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ORIGINAL RESEARCH ARTICLE

Social Vulnerability and Premature Cardiovascular Mortality Among US Counties, 2014 to 2018

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BACKGROUND: Substantial differences exist between United States counties with regards to premature (<65 years of age) cardiovascular disease (CVD) mortality. Whether underlying social vulnerabilities of counties influence premature CVD mortality is uncertain.

METHODS: In this cross-sectional study (2014–2018), we linked county-level CDC/ATSDR SVI (Centers for Disease Control and Prevention/Agency for Toxic Substances and Disease Registry Social Vulnerability Index) data with county-level CDC WONDER (Centers for Disease Control and Prevention Wide-Ranging Online Data for Epidemiological Research) mortality data. We calculated scores for overall SVI and its 4 subcomponents (ie, socioeconomic status; household composition and disability; minority status and language; and housing type and transportation) using 15 social attributes. Scores were presented as percentile rankings by county, further classified as quartiles on the basis of their distribution among all US counties (1st [least vulnerable]= 0 to 0.25; 4th [most vulnerable = 0.75 to 1.00]). We grouped age-adjusted mortality rates per 100 000 person-years for overall CVD and its subtypes (ischemic heart disease, stroke, hypertension, and heart failure) for nonelderly (<65 years of age) adults across SVI quartiles.

RESULTS: Overall, the age-adjusted CVD mortality rate per 100 000 person-years was 47.0 (ischemic heart disease, 28.3; stroke, 7.9; hypertension, 8.4; and heart failure, 2.4). The largest concentration of counties with more social vulnerabilities and CVD mortality were clustered across the southwestern and southeastern parts of the United States. The age-adjusted CVD mortality rates increased in a stepwise manner from 1st to 4th SVI quartiles. Counties in the 4th SVI quartile had significantly higher mortality for CVD (rate ratio, 1.84 [95% CI, 1.43–2.36]), ischemic heart disease (1.52 [1.09–2.13]), stroke (2.03 [1.12–3.70]), hypertension (2.71 [1.54–4.75]), and heart failure (3.38 [1.32–8.61]) than those in the 1st SVI quartile. The relative risks varied considerably by demographic characteristics. For example, among all ethnicities/races, non-Hispanic Black adults in the 4th SVI quartile versus the 1st SVI quartile exclusively had significantly higher relative risks of stroke (1.65 [1.07–2.54]) and heart failure (2.42 [1.29–4.55]) mortality. Rural counties with more social vulnerabilities had 2- to 5-fold higher mortality attributable to CVD and subtypes.

CONCLUSIONS: In this analysis, US counties with more social vulnerabilities had higher premature CVD mortality, varied by demographic characteristics and rurality. Focused public health interventions should address the socioeconomic disparities faced by underserved communities to curb the growing burden of premature CVD.

Key Words: cardiovascular disease ■ cross-sectional studies ■ heart failure ■ mortality, premature ■ myocardial ischemia ■ public health

Cardiovascular disease (CVD) accounts for the majority of premature deaths (<65 years of age) in the United States.[1] According to the US Vital Statistics, CVD was among the leading causes of death between 1999 and 2018 in adults <65 years of age.[2] Recent reports have shown that premature CVD

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Clinical Perspective

What is New?

- The United States counties with more social vulnerabilities had higher premature mortality (<65 years of age) attributable to cardiovascular disease and subtypes (ischemic heart disease, stroke, hypertension, and heart failure).
- The cardiovascular disease mortality varied by demographic characteristics and rurality.

What Are the Clinical Implications?

- The challenges faced by socioeconomically deprived counties and rural residents have sizeable public health implications.
- This study may inform future research and policy frameworks to address the social vulnerabilities of underserved populations and mitigate premature cardiovascular disease burden.

Nonstandard Abbreviations and Acronyms

ATSDR	Agency for Toxic Substances and Disease Registry
CDC	Centers for Disease Control and Prevention
COVID-19	coronavirus disease 2019
CVD	cardiovascular disease
HF	heart failure
IHD	ischemic heart disease
ICD-10	*International Classification of Disease 10th Revision*
RR	rate ratio
SDOH	social determinants of health
SVI	social vulnerability index
WONDER	Wide-Ranging Online Data for Epidemiological Research

mortality has increased in most US counties between 2010 and 2017.[3,4] Adverse social circumstances, referred to as social determinants of health (SDOH), including economic instability, poor access to health care, neighborhood deprivation, and racial/ethnic discrimination, predispose underserved communities to adverse CVD outcomes.[5] Moreover, disparities in cardiovascular care originate from various structural barriers that create unhealthy living and working environments, manifesting in economic deprivation and healthcare inequity for underserved populations.[6,7]

The Centers for Disease Control and Prevention (CDC) has proposed a conceptual framework comprising 3 pillars of care: (1) traditional clinical, (2) innovative clinical, and (3) total population or communitywide prevention.[8] This strategy aims to maximize the involvement of clinicians, public health practitioners, and insurers to integrate traditional clinical approaches with community-level factors that can influence health.[8] Assessment of SDOH that can influence cardiovascular health is critical for identifying socioeconomically deprived individuals and communities who may receive significant public health interventions.

