# Trends in lifetime risk and years of life lost due to diabetes in the USA, 1985–2011: a modelling study

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## Summary

**Background** Diabetes incidence has increased and mortality has decreased greatly in the USA, potentially leading to substantial changes in the lifetime risk of diabetes. We aimed to provide updated estimates for the lifetime risk of development of diabetes and to assess the effect of changes in incidence and mortality on lifetime risk and life-years lost to diabetes in the USA.

**Methods** We incorporated data about diabetes incidence from the National Health Interview Survey, and linked data about mortality from 1985 to 2011 for 598 216 adults, into a Markov chain model to estimate remaining lifetime diabetes risk, years spent with and without diagnosed diabetes, and life-years lost due to diabetes in three cohorts: 1985–89, 1990–99, and 2000–11. Diabetes was determined by self-report and was classified as any diabetes, excluding gestational diabetes. We used logistic regression to estimate the incidence of diabetes and Poisson regression to estimate mortality.

**Findings** On the basis of 2000–11 data, lifetime risk of diagnosed diabetes from age 20 years was 40·2% (95% CI 39·2–41·3) for men and 39·6% (38·6–40·5) for women, representing increases of 20 percentage points and 13 percentage points, respectively, since 1985–89. The highest lifetime risks were in Hispanic men and women, and non-Hispanic black women, for whom lifetime risk now exceeds 50%. The number of life-years lost to diabetes when diagnosed at age 40 years decreased from 7·7 years (95% CI 6·5–9·0) in 1990–99 to 5·8 years (4·6–7·1) in 2000–11 in men, and from 8·7 years (8·4–8·9) to 6·8 years (6·7–7·0) in women over the same period. Because of the increasing diabetes prevalence, the average number of years lost due to diabetes for the population as a whole increased by 46% in men and 44% in women. Years spent with diabetes increased by 156% in men and 70% in women.

**Interpretation** Continued increases in the incidence of diagnosed diabetes combined with declining mortality have led to an acceleration of lifetime risk and more years spent with diabetes, but fewer years lost to the disease for the average individual with diabetes. These findings mean that there will be a continued need for health services and extensive costs to manage the disease, and emphasise the need for effective interventions to reduce incidence.

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## Introduction

Lifetime risk of diagnosed diabetes for an American born in 2000 is estimated to be 33% for men and 39% for women, whereas the average 50 year old diagnosed with diabetes will lose an estimated 8·8 years of their lifespan.[1] Those estimates were the first to be reported for lifetime risk of diabetes, and a subsequent study from Australia reported slightly higher estimates.[2] The high lifetime risk of diabetes in the USA reflected the high incidence the disease had attained by the year 2000.[3] However, since that time, incidence of diagnosed diabetes in the USA has continued to increase in almost all age, sex, and race and ethnic strata, whereas mortality has declined in the population with and without diabetes.[4,5] Overall increases in new cases of diabetes have been driven mostly by cases diagnosed in middle age and older age, which are likely to be type 2 rather than type 1 disease.[3] Similar incidence trends have been reported in Canada, the UK, and Finland, and global prevalence estimates suggest incidence is increasing in most countries worldwide.[6-9] The simultaneous changes in incidence and mortality warrant re-examination of lifetime risk of diabetes and life-years lost due to diabetes. The new availability of long-term mortality data from the National Health Interview Survey (NHIS) now allows the first comprehensive assembly of data for diabetes incidence and mortality risk from a nationally representative study in the USA.[10,11]

Estimates of lifetime risk provide a unique and important perspective, and their use is increasingly being encouraged for clinical decision making and to prioritise public health interventions.[12] In this study, we used nationally representative diabetes surveillance data to provide updated estimates for the lifetime probability of development of diabetes, and to assess changes in incidence and mortality on lifetime risk and life-years lost due to diabetes in the USA.[11]

## Methods

### Study design and data sources

We obtained data for diabetes incidence for 1985–2011 from the NHIS, a continuous, yearly cross-sectional, nationally representative health survey of the US non-institutionalised population undertaken by the National Center for Health Statistics of the Centers for Disease

Control and Prevention.[13] The NHIS uses a multistage probability strategy to sample roughly 75 000 new adults every year. We measured mortality by linking yearly NHIS data to the National Death Index, from the date of NHIS interview to Dec 31, 2011, in accordance with previously described methods.[5,11] Our primary analysis compared incidence, mortality, and lifetime risk during three time periods (1985–89, 1990–99, and 2000–11) to represent the latest three decades. We chose 1985 as the starting point because it is the earliest year for which NHIS data has been linked to mortality files.

