HHS Public Access
Author manuscript
JAMA. Author manuscript; available in PMC 2017 September 14.

Published in final edited form as:
JAMA. 2017 May 16; 317(19): 1976–1992. doi:10.1001/jama.2017.4150.

Trends and Patterns of Geographic Variation in Cardiovascular Mortality Among US Counties, 1980–2014

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Abstract

IMPORTANCE—In the United States, regional variation in cardiovascular mortality is well-known but county-level estimates for all major cardiovascular conditions have not been produced.

OBJECTIVE—To estimate age-standardized mortality rates from cardiovascular diseases by county.

DESIGN AND SETTING—Deidentified death records from the National Center for Health Statistics and population counts from the US Census Bureau, the National Center for Health Statistics, and the Human Mortality Database from 1980 through 2014 were used. Validated small area estimation models were used to estimate county-level mortality rates from all cardiovascular diseases, including ischemic heart disease, cerebrovascular disease, ischemic stroke, hemorrhagic stroke, hypertensive heart disease, cardiomyopathy, atrial fibrillation and flutter, rheumatic heart disease, aortic aneurysm, peripheral arterial disease, endocarditis, and all other cardiovascular diseases combined.

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Statistical analysis: Roth, Dwyer-Lindgren, Bertozzi-Villa, Stubbs, Naghavi.
Obtained funding: Mokdad, Murray.
Administrative, technical, or material support: Roth, Morozoff, Mokdad, Murray.
Supervision: Roth, Naghavi, Mokdad, Murray.

Conflict of Interest Disclosures: The authors have completed and submitted the ICMJE Form for Disclosure of Potential Conflicts of Interest and none were reported.

Additional Contributions: We thank Shreya Shirude, MPH, Charlton Callender, BS, and Samuel B Finegold, BA (all with the Institute for Health Metrics and Evaluation, University of Washington), who provided assistance in preparing the manuscript and were compensated for their work.

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EXPOSURES—The 3110 counties of residence.

MAIN OUTCOMES AND MEASURES—Age-standardized cardiovascular disease mortality rates by county, year, sex, and cause.

RESULTS—From 1980 to 2014, cardiovascular diseases were the leading cause of death in the United States, although the mortality rate declined from 507.4 deaths per 100 000 persons in 1980 to 252.7 deaths per 100 000 persons in 2014, a relative decline of 50.2% (95% uncertainty interval [UI], 49.5%–50.8%). In 2014, cardiovascular diseases accounted for more than 846 000 deaths (95% UI, 827–865 thousand deaths) and 11.7 million years of life lost (95% UI, 11.6–11.9 million years of life lost). The gap in age-standardized cardiovascular disease mortality rates between counties at the 10th and 90th percentile declined 14.6% from 172.1 deaths per 100 000 persons in 1980 to 147.0 deaths per 100 000 persons in 2014 (posterior probability of decline >99.9%). In 2014, the ratio between counties at the 90th and 10th percentile was 2.0 for ischemic heart disease (119.1 vs 235.7 deaths per 100 000 persons) and 1.7 for cerebrovascular disease (40.3 vs 68.1 deaths per 100 000 persons). For other cardiovascular disease causes, the ratio ranged from 1.4 (aortic aneurysm: 3.5 vs 5.1 deaths per 100 000 persons) to 4.2 (hypertensive heart disease: 4.3 vs 17.9 deaths per 100 000 persons). The largest concentration of counties with high cardiovascular disease mortality extended from southeastern Oklahoma along the Mississippi River Valley to eastern Kentucky. Several cardiovascular disease conditions were clustered substantially outside the South, including atrial fibrillation (Northwest), aortic aneurysm (Midwest), and endocarditis (Mountain West and Alaska). The lowest cardiovascular mortality rates were found in the counties surrounding San Francisco, California, central Colorado, northern Nebraska, central Minnesota, northeastern Virginia, and southern Florida.

CONCLUSIONS AND RELEVANCE—Substantial differences exist between county ischemic heart disease and stroke mortality rates. Smaller differences exist for diseases of the myocardium, atrial fibrillation, aortic and peripheral arterial disease, rheumatic heart disease, and endocarditis.

Cardiovascular disease remains the leading cause of death in the United State despite declines in the national cardiovascular disease mortality rate between 1980 and 2015.[1] Mortality rates for smaller regions of the country such as counties can differ substantially from the national average.[2] County-level differences in mortality rates have important implications for local and national health policy.[3]

Death certificates remain an essential source of data for measuring long-term trends in public health.[4] Prior examinations of county-level cardiovascular disease mortality have been limited to only heart disease or stroke and have not accounted for the way in which deaths are attributed to other important cardiovascular disease or intermediate and nonspecific causes.

To examine geographic variation in cardiovascular disease mortality rates, death records from 1980 through 2014 were used to produce consistent and comparable estimates of cardiovascular disease mortality for all US counties.

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Methods

This analysis used methods that are reported in detail elsewhere[5] and described briefly herein. This research received institutional review board approval from the University of Washington (human subjects application 46665). Informed consent was not required because the study used deidentified data and was retrospective.

Data

This analysis used deidentified death records from the National Center for Health Statistics[6] and population counts from the US Census Bureau,[7] the National Center for Health Statistics,[8–10] and the Human Mortality Database.[11] Cause of death was available as an *International Classification of Diseases, Ninth Revision (ICD-9)* code prior to 1999 and as an *International Statistical Classification of Diseases and Related Health Problems, Tenth Revision (ICD-10)* code after 1999.

Deaths and population were tabulated by county, age group (0, 1–4, 5–9, …, 75–79, and ≥80 years), sex, year, and cause. County-level information on levels of education, income, race/ethnicity, Native American reservations, and population density derived from data that were provided by the US Census Bureau and the National Center for Health Statistics also were used. More detail on these data sources is provided in eTable 1 in the Supplement. In a small number of cases, counties were combined to ensure historically stable units of analysis. A description of which counties were grouped together appears in eTable 2 in the Supplement.

Cause List and Redistribution of Nonspecific and Intermediate Causes of Death

The cause list developed for the Global Burden of Disease study[1] was used for this analysis. This cause list is arranged hierarchically in 4 levels; within each level, the list is designed such that all deaths are assigned exactly 1 cause. All the causes from the Global Burden of Disease study cause list and the *ICD-9* and *ICD-10* codes that correspond to each cause appear in eTable 3 in the Supplement. The rules from the World Health Organization regarding use of the *ICD* codes require that the initiating condition of the causal chain of events leading to death be reported as the underlying cause of death. For example, ischemic heart disease has been considered an underlying cause of death across multiple revisions of the *ICD*.

Previous studies have documented the existence of nonspecific or intermediate causes in death registration data that may lead to misleading geographic and temporal patterns (for example, generalized atherosclerosis or heart failure assigned as an underlying cause of death).[12,13] Algorithms developed for the Global Burden of Disease study[1] were used to reallocate deaths assigned one of the “garbage codes” to plausible alternatives. First, plausible target causes were assigned for each garbage code or group of garbage codes. Second, deaths were reassigned to specified target codes according to proportions derived in 1 of 4 ways: (1) published literature or expert opinion; (2) regression models; (3) according to the proportions initially observed among targets; and (4) for human immunodeficiency virus and AIDS specifically, by comparison to years before human immunodeficiency virus and AIDS became widespread. Although the focus of this study is cardiovascular diseases, all causes (ie, both cardiovascular diseases and other causes) were analyzed concurrently.

Small Area Models

Bayesian, spatially explicit mixed-effects regression models were estimated for all-cause mortality and for each cause in the Global Burden of Disease study[1] hierarchy separately for males and females. The model for each cause was specified as:

$$D_{j,t,a} \sim \text{Poisson}\left(\mathrm{m_{j,t,a}} \cdot \mathrm{P_{j,t,a}}\right)$$
$$\log\left(\mathrm{m_{j,t,a}}\right)=\beta_0+\beta_1 \cdot \mathrm{X_{j,t}}+\gamma_{1,a,t}+\gamma_{2,j}+\left(\gamma_{3,j} \cdot t+\gamma_{4,j,t}\right)+\left(\gamma_{5,j} \cdot a+\gamma_{6,j,a}\right)$$

where $D_{j,t,a}$, $P_{j,t,a}$, and $m_{j,t,a}$ are the number of deaths, the population, and the underlying mortality rate, respectively, for county *j*, year *t*, and age group *a*. The model for $m_{j,t,a}$ contained 6 components: an intercept (β_0), fixed covariate effects (β_1), random age-time effects ($\gamma_{1,a,t}$), random spatial effects ($\gamma_{2,j}$), random space-time effects ($\gamma_{3,j}$ and $\gamma_{4,j,t}$), and random space-age effects ($\gamma_{5,j}$ and $\gamma_{6,j,a}$). Seven covariates were included: the proportion of the adult population that has graduated from high school, the proportion of the population that has Hispanic ethnicity, the proportion of the population that has black race, the proportion of the population that has a race other than black or white, the proportion of a county that is contained within a state or federal Native American reservation, the median household income, and the population density. The random effects γ_1,γ_2, γ_3 and γ_5 were assumed to follow conditional autoregressive distributions[14,15] that allow for smoothing over adjacent age groups and years (γ_1) or counties (γ_2, γ_3 and γ_5). The random effects γ_4 and γ_6 were assumed to follow independent mean-zero normal distributions.

Models were fit using the Template Model Builder package[16] in R version 3.2.4 (R Project for Statistical Computing).[17] A total of 1000 draws of $m_{j,t,a}$ were taken from the posterior distribution. These draws were raked[5,18] (ie, scaled along multiple dimensions) to ensure consistency between levels of the cause hierarchy (ie, at each level the sum of all child causes is equal to the estimate for the corresponding parent cause) and to ensure consistency with the most recent national estimates produced by the Global Burden of Disease study.[1] Mortality rates for both sexes combined were calculated from the population-weighted average of the sex-specific mortality rates. Age-standardized mortality rates were calculated using the 2010 US census population as the standard, and years of life lost were calculated by multiplying the mortality rate by the population by the age-specific life expectancy from the standard life table used in the Global Burden of Disease study[1] and then summing across all ages. Point estimates were calculated from the mean of all draws and 95% uncertainty intervals (UIs) were calculated from the 2.5th and 97.5th percentiles. Changes over time were considered statistically significant if the posterior probability of an increase (or decrease) was 95% or greater. No explicit correction for multiple testing (ie, across multiple counties) was applied; however, modeling all counties simultaneously is expected to mitigate the risk of spuriously detecting changes due to multiple testing.