The CDC/ATSDR SVI (Centers for Disease Control and Prevention/Agency for Toxic Substances and Disease Registry Social Vulnerability Index) integrates key social elements to determine a community's resilience to encounter natural calamity.[9] The SVI has shown to be a significant determinant of health outcomes, including cognition, disability, and overall mortality.[10,11] However, county-level variation in SVI and its association with premature CVD mortality remains undetermined. Herein, we performed a cross-sectional analysis of the national mortality database to measure the association of SVI with premature CVD mortality across US counties, stratified by demographic characteristics.

METHODS

The CDC's WONDER (Wide-Ranging Online Data for Epidemiological Research) and CDC/ATSDR SVI datasets used in this project are publicly available and are easily replicable from the methods described in the article. Therefore, the data, analytic methods, and study materials will not be made available to other researchers to reproduce the results or replicate the procedure.

Data Source

We used the Underlying Cause of Death files from the CDC WONDER database from 2014 to 2018.[2] This database relies on death certificates for US residents; the underlying cause of death is ascertained from the conditions entered by the physician on the cause of death section of the death certificate. Each death certificate identifies a single cause of death and demographic information. When the physician enters more than 1 cause, the underlying cause is determined by the sequence of conditions on the certificate, provision of the *International Classification of Disease 10th Revision* (*ICD-10*), and associated selection rules and modifications.

Hispanic ethnicity and the decedent's race information is reported by the funeral director as provided by an informant (the surviving next of kin) or, on the basis of observation, in the absence of an informant.[2] Race and Hispanic origin are reported separately on the death certificate as per standards put forth by the Office of Management and Budget.[12] The population estimates were abstracted from the Census Bureau estimates of US national, state, and county resident populations.[13] Race and ethnicity information from the census is by self-report.

We focused on natural deaths attributed to CVD and its subtypes: ischemic heart disease ([IHD] *ICD-10* codes: I20–I25), stroke (*ICD-10* codes: I60–I69), heart failure ([HF] *ICD-10* codes: I50), and hypertension (*ICD-10* codes: I10–I13, I15). We abstracted the number of cause-specific deaths and population sizes for age, sex, and ethnicity/race within the counties and by urban–rural classification of the counties. We restricted our analyses to participants 18 to 64 years of age, further grouped into young (<45 years of age) and middle-aged (45–64 years of age) adults, to focus on premature CVD mortality. For ethnicity/race, we classified study population into non-Hispanic White adults, non-Hispanic Black adults, and Hispanic adults. The prevalence of CVD mortality in non-Hispanic American Indian/Alaskan Native and Asian/Pacific Islander populations among all ethnicities/races was <5% (Figure I in the Data Supplement), with various counties reporting a minimal number of deaths (0–20) and unreliable mortality rates. Therefore, we did not report the analyses for these ethnic/racial groups. We used the National Center for Health Statistics 2013 Urban–Rural Classification Scheme and collapsed county-level population into urban (large metro [≥1 million], medium/small metro [50 000–999 999]), and rural (micropolitan and non-core [nonmetropolitan counties that did not qualify as micropolitan: <50 000]) counties.[14,15]

This study did not require institutional review board approval because the analysis used government-issued public use data without individually identifiable information.

Social Vulnerability Index

We abstracted SVI data from the CDC/ATSDR,[16] which outlines every US census tract on 15 social attributes using the American Community Survey data, and groups them into 4 related themes/social factors: socioeconomic status (below poverty, unemployed, income, no high school diploma); household composition and disability (≥65 years of age; ≤17 years of age; ≥5 years of age with a disability; single-parent households), minority status and language (minority; speak English "less than well"); and housing type and transportation (multi-unit structure, mobile home, crowding, no vehicle, group quarters).

In addition to census tract–level rankings, SVI files also provide corresponding rankings at the county level,[17] on the basis of the same method that measures census tract rankings. Accordingly, we estimated percentile ranking for the 15 individual variables, 4 themes, and overall position/overall SVI within the county, across counties within a particular state, and across the entire United States.[17] The percentile rank ranges from 0 to 1, with higher values exhibiting greater vulnerability than the lower values. In addition, given that the minority theme (all persons except non-Hispanic White adults) is part of SVI, which may influence the mortality estimates for ethnicity/race category, we also generated a modified SVI by excluding the minority theme and developed a modified percentile ranking for each county (Figure II in the Data Supplement). Additional details are reported in the Data Supplement.

Statistical Analysis

Because SVI was a county-level metric, we estimated age-adjusted (to the 2000 US population)[18] mortality rates per 100 000 person-years with 95% CIs for overall CVD and subtypes (IHD, stroke, HF, hypertension), and demographic groups within the counties (age, sex, ethnicity/race). We also stratified analyses by subgroups for the counties (ie, urban and rural). The continuous variables (eg, social attributes used in SVI) were presented as median and interquartile ranges (Table I in the Data Supplement). We classified the percentile rankings for overall (Figure 1) and modified SVI (Figure II in the Data Supplement) into quartiles (1st [least vulnerable], 0–0.25; 4th [most vulnerable], 0.75–1.00). We also classified percentile rankings for the 4 components/themes of SVI (Figure III through VI in the Data Supplement). We then aggregated age-adjusted mortality rates across overall and modified SVI quartiles. Because we aggregated across counties for these analyses, we included all counties regardless of population size and death counts.[19]

We estimated rate ratio (RR) and associated CIs (on the basis of approximation)[20] by comparing county-specific, age-adjusted mortality rates between the most vulnerable (4th) and least vulnerable (1st) SVI quartiles; 95% CIs that do not cross 1 were considered statistically significant. We used R Project for Statistical Computing (4.0.3) and Tableau 2020.4 for all analyses.

