



Contents available at [ScienceDirect](https://www.sciencedirect.com)

Diabetes Research
and Clinical Practice

journal homepage: www.elsevier.com/locate/diabres



International
Diabetes
Federation



Diabetes-attributable mortality in the United States from 2003 to 2016 using a multiple-cause-of-death approach



Fatima Rodriguez^{a,*}, Manuel R. Blum^{a,b,1}, Titilola Falasinnu^c, Katherine G. Hastings^d, Jiaqi Hu^d, Mark R. Cullen^d, Latha P. Palaniappan^d

^a Division of Cardiovascular Medicine, Stanford University School of Medicine, Stanford, CA, United States

^b Department of General Internal Medicine, Inselspital, Bern University Hospital, University of Bern, Switzerland

^c Department of Health Research and Policy, Stanford School of Medicine, Stanford, CA, United States

^d Division of Primary Care and Population Health, Stanford University School of Medicine, Stanford, CA, United States

ARTICLE INFO

Article history:

Received 1 November 2018

Received in revised form

18 December 2018

Accepted 9 January 2019

Available online 11 January 2019

Keywords:

Diabetes

Death records

Epidemiology

Disparities

ABSTRACT

Aims: Deaths attributable to diabetes may be underestimated using an underlying cause of death (COD) approach in U.S. death records. This study sought to characterize the burden of diabetes deaths using a multiple-cause of death approach (underlying and contributing COD) and to identify temporal changes in co-reported causes of death among those with diabetes listed anywhere on their death records.

Methods: COD were identified using data from the National Center for Health Statistics from 2003 to 2016. We calculated age-adjusted mortality rates for diabetes as the underlying or contributing COD by race/ethnicity. We used ICD-10 codes to identify leading causes of death among those with and without diabetes on their death records. We compared temporal changes in deaths due to cardiovascular disease, cerebrovascular disease, cancer, and other causes.

Results: The study population included 34,313,964 decedents aged ≥ 25 from 2003 to 2016. Diabetes was listed as an underlying COD in approximately 3.0% ($n = 1,031,000$) and 6.7% ($n = 2,295,510$) of the death records, respectively. Decedents with diabetes listed as an underlying COD experienced a 16% decline in mortality, and the race/ethnicity-specific average annual percentage changes (AAPC) showed significant declining trends for most groups (AAPC ranged from 0.18 to -2.83%). Cardiovascular disease remained the leading underlying COD among diabetes-attributable deaths, although its proportion of deaths fell from 31 to 27% over time. Co-reported COD diversified, and were more likely to include hypertension and hypertensive renal disease among those with diabetes on their death records.

Conclusions: Our findings underscore the importance of using a multiple-cause-of-death approach for more completely characterizing diabetes' contribution to mortality.

© 2019 Published by Elsevier B.V.

* Corresponding author at: Division of Cardiovascular Medicine, Stanford University, 870 Quarry Road, Falk CVRC, Stanford, CA 94305-5406, United States.

E-mail address: frodrigu@stanford.edu (F. Rodriguez).

¹ These authors contributed equally.

<https://doi.org/10.1016/j.diabres.2019.01.015>

0168-8227/© 2019 Published by Elsevier B.V.

1. Research in context

1.1. Evidence before this study

Previous studies reported that diabetes is underestimated as a cause of death on mortality records. U.S. mortality records indicate both the “underlying cause of death,” defined as the disease or injury that initiated the train of events leading directly to death and up to 20 “contributing causes of death.” Although the prevalence of diabetes in the adult US population continues to increase, outcomes in this population are improving, including cardiovascular mortality.

1.2. Added value of this study

Using over a decade of contemporary national U.S. mortality data, we characterized the burden of diabetes using a multiple-cause-of-death analysis and showed that mortality rates are declining for those with diabetes listed as a cause of death on their death records. We also uncovered differences in diabetes reporting by race/ethnicity, and showed that declining mortality trends apply to most, but not all race/ethnic groups. We showed that contributing causes of death diversified as cardiovascular mortality declined in diabetes-attributable deaths.

1.3. Implications of all the available evidence

Examining diabetes as an underlying cause of death results in significant underrepresentation of diabetes-attributable mortality. A multiple-cause of death analysis that includes both underlying and contributing causes of death better depicts the true contribution of diabetes to U.S. mortality. With the diversification of contributing causes of death in diabetes-attributable deaths, a focus on broader disease prevention strategies among individuals with diabetes – beyond cardiovascular disease – is warranted.

2. Background

Affecting almost 10% of the U.S. population, diabetes mellitus (DM) is a common chronic condition associated with significant premature morbidity and mortality [1–3]. DM has consistently been listed as one of the top causes of death among Americans, and is projected to become the seventh leading cause of death worldwide by 2030 [4]. Despite this burden, studies have shown that DM has been underestimated as a cause of death on death certificates for decades [5,6]. The Centers for Disease Control and Prevention indicated that only 35–40% of decedents with clinically diagnosed DM actually had DM listed on their death certificate, and that only 10–15% of these decedents had DM listed as the underlying cause of death [7].

U.S. mortality records report both the “underlying cause of death,” defined as the disease or injury that initiated the train of events leading directly to death and up to 20 “contributing causes of death.” [8] Because DM is less likely to be a primary

cause of death and more frequently contributes as a risk factor for cardiovascular and other leading causes of death, considering the burden of DM using multiple-cause-of-death analyses has been recommended by prior literature [9,10]. Using this type of approach may present a more complete picture of DM as a cause of death. In fact, other studies using a multiple-cause-of-death approach in various domestic and international settings have documented that DM is more than twice as likely to be listed as contributing than underlying cause of death [9–18]. Furthermore, there are temporal differences in DM reporting as an underlying versus contributing cause of death [19]. Our study extends prior work by considering a decade of contemporary death record data and examining these reporting patterns by race/ethnicity.