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Results

Geographic Variation in Mortality Due to All Types of Cardiovascular Disease

There were 31 992 547 deaths due to cardiovascular disease recorded between 1980 and 2014 (eTable 4 in the Supplement describes the proportion of deaths originally assigned garbage codes). From 1980 to 2014, cardiovascular diseases were the leading cause of death in the United States, although the mortality rate declined from 507.4 deaths per 100 000 persons in 1980 to 252.7 deaths per 100 000 persons in 2014, a relative decline of 50.2% (95% uncertainty interval [UI], 49.5%–50.8%) (eTable 5 in the Supplement). Cardiovascular diseases accounted for more than 846 thousand deaths (95% UI, 827–865 thousand deaths) and 11.7 million years of life lost (95% UI, 11.6–11.9 million years of life lost).

The Table summarizes the results for all cardiovascular disease causes in 2014 at the national and county level. The left side of the Table summarizes the burden of each cause at the national level in terms of deaths, years of life lost, and the age-standardized mortality rate. The right side of the Table summarizes the distribution of counties according to the estimated age-standardized mortality rate from each cause. Results by county for all years are available in an online visualization tool called US Health Map.

Among 3110 counties, large multicounty regions with the greatest age-standardized cardiovascular disease mortality rates (>90th percentile) were found throughout southeastern Oklahoma, the Mississippi River Valley, and eastern Kentucky (Figure 1A). States with the largest number of these counties included Mississippi (46 counties), Kentucky (38 counties), Oklahoma (38 counties), Tennessee (33 counties), Arkansas (28 counties), Louisiana (21 counties), Georgia (20 counties), Texas (19 counties), Alabama (16 counties), and Missouri (14 counties). The lowest cardiovascular mortality rates were found in the counties surrounding San Francisco, California, central Colorado, northern Nebraska, central Minnesota, northeastern Virginia, and southern Florida.

Trends and Variation in Cardiovascular Disease Mortality

All but 2 counties in the United States had statistically significant declines in age-standardized cardiovascular disease mortality rates between 1980 and 2014. The greatest absolute decline was observed in Menominee County, Wisconsin, where the mortality rate decreased 67.4% (95% UI, 62.2%–72.0%) from 862.0 (95% UI, 776.8–955.4) per 100 000 persons to 281.3 (95% UI, 248.7–315.5) per 100 000 persons.

The gap in age-standardized cardiovascular disease mortality rates between counties at the 10th and 90th percentile declined 14.6% from 172.1 deaths per 100 000 persons in 1980 to 147.0 deaths per 100 000 persons in 2014 (posterior probability of decline >99.9%) and at the 1st and 99th percentile (eTable 6 and eTable 7 in the Supplement). This decrease in variation in cardiovascular disease mortality rates overall was largely the result of decreasing variation in mortality rates due to ischemic heart disease (ratio between counties at the 90th and 10th percentile in 2014 was 2.0 [119.1 vs 235.7] deaths per 100 000 persons) and cerebrovascular disease (ratio in 2014 was 1.7 [40.3 vs 68.1] deaths per 100 000 persons). The gap in mortality rates due to rheumatic heart disease and aortic aneurysm also decreased by a smaller amount. There were statistically significant increases in the gap between the

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10th and 90th percentile and the 1st and 99th percentile for cardiomyopathy and myocarditis, atrial fibrillation and flutter, peripheral arterial disease, endocarditis, and other cardiovascular and circulatory diseases. For other cardiovascular disease causes, the ratio ranged from 1.4 (aortic aneurysm: 3.5 vs 5.1 deaths per 100 000 persons) to 4.2 (hypertensive heart disease: 4.3 vs 17.9 deaths per 100 000 persons).

Ischemic Heart Disease

Between 1980 and 2014, there were 21 191 274 deaths due to ischemic heart disease recorded in the United States. In 2014, the county-level age-standardized mortality rate due to ischemic heart disease ranged from 34.5 (95% UI, 30.0–39.2) per 100 000 persons in Pitkin County, Colorado, to 439.8 (95% UI, 405.1–477.6) per 100 000 persons in Franklin Parish, Louisiana (Figure 2). Counties with age-standardized mortality rates greater than the 90th percentile in 2014 were found in 26 states. The largest concentration of counties greater than the 90th percentile extended from central Oklahoma to eastern Kentucky and along the Mississippi River Valley. Counties outside this area with age-standardized ischemic heart disease mortality rates above the 90th percentile include Sioux County, North Dakota; Buffalo County, South Dakota; Chenango County, New York; Ogemaw County, Michigan; Mineral County, Nevada; Appanoose County, Iowa; and Hamilton County, Illinois. Counties with age-standardized mortality rates less than the 10th percentile were found in 41 states, primarily in western states extending from California to Minnesota, but also the southern coast of Maine, parts of Vermont, northern Virginia, central North Carolina, and individual counties throughout many other states, including in the southeast.

Although the national age-standardized ischemic heart disease mortality rate declined 56.8% (95% UI, 55.8%–57.8%) from 358.8 (95% UI, 352.6–364.7) per 100 000 persons to 155.0 (95% UI, 150.7–159.1) per 100 000 persons between 1980 and 2014, 7 counties had no detectable change in the age-standardized mortality rate due to ischemic heart disease. Only 1 county experienced a significant increase (Franklin Parrish County, Louisiana: 30.1% [95% UI, 17.2%–44.9%] increase from 338.0 [95% UI, 312.4–364.4] per 100 000 persons to 439.8 [95% UI, 405.1–477.6] per 100 000 persons). Decreases in ischemic heart disease mortality were widely distributed, as demonstrated by a percent decline in age-standardized ischemic heart disease mortality rate that was only weakly correlated with the original mortality rate in 1980 (correlation coefficient, 0.02; eFigure 1 in the Supplement).

Cerebrovascular Disease

There were 6 002 940 deaths due to cerebrovascular disease recorded between 1980 and 2014. The county-level age-standardized mortality rate due to cerebrovascular disease in 2014 ranged from 14.5 (95% UI, 13.0–16.2) per 100 000 persons in Summit County, Colorado, to 134.6 (95% UI, 127.6–141.9) per 100 000 persons in Angelina County, Texas (Figure 3). Counties with age-standardized mortality rates greater than the 90th percentile in 2014 were found in 27 states, with most in the South. Counties with mortality rates greater than the 90th percentile were concentrated in Arkansas, Mississippi, Tennessee, Alabama, southern Virginia, central South Carolina, and Georgia. Counties with age-standardized mortality rates less than the 10th percentile were found in 42 states, with many clustered in the southwest, Colorado, New York, New England, and southern Florida.

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Counties in the 90th percentile for ischemic stroke mortality rates were predominantly in the South, but also included clusters in northern Idaho, North Dakota, Missouri, and Humboldt and San Luis Obispo counties in California (eFigure 2 in the Supplement). Counties with high hemorrhagic stroke mortality rates greater than the 90th percentile were far more concentrated in the South, representing a majority of counties in Arkansas, Mississippi, Alabama, Tennessee, Georgia, and South Carolina, comprising the majority of the counties above the 90th percentile (eFigure 3 in the Supplement).

The age-standardized cerebrovascular mortality rate declined in most counties; however, there were 8 counties with no detectable change in the age-standardized mortality rate due to cerebrovascular disease and 1 county in which the mortality rate increased significantly (Angelina County, Texas: 11.5% [95% UI, 3.2% to 20.4%] increase from 120.7 [95% UI, 114.2 to 126.7] per 100 000 persons in 1980 to 134.6 [95% UI, 127.6 to 141.9] per 100 000 persons in 2014). There was an inverse correlation between the percent change in age-standardized cerebrovascular mortality rate and the mortality rate in 1980, with the highest risk counties having the largest decline in mortality rate (correlation coefficient, −0.44, eFigure 1 in the Supplement).

Hypertensive Heart Disease

There were 1 081 404 deaths due to hypertensive heart disease recorded between 1980 and 2014. Counties with hypertensive heart disease mortality rates greater than the 90th percentile were clustered in the South, especially in Mississippi (Figure 4). Counties with hypertensive heart disease mortality rates less than the 10th percentile were found almost entirely outside the South, with the exception of Starr and Hidalgo counties in Texas, which are located on the border between the United States and Mexico and encompass the cities of McAllen and Rio Grande City, Texas, and a cluster of 9 centered on Harrisonburg in northern Virginia.

The mortality rate due to hypertensive heart disease declined in 1684 counties (916 statistically significant) and increased in 1426 counties (651 statistically significant) between 1980 and 2014. Large increases were found clustered throughout Oklahoma, Arkansas, western Mississippi, northern Louisiana, and northern Texas, ranging from a 2% to 8% annualized increase over this period.

Cardiomyopathy and Myocarditis

From 1980 to 2014, there were 967 291 deaths due to cardio-myopathy and myocarditis recorded in the United States. Counties with cardiomyopathy and myocarditis mortality rates greater than the 90th percentile were found predominantly in the South, including central Louisiana, central South Carolina, Georgia, and southern Virginia, but also clusters in rural northern California, Alaska, northern New York state, central Ohio, southeastern Indiana, and urban areas including Franklin County, Ohio (Columbus), Wayne County, Michigan (Detroit), and Miami-Dade County, Florida (Figure 5).

Many of the counties with a cardiomyopathy and myocarditis mortality rate less than the 10th percentile were located in the Midwest and Mountain West extending south as far as the eastern Texas border with Mexico. The mortality rate due to cardiomyopathy and

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myocarditis increased for almost all counties after 1980, peaking in 1995 and then declining for almost all between 1995 and 2014.

Atrial Fibrillation

There were 314 988 deaths due to atrial fibrillation recorded between 1980 and 2014. Counties with an age-standardized mortality rate due to atrial fibrillation greater than the 90th percentile were clustered throughout Oregon, northern California, Utah, Idaho, northeastern Montana, central Minnesota, areas east of Kansas City, Missouri, and southwestern West Virginia (Figure 6).

Counties less than the 10th percentile were clustered along the border between the United States and Mexico, South Dakota, Iowa, southern Florida, and along the Mississippi River from the southern tip of Illinois to the Gulf of Mexico. From 1980 to 2014, the mortality rate due to atrial fibrillation declined for counties clustered around Phoenix, Arizona, New Orleans, Louisiana, and Washington, DC, while increasing for most other counties.