RESULTS

A total of 3143 (100%) US counties (Figure 1) were included in the analysis. The largest concentration of counties with more social vulnerabilities and CVD mortality were clustered across the southwestern and southeastern parts of the United States. Between 2014 and 2018, CVD deaths were 607 773 (1 064 785 064 person-years), amounting to an age-adjusted mortality

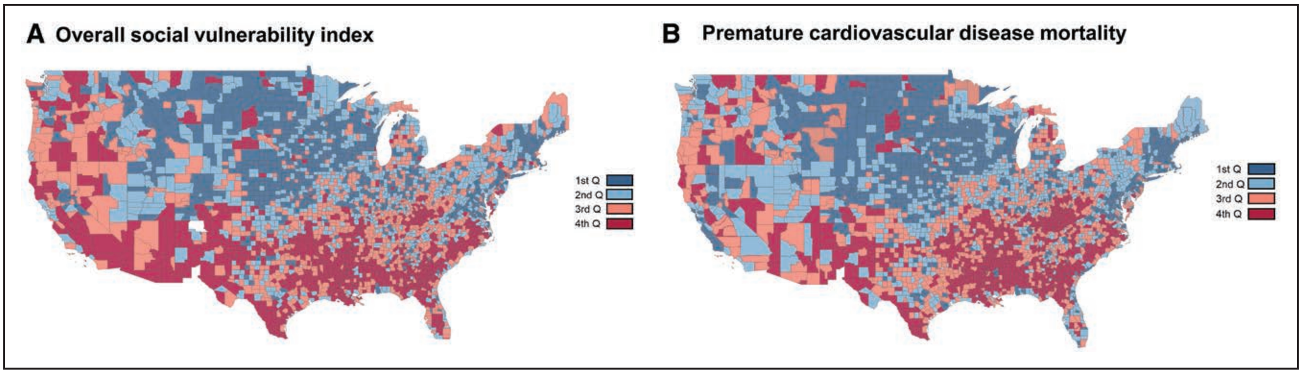

Figure 1. Social vulnerability index and premature cardiovascular disease mortality in the US, 2004–2018.
A, Counties by social vulnerability index quartiles, and (**B**) by age-adjusted cardiovascular disease mortality rates per 100 000 among adults <65 years of age, by social vulnerability index quartiles. Q indicates quartile.

rate of 47.0 (95% CI, 46.9–47.2). The age-adjusted mortality rate attributed to IHD was 28.3 ([28.2–28.4]; n=370 737); stroke, 7.9 ([7.8–8.0]; n=100 177); hypertension, 8.4 ([8.3–8.5]; n=109 941); and HF (2.4 [2.3–2.5]; n=31 918). Overall, age-adjusted CVD mortality rates were higher for middle-aged adults, men, and non-Hispanic Black individuals than their counterparts. Rural counties had higher age-adjusted CVD mortality rates than urban counties.

CVD Mortality

The age-adjusted CVD mortality rates were highest in the 4th SVI quartile (61.8 [95% CI, 61.3–62.2]) and lowest in the 1st SVI quartile (33.6 [33.3–43.0]; Table 1; RR, 1.84 [1.43–2.36]; Table 2). The mortality rates increased in a stepwise manner from lowest to highest SVI quartile. The RRs varied considerably across demographic subgroups. For example, young adults (RR, 2.10 [1.25–2.36]), and women (2.09 [1.53–2.86]) in the 4th SVI quartile had 2-fold higher CVD mortality than those in the 1st SVI quartile (Table 2). Both non-Hispanic White (1.72 [1.32–2.24]) and non-Hispanic Black (1.56 [1.28–1.91]) adults in the 4th SVI quartile had significantly higher RRs of CVD mortality than those in the 1st SVI quartile. Rural counties (2.13 [1.72–2.64]) had double the mortality risk in the 4th versus 1st SVI quartile. In analyses according to the modified SVI quartile, the gradient effect across 1st to 4th SVI quartile was consistent for overall CVD mortality and by age and sex stratification (Table II in the Data Supplement). For ethnicity/race, residents of counties with the greatest social vulnerabilities (4th SVI quartile) had significantly higher mortality rates than those living in the lowest social vulnerabilities (1st SVI quartile).

IHD and Stroke Mortality

The age-adjusted IHD mortality rates were highest in the 4th SVI quartile (34.4 [34.1–34.8]) and lowest in the 1st SVI quartile (22.5 [22.2–22.8]; RR, 1.52 [1.09–2.13]; Table III in the Data Supplement). Similarly, the age-adjusted stroke mortality rates were highest in the 4th SVI quartile (10.8 [10.6–11.0]) and lowest in the 1st SVI quartile (5.3 [5.2–5.4]; RR, 2.03 [1.12–3.70]; Table IV in the Data Supplement). The mortality rates attributable to IHD and stroke increased from lowest to highest SVI quartiles (Figure 2). Middle-aged adults, both sexes, and non-Hispanic White and non-Hispanic Black individuals in the 4th SVI quartile versus the 1st SVI quartile had significantly higher RRs of IHD mortality. Non-Hispanic Black adults in the 4th SVI quartile versus the 1st SVI quartile exclusively had higher RR of stroke mortality (1.65 [1.07–2.54]) in the ethnicity/race group.