The NHIS assessed diabetes by asking participants whether and when they had been diagnosed with any diabetes (other than during pregnancy for women). During 1985–96, diabetes cases were identified from the one-sixth of NHIS participants who were randomly assigned to be interviewed about metabolic diseases, whereas for 1997–2011 all adults were interviewed. Incidence was calculated as the number of cases in the previous year divided by the total number of people, excluding adults who had been diagnosed with diabetes for longer than 1 year.[14]

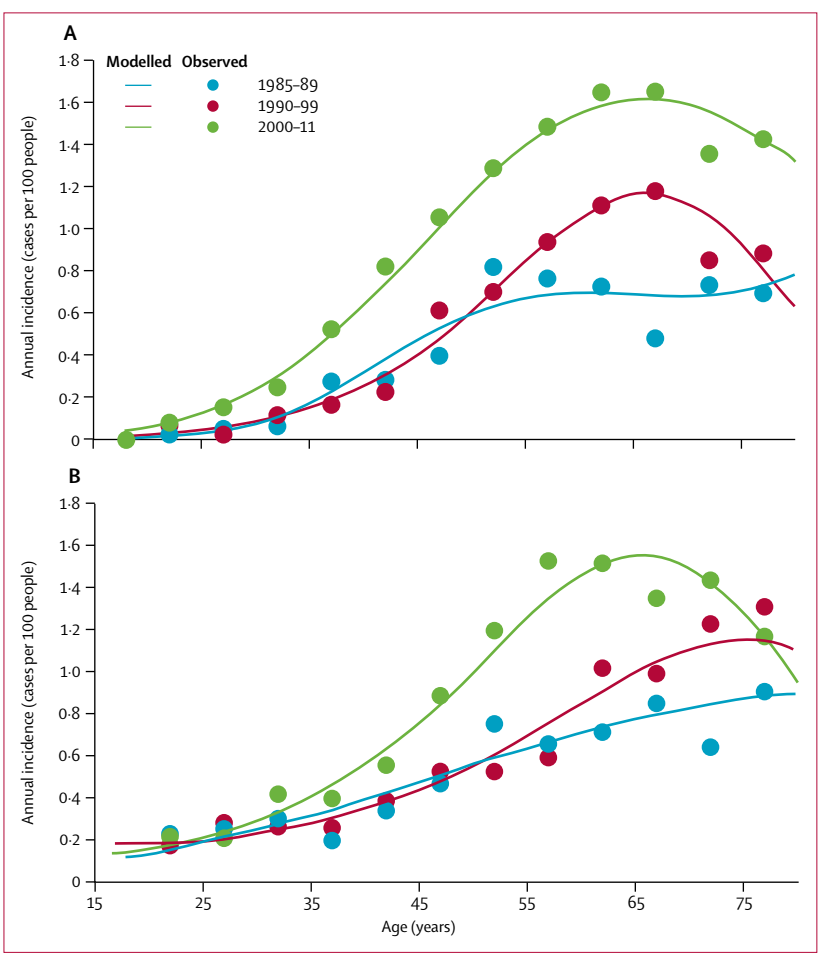


*Figure 1*: **Incidence of diagnosed diabetes in the USA in men (A) and women (B), by age and decade: the National Health Interview Survey, 1985–2011**

To enable extension of our estimates from birth to death, we augmented incidence and mortality estimates with published data from 2001–02 for children and young people (age 0–17 years) from the SEARCH study.[15] The SEARCH study is a multicentre registry from an overall population of more than 30 million children and young people. We applied the reported incidence and mortality in 2001–02 to all three time periods studied, with the assumption that the incidence and mortality in young people have remained generally stable over the past three decades.

## Estimation and modelling

We used logistic regression to estimate the incidence of diabetes, and Poisson regression to estimate mortality, each as a function of age, sex, race or ethnic origin (non-Hispanic white, non-Hispanic black, Hispanic), and period (1985–89, 1990–99, 2000–11). The final predictive model of age-specific incidence included a cubic term for age at interview, with interaction terms for period and sex. The predictive model of age-specific mortality included a quadratic term for age with interaction terms for period, sex, and status of prevalent diabetes, and used age as the time scale for survival analysis. We used Stata (version 13.1) to account for the complex multistage sampling design and to produce weighted average marginal estimates, standard errors, and 95% CIs.

On the basis of parameter estimates from the analyses described above, annual probabilities were entered into a discrete-time Markov chain model[16] with an interval length of 1 year during which individuals moved from one of three states (remaining non-diabetic, diabetic, dead) each year, to predict the remaining lifetime risk of diabetes by baseline age; the mean length of time (in years) that a person is expected to live with and without diabetes; and the number of life-years lost due to diabetes, calculated as the difference between life expectancies by diabetes status at the age of diagnosis. For example, the number of life-years lost for a person diagnosed at age 20 years is the difference in life expectancy of a person who died without developing diabetes and a person who was diagnosed with diabetes at age 20 years. We assumed that 5% of newly diagnosed cases revert to being non-diabetic in the first year, consistent with findings from the stratum of recently diagnosed adults in the usual-care group of adults with type 2 diabetes included in the Look AHEAD study.[17] We calculated years lost and spent with diabetes from two perspectives: first, conditional on a person being diagnosed with diabetes; and second, for the population as a whole, averaging across people with and without diabetes. The second perspective enables increasing prevalence in the population to affect the estimates of years spent with and lost due to diabetes. To estimate the relative effect of the changes of diabetes incidence versus mortality on lifetime risk, we did a counterfactual analysis in which we calculated lifetime risks and years lost and spent with diabetes for the

2000–11 cohorts, with the assumption that the diabetes incidence, and separately the mortality rates, remained at the 1985–89 levels.

As sensitivity analyses, we assessed the potential effect of the incidence of undiagnosed diabetes by adjusting the incidence by a multiplier (ranging from 1·25 to 1·35[18]), and to examine the potential effect of increasing detection we adjusted the multiplier for undiagnosed diabetes incidence over time, declining from 1·35 to 1·25. We did further sensitivity analyses in which we altered diabetes incidence and mortality before age 20 years, and diabetes incidence after age 85 years.

