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ORIGINAL RESEARCH

Impact of Social Vulnerability on Diabetes-Related Cardiovascular Mortality in the United States

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BACKGROUND: Social vulnerability impacts the natural history of diabetes as well as cardiovascular disease (CVD). However, there are little data regarding the social vulnerability association with diabetes-related CVD mortality.

METHODS AND RESULTS: County-level mortality data (where CVD was the underlying cause of death with diabetes among the multiple causes) extracted from the Centers for Disease Control multiple cause of death (2015–2019) and the 2018 Social Vulnerability Index databases were aggregated into quartiles based on their Social Vulnerability Index ranking from the least (first quartile) to the most vulnerable (fourth quartile). Stratified by demographic groups, the data were analyzed for overall CVD, as well as for ischemic heart disease, hypertensive disease, heart failure, and cerebrovascular disease. In the 5-year study period, 387 139 crude diabetes-related cardiovascular mortality records were identified. The age-adjusted mortality rate for CVD was higher in the fourth quartile compared with the first quartile (relative risk [RR], 1.66 [95% CI, 1.64–1.67]) with an estimated 39 328 excess deaths. Among the youngest age group (<55 years), those with the highest social vulnerability had 2 to 4 times the rate of cardiovascular mortality compared with the first quartile: ischemic heart disease (RR, 2.07 [95% CI, 1.97–2.17]; heart failure (RR, 3.03 [95% CI, 2.62–3.52]); hypertensive disease (RR, 3.79 [95% CI, 3.45–4.17]; and cerebrovascular disease (RR, 4.39 [95% CI, 3.75–5.13]).

CONCLUSIONS: Counties with greater social vulnerability had higher diabetes-related CVD mortality, especially among younger adults. Targeted health policies that are designed to reduce these disparities are warranted.

Key Words: cerebrovascular disease ■ diabetes ■ ischemic heart disease ■ social determinants of health ■ social vulnerability

Diabetes is prevalent in the United States, with >1 in 10 adult Americans having this disease, and another 38.0% are considered to be in the prediabetes group.[1] A diagnosis of diabetes is associated with increased mortality and reduced life expectancy by 12 to 16 years, particularly among young age groups.[2,3] One in 3 people with diabetes are affected by cardiovascular disease (CVD) (accounting for 50% of the mortality in this population).[4] This represents a high preventable burden in addition to other diabetes-related comorbidities such as chronic kidney disease.[5]

The social determinants of health (SDOH) have been increasingly recognized in clinical guidelines as CVD events risk predictors, above and beyond the classical modifiable and nonmodifiable risk factors.[6,7] Previous studies have shown that up to 80% of all health outcomes can be traced back to SDOH rather than directed health care interventions.[8–10] SDOH are often researched individually and include a variety of

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CLINICAL PERSPECTIVE

What Is New?

- This analysis demonstrates 66% higher diabetes-related cardiovascular mortality in the most socially vulnerable counties, with an estimated 39 328 excess deaths.
- Younger adults (<55 years of age), women, and racial and ethnic minority populations are the worst-impacted groups by social vulnerability.

What Are the Clinical Implications?

- By focusing on people with both diabetes and cardiovascular disease in the most vulnerable demographics, this research allows policymakers to reach informed decisions in allocating the limited resources through highly efficient and selective initiatives.
- Integrated health programs highlighting those with diabetes and cardiovascular disease in primary care settings for social risk assessment, and funding targeted social and health care intervention to the most impacted demographics mentioned above, are needed.

Nonstandard Abbreviations and Acronyms

AAMR	age-adjusted mortality rate
CDC	Centers for Disease Control and Prevention
CeVD	cerebrovascular disease
HTD	hypertensive disease
IHD	ischemic heart disease
mSVI	modified Social Vulnerability Index
RR	rate ratio
SDOH	social determinants of health
SVI	Social Vulnerability Index
WONDER	wide-ranging online data for epidemiologic research

factors relating to education, income, food security, employment, housing, social inclusion, and affordable health care access among other nonmedical aspects. However, SDOH that influence mortality disparities in CVD and diabetes are frequently entwined, which makes isolating these factors and examining them directly quite challenging. Hence, the demand for a collective measuring tool for the SDOH risk was recognized, with health care increasingly resorting to the Social Vulnerability Index (SVI) to meet this need.

The concept of social vulnerability initially emerged from risk management studies in response to natural disasters and evolved over several decades.[11] The Centers for Disease Control and Prevention (CDC) define social vulnerability as "the potential negative effects on communities caused by external stresses on human health."[12] Within this definition, several factors are incorporated such as poverty, crowded accommodation, and limited access to transportation that can negatively impact population health. Hence, social vulnerability can be a valuable instrument to examine the overall impact of several SDOH on clinical outcomes at the community level, with its readily availability making public health policies and resources efficiently targeted towards the right neighborhoods.

Social vulnerability exacerbates the health burden associated with CVDs and diabetes, given the challenges of affordability of medication, compliance, and navigation of the wide variety of health services involved in treatment strategy, risk factors control, lifestyle changes, and screening programs.[13–15] This adverse relationship has been previously demonstrated in studies that examined the association of SDOH with either CVD or diabetes.[16,17]

However, association of social vulnerability with diabetes-related cardiovascular mortality has not been previously quantified, nor whether this varies among different demographic groups. Therefore, this cross-sectional study analyzed the CDC multiple cause of death and the SVI databases to examine the association of social vulnerability with both diabetes-related overall CVD mortality as well as CVD individual components (ischemic heart disease [IHD], hypertensive disease [HTD], heart failure, and cerebrovascular disease [CeVD]) categorized according to sex, age, race, ethnicity, and urbanization.

METHODS

Since this study is based on publicly available database analysis at a population level and does not not involve living human subjects. individual consent and institutional review board approval were not applicable.

Data Availability

The data sets generated and used in the current study are available from the corresponding authors upon reasonable request. In addition, the data sources are publicly available through the CDC websites below:

WONDER: https://wonder.cdc.gov/mcd.html

ATSDR: https://www.atsdr.cdc.gov/placeandhealth/svi/index.html

Data Sources

The Wide-ranging Online Data for Epidemiologic Research (WONDER) databases were developed by the CDC and provide free access to public health and statistical research data. Mortality and population data for the current analysis were obtained from the multiple cause of death WONDER database, which records these statistics from death certificates, at the US county level, excluding US nonresidents deaths.[18] Death certificates would include demographic data, a single underlying cause of death, and up to 20 additional multiple causes. The World Health Organization definition for the underlying cause of death is used in this database: "the disease or injury which initiated the train of events leading directly to death, or the circumstances of the accident or violence which produced the fatal injury." Causes of death were categorized using the *International Classification of Diseases, Tenth Revision* (*ICD-10*). The multiple cause of death WONDER database provides an aggregate of mortality data linked to geographical areas with common demographic characteristics (such as age, sex, and race) but does not include social attributes (such as income, employment, education, housing), individual-level data, treatments, nor comorbidities unrelated to the cause of death.

Social vulnerability data were acquired through the free, publicly available CDC SVI database, created by the Geospatial Research, Analysis & Services Program of the Agency for Toxic Substances and Disease Registry.[12] At the time of this analysis, the latest available 2018 SVI database (released in 2020 and based on American Community Survey data in the 5 years between 2014 and 2018) provides the relative vulnerability of every US county by ranking them according to 15 social characteristics grouped into 4 related themes, namely: socioeconomic status (below poverty, unemployment, income, no high school diploma), housing type and transportation (multi-unit structures, mobile homes, crowding, no vehicle, group quarters), household composition and disability (65 years of age or older, 17 years of age or younger, disabled civilian, single-parent family), and language and minority status (minority, speaks English "less than well"). The ranking is based on percentiles with greater vulnerability as the value increases.