Although the prevalence of DM continues to increase, paralleling the obesity epidemic, outcomes among individuals with DM have been improving [20]. Even among individuals with DM, declining rates of cardiovascular disease deaths highlight the need to focus on broader disease prevention strategies [21]. Individuals with DM are now increasingly dying from other common causes of death such as cancer, renal disease, infections, and unintentional harm.

Thus, using national mortality records from 2003 to 2016, our study had two primary objectives: (1) to quantify recent mortality trends attributable to DM on the death records using underlying and contributing cause of death approaches; (2) to identify potential changes over time in co-reported causes of death among those with DM listed anywhere on their death records.

3. Methods

3.1. Study population

We examined U.S. mortality records from the National Center for Health Statistics (NCHS) Multiple Cause of Death mortality files from 2003 to 2016 for decedents in the 50 states and the District of Columbia. Year of death, sex, age at the time of death, sex, race/ethnicity, and educational attainment (less than high school, high school education, or more than high school education) were identified from NCHS. Race/ethnicity was recorded on death certificates by the funeral director using state guidelines and coded to the five NCHS categories of interest (i.e., Asian American/Pacific Islanders (herein Asian), non-Hispanic Black, Hispanic/Latinos (herein Hispanic), non-Hispanic White (NHW), and American Indian/Alaskan Native. Underlying cause of death was defined as the disease or injury that initiated the events resulting in death using the International Classification of Diseases, 10th revision (ICD-10) coding scheme [8]. Contributing causes of death included any other causes of death mentioned in the death certificates (up to 20), not including the underlying cause of death. A death record with an ICD-10 code E10-14 was considered to represent a DM-attributable death (multiple-cause-of-death approach), either as underlying cause of death or as contributing cause of death. Death records without one of the aforementioned ICD-10 codes were

considered to represent non-DM-attributable deaths. Only US residents who were 25 years or older at the time of death were included in the analysis due to small sample sizes in the younger age categories and to potentially exclude any cases of infant mortality.

3.2. Cause of death definitions

Underlying causes of death were classified into four general categories based on ICD-10 guidelines: cardiovascular (ICD-10 codes I00-09, I11, I13-59, I70-99), cerebrovascular (ICD codes I60-69), cancer (ICD codes C00-97), and other causes. The other causes of death of special interest among those with DM listed anywhere on the death certificate were defined according to the following categories: 1) Infectious disease (ICD codes J00-22, A00-99, B00-99), 2) Chronic respiratory disease (ICD codes J40-47), 3) Chronic liver disease (ICD codes K70, K73-74), 4) Hypertension or Hypertensive chronic kidney disease (ICD codes I10, I12), 5) Alzheimer disease (ICD code G30), 6) Accidents (ICD codes V01-99, W00-99, X01-59, Y85-86), 7) Self-harm (ICD codes X60-84, X87.0, U03), 8) Acute or chronic kidney disease (N17-19).

3.3. Statistical analysis

Age-adjusted mortality rates (AMRs) were calculated for DM as an underlying and contributing cause of death. For temporal trends, these were standardized to the 2000 U.S. Census population by age (5-year age categories). The population estimates by age category, sex and race/ethnicity were retrieved from the CDC WONDER database for the years 2003 to 2016 [22]. Demographic characteristics and frequencies/percentages of the number of causes of deaths were described for decedents with DM as the underlying cause of death, diabetes as either underlying or contributing cause of death and non-DM deaths. Between-group comparisons were made using two-sided t-tests for continuous variables and chi-squared tests for categorical variables. To quantify trends over time, average annual percent changes were calculated for each race/ethnic group separately using Joinpoint regression software with a grid search method and a maximum of two joinpoints, assuming uncorrelated errors (sensitivity analyses with fitting autocorrelated errors models with correlations of 0.1–0.3 were performed to assess the robustness of this assumption [results not shown]) [23].

Data management and analyses were performed in Stata (StataCorp. 2017. Stata Statistical Software: Release 15. College Station, TX: StataCorp LLC), R (version 3.5), and Joinpoint Regression Program (version 4.6.0.0 - April 2018; Statistical Methodology and Applications Branch, Surveillance Research Program, National Cancer Institute). Statistical tests were based on 2-sided tests with a significance level of 0.05.

4. Results

A total of 34,313,964 decedents over the age of 25 during 2003–2016 were included in our analysis. Table 1 shows the characteristics of decedents who had DM listed as an underlying cause of death, contributing cause of death or anywhere on

their death certificate as compared with decedents without mention of DM on their death certificates. DM was listed as an underlying and contributing cause of death in approximately 3.0 (n = 1,031,000) and 6.7% (n = 2,295,510) of the death records, respectively. Those with DM on their death certificate were younger at the time of death, more likely to be non-white, and have lower educational attainment levels ($p < 0.001$ for all comparisons). Those with DM on their death certificates were more likely to have more causes of death listed on their death certificates as compared with those without DM listed on the death certificate (4.4 vs. 2.7, $p < 0.001$).

The overall adjusted mortality rates declined overtime for all groups (Table 1). The adjusted mortality rates for DM as an underlying cause of death declined by 16% since 2003. A similar pattern was seen for DM as a contributing cause of death (adjusted mortality rate declined by 11%) and for DM listed anywhere on the death certificate (adjusted mortality rate declined by 13%). Fig. 1 shows the overall decline in age-adjusted mortality deaths for DM listed as an underlying cause of death. Death records were on average 2.23 (95% confidence interval 2.18–2.28) times more likely to report DM as a contributing cause of death than an underlying cause of death.