Rheumatic Heart Disease

There were 355711 deaths due to rheumatic heart disease recorded between 1980 and 2014. Counties with an age-standardized mortality rate due to rheumatic heart disease greater than the 90th percentile were clustered in Alaska, Mississippi, Alabama, Kentucky, and Utah as well as smaller clusters in Georgia, South Carolina, and South Dakota (Figure 7). Counties less than the 10th percentile were clustered in western Washington, southern California, and Arizona, the Texas border with Mexico, central Iowa, North Dakota, South Dakota, southern Florida, Maryland, southern New York state, New Jersey, and Rhode Island.

The national mortality rate due to rheumatic heart disease declined by 51.9% (95% UI, 49.2% to 54.4%) between 1980 and 2014. This decline was slowest throughout the South, however, and the age-standardized mortality rates due to rheumatic heart disease increased significantly in 2 counties: East Baton Rouge Parish, Louisiana (34.5% [95% UI, 8.0% to 68.1%] increase from 3.8 [95% UI, 3.3 to 4.4] per 100 000 persons in 1980 to 5.2 [95% UI, 4.4 to 6.0] per 100 000 persons in 2014) and East Feliciana Parish, Louisiana (38.6% [95% UI, −1.5% to 91.3%] increase from 4.5 [95% UI, 3.6 to 5.6] per 100 000 persons in 1980 to 6.2 [95% UI, 4.5 to 8.5] per 100 000 persons in 2014).

Aortic Aneurysm

From 1980 to 2014, there were 533 251 deaths due to aortic aneurysm recorded in the United States. Counties with an age-standardized mortality rate due to aortic aneurysm greater than the 90th percentile were scattered widely across the country, with the largest cluster in northern Minnesota and Wisconsin (Figure 8). Counties with mortality rates below the 10th percentile were found in the southern-most counties in California, Arizona, Texas, and Florida. The national mortality rate due to aortic aneurysm declined 49.4% (95% UI, 46.2% to 52.2%) from 1980 to 2014.

Counties with the most rapid decline were in Alaska, California, and surrounding Washington, DC, whereas the counties with the slowest decline were clustered in Arkansas,

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Mississippi, Tennessee, and Minnesota. There was a moderate inverse correlation between the percent change in age-standardized aortic aneurysm mortality rate and the mortality rate in 1980, which was the strongest correlation found among cardiovascular disease causes in this analysis (correlation coefficient −0.52; eFigure 1 in the Supplement).

Peripheral Arterial Disease

There were 199 423 deaths due to peripheral arterial disease recorded between 1980 and 2014. Counties with an age-standardized mortality rate due to peripheral arterial disease greater than the 90th percentile were found in small clusters throughout the South, in northern Michigan, in Wisconsin, and in many other states (Figure 9).

Mortality rates below the 10th percentile were found for many counties in the southwest, Colorado extending into southwestern Wyoming, in Alaska, in Mississippi, and in eastern New York state. Between 1980 and 2014, the national mortality rate due to peripheral arterial disease increased by 140% (95% UI, 117%–164%). During this same period, the gap between the 10th and 90th percentiles increased 163% from 0.5 to 1.4 per 100 000 persons (posterior probability of increase >99.9%).

Endocarditis

Between 1980 and 2014, 211 126 deaths due to endocarditis were recorded in the United States. Counties with mortality rates due to endocarditis greater than the 90th percentile were found in all but 16 states, with clusters in Alaska, the Mountain West, eastern Nebraska, northern Indiana, eastern Pennsylvania, upstate New York, southern Louisiana, and central Georgia (Figure 10).

Counties with rates below the 10th percentile were clustered in southern California, southern Texas, and in Iowa extending into southern Minnesota. The national mortality rate due to endocarditis increased by 45.7% (95% UI, 36.7%–54.0%) between 1980 and 2014, peaking in 2003 at 2.61 (95% UI, 2.52–2.69) deaths per 100 000. The largest declines since 2003 occurred in clusters of counties across the Mountain West, in Iowa, and in Maryland.

Other Cardiovascular and Circulatory Diseases

There were 1 135 138 deaths due to other cardiovascular and circulatory diseases recorded between 1980 and 2014. In 2014, this category primarily consisted of nonrheumatic valvular disorders (71.9%) and phlebitis, thrombophlebitis, portal vein thrombosis, and other vein disorders (14.1%) (eTable 8 in the Supplement). Clusters of counties with rates for this category greater than the 90th percentile occurred in western areas of Washington and Oregon, northern California, eastern Texas, and eastern Georgia, whereas counties with rates less than the 10th percentile were found clustered along the border between the United States and Mexico, southern Florida, and North Dakota (eFigure 4 in the Supplement). There was only a slight decrease in the national mortality rate (12.3%; 95% UI, 6.4%–17.2%) with the fastest increase found among a cluster of counties in eastern Texas centered on the city of Tyler, Texas, and in coastal Oregon and Washington.

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Discussion

This analysis found extensive geographic variation in death due to 11 cardiovascular diseases. The absolute difference in county-level cardiovascular disease mortality rates declined substantially over the past 35 years for both ischemic heart disease and cerebrovascular disease. Despite this decline in absolute differences between counties, large differences remained in 2014. These findings suggest major efforts are still needed to reduce geographic variation in risk of death due to ischemic heart disease and cerebrovascular diseases.

Compared with other research,[19–21] this study more broadly examined county-level patterns of death due to coronary and cerebrovascular arterial disease alone by including the first, to our knowledge, county-level analysis of death due to other major conditions, including diseases of the myocardium, atrial fibrillation, aortic and peripheral arterial diseases, rheumatic heart disease, and endocarditis. Comparable estimates have been produced by applying a uniform correction to nonspecific and intermediate garbage code causes of death. Consistency with all other causes of death, as well as national and global estimates, results from integration with the cause list developed for the ongoing Global Burden of Disease study.

This analysis reveals new patterns not observed when all cardiovascular deaths were considered together. For example, several cardiovascular disease conditions were clustered sub stantially outside the South, including atrial fibrillation (Northwest), aortic aneurysm (Midwest), and endocarditis (Mountain West and Alaska). Even though both the proportion of garbage codes and local practices for death reporting can vary by state, these clusters extend across state boundaries and most likely represent actual variation in disease mortality.

Data on trends and clustering of even rare causes of death can be an important source of public health information when data on disease incidence are unavailable. For example, high incidence of severe endocarditis has been described in Alaska separately from the finding of high mortality rates due to endocarditis.[22] Using this analysis, new hotspots of cardiovascular disease were identified in locations such as Angelina County, Texas (cerebrovascular disease), and northern Michigan (peripheral arterial disease).

In contrast to the national trend for cardiovascular disease mortality rates as a whole, mortality rates due to atrial fibrillation, endocarditis, and peripheral arterial disease have increased since 1980. Tracking long-term trends in mortality for these less common causes of cardiovascular disease is important given that clinical and public health recommendations for screening and treatment continue to evolve, including rapid adoption of direct oral anticoagulants for atrial fibrillation,[23] less frequent antibiotic prophylaxis for the prevention of endocarditis,[24] and more percutaneous revascularization for peripheral arterial disease.[25]

Geographic variation in cardiovascular disease mortality in the Unites States has been noted since at least 1949.[26] Thirty years ago researchers first noted an “enigma of the Southeast”[27] with high mortality rates in that region, often due to stroke, and a range of possible causes including environmental exposures related to coal and metal mining, housing and population density, and access to health care. A delay in the decline of stroke mortality has since been

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found in the stroke belt of the South but also outside the South, including Washington and Oregon.[28] A stroke buckle has been identified as well, composed of the coastal plains of North Carolina, South Carolina, and Georgia.[29] This analysis extends these findings to show additional counties with extremely high stroke mortality in California, Utah, North Dakota, South Dakota, and northern Idaho.

In 1986, researchers first reported the observation that the national cardiovascular mortality rate was actually "the weighted average of rates that were still increasing [in some regions] and those that had begun to decline" in others.[30] Recent analysis of all types of cardiovascular disease mortality has shown a shift in high-mortality counties from the Northeast to the South, and higher rates of cardiovascular disease hospitalization for high-mortality counties in southeast Oklahoma, Kentucky, and West Virginia.[4,19] Efforts to explain these patterns have been more limited. Regional patterns in US county mortality have been associated with lower elevation and higher levels of small particulate air pollution.[31,32] Regional variation in hospital outcomes following myocardial infarction also has been shown.[33]

The most comprehensive analysis of county-level cardiovascular disease risk factors to date, using data from the Behavioral Risk Factor Surveillance Survey, showed wide variation in levels of obesity, tobacco smoking, hypertension, and physical inactivity within almost all states. Further investigation is needed to better understand regional variation in the factors that lead to cardiovascular disease deaths. These factors can best be understood in 3 major categories: (1) variation in the level of exposure to metabolic, behavioral, and environmental risks for the residents of a county; (2) variation in the delivery of interventions that can modify risk due to these exposures over time; and (3) delivery of high-quality emergency services and acute medical care that improve health outcomes when cardiovascular events occur. Tobacco smoking and obesity carry particularly high relative risks for atherosclerotic vascular disease. Previous modeling has suggested that half of reductions in cardiovascular disease in the United States has been due to medical treatment and half has been due to risk factor reduction.[34]

A broader exploration of the quality of both facility- and community-based health interventions in the lowest- and highest-risk counties would be an important first step in reducing cardiovascular disease differences. Counties with successful implementation of broad-based interventions to reduce cardiovascular disease have been well described.[35] In particular, better county-level data are needed on dietary exposures, prehospital care, and access to high-quality chronic disease care. Exposure to risk early in life appears to be a particularly potent component of atherosclerotic vascular disease.[36] Anonymized linkage of existing health data sources, including household surveys, electronic health records, and cardiovascular disease registries with other data on health and nonhealth exposures will be necessary to expand and improve cardiovascular disease surveillance.

Limitations

This analysis has several limitations. Vital statistics data and census population data were used to calculate mortality rates and both of these sources are subject to error because deaths and individuals within the population may be missed or allocated to the wrong county.

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Autopsy is considered the criterion standard for death certification and studies[12] have demonstrated regional variation in misclassification bias in death certificates. An analysis of data from the Framingham Heart Study showed that death certificates were least accurate for individuals older than age 85 years and that no change in coding accuracy was observed over time.[37] An analysis of deaths in Maryland showed that the amount of diagnostic information available to the certifying physician was associated with the reporting of chronic heart disease.[38] To our knowledge, this is the first analysis of US county-level mortality that has applied a consistent method for correcting misclassification due to coding of unspecified or intermediate causes of death; however, the possibility of misclassification remains.