Hence, the SVI can provide a single measure for several SDOH, describing the socioeconomic settings, identifying disadvantaged communities, and thus help directing health policies and resources where disparities in diabetes-related CVD mortality are demonstrated. These key advantages of the SVI are contrasted with the drawback of not including other SDOH such as working conditions, food security, access to quality affordable health care, childhood development, and social discrimination, which may variably influence diabetes-related CVD mortality.

Study Sample

US counties were categorized and split into quartiles based on their 2018 SVI ranking from the least (first quartile) to the most vulnerable (fourth quartile). All mortality records were then extracted from the WONDER database by their vulnerability quartile that had both (1) CVD as the single underlying cause of death with (2) diabetes (*ICD-10* codes: E10–E14) among the multiple causes of death. The presence of other comorbidities in addition to diabetes among the multiple causes of death did not exclude these records. CVD was defined as composite of ischemic heart disease (IHD; *ICD-10* codes: I20–I25), hypertensive disease (HTD; *ICD-10* codes: I10–I15), heart failure (HF; including HF and cardiomyopathy, *ICD-10* codes: I50 and I42, respectively), and cerebrovascular disease (CeVD; *ICD-10* codes: I60–I69). The sample was further stratified by sex, age group, Hispanic or Latino origin, race, and urbanization status in addition to each component of CVD. The racial and ethnic groups were categorized according to their classification in the WONDER database. The urban category included large central metropolitan, large fringe metropolitan, medium metropolitan, and small metropolitan. In contrast, rural included micropolitan and noncore areas. The data were extracted for the 5 years between 2015 and 2019 to provide contemporary findings that were closely related to the 2018 SVI data set while avoiding suppressed and unreliable results from the WONDER database. A checklist, Strengthening The Reporting of Observational Studies in Epidemiology, has been included to further ensure the quality of this observational analysis (Data S1).

Statistical Analysis

Death certificates with recorded age of 15 years or older were included in the analysis to facilitate age adjustment of mortality figures to the 2000 US standard population (available only in 10-year age groups through the WONDER database). The age-adjusted mortality rate (AAMR) is presented per 100 000 population, with its 95% CI. The general population in the 5-year study period in the counties belonging to each of the SVI quartiles was the denominator for diabetes-related overall CVD (as well as CVD types) mortality rates in the corresponding SVI quartile. The denominators for diabetes-related overall CVD (as well as CVD types) mortality rates in the stratified groups (age, sex, Hispanic or Latino origin, race, and urbanization) were the number of people in their corresponding stratum in the counties belonging to each of the SVI quartiles (for example, the total number of male residents in counties belonging to the fourth SVI quartile as denominator for male diabetes-related overall CVD [as well as CVD types] mortality rate in the fourth SVI quartile). Records with missing age data were excluded from the analysis, while those with other missing demographic variables were only excluded from their respective per-group analysis. Rate ratios were calculated by contrasting the AAMR for each cardiovascular cause of death and demographic group in the most vulnerable counties (fourth quartile) to the corresponding AAMR in the least vulnerable counties (first quartile). The respective 95% CIs for the ratios were considered significant provided they did not cross the value of 1. These were estimated using the approximation method previously described in the literature.[19] Excess mortality due to social vulnerability was estimated by using the first quartile AAMR as a baseline. The absolute difference in AAMR between the fourth and the first SVI quartile was then divided by the fourth quartile AAMR to calculate the percentage of excess deaths. The fourth quartile deaths that were not accounted for by the first quartile AAMR were considered in excess.

Since the SVI does account for English-speaking ability and minority status among its 15 social variables, to avoid conflating the results, we used a modified SVI (mSVI) that excluded these 2 characteristics (language and minority status) and repeated the analysis for the racial and ethnic group stratification.

RESULTS

Out of the 3142 US counties in the SVI database, a total of 3139 counties were included in the analysis (3 counties were excluded due to missing data). A total of 387 139 crude diabetes-related cardiovascular mortality records were identified in the 5-year study period. The majority of these crude records were among the counties in the third quartile (32.4%) followed by those in the fourth, second, and the least vulnerable first quartile (28.5%, 24.3%, and 14.7%, in order). The proportion of crude mortality among female residents increased from the least vulnerable to the most vulnerable quartiles (40.4% in the first quartile to 43.1% in the fourth quartile). Similarly, the proportion of crude deaths in those <55 years of age rose with the increasing SVI quartile (5.7% in the first quartile versus 9.2% in the fourth quartile). The percentage of the crude number of deaths among the Hispanic or Latino population increased from 2.6% in the first quartile to 19.7% in the fourth quartile. Similarly, crude mortality in Black individuals increased from 5.6% in the least vulnerable quartile to 23.4% in the most vulnerable one, while the percentage of crude deaths in White individuals decreased (92.1% in the first quartile versus 71.2% in the fourth quartile). The crude mortality distribution for each quartile by demographic group is detailed in Table 1.

Table 1. Demographic Characteristics of Diabetes-Related Cardiovascular Death Certificates Between 2015 and 2019, Stratified by Social Vulnerability Index (SVI) Quartile

Characteristic	SVI quartile			
	First (n=56 974; 14.7%)	Second (n=94 122; 24.3%)	Third (n=125 545; 32.4%)	Fourth (n=110 498; 28.5%)
Sex				
Female, %	40.4	41.0	41.5	43.1
Male, %	59.6	59.0	58.5	56.9
Age, y				
<55, %	5.7	6.7	8.1	9.2
55–74, %	37.0	39.6	43.2	43.7
≥75, %	57.3	53.7	48.7	47.1
Hispanic or Latino origin				
Hispanic or Latino, %	2.6	5.1	8.2	19.7
Not Hispanic or Latino, %	97.2	94.5	91.4	79.9
Race				
White, %	92.1	83.5	77.4	71.2
Black or African American, %	5.6	10.0	18.6	23.4
Asian or Pacific Islander, %	1.8	5.7	3.2	3.8
American Indian or Alaska Native, %	0.5	0.8	0.8	1.7
Urbanization				
Urban, %	78.9	81.4	83.4	76.1
Rural, %	21.1	18.6	16.6	23.9

SVI indicates social vulnerability index.

CVD Mortality

The diabetes-related CVD AAMR was higher in the most vulnerable fourth quartile of the SVI compared with the least vulnerable first quartile (AAMR, 32.9 [95% CI, 32.7–33.1] versus AAMR, 19.8 [95% CI, 19.7–20.0], respectively) (Table 2). The AAMR increased with increasing SVI quartile both in overall CVD but also across the individual components of CVD (Figure 1) and for each year of the study period (Figure 2). A 66% higher AAMR (rate ratio [RR], 1.66 [95% CI, 1.64–1.67]) (Table 3) was observed in the most socially vulnerable fourth quartile compared with the first quartile with estimated 39328 excess deaths accounting for 39.6% of the fourth quartile mortality (Tables 4 and 5). The RR of AAMR in the fourth quartile compared with the first quartile of SVI was higher among female residents (RR, 1.79 [95% CI, 1.75–1.82]) in contrast with male residents (RR, 1.57 [95% CI, 1.55–1.59]). For those <55 years of age, counties in the highest social vulnerability quartile had 158% increased risk of mortality in comparison to those in the lowest social vulnerability quartile, and this age group was the worst overall affected demographic group (RR, 2.58 [95% CI, 2.48–2.69]). Similarly, for those 55 to 74 years of age, counties in the most socially vulnerable quartile had a 99% increased risk of mortality compared with those in the least socially vulnerable quartile (RR, 1.99 [95% CI, 1.96–2.02]), while for those 75 years of age or older, the increased risk in the most vulnerable quartile counties compared with the least vulnerable quartile was still significant but less prominent (RR, 1.37 [95% CI, 1.35–1.39]). Likewise, the association of social vulnerability with mortality was greater in urban areas (RR, 1.71 [95% 1.69–1.73]) compared with rural areas (RR, 1.42 [95% CI, 1.38–1.45]).