To generate confidence intervals for our primary estimates of lifetime risk, we used the transition rates and their variances estimated from the regression models to simulate the transitions of 100 000 individuals of specified race, sex, and baseline age with the Monte Carlo method. In the simulation, we considered both individual-level random (first-order) variations and the uncertainties of transition probabilities (second order).

### Role of the funding source

The main role of the sponsor was to provide funding, administrative oversight, and supervision to the national surveys used in these analyses. EWG—a representative of one of the co-sponsors—conceptualised and led the study design, data collection, data analyses, data interpretation, and writing of this report. EWG, YJC, and XZ had full access to all the data in the study, and EWG had final responsibility for the decision to submit for publication.

## Results

Our estimates are based on data for 598 216 adults (22 156 per year) sampled between 1985 and 2011. Between 1985–89 and 2000–11, incidence of diagnosed diabetes increased across the three decades in both men and women, with the greatest absolute increases noted in middle-aged and older adults between 1990–99 and 2000–11 (figure 1). For example, in 60–64 year olds, incidence increased from 0·73% (95% CI 0·28–1·18) to 1·65% (1·31–1·99) in men, and from 0·71% (0·32–1·10) to 1·51 (1·24–1·79) in women (figure 1). During the same period, mortality decreased in adults with and without diabetes (figure 2). For example, in 60–64 year olds, mortality decreased from 4·4% (95% CI 3·5–5·2) to 2·5% (2·3–2·6) in men with diabetes, and from 2·4% (1·8–3·0) to 1·8% (1·7–1·9) in women with diabetes (figure 2). In the population without diabetes, mortality decreased by a similar relative magnitude, but by a smaller absolute magnitude than recorded in adults with diabetes (figure 2).

In 2000–11, lifetime risk of diabetes from age 20 years was 40·2% (95% CI, 39·3–41·3%) in men and 39·3% (38·4–40·2%) in women (table 1). Lifetime risk from age 20 was highest for black women (55·2% [54·6–56·0]) and also exceeded 50% for Hispanic men and women (table 1). Remaining lifetime risk was only slightly lower at age 40 years than at age 20 years, and although the risk decreased with older age, it remained substantial at 60 years old, ranging from 21·1% to 37·4% across sex and ethnic groups (table 1).

From 1985–89 to 2000–11, lifetime risk increased more in men (by 20 percentage points) than it did in women (13 percentage points), with most of the increase in lifetime risk taking place in the past 2 decades (table 1). The increase in lifetime risk eliminated sex-related differences in lifetime risk for all race and ethnic groups except non-Hispanic black people, among whom women still have a notably higher risk than men at all ages

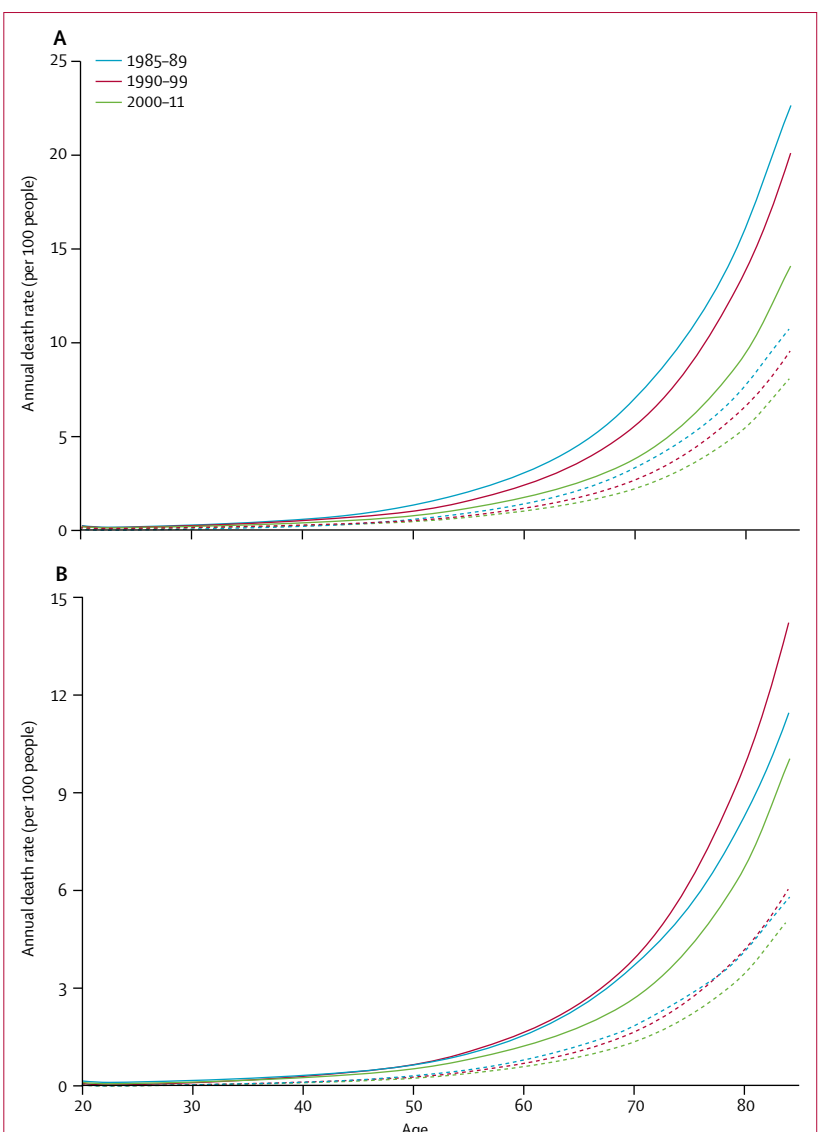


***Figure 2:*** **All-cause mortality in the USA in men (A) and women (B) with and without diagnosed diabetes, by age, decade, and sex: the National Health Interview Mortality Follow-up Survey, 1985–2011**
Solid lines represent population with diagnosed diabetes; dashed lines represent population without diagnosed diabetes.