The transition from the 9th to the 10th version of the *ICD* coding system is an example of 1 source of misclassification that the methods used in this analysis explicitly address. The *ICD-10* system was implemented for coding death certificates in the United States in 1999 and provided several thousand new and more detailed codes, a new alphanumeric coding scheme, and both renaming and regrouping of existing codes.[39] This analysis accounts for this change in the *ICD* system by (1) mapping both versions of coding to a common list of cardiovascular disease conditions, (2) applying consistent methods for garbage code redistribution across all versions of the *ICD*, (3) ensuring that the sum of these conditions equals the total amount of cardiovascular disease deaths in which larger counts and more consistent coding markedly reduce the potential for discontinuity between 1998 and 1999, and (4) smoothing estimates over both space and time at the level of counties. Even with these adjustments, changes in the *ICD* system in 1999 can result in small shifts in estimation for less common conditions in small counties between 1998 and 1999 (eg, aortic aneurysm in Alpine County, California, and endocarditis in the Kusilvak census area of Alaska).

These findings demonstrate the importance of the state-level redistribution of nonspecific and intermediate causes of death implemented in our analysis. In addition, the modeling method smooths mortality estimates such that real variation among counties may be underestimated. Vital registration systems attribute deaths to county of residence at the time of death and, in this analysis, no correction to migration between counties was applied. Because of this, exposure to important environmental risk factors (eg, air pollution) may have occurred outside the county where a death was ultimately assigned. However, previous analyses have found the effect of county-to-county population migration on county-level variation in all-cause mortality to be small.[40] In addition, patterns of death without correction for migration are of substantial interest to local policy makers and health systems.

Conclusions

Substantial differences exist between county ischemic heart disease and stroke mortality rates. Smaller differences exist for diseases of the myocardium, atrial fibrillation, aortic and peripheral arterial disease, rheumatic heart disease, and endocarditis.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Acknowledgments

Funding/Support: This work was funded by grant 72305 from the Robert Wood Johnson Foundation, grant 5P30AG047845-02 from the National Institute on Aging, and a philanthropic gift from John W. Stanton and Theresa E. Gillespie. Dr Roth reports receiving funding from the Bill and Melinda Gates Foundation.

Role of the Funder/Sponsor: The Robert Wood Johnson Foundation, the National Institute on Aging, and John W. Stanton and Theresa E. Gillespie had no role in the design and conduct of the study; collection, management, analysis, and interpretation of the data; preparation, review, or approval of the manuscript; and decision to submit the manuscript for publication.

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Key Points

Question

What are the trends and differences in cardiovascular disease mortality rates among US counties from 1980 to 2014?

Findings

In this study of small area estimation models applied to death records from the National Center for Health Statistics, the difference between county-level mortality rates declined substantially over the past 35 years for both ischemic heart disease and stroke; however, large differences remained in 2014. The largest concentration of counties with high cardiovascular disease mortality extended from southeastern Oklahoma along the Mississippi River Valley to eastern Kentucky, and several cardiovascular disease conditions were clustered substantially outside the South, including atrial fibrillation (Northwest), aortic aneurysm (Midwest), and endocarditis (Mountain West and Alaska).

Meaning

From 1980 to 2014, there were important changes in trends, patterns, and differences in cardiovascular disease mortality among US counties.

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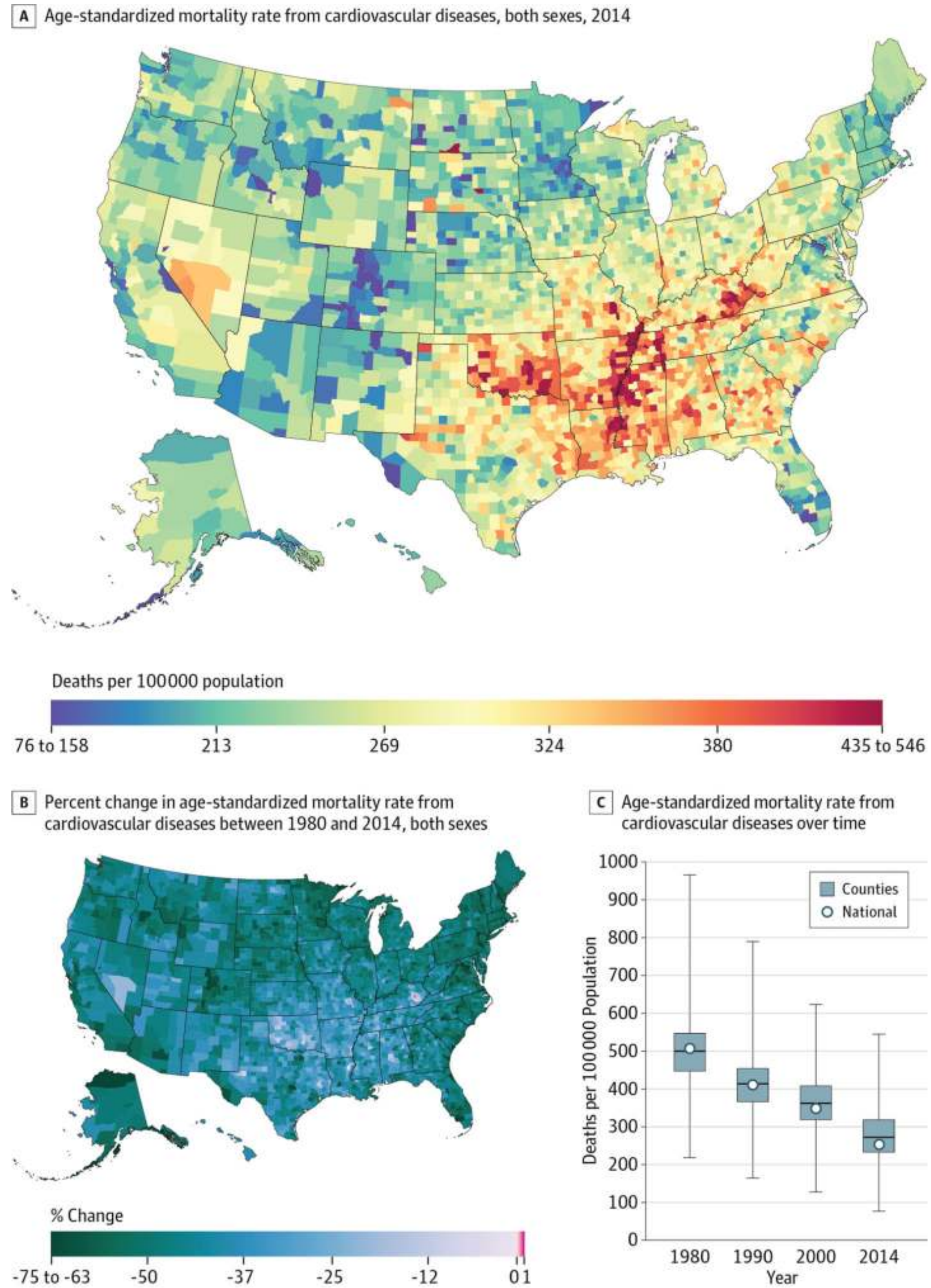

Figure 1. US County-Level Mortality From Cardiovascular Diseases

A, Age-standardized mortality rate for both sexes combined in 2014. B, Percent change in the age-standardized mortality rate for both sexes combined between 1980 and 2014. In panel A, the color scale is truncated at approximately the 1st and 99th percentiles as indicated by the range given on the scale. In panel B, the color scale is similarly truncated at the 1st percentile but not at the 99th percentile to avoid combining counties with decreases in the mortality rate and counties with increases in the mortality rate into a single group. C, Age-standardized mortality rate in 1980, 1990, 2000, and 2014. The bottom border, middle line, and top border of the boxes indicate the 25th, 50th, and 75th percentiles, respectively,

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across all counties; whiskers, the full range across counties; and circles, the national-level rate.

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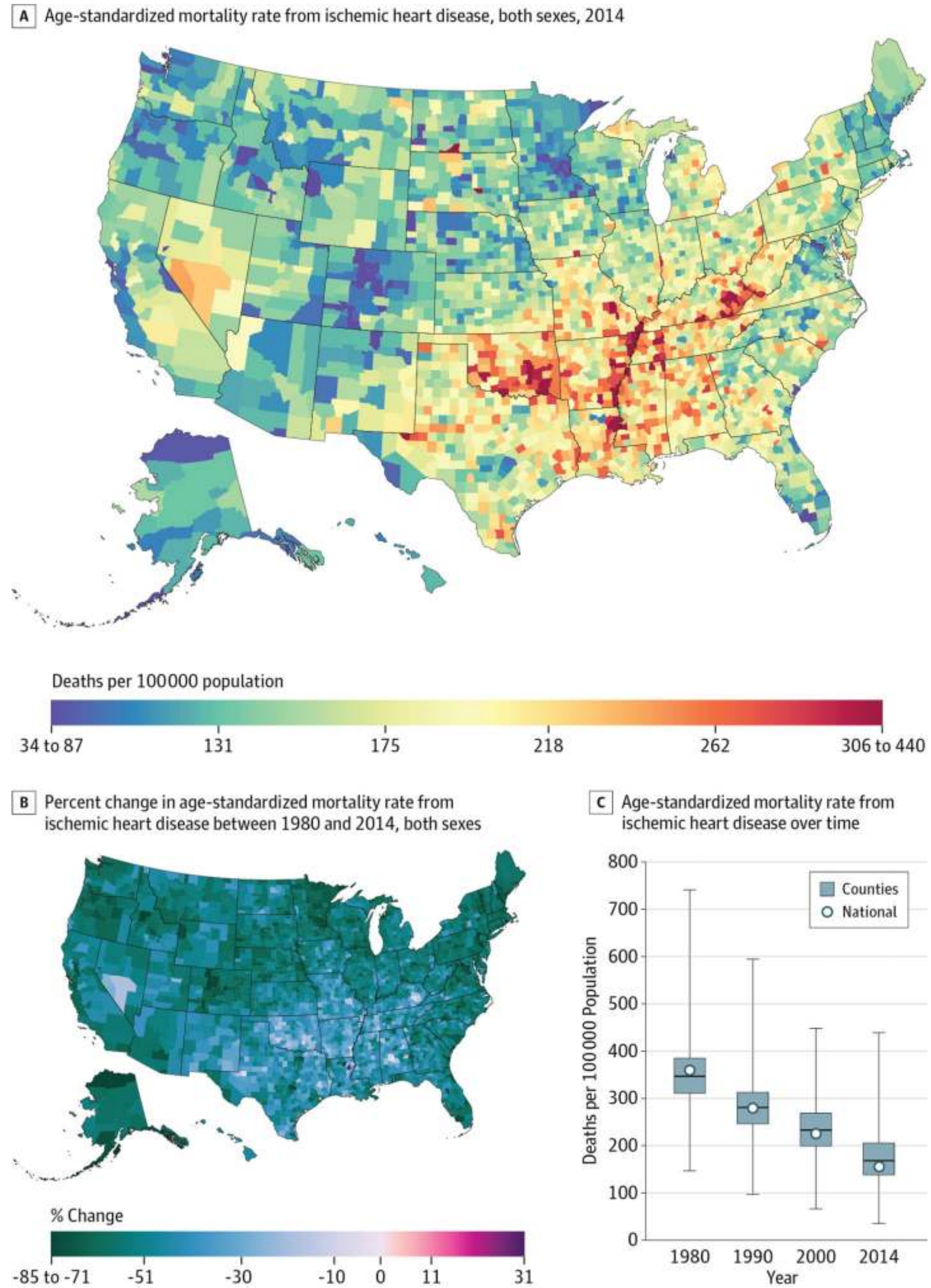