Race and ethnic mortality was also associated with social vulnerability within their respective stratified groups, with Hispanic or Latino (RR, 1.98 [95% CI, 1.90–2.06]), as well as Asian or Pacific Islander individuals (RR, 1.9, [95% CI, 1.85–2.07]), exhibiting the greatest risk of mortality in relation to the SVI quartiles followed by Black persons (RR, 1.60 [95% CI, 1.55–1.66]). In contrast, White individuals had 55% increase mortality risk in relation to social vulnerability (RR, 1.55

Table 2. Diabetes-Related Cardiovascular Age-Adjusted Mortality Rate (AAMR) per 100000 Population (with 95% CI) Between 2015 and 2019, Stratified by Social Vulnerability Index Quartile

Characteristic	AAMR			
	First quartile	Second quartile	Third quartile	Fourth quartile
Main causes of death				
Cardiovascular disease	19.8 [19.7–20.0]	22.5 [22.3–22.6]	25.1 [25.0–25.2]	32.9 [32.7–33.1]
Ischemic heart disease	13.0 [12.9–13.2]	14.0 [13.9–14.2]	15.5 [15.4–15.6]	19.6 [19.5–19.8]
Hypertensive diseases	2.3 [2.2–2.3]	3.1 [3.1–3.2]	4.2 [4.2–4.3]	5.8 [5.8–5.9]
Heart failure	1.7 [1.7–1.8]	1.9 [1.8–1.9]	1.9 [1.8–1.9]	2.5 [2.4–2.5]
Cerebrovascular disease	2.8 [2.8–2.9]	3.4 [3.4–3.5]	3.5 [3.5–3.6]	4.9 [4.8–5.0]
Sex				
Female	14.0 [13.8–14.2]	16.2 [16.1–16.4]	18.4 [18.2–18.6]	25.0 [24.7–25.2]
Male	27.2 [26.9–27.5]	30.3 [30.1–30.6]	33.4 [33.2–33.7]	42.7 [42.3–43.0]
Age, y				
<55	2.0 [2.0–2.1]	2.7 [2.6–2.8]	3.7 [3.6–3.8]	5.2 [5.1–5.3]
55–74	31.7 [31.3–32.1]	38.9 [38.5–39.3]	47.8 [47.3–48.2]	63.2 [62.6–63.8]
≥75	158.5 [156.8–160.2]	167.8 [166.3–169.3]	170.0 [168.7–171.4]	217.4 [215.5–219.2]
Hispanic or Latino origin				
Hispanic or Latino	16.7 [15.8–17.6]	23.1 [22.4–23.8]	24.1 [23.6–24.6]	33.0 [32.6–33.5]
Not Hispanic or Latino	19.9 [19.7–20.1]	22.4 [22.3–22.6]	25.2 [25.1–25.4]	33.0 [32.8–33.2]
Race				
White	19.7 [19.5–19.8]	21.7 [21.5–21.8]	23.4 [23.3–23.6]	30.5 [30.3–30.7]
Black or African American	28.4 [27.4–29.4]	35.7 [35.0–36.5]	37.6 [37.2–38.1]	45.5 [44.9–46.1]
Asian or Pacific Islander	12.4 [11.7–13.2]	19.2 [18.7–19.8]	20.1 [19.4–20.7]	24.4 [23.6–25.1]
American Indian or Alaska Native	26.7 [23.5–30.0]	27.8 [25.6–29.9]	27.1 [25.4–28.8]	34.5 [32.9–36.2]
Urbanization				
Urban	18.8 [18.6–19.0]	21.6 [21.4–21.7]	24.4 [24.2–24.5]	32.2 [32.0–32.4]
Rural	24.9 [24.4–25.3]	27.7 [27.3–28.1]	29.7 [29.3–30.1]	35.2 [34.8–35.7]

AAMR indicates age-adjusted mortality rate.

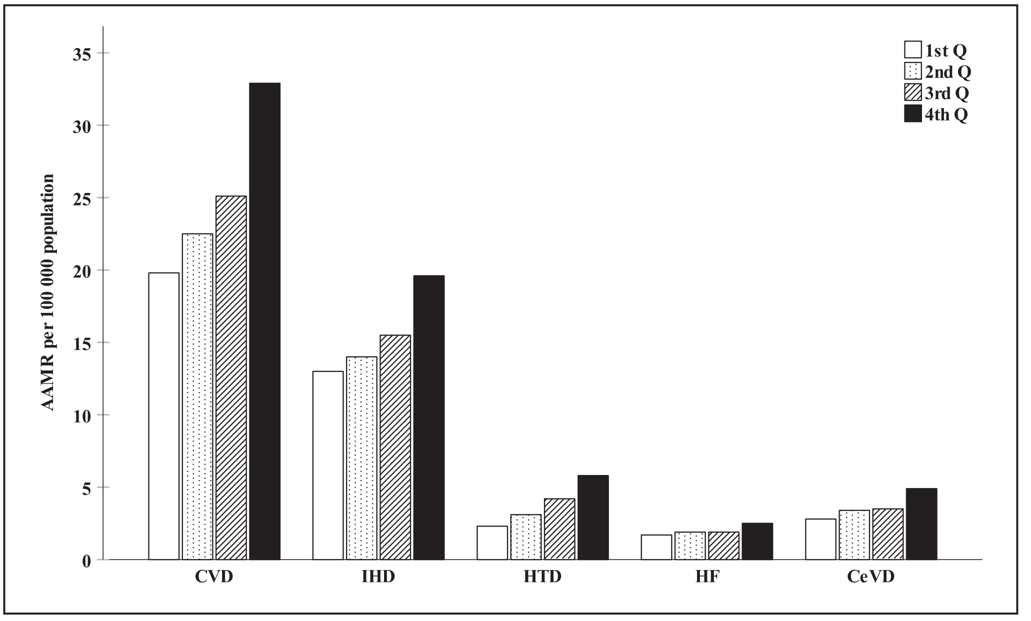

Figure 1. Diabetes-related cardiovascular age-adjusted mortality rate (AAMR) per 100000 population between 2015 and 2019, stratified by social vulnerability index quartile (Q).
CeVD indicates cerebrovascular disease; CVD, cardiovascular disease; HF, heart failure; HTD, hypertensive diseases; and IHD, ischemic heart disease.

[95% CI, 1.53–1.57]). The ethnic and racial results remain consistent when using the mSVI (Tables 6 and 7) except that mortality among White (RR, 1.72 [95% CI, 1.69–1.74]) persons had greater association with social vulnerability compared with Black individuals (RR, 1.48 [95% CI, 1.44–1.52]) within their respective stratified groups.