Hypertension and HF Mortality

The age-adjusted hypertension mortality rates were 12.2 (12.0–12.3) in the 4th SVI quartile and 4.5 (4.4–4.7) in the 1st SVI quartile (RR, 2.71 [1.54–4.75]; Table V in the Data Supplement). Similarly, age-adjusted HF mortality rates were 4.4 (4.3–4.5) in the 4th SVI quartile and 1.3 (1.1–1.4) in the 1st SVI quartile (RR, 3.38 [1.32–8.61]; Table VI in the Data Supplement). The RRs varied among demographic subgroups. Among all ethnicities/races, non-Hispanic Black adults in the 4th SVI quartile versus the 1st SVI quartile exclusively had higher RR of HF mortality (2.42 [1.29–4.55]). In addition, rural counties demonstrated 3- and 5-fold higher mortality rates attributable to hypertension and HF, respectively.

Table 1. Age-Adjusted Cardiovascular Disease Mortality Rates Per 100 000 (With 95% Confidence Intervals) Among Adults <65 Years of Age, by Social Vulnerability Index Across US Counties, 2014 to 2018

		Quartile			
Variable	Total	1st	2nd	3rd	4th
Overall	47.0 (46.9–47.2)	33.6 (33.3–34.0)	43.6 (43.4–43.8)	49.3 (49.1–49.5)	61.8 (61.3–62.2)
Age, y					
<45	10.2 (10.1–10.3)	6.9 (6.7–7.1)	9.3 (9.1–9.4)	10.5 (10.4–10.6)	14.5 (14.2–14.8)
45–64	119.6 (119.2–119.9)	86.2 (85.3–87.1)	111.0 (110.5–111.5)	125.6 (125.1–126.1)	154.6 (153.5–155.7)
Sex					
Men	66.2 (66.0–66.4)	48.8 (48.2–49.4)	61.7 (61.4–62.1)	69.2 (68.9–69.5)	85.7 (85.0–86.5)
Women	28.7 (28.6–28.9)	18.8 (18.4–19.1)	26.2 (26.0–26.4)	30.3 (30.1–30.5)	39.4 (39.0–39.9)
Ethnicity/race					
Non-Hispanic White	44.9 (44.7–45.0)	32.6 (32.2–32.9)	40.4 (40.2–40.6)	50.4 (50.1–50.6)	56.2 (55.7–56.8)
Non-Hispanic Black	87.7 (87.2–88.2)	62.6 (60.4–64.7)	82.9 (82.1–83.6)	89.4 (88.6–90.2)	98.0 (96.9–99.2)
Hispanic	31.2 (30.9–31.5)	23.0 (21.7–24.3)	28.5 (28.0–29.0)	32.7 (32.3–33.0)	31.1 (30.2–32.1)
County type					
Urban	44.6 (44.4–44.7)	31.7 (31.3–32.0)	42.7 (42.5–42.9)	46.0 (45.8–46.2)	56.1 (55.6–56.5)
Rural	61.6 (61.2–62.0)	39.4 (38.6–40.1)	49.7 (49.1–50.2)	73.1 (72.5–73.8)	84.2 (83.1–85.3)

Table 2. Association Between 4th (Highest Vulnerability) Versus 1st (Lowest Vulnerability) Social Vulnerability Index Quartile for Age-Adjusted Mortality Rates for Cardiovascular Disease and Its Subtypes Among Adults <65 Years of Age in US Counties, 2014 to 2018.

Variable	Cardiovascular disease (n = 607 773)	Ischemic heart disease (n = 370 737)	Stroke (n = 100 177)	Hypertension (n = 109 941)	Heart failure (n = 31 918)
Overall	1.84 (1.43–2.36)	1.52 (1.09–2.13)	2.03 (1.12–3.70)	2.71 (1.54–4.75)	3.38 (1.32–8.61)
Age, y					
<45	2.10 (1.25–3.51)	1.76 (0.83–3.73)	2.07 (0.65–6.54)	2.92 (1.06–7.99)	3.33 (0.46–23.66)
45– 64	1.79 (1.53–2.10)	1.49 (1.21–1.84)	2.02 (1.37–2.96)	2.62 (1.81–3.78)	3.46 (1.92–6.24)
Sex					
Men	1.75 (1.41–2.17)	1.46 (1.10–1.92)	2.18 (1.26–3.77)	2.53 (1.55–4.12)	3.50 (1.52–8.01)
Women	2.09 (1.53–2.86)	1.83 (1.17–2.87)	1.91 (0.98–3.70)	3.07 (1.55–6.07)	3.20 (1.06–9.57)
Ethnicity/race					
Non-Hispanic White	1.72 (1.32–2.24)	1.56 (1.12–2.18)	1.71 (0.81–3.38)	2.29 (1.20–4.34)	2.90 (0.97–8.70)
Non-Hispanic Black	1.56 (1.28–1.91)	1.38 (1.02–1.86)	1.65 (1.07–2.54)	1.62 (1.09–2.42)	2.42 (1.29–4.55)
Hispanic	1.35 (0.95–1.92)	1.35 (0.85–2.15)	1.24 (0.58–2.67)	1.67 (0.71–3.96)	0.78 (0.12–5.09)
County type					
Urban	1.76 (1.36–2.30)	1.51 (1.06–2.15)	1.90 (1.01–3.56)	2.41 (1.35–4.29)	2.92 (1.06–7.99)
Rural	2.13 (1.72–2.64)	1.69 (1.28–2.25)	2.56 (1.54–4.27)	3.60 (2.14–6.03)	5.75 (2.72–12.12)