Figure 2. US County-Level Mortality From Ischemic Heart Disease

A, Age-standardized mortality rate for both sexes combined in 2014. B, Percent change in the age-standardized mortality rate for both sexes combined between 1980 and 2014. In panel A, the color scale is truncated at approximately the 1st and 99th percentiles as indicated by the range given on the scale. In panel B, the color scale is similarly truncated at the 1st percentile but not at the 99th percentile to avoid combining counties with decreases in the mortality rate and counties with increases in the mortality rate into a single group. C, Age-standardized mortality rate in 1980, 1990, 2000, and 2014. The bottom border, middle line, and top border of the boxes indicate the 25th, 50th, and 75th percentiles, respectively,

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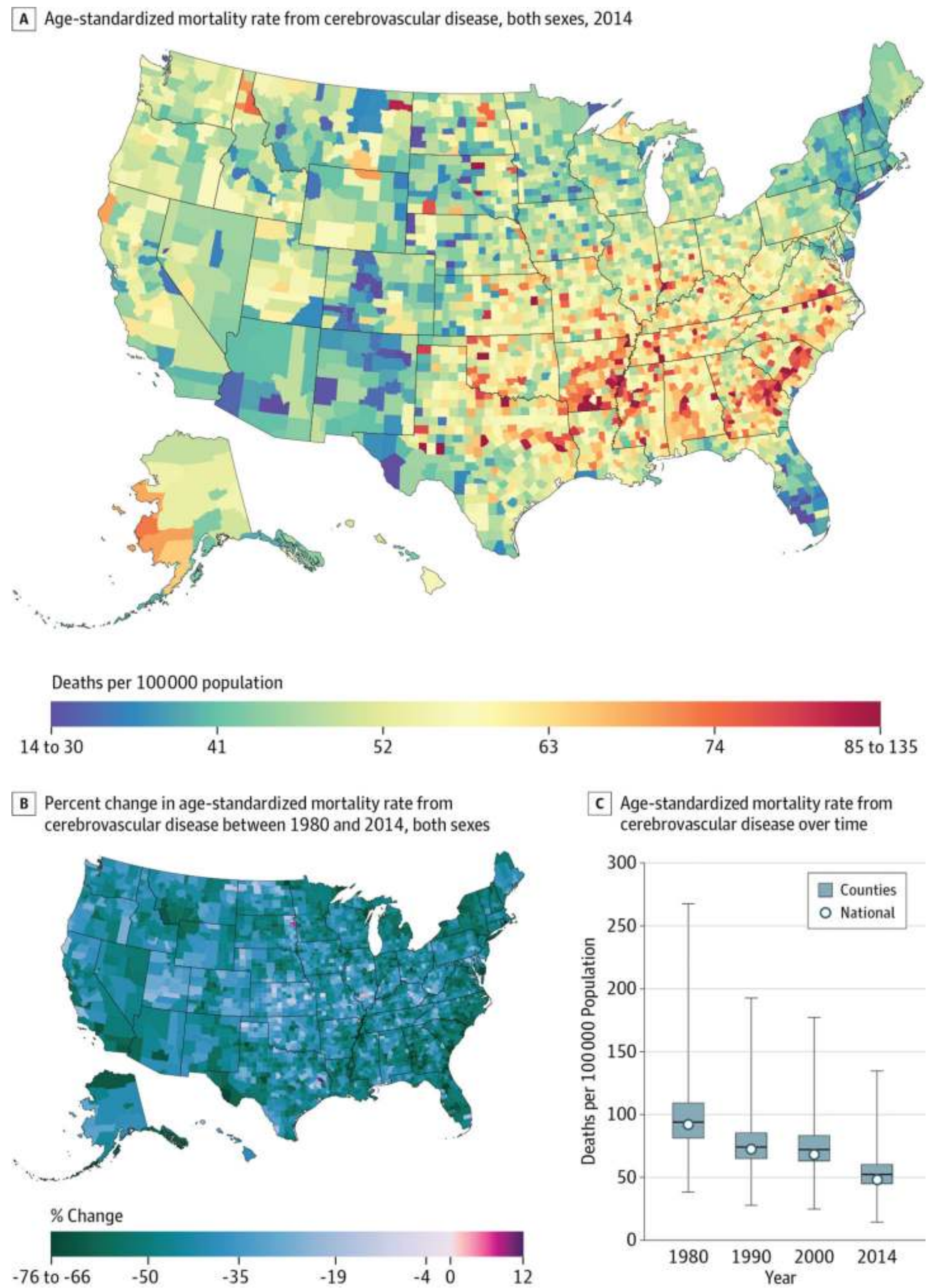

Figure 3. US County-Level Mortality From Cerebrovascular Disease

A, Age-standardized mortality rate for both sexes combined in 2014. B, Percent change in the age-standardized mortality rate for both sexes combined between 1980 and 2014. In panel A, the color scale is truncated at approximately the 1st and 99th percentiles as indicated by the range given on the scale. In panel B, the color scale is similarly truncated at the 1st percentile but not at the 99th percentile to avoid combining counties with decreases in the mortality rate and counties with increases in the mortality rate into a single group. C, Age-standardized mortality rate in 1980, 1990, 2000, and 2014. The bottom border, middle line, and top border of the boxes indicate the 25th, 50th, and 75th percentiles, respectively,

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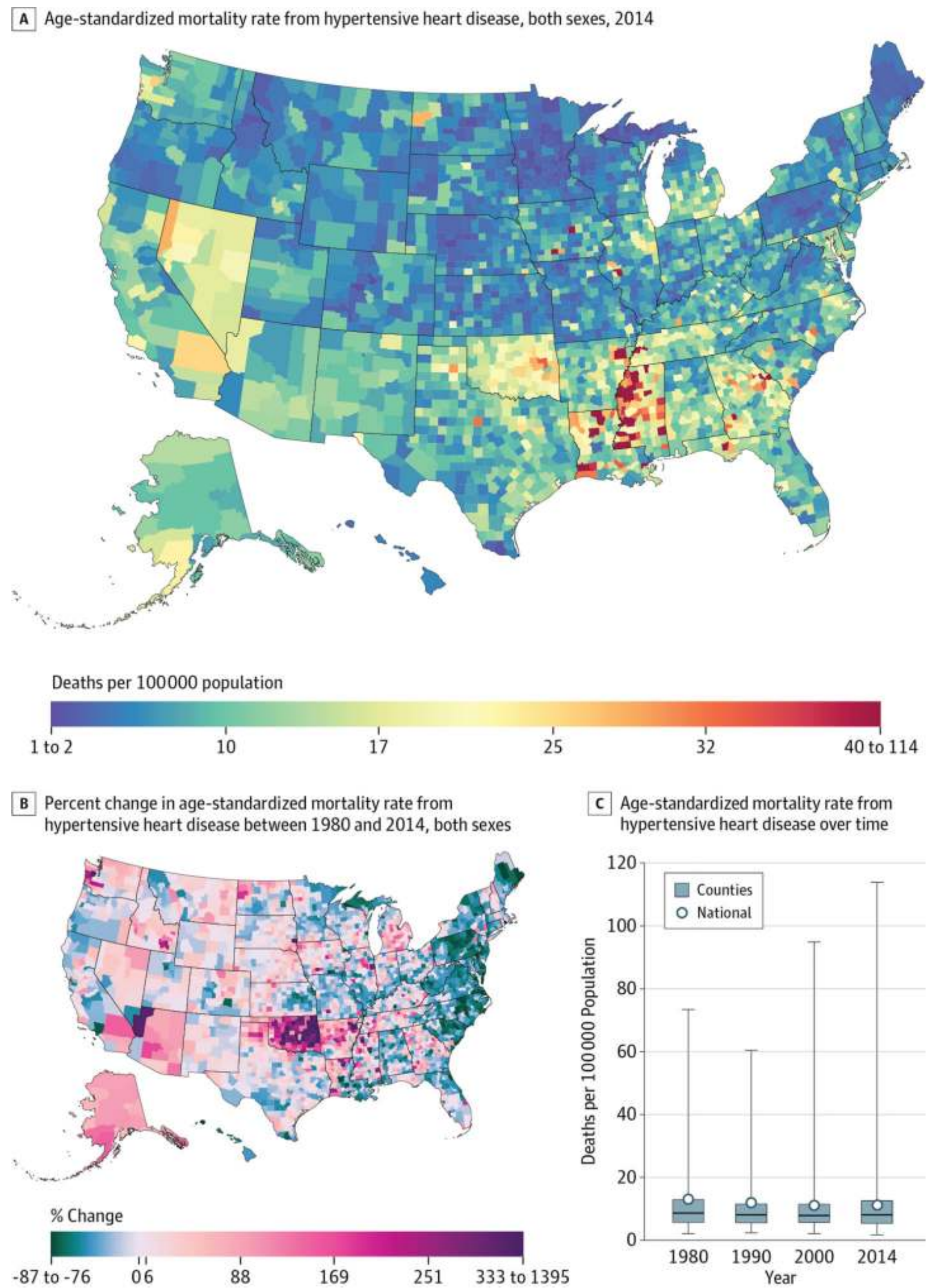

Figure 4. US County-Level Mortality From Hypertensive Heart Disease

A, Age-standardized mortality rate for both sexes combined in 2014. B, Percent change in the age-standardized mortality rate for both sexes combined between 1980 and 2014. In panels A and B, the color scale is truncated at approximately the 1st and 99th percentiles as indicated by the range given in the color scale. C, Age-standardized mortality rate in 1980, 1990, 2000, and 2014. The bottom border, middle line, and top border of the boxes indicate the 25th, 50th, and 75th percentiles, respectively, across all counties; whiskers, the full range across counties; and circles, the national-level rate.