IHD Mortality

The diabetes-related IHD AAMR was >50% higher (RR, 1.51 [95% CI, 1.48–1.53]) between the least vulnerable first SVI quartile (AAMR, 13.0 [95% CI, 12.9–13.2]) to the most vulnerable fourth SVI quartile (AAMR, 19.6 [95% CI, 19.5–19.8]) with estimated 19909 excess deaths accounting for 33.6% of this fourth quartile

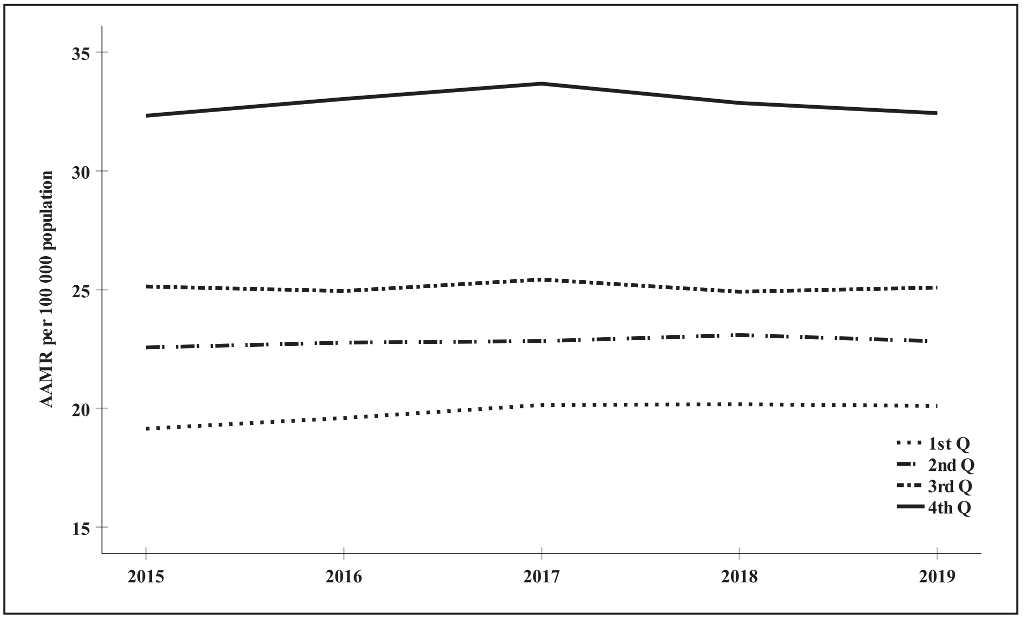

Figure 2. Diabetes-related cardiovascular age-adjusted mortality rate (AAMR) per 100000 population per year, stratified by social vulnerability index quartile (Q).

Table 3. Rate Ratios of Diabetes-Related Cardiovascular Age-Adjusted Mortality Rate (AAMR) in the Fourth Quartile Versus the First Quartile of the Social Vulnerability Index (With 95% CI), Stratified by Main Cause of Cardiovascular Death

Characteristic	Cardiovascular disease	Ischemic heart disease	Hypertensive diseases	Heart failure	Cerebrovascular disease
Overall	1.66 [1.64–1.67]	1.51 [1.48–1.53]	2.58 [2.50–2.66]	1.44 [1.39–1.50]	1.73 [1.68–1.78]
Sex					
Female	1.79 [1.75–1.82]	1.67 [1.63–1.71]	2.60 [2.48–2.73]	1.43 [1.35–1.52]	1.76 [1.68–1.83]
Male	1.57 [1.55–1.59]	1.42 [1.40–1.45]	2.62 [2.52–2.73]	1.43 [1.36–1.50]	1.67 [1.61–1.74]
Age, y					
<55	2.58 [2.48–2.69]	2.07 [1.97–2.17]	3.79 [3.45–4.17]	3.03 [2.62–3.52]	4.39 [3.75–5.13]
55–74	1.99 [1.96–2.02]	1.75 [1.72–1.78]	3.27 [3.12–3.42]	1.83 [1.72–1.94]	2.39 [2.28–2.51]
≥75	1.37 [1.35–1.39]	1.29 [1.26–1.31]	1.98 [1.90–2.06]	1.16 [1.11–1.21]	1.41 [1.37–1.46]
Hispanic or Latino origin					
Hispanic or Latino	1.98 [1.90–2.06]	1.93 [1.84–2.03]	2.83 [2.54–3.17]	1.73 [1.51–1.99]	1.68 [1.54–1.84]
Not Hispanic or Latino	1.66 [1.64–1.68]	1.50 [1.48–1.53]	2.63 [2.55–2.72]	1.47 [1.41–1.53]	1.68 [1.63–1.74]
Race					
White	1.55 [1.53–1.57]	1.46 [1.43–1.48]	2.22 [2.15–2.30]	1.32 [1.27–1.38]	1.59 [1.54–1.64]
Black or African American	1.60 [1.55–1.66]	1.44 [1.38–1.51]	2.29 [2.12–2.47]	1.50 [1.34–1.68]	1.51 [1.39–1.63]
Asian or Pacific Islander	1.96 [1.85–2.07]	2.00 [1.85–2.15]	2.13 [1.81–2.49]	2.04 [1.60–2.60]	1.75 [1.54–1.99]
American Indian or Alaska Native	1.29 [1.16–1.43]	1.08 [0.95–1.23]	2.90 [2.06–4.09]	1.23 [0.84–1.80]	1.42 [1.07–1.88]
Urbanization					
Urban	1.71 [1.69–1.73]	1.57 [1.55–1.60]	2.68 [2.59–2.77]	1.40 [1.34–1.46]	1.77 [1.71–1.82]
Rural	1.42 [1.38–1.45]	1.26 [1.22–1.30]	2.28 [2.11–2.46]	1.51 [1.39–1.65]	1.50 [1.41–1.61]

mortality. This was observed across the study period (Figure 3). Within their respective stratified groups, female sex (RR, 1.67 [95% CI, 1.63–1.71]), age <55 years (RR, 2.07 [95% CI, 1.97–2.17]), Hispanic or Latino (RR, 1.93 [95% CI, 1.84–2.03]), Asian or Pacific Islander (RR, 2.00 [95% CI, 1.85–2.15]), and urban populations (RR, 1.57 [95% CI, 1.55–1.60]) were the demographic groups demonstrating the greatest adverse association with social vulnerability compared with their counterparts in the least vulnerable quartile (Table 3). Both Black (RR, 1.44 [95% CI, 1.38–1.51]) and White (RR, 1.46 [95% CI, 1.43–1.48]) racial groups had an increase in diabetes-related IHD AAMR in relation to worsening social vulnerability.

Using the mSVI (Table 7), the ethnic and racial results remained generally consistent except that within their respective stratified groups, among White population (RR, 1.64 [95% CI, 1.61–1.67]) there was a higher association with social vulnerability compared with Black individuals (RR, 1.34 [95% CI, 1.29–1.39]).

Hypertensive Diseases Mortality

The diabetes-related HTD AAMR was more than double (RR, 2.58 [95% CI, 2.50–2.66]), from 2.3 (95% CI, 2.2–2.3) in the first SVI quartile to 5.8 (95% CI, 5.8–5.9) in the fourth SVI quartile with estimated 10 816 excess deaths accounting for 61.2% of this fourth quartile mortality. This was consistent, with a slowly rising trend, across the study period (Figure 4) and represented the greatest association of social vulnerability among the cardiovascular causes of death (Figure 5). Within their respective stratified groups, male sex (RR, 2.62 [95% CI, 2.52–2.73]), <55 years of age (RR, 3.79 [95% CI, 3.45–4.17]), Hispanic or Latino (RR, 2.83 [95% CI, 2.54–3.17), Native American (RR, 2.90 [95% CI, 2.06–4.09]) followed by Black (RR, 2.29 [95% CI, 2.12–2.47]), and urban (RR, 2.68 [95% CI, 2.59–2.77]) were the worst-affected demographic groups by social vulnerability compared with their counterparts in the least vulnerable quartile (Table 3).

Applying the mSVI (Table 7) demonstrates that within their respective stratified groups, non-Hispanic or Latino (RR, 2.43 [95% CI, 2.36–2.51]), Native American (RR, 2.30 [95% CI, 1.82–2.91), and White (RR 2.17 [95% CI, 2.10–2.25]) populations had the greatest adverse association with social vulnerability compared with their counterparts in the least vulnerable quartile.

