascular disease mortality trends. Whole-of-jurisdiction datasets were stratified by age, sex, and diabetes status. Data were all of high quality, except for one dataset of medium quality, as scored by the modified Newcastle–Ottawa Scale.

Declines in heart failure mortality over time have been less marked than declines in CHD and cerebrovascular disease mortality, and there was an increase in heart failure mortality in one of seven jurisdictions. The MRR for heart failure, comparing people with and without diabetes, did not decrease in any of the jurisdictions studied. Current efforts to manage diabetes appear to have narrowed the gap between people with and without diabetes in terms of atherosclerotic CVD mortality, but not in terms of heart failure mortality. Continued efforts in diabetes management, especially in relation to heart failure, are recommended to ensure further long-term improvements.

Contributors

DJM, EWG, MEP, and JES conceived the study and made contacts with contributing centres. DJM, LC, and JYG oversaw the practical gathering of data from the centres. LC was responsible for the database. JIM, DJM, and BC designed and undertook the statistical analysis. TL and HS performed the analysis of the other causes of death for CHD, heart failure, and diabetes deaths for Denmark, and KF performed this analysis for Scotland. JYG collated the full statistical analysis output. JYG and DJM wrote the manuscript. All other authors curated data from centres into the standardised form. All authors contributed to data interpretation and critical evaluation, contributed to the editing of the report, and approved the final submitted version of the manuscript. DJM, LC, and JIM verified the data and had access to the raw data (aggregate). DJM, LC, and JIM are the guarantors of data and analysis integrity, and DJM had final responsibility for the decision to submit for publication.

Declaration of interests

JIM has received consulting fees from Familial Hypercholesterolaemia Europe. KF's institute, the University of Edinburgh, received support from the Baker Heart and Diabetes Institute for her involvement in this project. PK has received consulting fees from Familial Hypercholesterolaemia. HS has received personal fees for statistical consulting from Novartis, Pfizer, MSD, Neumirna, and Vesper Bio Aps. RCV has received support for attending a Novo Nordisk obesity summit. SF has received advisory board honoraria from Mylan, Pfizer, and Sanofi, and presentation honoraria from Astra Zeneca, Boehringer-Ingelheim, Eli Lilly, and Novo Nordisk. JES has received consulting fees from GSK, Astra Zeneca, Sanofi, Novo Nordisk, Eli Lilly, Roche, and Abbott; payment for being on programs committee for Astra Zeneca; and payment for lectures for Astra Zeneca, Boehringer Ingelheim, Novo Nordisk, Roche, Zuellig Pharmaceutical, and Eli Lilly.

Data sharing

Aggregated data might be made available upon reasonable request to the corresponding author. There might be limitations on what the data can be used for, subject to approval from the data custodians. The syntax used for the analysis is available at https://github.com/jimb0w/CCVD.

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