| | Men | | | | Women | | | |
|---|---|---|---|---|---|---|---|---|
| | 1985–89 | 1990–99 | 2000–11 | p value* | 1985–89 | 1990–99 | 2000–11 | p value* |
| **Overall** | | | | | | | | |
| Birth | 20·7% (18·5–23·2) | 24·0% (22·6–25·4) | 40·2% (39·2–41·3) | <0·0001 | 27·1% (25·1–29·1) | 30·1% (28·7–31·3) | 39·6% (38·6–40·5) | <0·0001 |
| 20 years | 20·4% (18·3–23·1) | 23·8% (22·4–25·3) | 40·2% (39·3–41·3) | <0·0001 | 26·7% (24·7–28·7) | 29·6% (28·3–30·9) | 39·3% (38·4–40·2) | <0·0001 |
| 40 years | 19·4% (17·2–22·1) | 23·0% (21·5–24·6) | 37·9% (36·9–39·1) | <0·0001 | 23·4% (21·4–25·5) | 26·6% (25·2–28·0) | 36·0% (35·1–37·0) | <0·0001 |
| 60 years | 12·8% (10·5–15·3) | 16·1% (14·7–17·6) | 26·0% (24·8–27·1) | <0·0001 | 16·7% (14·8–18·9) | 20·1% (18·6–21·4) | 24·4% (23·4–25·6) | <0·0001 |
| **Non-Hispanic white** | | | | | | | | |
| Birth | 19·2% (18·3–20·2) | 21·7% (21·2–22·1) | 37·0% (36·6–37·5) | <0·0001 | 25·1% (24·0–26·3) | 26·5% (26·0–27·2) | 34·0% (33·6–34·3) | <0·0001 |
| 20 years | 19·0% (18·0–20·0) | 21·4% (20·9–21·9) | 36·9% (36·5–37·4) | <0·0001 | 24·7% (23·5–26·0) | 26·1% (25·5–26·7) | 33·7% (33·3–34·0) | <0·0001 |
| 40 years | 18·1% (17·1–19·1) | 20·8% (20·3–21·3) | 34·9% (34·5–35·4) | <0·0001 | 21·7% (20·6–23·1) | 23·6% (23·0–24·2) | 31·0% (30·7–31·4) | <0·0001 |
| 60 years | 12·0% (11·0–13·2) | 14·6% (14·0–15·1) | 24·1% (23·6–24·7) | <0·0001 | 15·6% (14·3–17·1) | 17·9% (17·3–18·6) | 21·1% (20·8–21·5) | <0·0001 |
| **Non-Hispanic black** | | | | | | | | |
| Birth | 27·5% (24·7–30·5) | 30·9% (28·8–33·0) | 44·7% (42·4–47·2) | <0·0001 | 41·4% (39·7–43·1) | 41·4% (40·4–42·4) | 55·3% (54·6–56·0) | <0·0001 |
| 20 years | 27·4% (24·7–30·4) | 30·8% (28·8–33·0) | 44·8% (42·5–47·5) | <0·0001 | 41·1% (39·4–42·9) | 41·1% (40·1–42·0) | 55·2% (54·6–56·0) | <0·0001 |
| 40 years | 26·1% (23·2–29·2) | 30·1% (28·1–32·3) | 42·6% (40·3–45·4) | <0·0001 | 36·6% (34·9–38·5) | 37·5% (36·4–38·5) | 51·8% (51·0–52·6) | <0·0001 |
| 60 years | 16·8% (13·9–20·4) | 21·7% (19·6–23·8) | 29·8% (26·9–32·9) | <0·0001 | 26·7% (25·0–29·0) | 29·1% (27·9–30·2) | 37·4% (36·5–38·2) | <0·0001 |
| **Hispanic** | | | | | | | | |
| Birth | 26·1% (24·1–28·2) | 34·2% (33·1–35·4) | 51·8% (51·0–52·4) | <0·0001 | 35·1% (32·6–37·4) | 44·4% (43·3–45·6) | 51·5% (50·8–52·1) | <0·0001 |
| 20 years | 26·0% (23·9–28·2) | 34·2% (33·1–35·5) | 52·0% (51·3–52·7) | <0·0001 | 34·7% (32·3–37·1) | 44·1% (43·0–45·3) | 51·3% (50·7–52·0) | <0·0001 |
| 40 years | 24·8% (22·5–27·1) | 33·4% (32·2–34·6) | 49·6% (48·9–50·4) | <0·0001 | 31·0% (28·4–33·7) | 40·4% (39·2–41·7) | 47·9% (47·3–48·6) | <0·0001 |
| 60 years | 16·6% (14·3–19·1) | 24·1% (22·9–25·5) | 35·9% (34·9–36·8) | <0·0001 | 23·0% (20·0–25·9) | 31·7% (30·4–33·1) | 34·3% (33·5–35·0) | 0·001 |

Data in parentheses are 95% CIs. *For comparison of lifetime risk between 1985–89 and 2000–11.