HF Mortality

Diabetes-related HF AAMR increased by 44% (RR, 1.44 [95% CI, 1.39–1.50]) from 1.7 (95% CI, 1.7–1.8) in the first SVI quartile to 2.5 (95% CI, 2.4–2.5) in the fourth SVI quartile with 2308 excess deaths estimated accounting for 30.8% of this fourth quartile mortality. Although

Table 4. Estimated Excess Diabetes-Related Cardiovascular Deaths in the Most Vulnerable Counties (Fourth Social Vulnerability Index Quartile) Using the First Social Vulnerability Index Quartile Age-Adjusted Mortality Rate (AAMR) as a Baseline

Characteristic	Cardiovascular disease	Ischemic heart disease	Hypertensive diseases	Heart failure	Cerebrovascular disease
Overall	39 328	19 909	10 816	2308	6273
Sex					
Female	17 033	8505	4617	925	2939
Male	22 818	11 856	6423	1366	3218
Age, y					
<55	6476	3046	1943	600	838
55–74	24 383	13 094	6303	1429	3591
≥75	13 706	6620	3900	565	2628
Hispanic or Latino origin					
Hispanic or Latino	14 728	8551	3280	858	2043
Not Hispanic or Latino	27 746	14 004	7874	1730	4079
Race					
White	23 630	12 960	5748	1209	3577
Black or African American	10 267	4367	3769	735	1410
Asian or Pacific Islander	2129	1322	327	130	359
American Indian or Alaska Native	537	103	298	33	106
Urbanization					
Urban	32 634	17 070	9047	1565	4990
Rural	6114	2539	1863	641	1090

the disparity seems to have narrowed in the past few years of the study period, this was largely due to rising mortality in the first SVI quartile (Figure 6). Within their respective stratified groups, while the strength of the association of the social vulnerability was similar between sexes, those in the <55 years of age (RR, 3.03 [95% CI, 2.62–3.52]), Hispanic or Latino (RR, 1.73 [95% CI, 1.51–1.99]), Asian or Pacific Islander (RR, 2.04 [95% CI, 1.60–2.60]), followed by Black (RR, 1.50 [95% CI, 1.34–1.68]), and rural (RR, 1.51 [95% CI, 1.39–1.65) demographic groups showed the greatest unfavorable association with social vulnerability compared with their counterparts in the least vulnerable quartile (Table 3).

The racial and ethnic groups results remained consistent using the mSVI (Table 7) apart from demonstrating that among the population of American natives, there was 90% higher diabetes-related HF mortality (RR, 1.90 [95% CI, 1.33–2.72]) in the most vulnerable counties compared with their counterpart in the least vulnerable quartile within their respective stratified group.

Cerebrovascular Disease Mortality

AAMR for diabetes-related CeVD in the fourth SVI quartile (AAMR 4.9 [95% CI, 4.8–5.0]) was 73% higher (RR, 1.73 [95% CI, 1.68–1.78]) compared with the first SVI quartile (AAMR, 2.8 [95% CI, 2.8–2.9]) with estimated 6273 excess deaths accounting for 42.3% of this fourth quartile mortality. This was steady across the study period (Figure 7). Within their respective stratified groups, female sex (RR, 1.76 [95% CI, 1.68–1.83]), <55 years of age (RR, 4.39, [95% CI, 3.75–5.13), Asian or Pacific Islander (RR 1.75, [95% CI, 1.54–1.99), and urban populations (RR, 1.77 [95% CI, 1.71–1.82]) were the most adversely associated demographic groups with social vulnerability compared with their counterparts in the least vulnerable quartile (Table 3). Both Black (RR, 1.51 [95% CI, 1.39–1.63]) and White (RR, 1.59 [95% CI, 1.54–1.64]) racial groups had >50% increase in diabetes-related CeVD AAMR in relation to worsening social vulnerability.

Within their respective stratified groups using the mSVI, non-Hispanic or Latino (RR, 1.80 [95% CI, 1.74–1.85]), Asian or Pacific Islander (RR, 1.78 [95% CI, 1.57–2.02]), and White (RR, 1.77 [95% CI, 1.71–1.83]) populations in the most vulnerable quartile were the most adversely associated racial and ethnic groups with social vulnerability compared with their counterparts in the least vulnerable counties.

DISCUSSION

This national data analysis of diabetes-related cardiovascular mortality highlights several important

Table 5. Proportion of Excess Diabetes-Related Cardiovascular Age-Adjusted Mortality Rate (AAMR) in the Most Vulnerable Counties (Fourth Social Vulnerability Index Quartile) Out of Their Respective Total AAMR, Using the First Social Vulnerability Index Quartile AAMR as a Baseline

Characteristic	Cardiovascular disease	Ischemic heart disease	Hypertensive diseases	Heart failure	Cerebrovascular disease
Overall, %	39.6	33.6	61.2	30.8	42.3
Sex					
Female, %	44.0	40.1	61.5	30.0	43.0
Male, %	36.3	29.7	61.9	30.1	40.2
Age, y					
<55, %	61.3	51.6	73.6	67.0	77.2
55–74, %	49.8	42.8	69.4	45.2	58.2
≥75, %	27.1	22.3	49.5	13.7	29.3
Hispanic or Latino origin					
Hispanic or Latino, %	49.4	48.3	64.7	42.3	40.7
Not Hispanic or Latino, %	39.7	33.5	62.0	32.1	40.5
Race					
White, %	35.6	31.4	55.0	24.5	37.2
Black or African American, %	37.6	30.8	56.3	33.3	33.7
Asian or Pacific Islander, %	48.9	49.9	52.9	51.0	42.9
American Indianor Alaska Native, %	22.6	7.4	65.5	18.8	29.5
Urbanization					
Urban, %	41.6	36.4	62.6	28.5	43.4
Rural, %	29.4	20.5	56.2	33.9	33.5

disparities by social vulnerability that contributed to >39000 extra lives lost and appears to be prominently demonstrated in certain groups such as racial and ethnic minorities, female sex, urban residents, and younger age groups. First, the AAMR for diabetes-related CVD (and its individual components) was much higher in counties in the highest quartile of social vulnerability, with two-thirds increase in overall diabetes cardiovascular deaths in comparison with the least socially vulnerable quartile. Second, individuals in the youngest group (<55years) were the most adversely associated age group with social vulnerability both in overall diabetes-related CVD as well as its individual components with more than double the IHD, more than triple the HF, almost fourfold the HTD, and more than quadruple the CeVD mortalities in the most socially vulnerable counties. Third, social vulnerability association among female sex was more pronounced, particularly with regard to IHD and CeVD deaths. Fourth, Asian or Pacific Islander and Hispanic or Latino individuals all experienced greater excesses in diabetes cardiovascular mortality within the highest social vulnerability quartile in comparison to White persons. This national-level analysis provides a unique insight

Table 6. Diabetes-Related Cardiovascular Age-Adjusted Mortality Rate (AAMR) per 100000 Population (With 95% CI) Between 2015 and 2019, Stratified by the Modified Social Vulnerability Index Quartiles That Excluded Language and Minority Status

Characteristic	AAMR			
	First quartile	Second quartile	Third quartile	Fourth quartile
Hispanic or Latino origin				
Hispanic or Latino	18.9 [18.2–19.6]	23.8 [23.3–24.3]	28.6 [28.1–29.0]	36.2 [35.5–37.0]
Not Hispanic or Latino	19.5 [19.3–19.6]	22.8 [22.6–22.9]	28.3 [28.1–28.5]	34.8 [34.5–35.0]
Race				
White	19.0 [18.8–19.1]	21.5 [21.3–21.6]	26.6 [26.4–26.7]	32.5 [32.2–32.8]
Black or African American	31.0 [30.2–31.8]	36.9 [36.3–37.5]	41.1 [40.6–41.7]	46.0 [45.2–46.7]
Asian or Pacific Islander	15.8 [15.2–16.3]	20.1 [19.6–20.7]	22.1 [21.4–22.7]	27.4 [25.8–28.9]
American Indianor Alaska Native	24.7 [22.2–27.2]	28.5 [26.7–30.4]	23.8 [22.1–25.5]	39.9 [37.9–41.9]

AAMR indicates age-adjusted mortality rate.