DISCUSSION

In this analysis, counties with more social vulnerabilities had higher premature CVD mortality, varied by demographic characteristics and rurality. For example, women living in counties with social vulnerabilities had 2-fold higher CVD mortality, and non-Hispanic Black residents of the most vulnerable counties had higher RRs of stroke and HF mortality than those in the least vulnerable counties. In addition, rural counties with significant social vulnerabilities had markedly higher CVD mortality rates. Our findings highlight the socioeconomic disparities faced by county residents and their impact on overall and cause-specific premature CVD mortality.

Other measures of SDOH, such as the area deprivation index[21] or social deprivation index,[22] share an overarching theme with SVI. However, in contrast with SVI, area deprivation index predominantly focuses on economic deprivation,[21] and the social deprivation index covers limited social characteristics (poverty; <12 years of education; single-parent household; rented housing unit; overcrowded housing unit; household without a car; nonemployed adults ≤65 years of age), making it a relatively narrower SDOH scale.[22] In addition, the SVI covers some unique variables (eg, minority status; English language insufficiency; elderly [>65 years of age]; children [<18 years of age]; >5 years of age with a disability), thereby

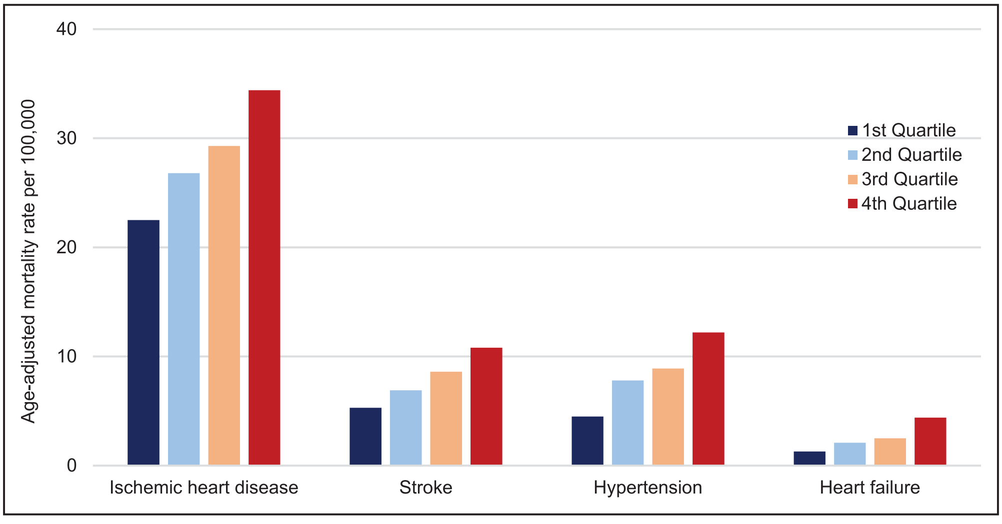

Figure 2. **Age-adjusted mortality rates per 100 000 for cardiovascular disease subtypes among adults <65 years of age, by social vulnerability index quartiles across US counties, 2014–2018.**

forming a broader scale with which to measure the social risk of communities.

We noted that women living in more socially vulnerable counties had double the risk of premature CVD mortality than those in less vulnerable counties. Overall, CVD mortality has increased in women during the last 2 decades in the United States, mainly driven by mortality among women 25 to 34 years of age and 55 to 64 years of age.[23,24] Women face considerable barriers to equitable living and working conditions, including lower educational attainment and incomes; greater financial dependence; and gendered societal roles that may affect their health and wellbeing.[25] A recent county-level analysis showed that an increase in economic prosperity metric was associated with fewer CVD deaths in middle-aged women.[26] In addition, systemic factors may exacerbate the social burden experienced by women and worsen CVD outcomes. For example, evidence showed that after adjusting for education, employment, income, insurance status, marital status, and contact with health care, women with atherosclerotic CVD were more likely to experience poor patient–provider communication, lower health care satisfaction, poor perceived health status, and lower health-related quality of life, relative to men.[27] While many of these structural barriers are not captured by the SVI, they may contribute to the observed disparities as underlying determinants of CVD mortality, indicating greater disadvantage for women.