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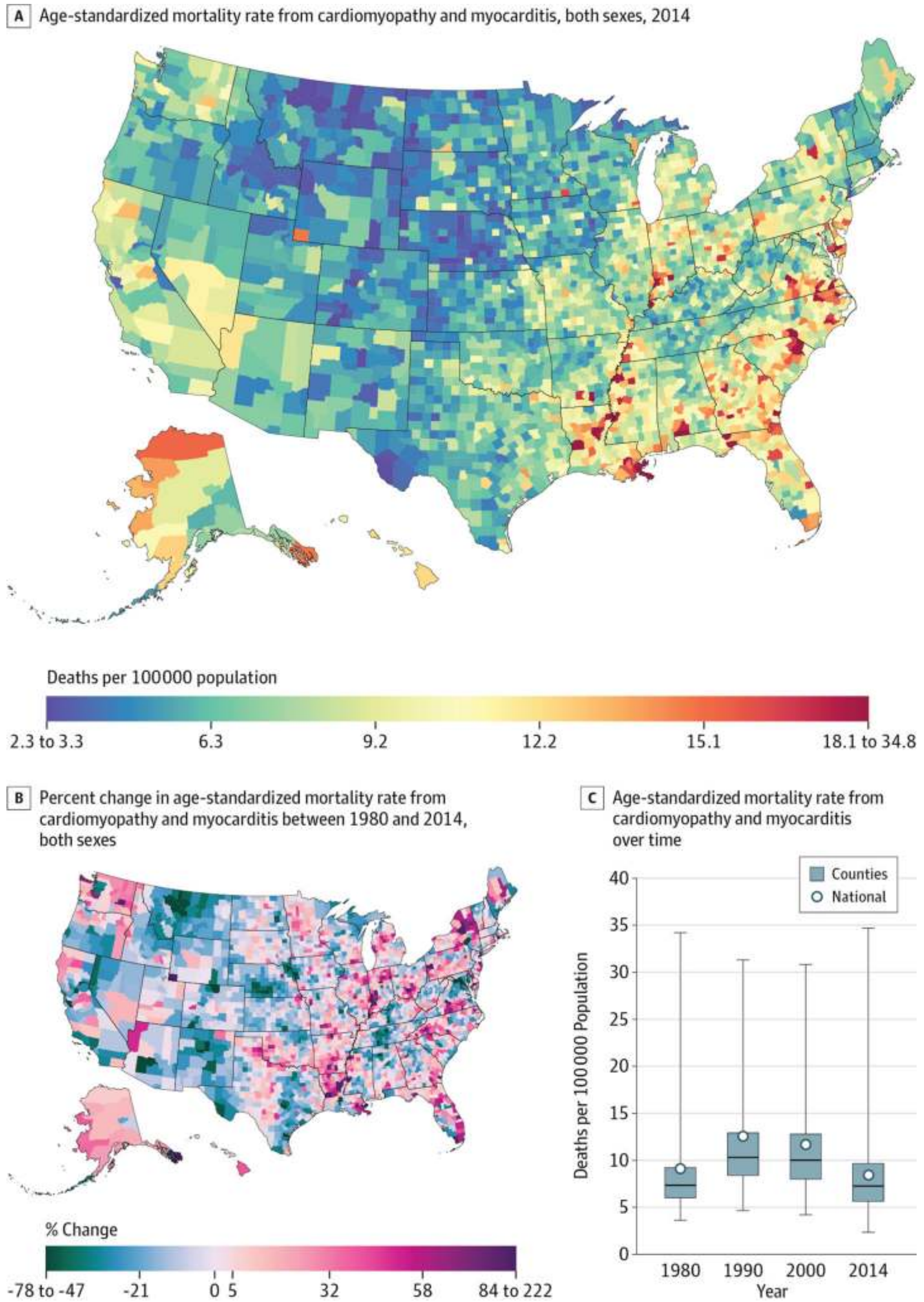

Figure 5. US County-Level Mortality From Cardiomyopathy and Myocarditis

A, Age-standardized mortality rate for both sexes combined in 2014. B, Percent change in the age-standardized mortality rate for both sexes combined between 1980 and 2014. In panels A and B, the color scale is truncated at approximately the 1st and 99th percentiles as indicated by the range given in the color scale. C, Age-standardized mortality rate in 1980, 1990, 2000, and 2014. The bottom border, middle line, and top border of the boxes indicate the 25th, 50th, and 75th percentiles, respectively, across all counties; whiskers, the full range across counties; and circles, the national-level rate.

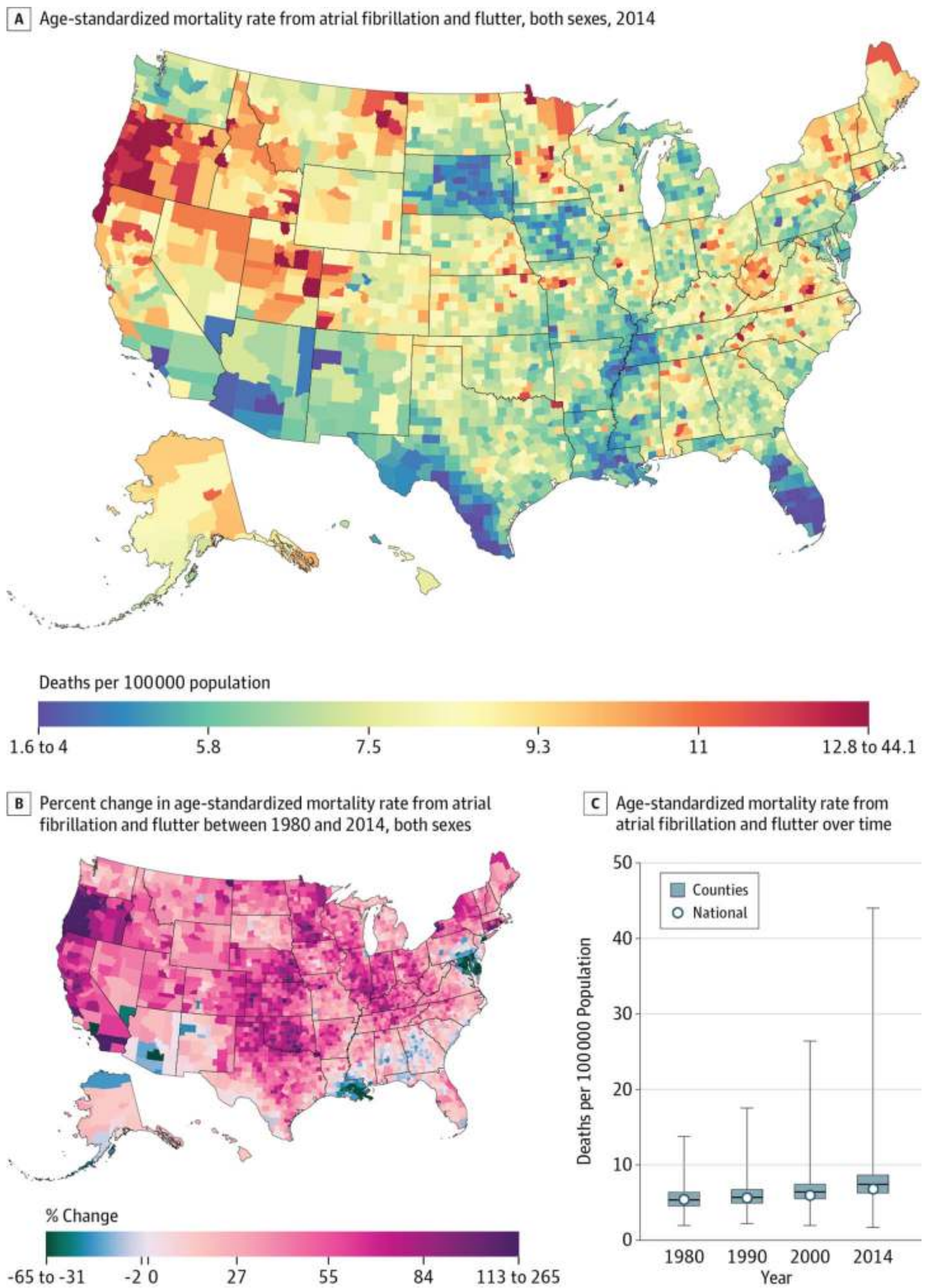

Figure 6. US County-Level Mortality From Atrial Fibrillation and Flutter

A, Age-standardized mortality rate for both sexes combined in 2014. B, Percent change in the age-standardized mortality rate for both sexes combined between 1980 and 2014. In panels A and B, the color scale is truncated at approximately the 1st and 99th percentiles as indicated by the range given in the color scale. C, Age-standardized mortality rate in 1980, 1990, 2000, and 2014. The bottom border, middle line, and top border of the boxes indicate the 25th, 50th, and 75th percentiles, respectively, across all counties; whiskers, the full range across counties; and circles, the national-level rate.