Table 7. Rate Ratios (With 95% CI) of Diabetes-Related Cardiovascular Age-Adjusted Mortality Rate (AAMR) in the Fourth Quartile Versus the First Quartile of the Modified Social Vulnerability Index That Excluded Language and Minority Status, Stratified by Main Cause of Cardiovascular Death

Characteristic	Cardiovascular disease	Ischemic heart disease	Hypertensive diseases	Heart failure	Cerebrovascular disease
Hispanic or Latino origin					
Hispanic or Latino	1.92 [1.86–1.98]	1.93 [1.85–2.01]	2.17 [2.01–2.34]	1.94 [1.73–2.19]	1.71 [1.59–1.83]
Not Hispanic or Latino	1.78 [1.76–1.81]	1.66 [1.64–1.69]	2.43 [2.36–2.51]	1.70 [1.63–1.77]	1.80 [1.74–1.85]
Race					
White	1.72 [1.69–1.74]	1.64 [1.61–1.67]	2.17 [2.10–2.25]	1.55 [1.48–1.62]	1.77 [1.71–1.83]
Black or African American	1.48 [1.44–1.52]	1.34 [1.29–1.39]	1.93 [1.82–2.04]	1.56 [1.42–1.70]	1.45 [1.36–1.54]
Asian or Pacific Islander	1.74 [1.64–1.84]	1.68 [1.55–1.81]	1.76 [1.53–2.04]	2.09 [1.66–2.63]	1.78 [1.57–2.02]
American Indian or Alaska Native	1.61 [1.48–1.76]	1.45 [1.30–1.62]	2.30 [1.82–2.91]	1.90 [1.33–2.72]	1.57 [1.25–1.96]

into the association of social vulnerability, studying a collection of the social determinants of health, with diabetes-related CVD mortality and adds to the growing evidence of its impact. In addition to raising the awareness, this article utilizes the readily available SVI data in identifying counties where social and public health care policies can be targeted with the aim to provide additional support and education to improve treatment and prevention of CVD for the high-risk demographics with diabetes detected in this study.

Integrated health programs have been shown to improve the outcomes of chronic conditions. This has been well demonstrated in the context of diabetes, with growing drive for a similar approach in CVD care.[20,21] However, the integration of social wellbeing into health care is still being modeled, tested, and improved. Unfortunately, health resources are scarce and efficient allocation is often challenging. Therefore, targeted distribution of these resources is vital. By focusing on people with both diabetes and CVD in the most vulnerable demographics, this research allows policymakers to reach informed decisions in allocating these limited resources through highly efficient and selective initiatives. Previous research has uncovered the need for a validated social risk measurement,[22] which the current analysis demonstrated that the SVI can be used as such a tool. In the context of the current analysis, such an integrated system would require sharing

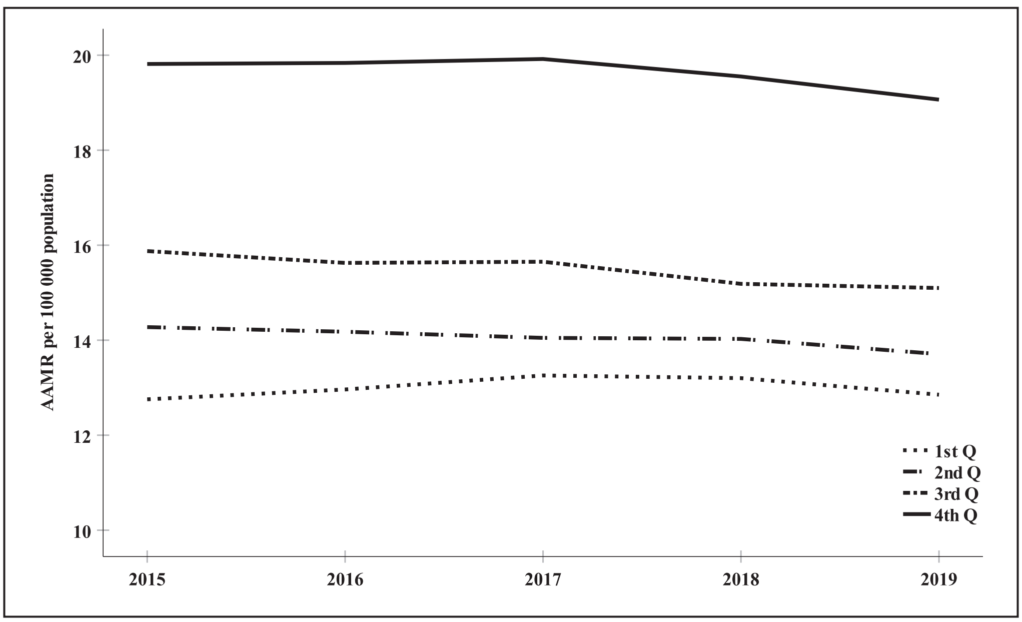

Figure 3. Age-adjusted mortality rate (AAMR) for diabetes-related ischemic heart disease per 100 000 population per year, stratified by social vulnerability index quartile (Q).

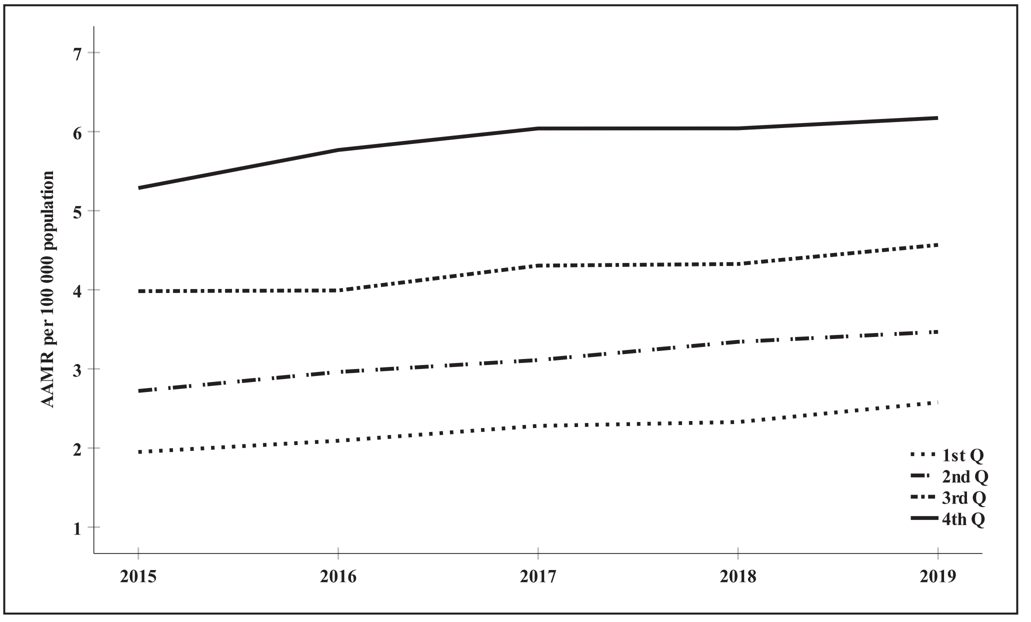

Figure 4. Age-adjusted mortality rate (AAMR) for diabetes-related hypertensive diseases per 100 000 population per year, stratified by social vulnerability index quartile (Q).

of information across the social and health care services, highlighting those with diabetes and CVD in primary care settings for social risk assessment, and fund targeted social intervention to the demonstrated most vulnerable demographics as well as health care intervention through the same budget.