DM-attributable deaths decreased among all racial/ethnic groups, although there were differences in DM reporting on the death records by race/ethnicity (Fig. 2). Non-Hispanic Blacks were more likely to have DM as both an underlying and contributing cause of death as compared with all other racial/ethnic groups, whereas NHWs and Asians were least likely to have DM listed anywhere on their death records. Except for the group of Alaskan Natives/American Indians, the race/ethnic specific average annual percent changes showed statistically significant declining trends both for DM as an underlying and contributing cause of death (Table 3).

Cardiovascular disease has remained the leading cause of death among those with DM listed as underlying or contributing cause of death on their death certificates (Fig. 3). However, cardiovascular and cerebrovascular disease as underlying cause of death are decreasing for both the general population and for those with DM listed as a contributing cause of death on their death records. In 2002, cardiovascular diseases accounted for 45% of the underlying causes of death among those with DM listed as contributing cause of death as compared to 39% in 2016. Cancer deaths account for an overall smaller proportion of underlying causes of deaths among those with DM as a contributing cause of death versus those without DM.

Table 2 shows the distribution of the leading underlying causes of death among those with DM listed as an underlying or contributing cause of death versus those without DM mentioned on their death certificates for the years 2003 and 2016. Overall, decedents with DM listed on their death certificate were more likely to have cardiovascular disease listed on their death certificates and less likely to have cancer listed anywhere on their death records. Hypertension and hypertensive renal diseases accounted for a greater proportion of deaths among those with DM on their death certificates. In 2016, 14 and 11% of those with DM as an underlying or contributing cause of death on their death records, respectively, also had hypertension/hypertensive renal disease listed. Compared

Table 1 – Characteristics of the descendants by diabetes reporting status from 2003 to 2016 (n = 34,313,964).

	Diabetes as underlying cause	Diabetes as contributing cause	Diabetes multiple cause of death	Non-diabetes deaths	All deaths
N (2003–2016)	1,031,000	2,295,510	3,326,510	30,987,454	34,313,964
Female (n, %)	503,377 (49)	1,106,799 (48)	1,610,176 (48)	1,5704,807 (51)	17,314,983 (50)
Age (mean, SD)	72.5 (14.1)	74.6 (12.9)	73.9 (13.3)	74.5 (16.0)	74.5 (15.8)
Race/ethnicity (n, %)					
NH White	715,956 (69)	1,705,388 (74)	2,421,344 (73)	25,213,988 (81)	27,635,332 (81)
NH Black	178,723 (17)	324,098 (14)	502,821 (15)	3,389,848 (11)	3,892,669 (11)
Asian/PI	27,119 (3)	61,675 (3)	88,794 (3)	601,157 (5)	689,951 (2)
Hispanic	97,284 (9)	185,667 (8)	282,951 (9)	1,617,401 (5)	1,900,352 (6)
Alaskan Native/American Indian	11,918 (1)	18,682 (1)	30,600 (1)	165,060 (1)	195,660 (1)
Education (n, %)					
< High school	293,898 (30)	646,844 (29)	940,742 (29)	7,511,341 (25)	8,452,083 (26)
High school	420,349 (42)	937,674 (42)	1,358,023 (42)	12,822,772 (43)	14,180,795 (43)
> High school	280,809 (28)	629,148 (28)	909,957 (28)	9,490,113 (32)	10,400,070 (31)
Average number of COD (mean, SD)	3.8 (1.6)	4.7 (1.8)	4.4 (1.8)	2.7 (1.6)	2.9 (1.7)
Number of COD (n, %)					
1	38,903 (4)	1 (0)	38,904 (1)	8,193,357 (26)	8,232,261 (24)
2	152,632 (15)	170,881 (7)	323,513 (10)	8,238,840 (27)	8,562,353 (25)
3	300,138 (29)	449,339 (20)	749,477 (23)	6,510,455 (21)	7,259,932 (21)
4	263,015 (26)	568,465 (25)	831,480 (25)	4,038,872 (13)	4,870,352 (14)
5	140,907 (14)	468,712 (20)	609,619 (18)	2,103,400 (7)	2,713,019 (8)
6	71,945 (7)	303,537 (13)	375,482 (11)	1,025,049 (3)	1,400,531 (4)
7	34,588 (3)	169,406 (7)	203,994 (6)	478,841 (2)	682,835 (2)
≥8	28,872 (3)	165,169 (7)	194,041 (6)	398,640 (1)	592,681 (2)
Adjusted mortality rate (n per 100,000; 95% CI)					
2003–2005	37.7 (37.6–37.9)	79.1 (78.9–79.3)	116.8 (116.5–117.1)	1097.3 (1096.5–1098.2)	1214.1 (1213.2–1215.0)
2006–2010	32.8 (32.7–33.0)	76.0 (75.8–76.2)	108.8 (108.6–109.0)	1022.1 (1021.5–1022.7)	1130.9 (1130.3–1131.6)
2011–2016	31.3 (31.3–31.4)	70.5 (70.3–70.6)	101.8 (101.6–102.0)	989.4 (988.9–990.0)	1091.2 (1090.7–1091.8)

Abbreviations: CI, confidence interval; COD, cause of death; n, number; NH, non-hispanic; PI, Pacific Islander; SD, standard deviation.

For all comparisons of “Multiple Cause of Death” vs. “Non-Diabetes deaths”, p-value < 0.0001. Adjusted mortality rate was adjusted to US Census 2000 population by age.