***Table 1:*** **Lifetime risk of diagnosed diabetes, from baseline age, by time period in US adults, 1985–2011**

| | Men | | | | Women | | | |
|---|---|---|---|---|---|---|---|---|
| | 1985–89 | 1990–99 | 2000–11 | p value* | 1985–89 | 1990–99 | 2000–11 | p value* |
| **Mean life-years lost** | | | | | | | | |
| Birth | 10·1 (8·2–11·8) | 10·5 (9·3–11·8) | 8·5 (7·2–9·7) | <0·0001 | 9·6 (8·8–10·5) | 11·1 (10·8–11·3) | 9·4 (9·2–9·6) | <0·0001 |
| 20 years | 8·3 (6·4–9·9) | 8·6 (7·4–9·8) | 6·4 (5·2–7·7) | <0·0001 | 7·7 (6·9–8·6) | 9·2 (9·0–9·5) | 7·4 (7·2–7·5) | <0·0001 |
| 40 years | 7·6 (5·6–9·2) | 7·7 (6·5–9·0) | 5·8 (4·6–7·1) | 0·010 | 7·4 (6·6–8·2) | 8·7 (8·4–8·9) | 6·8 (6·7–7·0) | <0·0001 |
| 60 years | 5·9 (3·9–7·4) | 5·9 (4·7–7·1) | 4·6 (3·4–5·8) | 0·030 | 6·2 (5·4–7·1) | 7·2 (6·9–7·4) | 5·7 (5·5–5·8) | <0·0001 |
| **Mean years with diabetes** | | | | | | | | |
| Birth | 64·4 (63·4–66·1) | 65·2 (64·3–66·2) | 69·4 (68·5–70·4) | <0·0001 | 72·3 (71·6–72·9) | 70·7 (70·5–72·8) | 73·6 (73·5–73·8) | <0·0001 |
| 20 years | 46·7 (45·7–48·4) | 47·6 (46·7–48·6) | 52·0 (51·1–53·0) | <0·0001 | 54·5 (53·8–55·1) | 52·9 (52·7–53·0) | 56·0 (55·9–56·1) | <0·0001 |
| 40 years | 28·4 (27·4–29·9) | 29·9 (29·1–30·9) | 33·8 (32·8–34·7) | <0·0001 | 35·3 (34·6–36·0) | 34·0 (33·8–34·2) | 37·4 (37·3–37·5) | <0·0001 |
| 60 years | 13·4 (12·4–15·0) | 14·8 (14·0–15·7) | 17·7 (16·8–18·6) | <0·0001 | 18·6 (17·9–19·2) | 17·5 (17·3–17·7) | 20·5 (20·4–20·6) | <0·0001 |

Data in parentheses are 95% CIs. *For comparison of lifetime risk between 1985–89 and 2000–11.

***Table 2:*** **Mean number of years of life lost due to diabetes and years spent with diabetes according to age at diagnosis, by time period in US adults, 1985–2011**

(table 1). The largest increase in lifetime risk was in Hispanic men aged 20 years (table 1).

Sensitivity analyses in which we altered incidence and mortality before age 20 years had negligible effects on estimates of lifetime risk (appendix). However, incorporation of hypothetical estimates of incidence of undiagnosed diabetes cases increased estimates of lifetime risk by 7–9 percentage points for the overall population (appendix). Changing the rate of undiagnosed diabetes had little effect on the overall increase in lifetime risk (appendix).

See Online for appendix

The number of life-years lost for an average man diagnosed at age 40 years decreased by 1·8 years between 1985–89 and 2000–11 (table 2). Among women, the main decreases in life-years lost to diabetes were between 1990–99 and 2000–11 (table 2). Fewer years were lost to diabetes in individuals diagnosed at later ages, but the amount of change over time was similar to those diagnosed earlier in life. Decreases in life-years lost due to diabetes were accompanied by increases in the number of years spent with the disease, particularly in men. The average man diagnosed at age 40 years spends 33·8 years

| | Men | | | | Women | | | |
|---|---|---|---|---|---|---|---|---|
| | 1985–89 | 1990–99 | 2000–11 | Percentage change | 1985–89 | 1990–99 | 2000–11 | Percentage change |
| **Years lost due to diabetes (per 1000 adults*)** | | | | | | | | |
| Overall | 2034 | 2022 | 2968 | 46·0% | 2243 | 2927 | 3230 | 44·0% |
| Non-Hispanic white | 1877 | 1794 | 2649 | 41·1% | 2045 | 2512 | 2650 | 29·6% |
| Non-Hispanic black | 2882 | 2792 | 3553 | 23·3% | 3924 | 4456 | 5365 | 36·7% |
| Hispanic | 2699 | 3115 | 4201 | 55·6% | 2913 | 4782 | 4504 | 54·6% |
| **Years spent with diabetes (per 1000 adults*)** | | | | | | | | |
| Overall | 4760 | 5463 | 12 199 | 156·3% | 7728 | 7933 | 13 097 | 69·5% |
| Non-Hispanic white | 4374 | 4844 | 10 818 | 147·3% | 7021 | 6707 | 10 622 | 51·3% |
| Non-Hispanic black | 6430 | 7040 | 13 446 | 109·1% | 12 781 | 11 500 | 19 860 | 55·4% |
| Hispanic | 6112 | 8242 | 17 553 | 187·2% | 10 752 | 12 928 | 19 242 | 79·0% |

*Denominator includes people with and without diabetes.