Non-Hispanic Black residents of the most vulnerable counties had the highest CVD mortality among all ethnicities/races. In particular, relative estimates of stroke and HF mortality were exclusively higher in non-Hispanic Black individuals. The excess CVD mortality is attributable to many factors, including suboptimal CVD profile and adverse SDOH.[28] In the REGARDS study (Reasons for Geographic and Racial Disparities in Stroke), Black individuals had a 34% higher RR of stroke after adjusting for age and gender.[29] Another study reported that non-Hispanic Black individuals were more likely to live in socially deprived census tracts and had a higher proportion of chronic comorbidities and 30-day adverse event rates with HF.[28] Data have shown that hospitals that treat a high volume of non-Hispanic Black individuals were more frequently penalized by the Centers for Medicare and Medicaid Services' value-based programs, even after adjusting for safety-net status.[30] In this perspective, concerted multifaceted efforts focusing on social, financial, and health systems are mandated to mitigate social disparities experienced by these ethnic/racial minorities.

The rural–urban mortality difference has widened between 1999 and 2019 in the United States, with a substantial rise in the total and CVD mortality for rural residents 25 to 64 years of age.[14,31]

Demographic changes, socioeconomic meltdown, neighborhood disadvantage, and limited health care access predispose underserved rural residents to adverse CVD outcomes.[14,19,31] These findings also carry implications: consider the striking health disparities faced by rural residents, as well as ethnic/racial minorities, during the coronavirus disease 2019 (COVID-19) pandemic. For example, a recent CDC report showed that US counties with the highest social vulnerabilities—particularly in rural areas and those with a higher proportion of ethnic/racial minority residents—were more prone to become COVID-19 hotspots.[9] Another population-based study found that SDOH burden was associated with lower adherence to COVID-19 risk-limiting practices.[32] The socioeconomic challenges faced by rural residents have sizeable health implications and require widespread public health efforts to address social vulnerabilities and close the rural–urban mortality gap.

The findings of this study carry significant implications. For advancing the cause of health equity, policy efforts should advocate for integrating SDOH into existing clinical delivery support systems and promote investments in developing social risk assessment tools that enable health care providers to target socially vulnerable populations.[33,34] This must be accompanied by workforce training to provide SDOH-informed care to underserved and marginalized populations. Ideally, in-person visits should take precedence over telehealth for social and health assessment of the patient. Telehealth services are critical for the health care settings and have been instrumental in maintaining physical distancing during the COVID-19 pandemic. However, considering that up to 10% of the US population lack broadband access,[35] a widespread adaptation to telehealth delivery may further the digital divide and indirectly deteriorate cardiovascular care. State programs, such as Medicaid expansion, have improved cardiovascular outcomes and reduced gaps in care.[36] Since nearly 30% of Medicaid enrollees have CVD, expanding Medicaid services to nonelderly adults facing adverse social circumstances may narrow the health disparities.[36] Last, extending care outside the clinical setting and using population- and community-wide interventions may yield considerable health gains.[9] For example, Massachusetts successfully expanded its cost-free insurance Medicaid coverage for tobacco cessation programs (medications, patient counseling, and public information campaigns).[37]

Our study has several limitations. We could not establish causality or the direction of association because of the cross-sectional design. For example, the probability of reverse association exists (ie, worsening social vulnerability because of increasing CVD mortality). The SVI is a broad measure of social disadvantage and does not cover relevant social elements such as food insecurity, community/social contextual factors, and barriers to health care access. Besides age, mortality rates were not adjusted for other demographic characteristics or traditional CVD risk factors. Therefore, residual confounding attributable to these variables could not be accounted

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for. Since we performed aggregate-level analyses at the county level and not each individual with a death record in the CDC WONDER database, individual-level inferences cannot be made. Potential miscoding issues may exist, especially during the cause of death determination on the death certificates.

The data on non-Hispanic American Indian/Alaskan Native and Asian/Pacific Islander were not reported because of unreliable mortality estimates. On the same note, the minority theme in the SVI could potentially influence the results. Therefore, we performed additional analyses using a modified SVI (excluding minority theme) scale, and the results showed consistently higher CVD mortality rates between the 4th versus 1st SVI quartiles for ethnicities/races. Last, among large urban counties, within-county variation probably exists as they may have a mix of census tracts with a large differential in SVI. However, the CDC provided the margin of error to describe the precision of measures and was reasonably reliable for estimating county-level SVI rankings.[38]

In summary, premature CVD mortality was higher in counties with more significant social vulnerabilities. These findings illustrate the socioeconomic, demographic, and geographical distributions of premature CVD mortality. This information may inform future research and policy and help identify socially vulnerable populations that may benefit from evidence-based public health interventions.