The association of SVI with specific diabetes mortality in the literature is limited since the most common cause of death among people with diabetes is CVD, which often effectively competes to be the primary mortality cause on death certificates. Using diabetes-related CVD mortality permits the study of the association between the most common cause of mortality in this population with social vulnerability. Isolated SDOH have been associated with overall diabetes mortality, such as the lack of high school education (hazard ratio,

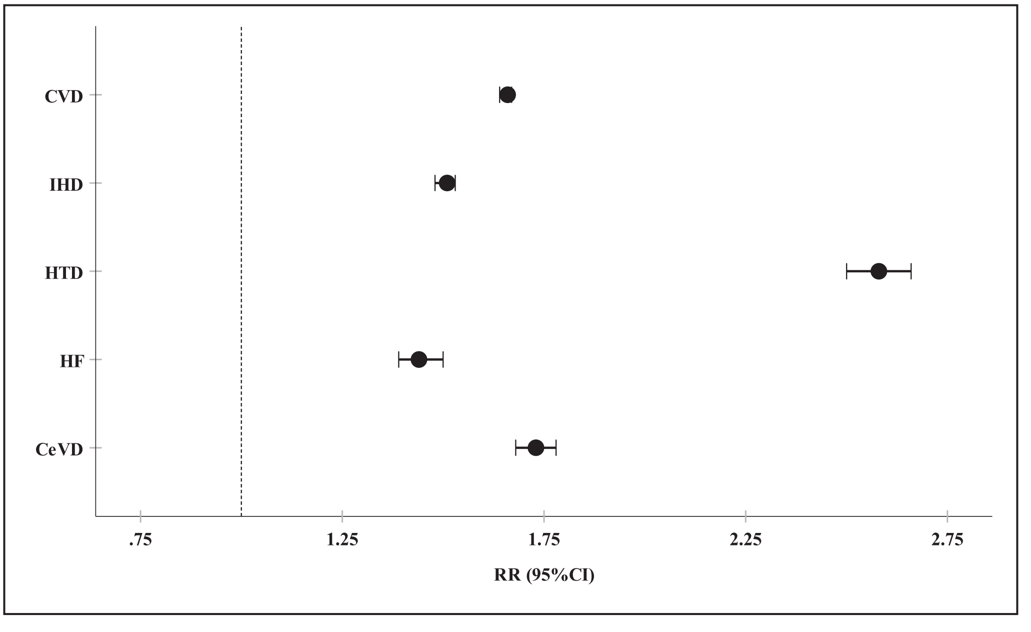

Figure 5. Rate ratios (RRs) of diabetes-related cardiovascular age-adjusted mortality rate in the fourth quartile versus the first quartile of the social vulnerability index (with their 95% CI).
CeVD indicates cerebrovascular disease; CVD, cardiovascular disease; HF, heart failure; HTD, hypertensive diseases; and IHD, ischemic heart disease.

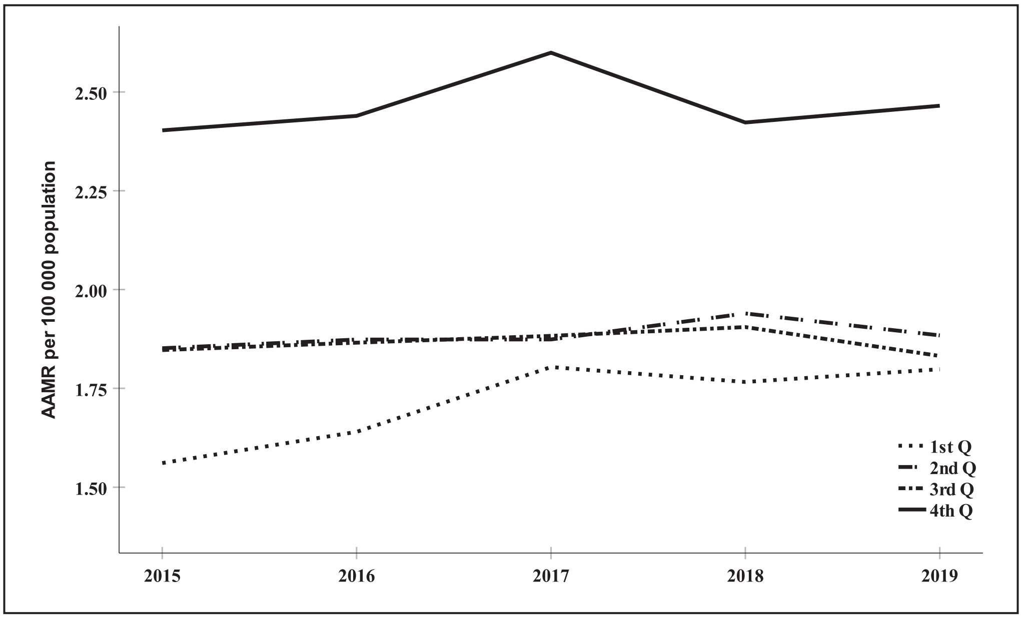

Figure 6. Age-adjusted mortality rate (AAMR) for diabetes-related heart failure per 100000 population per year, stratified by social vulnerability index quartile (Q).

2.05 [95% CI, 1.78–2.35]), and below-poverty family income (hazard ratio, 2.41 [95% CI, 2.05–2.84]), although their relationship with diabetes-related cardiovascular mortality remains unknown.[23] These figures are higher than those that have been described in the current report, which is likely due to analyses of different populations, as well as cause-specific SDOH that may impact on mortality differentially. A strength of the current analysis is the use of the more encompassing SVI that provides a more holistic assessment of SDOH rather than focusing on individual causes.

Previous work by Khan et al demonstrated an 84% increase in CVD deaths in the most socially vulnerable groups.[24] Our current analysis similarly shows a 66% increase in diabetes-related CVD mortality in the most socially vulnerable counties. This effect is most likely

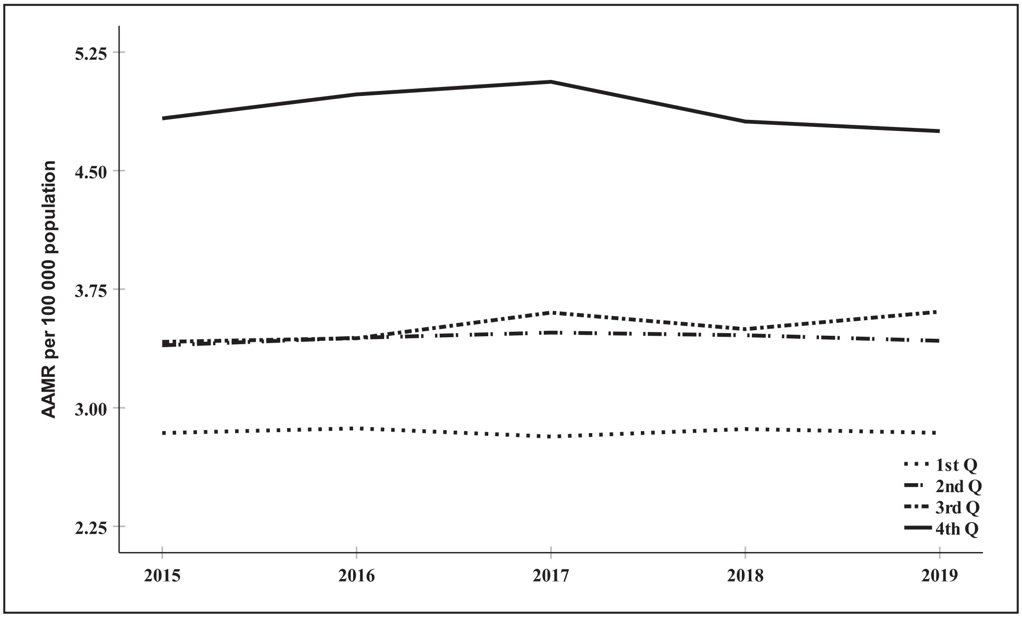

Figure 7. Age-adjusted mortality rate (AAMR) for diabetes cerebrovascular disease per 100000 population per year, stratified by social vulnerability index quartile (Q).