***Table 3*: Cumulative years lost due to diabetes and years spent with diabetes, by race or ethnic origin, and time period, in the overall population of US adults, 1985–2011**

(95% CI 32·8–34·7) with the disease (*vs* 28·4 years [27·4–29·9] in 1985–89), whereas the average woman diagnosed at age 40 spends 37·4 years (37·3–37·5) with the disease (*vs* 35·3 years [34·6–36·0] in 1985–89). Differences in life-years lost due to diabetes by race or ethnic origin are shown in the appendix.

When expressed per 1000 adults in the overall population (ie, including adults with and without diabetes, thus allowing changing prevalence to affect the estimates), the cumulative number of life-years lost to diabetes increased by 46·0% in men and 44·0% in women (table 3). The cumulative number of years spent with diabetes (per 1000 adults in the population) increased by 156·3% in men and by 69·5% in women (table 3).

In analyses that retained mortality at 1985–89 levels while allowing diabetes incidence levels to increase, lifetime diabetes risk increased by 17·2 percentage points for men and 11·8 percentage points for women, equivalent to 88% and 95%, respectively, of the change recorded in the primary analyses (table 4). Conversely, when diabetes incidence was retained at 1985–89 levels, lifetime risk increased by 2·4 percentage points in men and 0·5 percentage points in women, equivalent to 12% and 4%, respectively, of the magnitude of change recorded in the main analyses (table 4). However, mortality played a larger part with increasing age, accounting for 19% of the increase in lifetime risk in men aged 60 years (table 4).

| | Estimated change in lifetime risk (1985–89 to 2000–11) | Scenario: no change in mortality rate | | Scenario: no change in diabetes incidence | |
|---|---|---|---|---|---|
| | Percentage-point increase | Percentage-point Increase | Overall change | Percentage-point Increase | Overall change |
| **Men** | | | | | |
| Birth | 19·6 | 17·2 | 88·0% | 2·4 | 12·3% |
| 20 years | 19·8 | 17·4 | 87·9% | 2·5 | 12·4% |
| 40 years | 18·5 | 15·9 | 86·4% | 2·7 | 14·5% |
| 60 years | 13·2 | 10·7 | 81·2% | 2·6 | 19·4% |
| **Women** | | | | | |
| Birth | 12·5 | 11·8 | 94·6% | 0·5 | 4·1% |
| 20 years | 12·6 | 11·9 | 94·5% | 0·5 | 4·4% |
| 40 years | 12·6 | 11·7 | 92·8% | 0·8 | 6·6% |
| 60 years | 7·7 | 6·8 | 88·1% | 0·9 | 11·1% |

***Table 4*: Counterfactual analysis of the magnitude of lifetime risk of diabetes on the basis of counterfactual scenarios retaining mortality or incidence levels**

## Discussion

Our findings show that, for the average American born between 2000 and 2011, the probability of developing diagnosed diabetes during life is 40%, substantially higher than previous estimates that were based on incidence and mortality from the 1990s. The increased lifetime risk was driven mainly by the increase in incidence of diagnosed diabetes, and to a lesser extent, the decline in mortality of the general population. During the same time, a large reduction in mortality rates in the US population with diabetes has increased the mean number of years spent with the disease and decreased the mean number of years lost to the disease. These findings predict a continuation of the position of diabetes as one of the central chronic disease threats to the US population, and of its contribution to wide-ranging morbidity and high use of health-care resources.

Two other important shifts in the nature of the diabetes epidemic are evident. First, the lifetime risk of diabetes in men drew even with women, emphasising the prominent decline in mortality and the continued increasing diabetes incidence, in addition to the already higher diabetes incidence in men compared with women. Second, the synergistic effect of increasing diabetes incidence and declining mortality on lifetime risk are particularly profound for ethnic minorities; the lifetime risk exceeds 50% for non-Hispanic black women

and Hispanic individuals of both sexes, and is 45% for black men.

The combination of increasing lifetime risk with decreasing life-years lost shows the simultaneous successes in care and secondary prevention in the face of an inability to reduce diabetes incidence in the past two decades, despite impressive evidence from various clinical trials for the primary prevention of diabetes.[19,20] Our findings about diabetes incidence and mortality in the USA confirm those from both the NHIS and National Health and Nutrition Examination Survey (NHANES) follow-up studies.[5,15,21] Increasing incidence has been attributed ecologically to an increasing prevalence of central obesity, total dietary intake, and a shift in the ratio of refined versus unrefined carbohydrates and simple sugars, increased portion sizes, and decreases in energy expenditure.[15,22] Decreasing mortality in the general population and in the population with diabetes is mainly due to reductions in cardiovascular disease mortality, which have been attributed to a diverse combination of medical treatment, preventive care, and risk-factor modification.[19,23]