ARTICLE INFORMATION

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Supplemental Materials

Data Supplement Figures I–VI

Data Supplement Tables I–VI

REFERENCES

1. Andersson C, Vasan RS. Epidemiology of cardiovascular disease in young individuals. *Nat Rev Cardiol.* 2018;15:230–240. doi: 10.1038/nrcardio.2017.154
2. Centers for Disease Control and Prevention (CDC) Wide-Ranging Online Data for Epidemiologic Research (WONDER). Underlying Cause of Death 1999-2019. Accessed December 6, 2020. https://wonder.cdc.gov/wonder/help/ucd.html#
3. Ritchey MD, Wall HK, George MG, Wright JS. US trends in premature heart disease mortality over the past 50 years: where do we go from here? *Trends Cardiovasc Med.* 2020;30:364–374. doi: 10.1016/j.tcm.2019.09.005
4. Roth GA, Dwyer-Lindgren L, Bertozzi-Villa A, Stubbs RW, Morozoff C, Naghavi M, Mokdad AH, Murray CJL. Trends and patterns of geographic variation in cardiovascular mortality among US counties, 1980-2014. *JAMA.* 2017;317:1976–1992. doi: 10.1001/jama.2017.4150
5. Havranek EP, Mujahid MS, Barr DA, Blair IV, Cohen MS, Cruz-Flores S, Davey-Smith G, Dennison-Himmelfarb CR, Lauer MS, Lockwood DW, et al; American Heart Association Council on Quality of Care and Outcomes Research, Council on Epidemiology and Prevention, Council on Cardiovascular and Stroke Nursing, Council on Lifestyle and Cardiometabolic Health, and Stroke Council. Social determinants of risk and outcomes for cardiovascular disease: a scientific statement from the American Heart Association. *Circulation.* 2015;132:873–898. doi: 10.1161/CIR.0000000000000228
6. Graham G. Disparities in cardiovascular disease risk in the United States. *Curr Cardiol Rev.* 2015;11:238–245. doi: 10.2174/1573403x11666141122220003
7. Carnethon MR, Pu J, Howard G, Albert MA, Anderson CAM, Bertoni AG, Mujahid MS, Palaniappan L, Taylor HA Jr, Willis M, et al; American Heart Association Council on Epidemiology and Prevention; Council on Cardiovascular Disease in the Young; Council on Cardiovascular and Stroke Nursing; Council on Clinical Cardiology; Council on Functional Genomics and Translational Biology; and Stroke Council. Cardiovascular health in African Americans: a scientific statement from the American Heart Association. *Circulation.* 2017;136:e393–e423. doi: 10.1161/CIR.0000000000000534
8. Auerbach J. The 3 buckets of prevention. *J Public Health Manag Pract.* 2016;22:215–218. doi: 10.1097/PHH.0000000000000381
9. Dasgupta S, Bowen VB, Leidner A, Fletcher K, Musial T, Rose C, Cha A, Kang G, Dirlikov E, Pevzner E, et al. Association between social vulnerability and a county's risk for becoming a COVID-19 hotspot - United States, June 1-July 25, 2020. *MMWR Morb Mortal Wkly Rep.* 2020;69:1535–1541. doi: 10.15585/mmwr.mm6942a3
10. Wallace LM, Theou O, Pena F, Rockwood K, Andrew MK. Social vulnerability as a predictor of mortality and disability: cross-country differences in the survey of health, aging, and retirement in Europe (SHARE). *Aging Clin Exp Res.* 2015;27:365–372. doi: 10.1007/s40520-014-0271-6
11. Armstrong JJ, Andrew MK, Mitnitski A, Launer LJ, White LR, Rockwood K. Social vulnerability and survival across levels of frailty in the Honolulu-Asia Aging Study. *Age Ageing.* 2015;44:709–712. doi: 10.1093/ageing/afv016
12. Burhansstipanov L, Satter DE. Office of Management and Budget racial categories and implications for American Indians and Alaska Natives. *Am J Public Health.* 2000;90:1720–1723. doi: 10.2105/ajph.90.11.1720
13. United States Census. Population and Housing Unit Estimates. Accessed December 25, 2020. https://www.census.gov/programs-surveys/popest.html
14. Cross SH, Mehra MR, Bhatt DL, Nasir K, O'Donnell CJ, Califf RM, Warraich HJ. Rural-urban differences in cardiovascular mortality in the US, 1999–2017. *JAMA.* 2020;323:1852–1854. doi: 10.1001/jama.2020.2047
15. Spencer JC, Wheeler SB, Rotter JS, Holmes GM. Decomposing mortality disparities in urban and rural U.S. counties. *Health Serv Res.* 2018;53:4310–4331. doi: 10.1111/1475-6773.12982
16. Agency for Toxic Substances and Disease Registry. CDC/ATSDR Social Vulnerability Index. Accessed December 6, 2020. https://www.atsdr.cdc.gov/placeandhealth/svi/index.html
17. Centers for Disease Control. CDC SVI 2018 Documentation - 1/31/2020. Accessed December 6, 2020. https://svi.cdc.gov/Documents/Data/2018_SVI_Data/SVI2018Documentation.pdf
18. Hoyert DL, Anderson RN. Age-adjusted death rates: trend data based on the year 2000 standard population. *Natl Vital Stat Rep.* 2001;49:1–6.
19. Shiels MS, Berrington de González A, Best AF, Chen Y, Chernyavskiy P, Hartge P, Khan SQ, Pérez-Stable EJ, Rodriquez EJ, Spillane S, et al. Premature mortality from all causes and drug poisonings in the USA according to socioeconomic status and rurality: an analysis of death certificate data