mediated by the adverse association of social determinants of health on risk factors that are known to impact on cardiovascular mortality in people with diabetes, namely, glycemic control, obesity, lipid levels, and blood pressure.[15,25] For example, among those with limited income, poor glycemic control is 40% more likely and has twice the risk of having severe hypoglycemia.[26,27] The level of education has been similarly implicated, with those with low versus high education having a greater frequency of severe hypoglycemia episodes.[28] Furthermore, patients with both diabetes and CVD encounter greater financial burden than those with either of these conditions alone, with more treatment costs, medication side effects, and follow-up visits. Residential deprivation has been associated with worse glycemic control and subsequently higher risk for micro- and macrovascular complications.[29,30] For example, those who have type 1 diabetes and who reside in deprived areas have been found to have almost 3 times the risk for developing diabetic retinopathy (hazard ratio, 2.95 [95% CI, 1.08–8.00]) compared with those who live in less socioeconomically challenged regions.[31] The linearity of social vulnerability association with cardiovascular outcomes has been demonstrated, where each additional social determent of health was associated with increase in the incidence of age-adjusted fatal myocardial infarction per 1000 person-years (1.30, 1.44, 2.05, 2.86; for 0, 1, 2, 3 or more, respectively) as well as nonfatal events.[32]

In the current analysis, however, the detrimental association of diabetes-related CVD mortality with the SVI was lower compared with that of overall CVD mortality with the SVI in the Khan et al article. (66% versus 84% increase in mortality in association with the SVI, respectively).[24] This could reflect the beneficial effects of the already more established integrated care pathways for diabetes management. On the other hand, this detrimental association with the SVI was much more pronounced in the younger age groups in relation to diabetes-related CVD mortality compared with overall CVD mortality, especially in the case of cerebrovascular deaths (339% versus 118% increase in mortality in association with the SVI, respectively). This might be related to the more accelerated consequences of limited access to affordable health care among this segment of the population compounded by the presence of these 2 morbidities combined.

It is concerning that the most adversely associated demographic with social vulnerability, when taking diabetes into consideration, was the youngest age group (<55 years old) with even worse impact compared with analysis in the overall population.[24] The Berman et al recent analysis of young (≤50 years old) patients with myocardial infarction reported that those in the most deprived neighborhoods had more than double the risk for cardiovascular mortality when compared with those residing in the least socioeconomic disadvantaged zones.[33] A recent systematic review concluded that early-onset diabetes is a growing health concern, particularly in sociodemographically vulnerable populations.[34] Furthermore, young-onset diabetes is a more severe phenotype with higher incidence of CVD and mortality.[35] This is in line with the forecasted epidemic of CVD based upon the growth of risk factors including obesity, unhealthy diet, and sedentary lifestyle in this segment of the population that preferentially affect those with adverse SDOH.[36] Furthermore, there has been a generational shift in the perception of healthy body weight that particularly affected overweight women from Black or Hispanic or Latino background, as well as those with lower educational background.[37,38] In addition, particularly among young people with diabetes, economic factors such as income and health insurance were associated with higher cost-related nonadherence to medication.[39] While the number of adverse socioeconomic factors have also been associated with incremental increases in the incidence of stroke among those <75 years of age,[40] the current article demonstrates an apparently even more amplified association among younger people (<55 years of age) when diabetes is considered, given the added adverse effects described above that are often mediated by social vulnerability in this segment of the population. Another explanatory factor for this particular age group's adverse association with social vulnerability is access to publicly funded assistance with prescription cost that starts at an older age. This is reflected in a strong association between low socioeconomic status and the risk of death, myocardial infarction, and stroke among young people (<65 years of age) with diabetes (adjusted hazard ratio, 1.51 [95% CI, 1.45–1.56]), which diminished significantly in older adults.[41] Older adults are also more likely to be on Medicare and therefore have greater ability to access and afford health care, unlike younger patients, who are also less likely to have health insurance or to be adequately insured unless they have employment-based insurance or qualify for Medicaid.[42]

Although CVD mortality was higher in men across all the SVI quartiles, social vulnerability appears to attenuate the protective effect of female sex on cardiovascular mortality to the point that CVD mortality among female residents in the fourth SVI quartile almost matched mortality among men in the first SVI quartile. A Canadian population-based study showed that women were more susceptible to SDOH (such as low income and food insecurity) in developing new diabetes.[43,44] The mechanism for higher social susceptibility among women with diabetes is not yet clear, but a number of factors have been postulated.[45] For example, low education level can often lead to unhealthy lifestyle and as a result obesity and subsequent diabetes, an association that is particularly evident among women.[46] Once diagnosed with diabetes, women had poorer control of traditional cardiovascular risk factors and were less likely to receive guideline-directed therapies for CVD, such as after acute myocardial infarction.[47,48]

Racial and ethnic minorities are preferentially exposed to unfavorable SDOH. The addition of further social vulnerabilities, as is the case in counties in the fourth SVI quartile, would understandably magnify this adverse association further. For example, a study among an Asian American population found that those with limited fluency in English language (62%) were more likely to not receive regular medical follow-ups, thereby having a higher rate of unmet medical care, and exhibit difficulty communicating their health care needs.[49] In addition, despite Asian or Pacific Islander patients being the highest risk racial and ethnic group for developing diabetes, they were the least likely to receive recommended screening for diabetes.[50] Similarly, compared with those from White background, Black people with neighborhood or individual poverty were associated with higher odds of developing diabetes, while professional employment, higher earnings, and higher education level has been directly associated with an improved glycemic control in this population.[51,52] Likewise, a study examining the socioeconomic impact on the Hispanic or Latino population with type 2 diabetes found that those receiving heating assistance had higher fasting plasma glucose, while a lower income in this population was associated with higher levels of glycated hemoglobin.[53] These factors are likely to add to the existing racial disparities in CVD outcomes.[54] These racial and ethnic disparities, including those observed in the current analysis, are complex and include differences in comorbid conditions, living conditions, access to treatment, and can at least partly relate to the well-documented structural racism in health care as well as in society.[55–57] The lower utilization and access to health care, the poorer quality of care, the underrepresentation in health care workforce, the explicit bias, microaggressions (subtle intentional or unintentional behaviors, attitudes, or slights against marginalized groups), and unconscious biases in patient–provider interactions are some of the instances that can lead to racial and ethnic inequalities in clinical outcomes that are often exacerbated by social vulnerability.[58–61]

This analysis also has limitations, many of which relate to the use of data from national sources. First, the SVI is based on American Community Survey data (which does not include all the SDOH such as food security in particular) and is therefore dependent on the accuracy and completeness of the information entered to identify vulnerable counties. Second, the WONDER database is similarly reliant on the accuracy and completeness of the information being entered into the death certificates. Third, although the SVI accounts for household age composition (65 years of age or older, 17 years of age or younger), because the study excluded mortalities <15 years of age and used age-adjusted mortality rates for analysis, these have limited the impact of this confounder. Fourth, the distribution of comorbidities, therapeutics, and compliance with treatment were not known as well as diabetes-related noncardiovascular mortality. Fifth, the data are aggregated at the county level rather than at the individual patient level. Sixth, stratification by health insurance status is not available in the WONDER database, which also does not include US nonresidents in its data that might have influenced the results. Seventh, to avoid unreliable (or suppressed) rates from the WONDER database, further stratification by the type of diabetes was not performed. Finally, this analysis did not examine diabetes as the single underlying cause of death with CVD as contributory cause (ie, CVD-related diabetes mortality), which can be a competing diagnosis on death certificates.

In conclusion, counties with greater social vulnerability were associated with higher diabetes-related cardiovascular mortality, particularly among younger adults, female sex, and marginalized racial and ethnic populations. Targeted health programs that are designed to improve treatment and prevention among these demographics with diabetes, as well as joined-up public health policies to address these disparities, are warranted.

ARTICLE INFORMATION

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Supplemental Material

Data S1

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