The increased incidence of diabetes and lifetime risk could also be affected by increased case detection and changing diagnostic definitions, but few data are available with which to directly quantify such an effect. The effect of a shift in the diagnostic definition in 1997—which de-emphasised the oral glucose tolerance test, encouraged measurement of fasting plasma glucose, and lowered the fasting plasma glucose-based threshold for diagnosis—remains unclear. Removal of the oral glucose tolerance test from epidemiological definitions led to a decrease in prevalence, but in practice, this decrease was probably offset by increased use of fasting plasma glucose and by increased awareness of diabetes in general.[24] Surveillance data suggest that incidence of diagnosed diabetes increased continuously during the 1990s both before and after the changes in diagnostic guidelines. However, although the proportion of cases that are undiagnosed in older adults and some demographic subgroups has decreased slightly since the late 1990s, the prevalence of undiagnosed diabetes and the age at diagnosis remain unchanged.[25,26] Findings from our sensitivity analyses confirm that lifetime risk is substantially higher when undiagnosed cases are factored in. When the analysis was adjusted to simulate an increase in detection, lifetime risk still increased greatly over time, suggesting that increasing detection is not a dominant factor in the increased lifetime risk.

National estimates of lifetime risk are sparse because their calculation requires incidence and mortality data from populations with and without diabetes across a broad age span. Our lifetime risk estimates from the 1980s to 1990s are slightly lower than those previously reported by Narayan and colleagues[1] in 2003.Although the modelling approaches used were similar, the mortality estimates were different, because we used newly available and more direct, nationally representative mortality estimates. Our most recent lifetime risk estimates (ie, 2000–11) are slightly higher, and our estimates from previous decades slightly lower, than those reported from 2000 for Australia, but we are not aware of other published national estimates of the change in lifetime risk.[2] The profile of increasing incidence and declining mortality in the UK, Canada, and Finland suggest that similar dynamics in lifetime risk are also taking place in these countries.[6-8] A few countries, including Denmark and Sweden, have each reported similar declines in mortality, but stable incidence, and thus might have smaller increases in lifetime risk than reported for the other countries.[27,28] However, no estimates of trends in incidence and mortality in the population with diabetes have been reported from low-income or middle-income countries, thus lifetime risk estimates in those countries are unknown.[2,7,28]

Our estimates are subject to several limitations and sources of imprecision. Incidence estimates were based on self-reported diagnosed diabetes and thus do not include incidence of undiagnosed diabetes or account for the potential increase in case detection. In addition to leading to an underestimate of lifetime risk, increased case detection could lead to a healthier denominator over time and could affect mortality rates in the population with diabetes. Such an effect would reduce the number of years lost due to diabetes but would have had little effect on lifetime risk estimates,

***Panel:* Research in context**

**Systematic review**

We searched PubMed for Engligh-language articles published between 1980 and 2014, with the search terms "diabetes", "lifetime risk", and "future risk". At least two nationally representative studies[1,2] of lifetime risk have been done (in the USA and Australia) on the basis of epidemiological estimates of diabetes incidence and mortality from the 1990s and early 2000s. However, the incidence of diagnosed diabetes has increased and mortality has decreased in both the diabetic and non-diabetic population since the time of the earlier lifetime risk estimates. New national data[10,11] for diabetes incidence and mortality have enabled us to assess the changes in lifetime risk of diabetes life-years lost due to diabetes and spent with diabetes for the average individual and the population as a whole.

**Interpretation**

We incorporated updated incidence and mortality data from nationally representative surveys in the USA to examine the changes in lifetime risk and years of life lost to diabetes after the changes to incidence and mortality that have taken place. Our findings show that continued increases in incidence of diagnosed diabetes, and declining mortality, have led to an acceleration of lifetime risk and more years spent with diabetes. Lifetime risk for the average American from birth has reached 40%, representing an increase of 20 percentage points increase in men and of 13 percentage points in women since the 1980s. Mortality reductions in the diabetic population have increased the average number of years spent with the disease and decreased the average number of years lost. However, large increases in diabetes prevalence have increased the cumulative number of years lost to diabetes and increased the number of years spent with diabetes. These findings mean that there will be a continued need for health services, and extensive costs to manage the disease, and points to the need for effective interventions to reduce incidence.

which are more affected by mortality in the general population than in the population with diabetes. Second, our analyses lacked data to differentiate type 1 and type 2 diabetes, for which the magnitude of changes in incidence and mortality might differ. Third, our absence of nationally representative data for people younger than age 20 years required us to assume that there was no change in incidence or mortality over time in that group. Because a very small proportion of the overall incident cases and deaths happen before 20 years old, this assumption has a negligible effect on lifetime risk but is necessary to express lifetime risk from birth. Fourth, our primary tables included 48 inference tests, which could increase the rate of type 1 error if a traditional significance threshold ($p<0·05$) were used. However, the primary changes were significant at the p less than 0·0001 level, showing that our findings are robust. Fifth, several fundamental factors exist, including socioeconomic status, levels of obesity, and physical inactivity, for which lifetime risk can vary substantially. Policy makers might benefit from future analyses to quantify lifetime risk according to common diabetes-related risk factors. Finally, our estimates lack assessment of the degree of morbidity in the population with diabetes and do not establish whether additional life-years gained over time offer a similar quality of life. Although rates of selected diabetes complications have declined during the time period of study,[29] the increase in number of years spent with diabetes could conceivably increase the cumulative incidence of diabetes-related morbidity. Despite these limitations, this analysis is the first to quantify both incidence and mortality by age, sex, and period-related effects to the most recent decade, and the first examination of their implications for lifetime risk. The NHIS is one of the most comprehensive health surveys, with annual response rates of approximately 90%. As such, it provides an appropriate model and benchmark from which other national studies can examine lifetime risk of diabetes and related chronic conditions (panel).