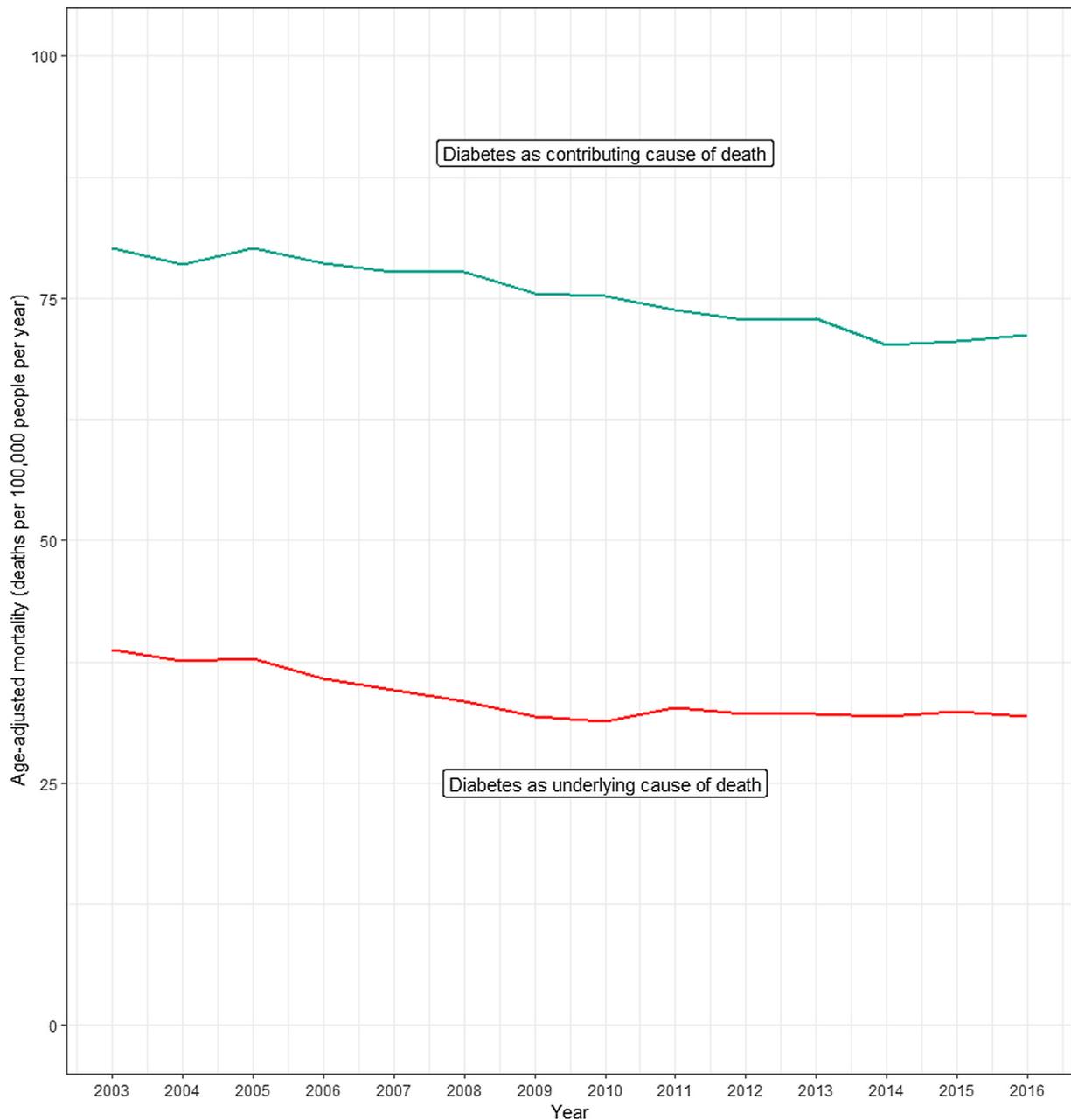


Fig. 1 – Age-adjusted mortality (per 100,000) by diabetes as an underlying versus contributing causes of death, 2003–2016.

with 2003, the “Other” non-leading causes of death occurred more frequently in 2016 in all groups (32 vs 23% in those with DM listed as an underlying cause of death, and 34 vs 26% in those with DM listed as a contributing cause of death).

5. Discussion

Using national death records, we identified contemporary trends in mortality for those with DM listed on the death certificate compared to those without DM listed. Overall, deaths have decreased similarly for both groups (with and without DM on death certificates) over the study period (2003–2016).

We also documented changing patterns in the etiology of underlying cause of death among those with DM listed on their death certificates. We found that by using only an underlying cause of death, DM-attributable causes of deaths may be significantly undercounted. Although disparities in DM-attributable deaths were noted by race/ethnicity, all groups except Alaskan Natives/American Indians experienced an overall decline in DM-attributable deaths as measured by both underlying and contributing cause of death on mortality records. Over the last 13 years, there has been a steady decline in total mortality and cardiovascular disease mortality among patients with DM listed on their death records.