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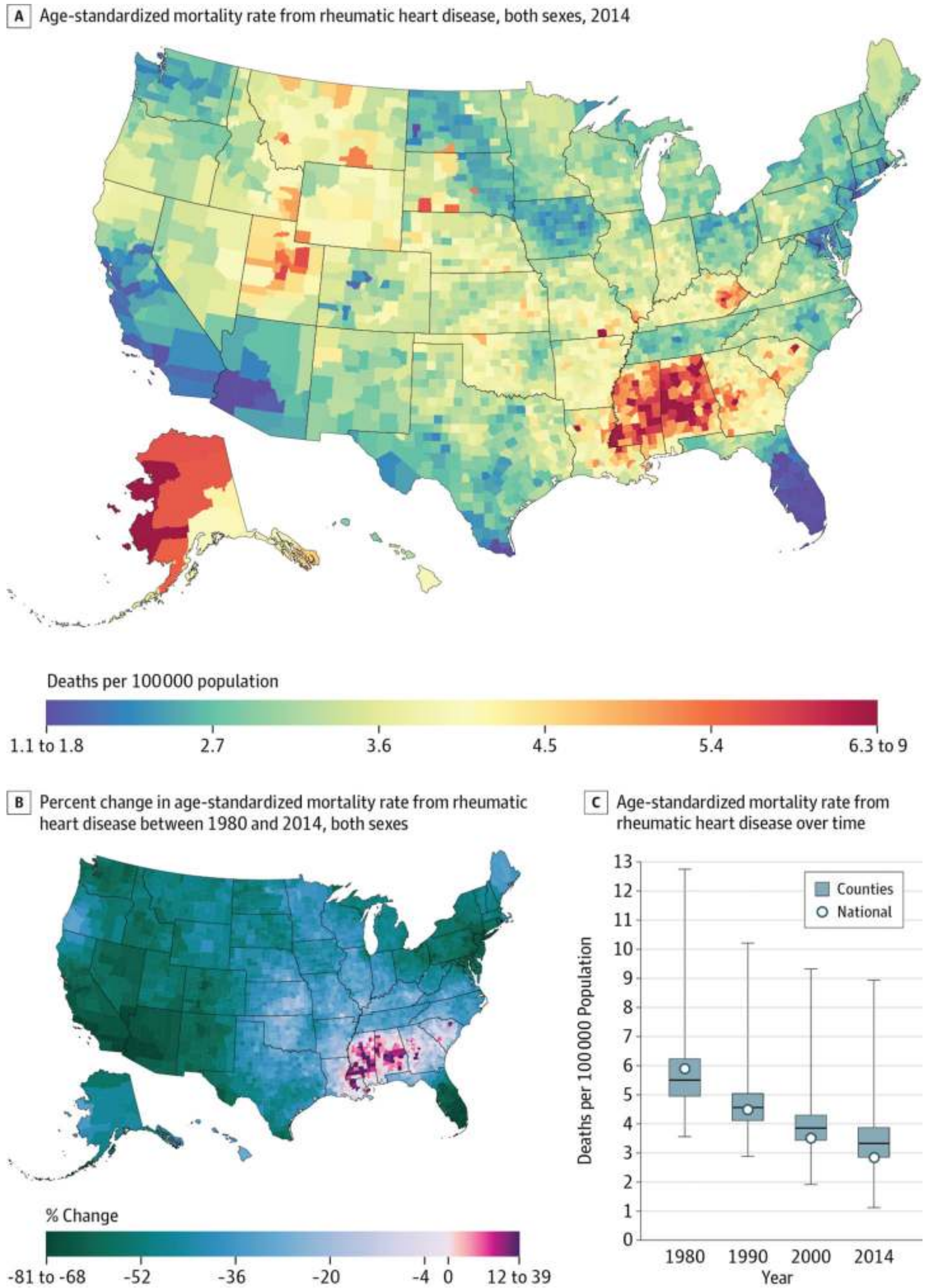

Figure 7. US County-Level Mortality From Rheumatic Heart Disease

A, Age-standardized mortality rate for both sexes combined in 2014. B, Percent change in the age-standardized mortality rate for both sexes combined between 1980 and 2014. In panels A and B, the color scale is truncated at approximately the 1st and 99th percentiles as indicated by the range given in the color scale. C, Age-standardized mortality rate in 1980, 1990, 2000, and 2014. The bottom border, middle line, and top border of the boxes indicate the 25th, 50th, and 75th percentiles, respectively, across all counties; whiskers, the full range across counties; and circles, the national-level rate.

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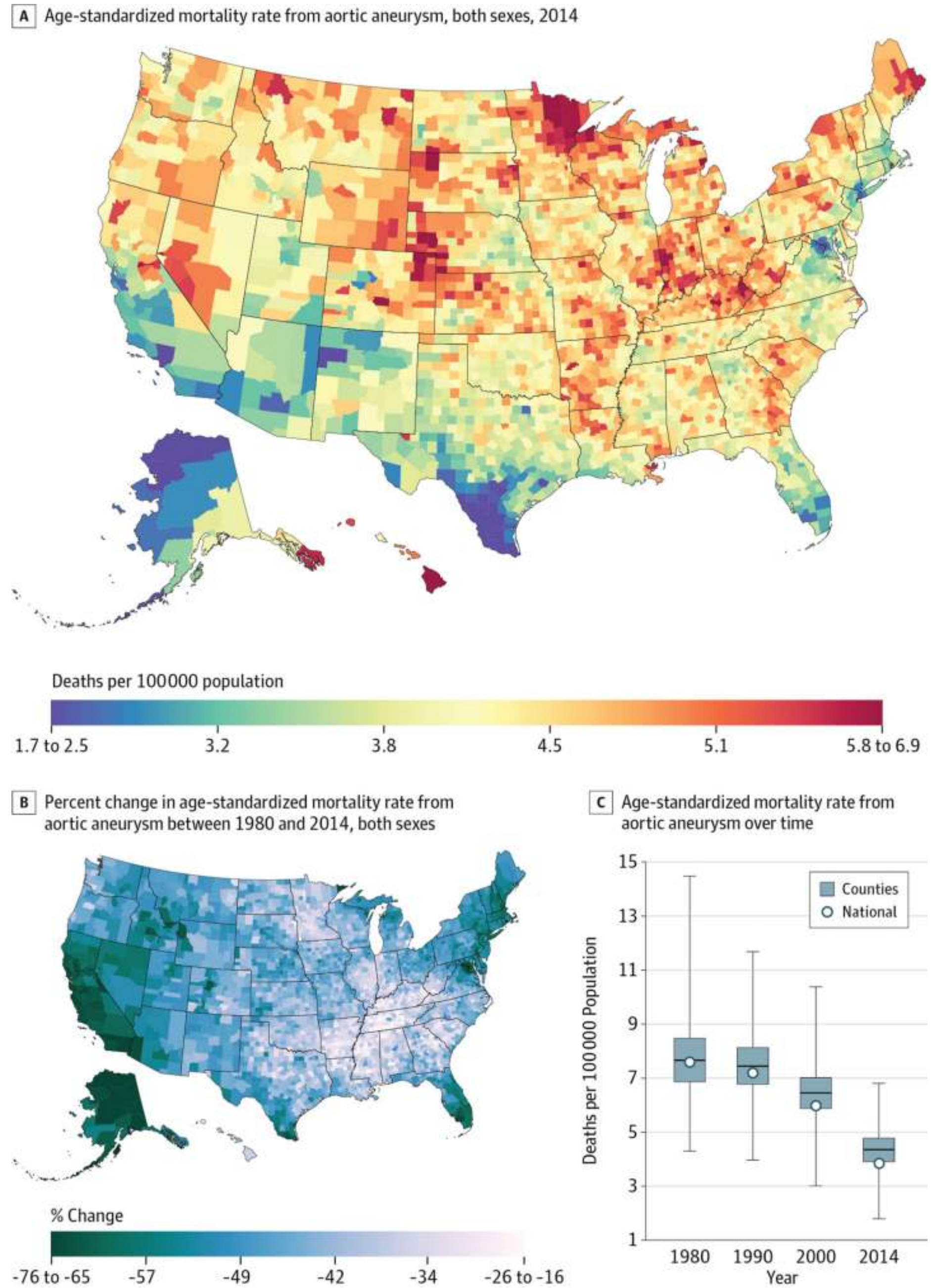

Figure 8. US County-Level Mortality From Aortic Aneurysm

A, Age-standardized mortality rate for both sexes combined in 2014. B, Percent change in the age-standardized mortality rate for both sexes combined between 1980 and 2014. In panels A and B, the color scale is truncated at approximately the 1st and 99th percentiles as indicated by the range given in the color scale. C, Age-standardized mortality rate in 1980, 1990, 2000, and 2014. The bottom border, middle line, and top border of the boxes indicate the 25th, 50th, and 75th percentiles, respectively, across all counties; whiskers, the full range across counties; and circles, the national-level rate.

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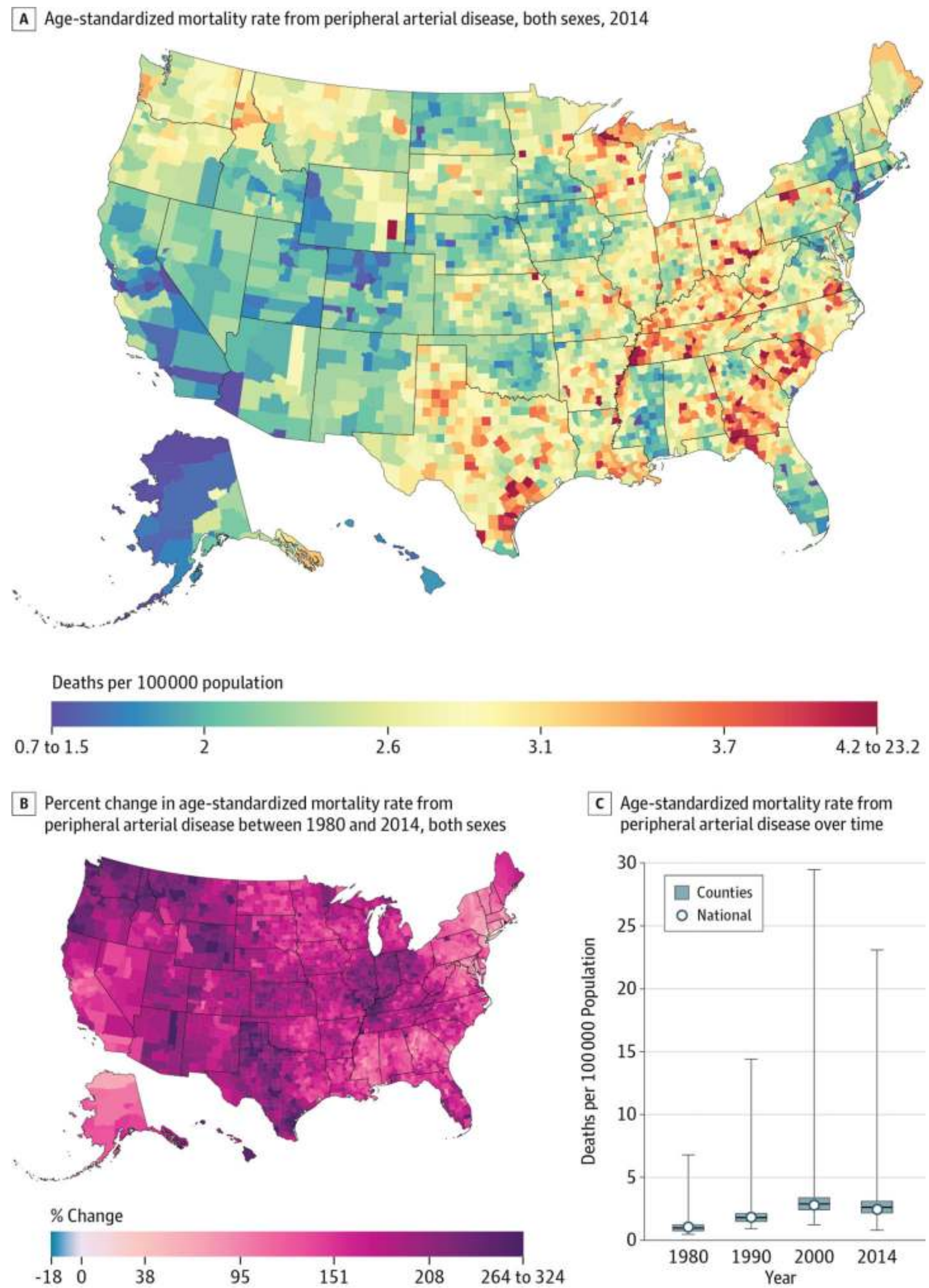