Our findings have important implications at several levels. First, the dominant effect of incidence on lifetime risk is a reminder that primary prevention approaches have not kept pace with incidence trends, warranting wider implementation of lifestyle-change programmes to prevent or delay onset of type 2 diabetes.[30] The best strategies for primary prevention will include a combination of focused programmes for high-risk adults and population-wide approaches to reduce the underlying risk of the population; the relative mix of these approaches is likely to vary with the context in individual countries. Second, reductions in mortality have paradoxically contributed to the increase in cumulative incidence of diabetes because people have a longer lifespan during which to develop the disease, and also survive longer after diagnosis. Although secondary prevention approaches have been successful in reducing rates of complications and mortality,[19,29] the increase in the number of years spent with the disease shows that there will not only be a continued demand for health services, but also extensive costs to manage the large population with diabetes. The combination of ongoing demand and high costs will continue the need for innovation and improved implementation of effective secondary prevention programmes to restrict the effect of diabetes on quality of life, health systems, and families.

**Contributors**

EWG and KMVN conceived and designed the study, and drafted the manuscript. EWG, YJC, and ALA obtained data. EWG, YJC, XZ, and TT analysed and interpreted data. All authors revised the manuscript for important intellectual content. YJC, XZ, and TT did statistical analyses. EWG and ALA provided administrative, technical, and material support.

**Declaration of interests**

We declare no competing interests.

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# The US diabetes epidemic: tip of the iceberg

Joseph Sohm; Visions of America/CORBIS

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Diabetes prevalence has increased at an unprecedented rate worldwide, mostly because of ageing populations, rising obesity rates, unhealthy eating habits, and increasingly sedentary lifestyles.[1] Diabetes, mostly type 2, now affects a staggering 347 million people worldwide.[1] Presently, close to 10% of adults have been diagnosed with the disease, with the highest prevalence in developed nations such as the USA.[1] However, these figures are just the tip of the iceberg.

In *The Lancet Diabetes & Endocrinology*, Edward Gregg and colleagues[2] combined data from nationally representative US population interviews and death certificates for more than half a million adults to estimate trends in lifetime risk of diabetes and life-years lost due to diabetes. Although age-standardised incidence is most often used to estimate the risk of disease for a given population, this method does not account for differences in life expectancy and competing risks of death. Estimates of lifetime risk, which combine both incidence and mortality data, provide a better prediction of long-term future disease burden for a given population than does age-standardised incidence.

Gregg and colleagues' findings showed that across only 26 years, the lifetime risk of diabetes for an average 20-year-old American person rose from 20·4% (95% CI 18·3–23·1) for men and 26·7% (24·7–28·7) for women in 1985–89, to 40·2% (39·3–41·3) for men and 39·3% (38·4–40·2) for women in 2000–11. In other words, two of every five Americans now entering adulthood can expect to develop diabetes during their lifetime. The outlook is even worse for ethnic minority groups, with a 45% lifetime risk of diabetes for non-Hispanic black men, and greater than 50% risk for non-Hispanic black women and Hispanic men and women. Moreover, because these results are based on self-reported diagnosed cases, they probably underestimate the true future burden of diabetes.

Increases in lifetime risk of diabetes are due to both rising incidence and longer overall life expectancy in the general population. There has been a greater absolute decline in mortality in the population with diabetes than in the non-diabetic population, resulting in an almost 2-year improvement in life-years lost for someone diagnosed at age 40 years. Whereas this finding is good news for individual patients, the overwhelming increase in prevalence of diabetes means a worrisome almost 50% increase in the cumulative number of life-years lost due to diabetes on a population level. For every 1000 US adults, about 3000 cumulative years of life are now lost to diabetes, whereas 12 000–13 000 years are spent living with diabetes.

Improvements in diabetes prognosis might be a sign of real progress, signalling advances in diabetes care and reductions in complications in the past two decades.[3] However, as acknowledged by the investigators, an important caveat should be considered. Changing diagnostic criteria and higher screening rates could have led to more diabetes cases being diagnosed at an earlier stage. This effect, termed stage migration, might spuriously lower death rates in later years because healthier patients have lower mortality.[4] Being able to account for differences in stage of disease over time would provide a more accurate estimate of the changing prognosis of diabetes.

The trends reported by Gregg and colleagues are probably similar across the developed world, where large increases in diabetes prevalence in the past two decades have been reported.[1,5,6] As the number of diabetes cases continues to increase and patients continue to live longer, health-care systems will increasingly be challenged to meet their needs. Therefore, new and less resource-intense models of care for diabetes are required to address this growing demand. However, implementation of these models might not be enough. With close to half of the adult population estimated to develop diabetes during their lifetime, gains made in diabetes outcomes will soon be overtaken by the sheer number of people needing care.

Primary prevention strategies are urgently needed. Excellent evidence has shown that diabetes can be prevented with lifestyle changes.[7,8] However, provision of these interventions on an individual basis might not be sustainable. Only a population-based approach to prevention can address a problem of this magnitude. Prevention strategies should include optimisation of urban planning, food-marketing policies, and work and school environments that enable individuals to make healthier lifestyle choices.[9,10] With an increased focus on interventions aimed at children and their families, there might still be time to change the fate of our future generations by lowering their risk of type 2 diabetes.

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