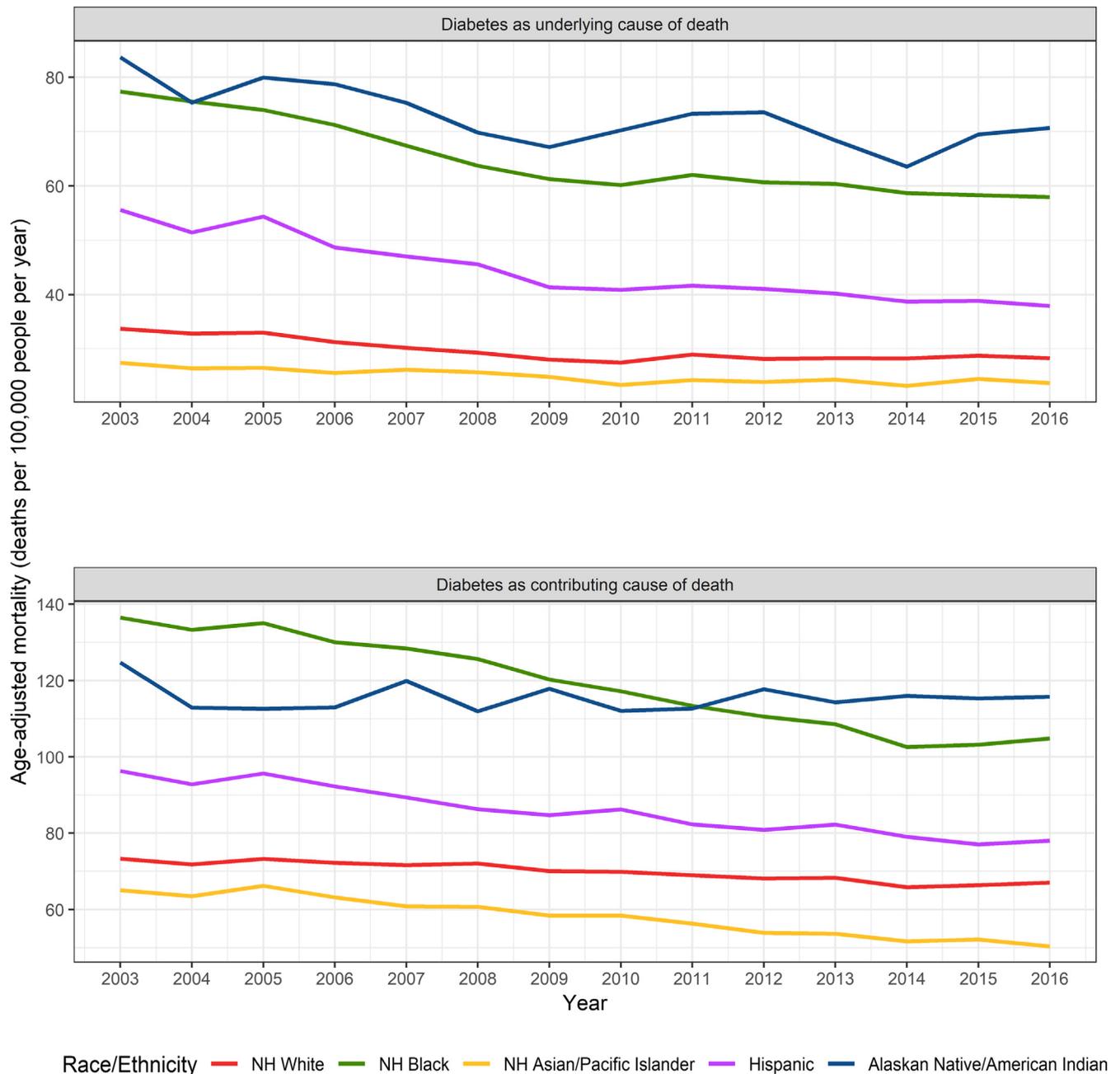


Fig. 2 – Age-adjusted changes in diabetes mortality by race/ethnicity, 2003–2016.

Given the decrease in competing causes of death, there is an increasing proportion of deaths attributable to other etiologies such as hypertension and hypertensive renal disease.

We found that only 3% of death records reported DM as an underlying cause of death. When considering DM as anywhere on the death records (a multiple-cause-of-death approach), this rose to 9.7%, more closely paralleling the estimated population prevalence of DM [24]. These results extend prior work that has shown that DM is underestimated as an underlying cause of death in the U.S. death records [9,11–17]. Similar to our findings, using a multiple-cause-of-death approach increases the documented prevalence of DM in international death certificates by 2 to 4-fold [10,18]. Other

results from the Translating Research into Action for Diabetes (TRIAD) Study found an increasing trend of recording DM as an underlying cause of death from 2000 to 2007, but not for the recording of DM anywhere on the death certificate [19]. Our findings underscore that considering only a single underlying cause of death may obfuscate important contributions from multisystem chronic diseases like DM to mortality.

Our results are concordant with recently published report showing the declining rates of vascular disease among individuals with DM [21]. Using data from the National Health Interview Survey Linked Mortality files, the investigators found that from 1988 to 2015, all-cause mortality declined among individuals with DM. The proportion of deaths from