Figure 9. US County-Level Mortality From Peripheral Arterial Disease

A, Age-standardized mortality rate for both sexes combined in 2014. B, Percent change in the age-standardized mortality rate for both sexes combined between 1980 and 2014. In panel A, the color scale is truncated at approximately the 1st and 99th percentiles as indicated by the range given on the scale. In panel B, the color scale is similarly truncated at the 99th percentile but not at the 1st percentile to avoid combining counties with decreases in the mortality rate and counties with increases in the mortality rate into a single group. C, Age-standardized mortality rate in 1980, 1990, 2000, and 2014. The bottom border, middle line, and top border of the boxes indicate the 25th, 50th, and 75th percentiles, respectively,

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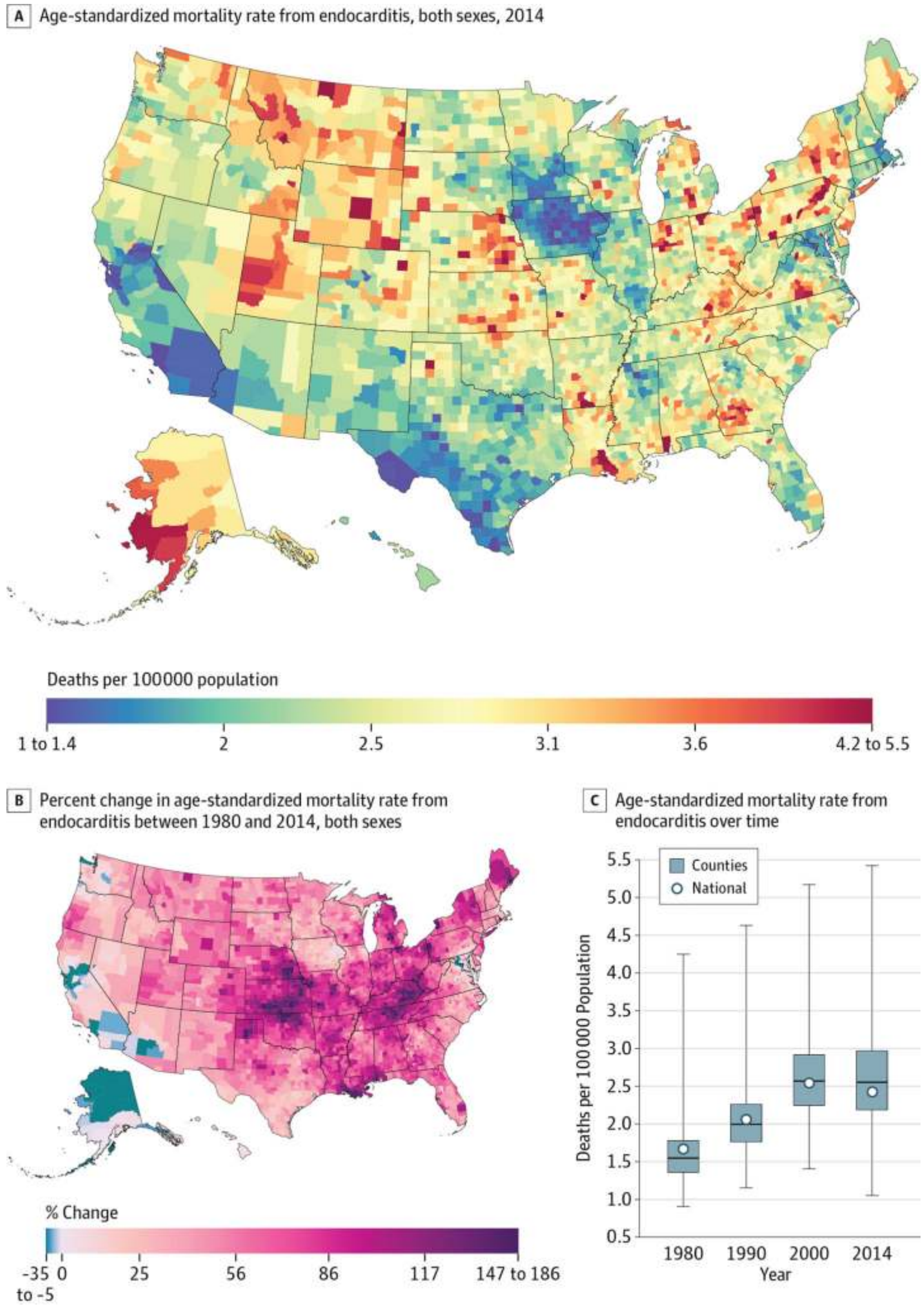

Figure 10. US County-Level Mortality From Endocarditis

A, Age-standardized mortality rate for both sexes combined in 2014. B, Percent change in the age-standardized mortality rate for both sexes combined between 1980 and 2014. In panels A and B, the color scale is truncated at approximately the 1st and 99th percentiles as indicated by the range given in the color scale. C, Age-standardized mortality rate in 1980, 1990, 2000, and 2014. The bottom border, middle line, and top border of the boxes indicate the 25th, 50th, and 75th percentiles, respectively, across all counties; whiskers, the full range across counties; and circles, the national-level rate.

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Table

National Deaths, Years of Life Lost (YLLs), Age-Standardized Mortality Rate, and Distribution of Age-Standardized Mortality Rates at the US County Level in 2014

	National Deaths, YLLs, and Mortality Rate						US County-Level Mortality Rates								
							No. of Deaths/100 000 Population								
Cause of Death	Deaths, No. × 1000 (95% UI)	Rank	YLLs, No. × 1000 (95% UI)	Rank	Mortality Rate No./100 000 Population (95% UI)	Rank	Minimum	10th Percentile	Median	90th Percentile	Maximum	90th Minus 10th Percentile No./100 000 Population[a]	Rank	90th/10th Percentile Ratio[b]	Rank
Cardiovascular diseases[c]	846.3 (827.5–865.1)		11 735.8 (11 562.6–11 899.3)		252.7 (247.1–258.3)		77.0	209.2	272.3	356.2	545.2	147.0		1.7	
Ischemic heart disease	519.9 (505.2–533.4)	1	7177.2 (7009.5–7314.3)	1	155.0 (150.7–159.1)	1	34.5	119.1	168.2	235.7	439.8	116.7	1	2.0	3
Cerebrovascular disease	161.8 (155.8–168.1)	2	2024.0 (1962.1–2089.7)	2	48.4 (46.6–50.3)	2	14.5	40.3	52.3	68.1	134.6	27.7	2	1.7	8
Ischemic stroke[d]	109.4 (105.0–113.8)		1079.0 (1041.3–1118.9)		32.7 (31.4–34.0)		9.2	26.8	35.5	46.7	100.8	19.9		1.7	
Hemorrhagic stroke[d]	52.4 (50.2–54.9)		945.0 (912.9–978.8)		15.7 (15.0–16.4)		5.3	12.8	16.5	22.5	45.2	9.7		1.8	
Hypertensive heart disease	37.4 (34.3–39.4)	4	647.5 (562.1–676.0)	3	11.2 (10.3–11.8)	4	1.6	4.3	8.2	17.9	113.8	13.6	3	4.2	1
Cardiomyopathy and myocarditis	28.0 (26.9–29.2)	5	559.5 (538.6–582.1)	5	8.4 (8.1–8.8)	5	2.3	4.7	7.2	12.1	34.7	7.3	4	2.6	2
Atrial fibrillation and flutter	22.7 (19.3–26.3)	6	191.5 (168.0–215.3)	7	6.8 (5.8–7.9)	6	1.7	5.6	7.4	9.7	44.0	4.1	6	1.7	5
Rheumatic heart disease	9.5 (9.1–9.9)	8	139.1 (133.3–144.7)	8	2.8 (2.7–3.0)	8	1.1	2.5	3.3	4.4	8.9	1.9	7	1.7	6
Aortic aneurysm	12.8 (12.3–13.4)	7	201.2 (194.0–209.2)	6	3.8 (3.7–4.0)	7	1.8	3.5	4.3	5.1	6.8	1.5	8	1.4	10
Peripheral arterial disease	8.2 (7.5–8.9)	9	96.5 (89.6–103.5)	10	2.4 (2.2–2.6)	9	0.8	2.0	2.6	3.4	23.1	1.4	10	1.7	7

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	National Deaths, YLLs, and Mortality Rate						US County-Level Mortality Rates								
							No. of Deaths/100 000 Population								
Cause of Death	Deaths, No. × 1000 (95% UI)	Rank	YLLs, No. × 1000 (95% UI)	Rank	Mortality Rate No./100 000 Population (95% UI)	Rank	Minimum	10th Percentile	Median	90th Percentile	Maximum	90th Minus 10th Percentile No./100 000 Population[a]	Rank	90th/10th Percentile Ratio[b]	Rank
Endocarditis	8.1 (7.7–8.5)	10	134.8 (129.5–140.2)	9	2.4 (2.3–2.5)	10	1.1	1.9	2.6	3.3	5.4	1.5	9	1.8	4
Other cardiovascular and circulatory diseases	37.9 (36.3–39.7)	3	564.4 (543.4–587.4)	4	11.3 (10.9–11.9)	3	4.5	9.8	12.4	15.1	40.9	5.3	5	1.5	9

Abbreviation: UI, uncertainty interval.

[a]Measure of absolute geographic differences.

[b]Measure of relative geographic differences.

[c]Not included in the rankings.

[d]Subtype of cerebrovascular disease and not included in the rankings.