by county from 2000-15. *Lancet Public Health.* 2019;4:e97–e106. doi: 10.1016/S2468-2667(18)30208-1
20. Rothman KJ. *Epidemiology: An Introduction*. Oxford University Press; 2012.
21. Knighton AJ, Savitz L, Belnap T, Stephenson B, VanDerslice J. Introduction of an area deprivation index measuring patient socioeconomic status in an integrated health system: implications for population health. *EGEMS (Wash DC).* 2016;4:1238. doi: 10.13063/2327-9214.1238
22. The Robert Graham Center. Social Deprivation Index (SDI). Accessed December 6, 2020. https://www.graham-center.org/rgc/maps-data-tools/sdi/social-deprivation-index.html
23. Sidney S, Quesenberry CP Jr, Jaffe MG, Sorel M, Nguyen-Huynh MN, Kushi LH, Go AS, Rana JS. Recent trends in cardiovascular mortality in the United States and public health goals. *JAMA Cardiol.* 2016;1:594–599. doi: 10.1001/jamacardio.2016.1326
24. Khan SU, Yedlapati SH, Lone AN, Khan MS, Wenger NK, Watson KE, Gulati M, Hays AG and Michos ED. A comparative analysis of premature heart disease- and cancer-related mortality in women in the USA, 1999–2018. *Eur Heart J Qual Care Clin Outcomes.* 2021. 10.1093/ehjqcco/qcaa099
25. Shaw LJ, Pepine CJ, Xie J, Mehta PK, Morris AA, Dickert NW, Ferdinand KC, Gulati M, Reynolds H, Hayes SN, et al. Quality and equitable health care gaps for women: attributions to sex differences in cardiovascular medicine. *J Am Coll Cardiol.* 2017;70:373–388. doi: 10.1016/j.jacc.2017.05.051
26. Khatana SAM, Venkataramani AS, Nathan AS, Dayoub EJ, Eberly LA, Kazi DS, Yeh RW, Mitra N, Subramanian SV, Groeneveld PW. Association between county-level change in economic prosperity and change in cardiovascular mortality among middle-aged US adults. *JAMA.* 2021;325:445–453. doi: 10.1001/jama.2020.26141
27. Okunrintemi V, Valero-Elizondo J, Patrick B, Salami J, Tibuakuu M, Ahmad S, Ogunmoroti O, Mahajan S, Khan SU, Gulati M, et al. Gender differences in patient-reported outcomes among adults with atherosclerotic cardiovascular disease. *J Am Heart Assoc.* 2018;7:e010498. doi: 10.1161/JAHA.118.010498
28. Patel SA, Krasnow M, Long K, Shirey T, Dickert N, Morris AA. Excess 30-day heart failure readmissions and mortality in Black patients increases with neighborhood deprivation. *Circ Heart Fail.* 2020;13:e007947. doi: 10.1161/CIRCHEARTFAILURE.120.007947
29. Reshetnyak E, Ntamatungiro M, Pinheiro LC, Howard VJ, Carson AP, Martin KD, Safford MM. Impact of multiple social determinants of health on incident stroke. *Stroke.* 2020;51:2445–2453. doi: 10.1161/STROKEAHA.120.028530
30. Aggarwal R, Hammond JG, Joynt Maddox KE, Yeh RW, Wadhera RK. Association between the proportion of Black patients cared for at hospitals and financial penalties under value-based payment programs. *JAMA.* 2021;325:1219–1221. doi: 10.1001/jama.2021.0026
31. Cross SH, Califf RM, Warraich HJ. Rural-urban disparity in mortality in the US from 1999 to 2019. *JAMA.* 2021;325:2312–2314. doi: 10.1001/jama.2021.5334
32. Hagan KK, Javed Z, Cainzos-Achirica M, Sostman D, Vahidy FS, Valero-Elizondo J, Acquah I, Yahya T, Kash B, Andrieni JD, et al. Social determinants of adherence to COVID-19 risk mitigation measures among adults with cardiovascular disease. *Circ Cardiovasc Qual Outcomes.* 2021;14:e008118. doi: 10.1161/CIRCOUTCOMES.121.008118
33. Schultz WM, Kelli HM, Lisko JC, Varghese T, Shen J, Sandesara P, Quyyumi AA, Taylor HA, Gulati M, Harold JG, et al. Socioeconomic status and cardiovascular outcomes: challenges and interventions. *Circulation.* 2018;137:2166–2178. doi: 10.1161/CIRCULATIONAHA.117.029652
34. Khoury MJ, Iademarco MF, Riley WT. Precision public health for the era of precision medicine. *Am J Prev Med.* 2016;50:398–401. doi: 10.1016/j.amepre.2015.08.031
35. Anderson M, Perrin A, Jiang J and Kumar M. 10% of Americans don't use the internet. Who are they. *Pew Research Center.* 2019;22.
36. Khatana SAM, Bhatla A, Nathan AS, Giri J, Shen C, Kazi DS, Yeh RW, Groeneveld PW. Association of Medicaid expansion with cardiovascular Mortality. *JAMA Cardiol.* 2019;4:671–679. doi: 10.1001/jamacardio.2019.1651
37. Warner DD, Land TG, Rodgers AB, Keithly L. Integrating tobacco cessation quitlines into health care: Massachusetts, 2002–2011. *Prev Chronic Dis.* 2012;9:E133. doi: 10.5888/pcd9.110343
38. Hughes MM, Wang A, Grossman MK, Pun E, Whiteman A, Deng L, Hallisey E, Sharpe JD, Ussery EN, Stokley S, et al. County-level COVID-19 vaccination coverage and social vulnerability - United States, December 14, 2020–March 1, 2021. *MMWR Morb Mortal Wkly Rep.* 2021;70:431–436. doi: 10.15585/mmwr.mm7012e1