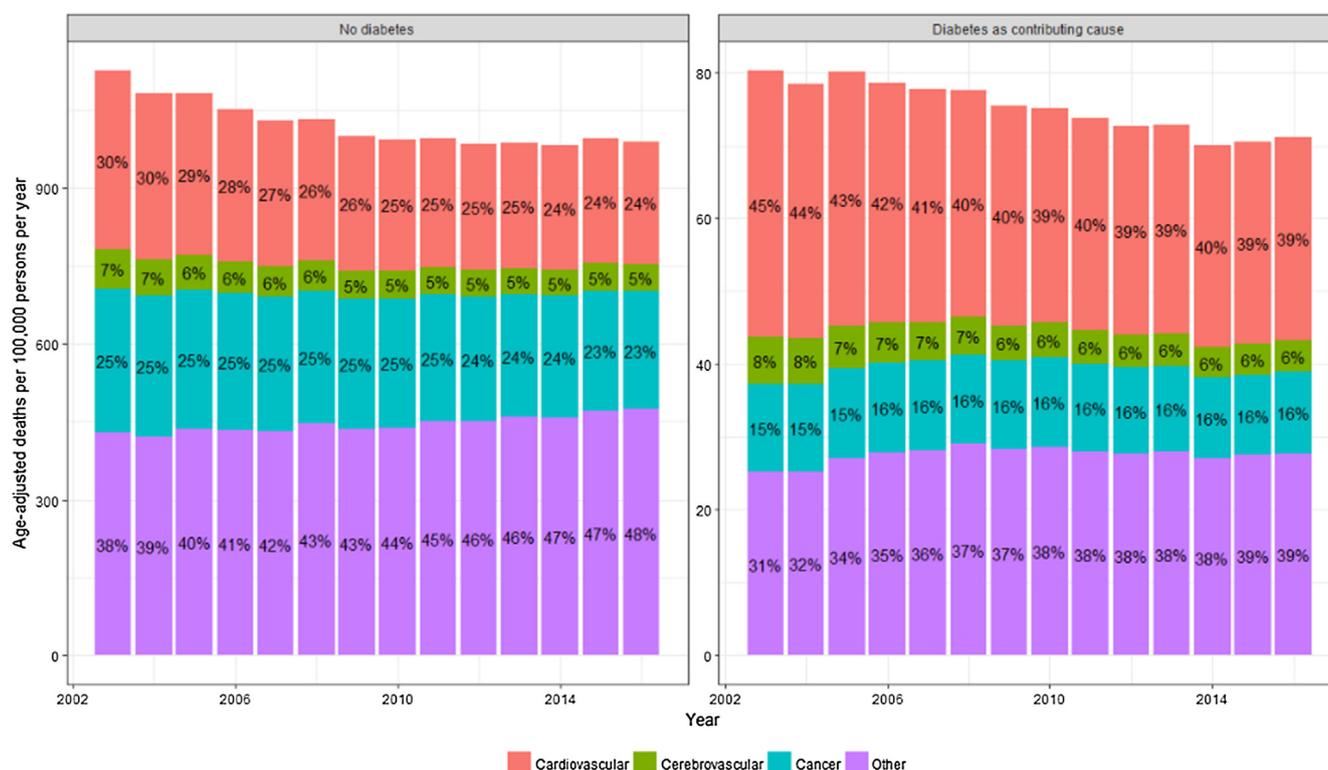


Fig. 3 – Underlying causes of death due to cardiovascular disease, cerebrovascular disease, and other causes by diabetes status.

vascular causes declined whereas the proportion of non-cancer, non-vascular deaths increased among individuals with DM. Similar to our study, this data showed that the proportion of death from cancer among individuals with diabetes did not significantly increase over time.

Our study also uncovered differences in DM reporting on death records by race/ethnicity. Blacks, Alaskan Indian/Native Americans, and Hispanics were more likely to have DM listed as an underlying and contributing cause of death as compared to NHWs. This is likely explained to a higher prevalence of DM in racial/ethnic minority groups in the U.S. All race/ethnic groups except Alaskan Indians/Native Americans experienced a decline in DM-attributable deaths during the study period. This trend likely may be attributed to the high prevalence of DM and its complications among Alaskan Indians/Native Americans [25,26]. Prevention programs targeting this small but significant portion of the U.S. population are needed to ensure that all groups may benefit from the overall observed reduction in DM-related deaths.

Similar to other studies, our results show favorable changes in mortality among patients with DM listed on their death records [20,27]. Overall death rates are declining among those with DM listed on their death records and the causes of death are increasingly diverse. This likely reflects significant strides in preventive health measures among individuals with DM and others. The reduction in CVD deaths may also be explained by overall improvement in the treatment of myocardial infarctions as well as primary and secondary CVD prevention efforts among individuals with diabetes

[28]. Although DM is associated with an increased risk of a wide range of CVD, the risks have been shown to vary by CVD subtype [29]. Increasingly, as novel DM drugs continue to improve cardiovascular outcomes, we expect the positive reductions in CVD mortality among individuals with diabetes to continue [30].

DM is a multisystem disease and, as DM-related vascular complications continue to decline, a rise in other causes of death is expected. For example, we found that those with DM on their death record as three times as likely to have hypertension and renal disease co-reported on their death records. These findings have important clinical and public health interventions to reduce DM-related morbidity. In addition to improving glycemic control among individuals with DM, interventions seeking to aggressively control hypertension and diabetic nephropathy may provide significant gains in diabetic mortality.

Our results should be interpreted in the light of several limitations. First, reporting errors in death records may have impacted our findings. Studies have shown that nearly one-third of all death certificates may be erroneously completed, particularly for DM [5,6,31–33]. The misattribution of DM in death certificates may be due to a variety of problems such as inaccuracies at several steps in the certification process [34], missing information [35], and poor accuracy in resident-physician completion of death certificates. DM may be particularly prone to inaccurate reporting on death records due to the medical subjectivity and interpretation of identifying DM as a contribution to death [16,17,36]. Our study does

Table 2 – Co-reported causes of death by diabetes reporting status in death records, 2003 and 2016.

Description	ICD10 codes	N (%)		
YEAR 2003				
Cardiovascular disease	I00-09, I11, I13-I59, I70-99	Diabetes = underlying	Diabetes = contributing	No diabetes
Cancer	C00-97	79,493 (41)	192,087 (37)	1,647,121 (30)
Infectious disease	J00-22, A00-99, B00-99	2424 (1)	33,125 (6)	665,282 (12)
Chronic respiratory disease	J40-47	10,618 (5)	29,304 (6)	376,278 (7)
Cerebrovascular disease	I60-69	3386 (2)	21,481 (4)	235,199 (4)
Hypertension/Hypertensive renal disease	I10, I12	10,551 (5)	24,971 (5)	241,285 (4)
Accident	V01-99, W00-99, X01-59, Y85-86	20,146 (10)	46,537 (9)	186,087 (3)
Chronic liver disease	K70, K73-74	800 (0)	5009 (1)	119,651 (2)
Acute or chronic kidney disease	N17-19	603 (0)	3419 (1)	39,918 (1)
Intentional self-harm	X60-84, X87.0, U03	20,649 (11)	26,819 (5)	168,517 (3)
Alzheimer dementia	G30	3 (0)	156 (0)	27,663 (0)
Other	–	1181 (1)	5711 (1)	92,569 (2)
Total number of COD		45,089 (23)	133,916 (26)	1,754,474 (32)
		194,943	522,535	5,554,044
YEAR 2016				
Cardiovascular disease	I00-09, I11, I13-I59, I70-99	Diabetes = underlying	Diabetes = contributing	No diabetes
Cancer	C00-97	85,963 (39)	222,120 (32)	1,662,058 (24)
Infectious disease	J00-22, A00-99, B00-99	2622 (1)	43,891 (6)	750,642 (11)
Chronic respiratory disease	J40-47	9115 (4)	30,578 (4)	387,633 (6)
Cerebrovascular disease	I60-69	5243 (2)	33,265 (5)	274,983 (4)
Hypertension/Hypertensive renal disease	I10, I12	8173 (4)	23,192 (3)	216,241 (3)
Accident	V01-99, W00-99, X01-59, Y85-86	31,300 (14)	74,887 (11)	262,113 (4)
Chronic liver disease	K70, K73-74	860 (0)	8799 (1)	179,871 (3)
Acute or chronic kidney disease	N17-19	1008 (0)	5721 (1)	64,275 (1)
Intentional self-harm	X60-84, X87.0, U03	4346 (2)	6512 (1)	188,497 (3)
Alzheimer dementia	G30	2 (0)	228 (0)	40,181 (1)
Other	–	1012 (0)	9013 (1)	132,198 (2)
Total number of COD		70,601 (32)	238,599 (34)	2,692,289 (39)
		220,245	696,805	6,850,981

COD = causes of death.

Table 3 – Annual percent change in diabetes mortality by race/ethnicity, 2003–2016.

Race/ethnicity	Diabetes as an underlying cause of death		Diabetes as a contributing cause of death		
	AAPC (95% CI)		p-value	AAPC (95% CI)	p-value
NH White	–1.56 (–2.03 to –1.08)		<0.001	–0.95 (–1.11 to –0.78)	<0.001
NH Black	–2.24 (–2.68 to –1.80)		<0.001	–2.06 (–2.66 to –1.46)	<0.001
Asian/PI	–0.91 (–1.34 to –0.48)		<0.001	–2.17 (–2.43 to –1.92)	<0.001
Hispanic	–2.83 (–3.52 to –2.14)		<0.001	–1.79 (–2.04 to –1.55)	<0.001
Alaskan Native/American Indian	–0.80 (–1.99 to 0.40)		0.19	0.18 (–0.26 to 0.62)	0.39

Abbreviation: AAPC, average annual percent change; CI, confidence interval; NH, non-Hispanic.

not account for the true DM prevalence on the population but instead uses a multiple-cause-of-death approach to determine the burden of DM on overall mortality and cause-specific mortality as measured by the death records.

6. Conclusion

In summary, using contemporary national mortality records, we document significant underrepresentation of DM on mortality examining DM as an underlying cause of death. A multiple-cause-of-death analysis that includes both underlying and contributing causes of death better depicts the true contribution of DM in U.S. mortality. Those with DM listed on their death certificates have experienced an overall decline in death rates and other co-reported causes of death have diversified.

Funding sources

Dr. Rodriguez was supported by the McCormick Galiban Faculty Fellowship from Stanford University. Dr. Blum was funded by a grant from the Swiss National Science Foundation (P2BEP3_175289). Dr. Falasinnu was funded by a Diversity Supplement for NHLBI from the CASPER grant (1R01HL126172-01A1).

Declaration of interests

The authors have no disclosures to report.

Author contributions

FR and LP contributed to the study conception and design. MB, TF, and JH analyzed and interpreted the data. KH and MC contributed to data interpretation. All authors contributed to the drafting of the manuscript, provided critical revisions, approved the final version, and are agreeable to being accountable for all aspects of the work.

REFERENCES

- [1] Economic costs of diabetes in the U.S. in 2012. *Diabetes Care* 2013;36(4):1033–46.
- [2] Gregg EW, Zhuo X, Cheng YJ, Albright AL, Narayan KM, Thompson TJ. Trends in lifetime risk and years of life lost due to diabetes in the USA, 1985–2011: a modelling study. *Lancet Diabetes Endocrinol* 2014;2(11):867–74.
- [3] Tancredi M, Rosengren A, Svensson AM, et al. Excess mortality among persons with type 2 diabetes. *N Engl J Med* 2015;373(18):1720–32.
- [4] Mathers CD, Loncar D. Projections of global mortality and burden of disease from 2002 to 2030. *PLoS Med* 2006;3(11):e442.
- [5] Centers for Disease Control. Sensitivity of death certificate data for monitoring diabetes mortality–diabetic eye disease follow-up study, 1985–1990. *MMWR Morb Mortal Wkly Rep* 1991;40(43):739–41.
- [6] Fuller JH, Elford J, Goldblatt P, Adelstein AM. Diabetes mortality: new light on an underestimated public health problem. *Diabetologia* 1983;24(5):336–41.
- [7] Centers for Disease Control and Prevention. National diabetes statistics report: estimates of diabetes and its burden in the United States, 2014. Atlanta, GA: US Department of Health and Human Services. 2014; 2014.
- [8] Centers for Disease Control and Prevention. Physicians' Handbook on Medical Certification of Death. 2003; https://www.cdc.gov/nchs/data/misc/hb_cod.pdf. Accessed September 2017; 2017.
- [9] Israel RA, Rosenberg HM, Curtin LR. Analytical potential for multiple cause-of-death data. *Am J Epidemiol* 1986;124(2):161–79.
- [10] Park J, Peters PA. Mortality from diabetes mellitus, 2004 to 2008: A multiple-cause-of-death analysis. *Health Rep* 2014;25(3):12.
- [11] Stokes A, Preston SH. Deaths attributable to diabetes in the United States: comparison of data sources and estimation approaches. *PLoS One* 2017;12(1):e0170219.
- [12] Andresen EM, Lee JA, Pecoraro RE, Koepsell TD, Hallstrom AP, Siscovick DS. Underreporting of diabetes on death certificates, King County, Washington. *Am J Public Health* 1993;83(7):1021–4.
- [13] Whittall D, Glatthaar C, Knuiman M, Welborn T. Deaths from diabetes are under-reported in national mortality statistics. *Med J Australia* 1990;152(11):598–600.
- [14] McEwen LN, Kim C, Haan M, et al. Diabetes reporting as a cause of death. Results from the Translating Research Into Action for Diabetes (TRIAD) study 2006;29(2):247–53.
- [15] Penman A. Excess mortality due to diabetes in Mississippi and the estimated extent of underreporting on death certificates. *J Miss State Med Assoc* 2003;44(10):319–25.
- [16] Will JC, Vinicor F, Stevenson J. Recording of diabetes on death certificates: Has it improved? *J Clin Epidemiol* 2001;54(3):239–44.
- [17] Cheng WS, Wingard DL, Kritiz-Silverstein D, Barrett-Connor E. Sensitivity and specificity of death certificates for diabetes. *Diabetes Care* 2008;31(2):279–84.
- [18] Fedeli U, Zoppini G, Goldoni CA, Avossa F, Mastrangelo G, Saugo M. Multiple causes of death analysis of chronic

- diseases: the example of diabetes. *Popul Health Metr* 2015;13:21.
- [19] McEwen LN, Karter AJ, Curb JD, Marrero DG, Crosson JC, Herman WH. Temporal trends in recording of diabetes on death certificates: results from Translating Research Into Action for Diabetes (TRIAD). *Diabetes Care* 2011;34(7):1529–33.
- [20] Tsujimoto T, Kajio H, Sugiyama T. Favourable changes in mortality in people with diabetes: US NHANES 1999–2010. *Diabetes Obes Metab* 2018;20(1):85–93.
- [21] Gregg EW, Cheng YJ, Srinivasan M, et al. Trends in cause-specific mortality among adults with and without diagnosed diabetes in the USA: an epidemiological analysis of linked national survey and vital statistics data. *Lancet* 2018;391(10138):2430–40.
- [22] National Center for Health Statistics. U.S. census populations with bridged race categories. Available at: https://www.cdc.gov/nchs/nvss/bridged_race.htm.
- [23] Kim HJ, Fay MP, Feuer EJ, Midthune DN. Permutation tests for joinpoint regression with applications to cancer rates. *Stat Med* 2000;19(3):335–51.
- [24] Menke A, Casagrande S, Geiss L, Cowie CC. Prevalence of and trends in diabetes among adults in the United States, 1988–2012. *JAMA* 2015;314(10):1021–9.
- [25] Centers for disease control and prevention. Diabetes prevalence among American Indians and Alaska natives and the overall population—United States, 1994–2002. *MMWR Morbidity and mortality weekly report*. 2003;52(30):702–4.
- [26] Espey DK, Jim MA, Cobb N, et al. Leading causes of death and all-cause mortality in American Indians and Alaska Natives. *Am J Public Health* 2014;104(Suppl 3):S303–11.
- [27] Cheng YJ, Imperatore G, Geiss LS, et al. Trends and disparities in cardiovascular mortality among U.S. adults with and without self-reported diabetes mellitus, 1988–2015. *Diabetes Care* 2018.
- [28] Benjamin EJ, Blaha MJ, Chiuve SE, et al. Heart disease and stroke statistics-2017 update: a report from the American heart association. *Circulation* 2017;135(10):e146–603.
- [29] Shah AD, Langenberg C, Rapsomaniki E, et al. Type 2 diabetes and incidence of cardiovascular diseases: a cohort study in 1.9 million people. *Lancet Diabetes Endocrinol* 2015;3(2):105–13.
- [30] Newman JD, Vani AK, Aleman JO, Weintraub HS, Berger JS, Schwartzbard AZ. The changing landscape of diabetes therapy for cardiovascular risk reduction: JACC state-of-the-art review. *J Am Coll Cardiol* 2018;72(15):1856–69.
- [31] Wexelman BA, Eden E, Rose KM. Survey of New York City resident physicians on cause-of-death reporting, 2010. *Preventing Chronic Disease* 2013;10:E76.
- [32] Cheng TJ, Lin CY, Lu TH, Kawachi I. Reporting of incorrect cause-of-death causal sequence on death certificates in the USA: using hypertension and diabetes as an educational illustration. *Postgrad Med J* 2012;88(1046):690–3.
- [33] McAllum C, St George I, White G. Death certification and doctors' dilemmas: a qualitative study of GPs' perspectives. *Br J Gen Pract* 2005;55(518):677–83.
- [34] Myers KA, Farquhar DR. Improving the accuracy of death certification. *CMAJ* 1998;158(10):1317–23.
- [35] Mieno MN, Tanaka N, Arai T, et al. Accuracy of death certificates and assessment of factors for misclassification of underlying cause of death. *J Epidemiol* 2016;26(4):191–8.
- [36] Lu T-H, Walker S, Johansson LA, Huang C-N. An international comparison study indicated physicians' habits in reporting diabetes in part I of death certificate affected reported national diabetes mortality. *J Clin Epidemiol* 2005;58(11):1150–7.