The Journal of Clinical Hypertension

WILEY

ORIGINAL ARTICLE OPEN ACCESS

Trends and Disparities in Heart Failure Mortality Among Hypertensive Older Adults in the United States: A 22-Year Retrospective Study

Ahmed Raza[1] | Manal Kaleem[2] | Muhammad Aliyan Ahmed Shaikh[3] | Fatima Mansoor[4] | Muhammad Ansab[1] | Mustafa Turkmani[5,6] | Ubaid Khan[7]

[1]Department of Medicine, Services Institute of Medical Sciences, Lahore, Pakistan | [2]Department of Medicine, Dow University of Health Sciences, Karachi, Pakistan | [3]Department of Surgery, Dr. Ruth KM PFAU Civil Hospital, Karachi, Pakistan | [4]Department of Medicine, Karachi Medical and Dental College, Karachi, Pakistan | [5]Faculty of Medicine, Michigan State University, East Lansing, Michigan, USA | [6]Department of Internal Medicine, McLaren Health Care, Oakland, Michigan, USA | [7]Division of Cardiology, University of Maryland School of Medicine, Baltimore, USA

Correspondence: Ahmed Raza (ahmed786raza3@gmail.com) | Mustafa Turkmani (turkman5@msu.edu)

Received: 5 March 2025 | **Revised:** 9 April 2025 | **Accepted:** 21 April 2025

Funding: The authors received no specific funding for this work.

Keywords: demographic variations | heart failure | hypertension | mortality trends | mortality

ABSTRACT

Hypertension (HTN) is a significant risk factor for heart failure (HF), and both significantly contribute to cardiovascular mortality. This study aims to examine trends and disparities in HF-related mortality among hypertensive older adults (≥65 years) in the United States from 1999 to 2020. Centers for Disease Control and Prevention—Wide-ranging Online Data for Epidemiologic Research (CDC-WONDER) database data were analyzed, focusing on HTN as the underlying cause and HF as the contributing cause of death. Age-adjusted mortality rates (AAMRs) and crude rates were stratified by gender, race/ethnicity, age groups, urban–rural status, and geographic regions. The Joinpoint regression program was used to calculate annual percentage changes (APCs) and average annual percentage changes (AAPCs). A total of 259 079 HF-related deaths occurred among hypertensive older adults, with an overall AAMR increase from 11.27 in 1999 to 41.05 in 2020, indicating a clear upward trend (AAPC: 5.51%). Females had higher AAMRs (28.57) than males (25.56); however, males showed a steeper rise in mortality (AAPC: 6.15% vs. 5.23%). Non-Hispanic Blacks had the highest AAMR (43.99), while NH Whites exhibited the most significant increase (AAPC: 5.92%). Mortality rates were highest in the West (AAMR: 34.57) and lowest in the Northeast (21.44). Non-metropolitan areas had a higher AAMR than metropolitan areas (30.69 vs. 26.52). These findings emphasize the necessity for targeted interventions to diminish disparities and tackle increasing mortality rates in vulnerable populations, especially among women, NH Blacks, individuals in the West, and those living in non-metropolitan areas.

1 | Introduction

Hypertension (HTN) and heart failure (HF) are the second and the third leading causes of death due to cardiovascular diseases, after coronary heart disease [1]. According to the World Health Organization (WHO), HTN is the persistent elevation of systolic or diastolic blood pressure (BP) to or above 140 and 90 mm Hg, respectively [2]. It is the leading cause of CVS morbidity and premature mortality, with a global disease prevalence of 31.1% in the adult population (1.39 billion adults worldwide) [3]. Although there are advancements in the health care system and better knowledge and treatment options available, mortality due to HTN is on the rise in the United Status [4]. HF has also shown an overall increase in age-adjusted mortality rates (AAMRs) in young adults in the United States [5]. It has shown a trend of increasing prevalence in the elderly population globally, especially in low and middle-income regions [6]. Despite advancements in management techniques and medications, HF still has a poor prognosis [7] and accounts for 9.91 million years lost due to disability worldwide and a global economic burden of $346.17 billion [6].

HTN accounts for one of the leading etiologies of HF, with the association being higher for HF due to preserved ejection fraction [8]. The traditional culprit for this association has been left ventricular hypertrophy and diastolic dysfunction. Still, HTN plays a role in HF in several ways, including but not limited to both diastolic and systolic dysfunction as well as neurohormonal changes resulting from chronic activation of the renin-angiotensin-aldosterone system, causing deleterious effects on the heart due to increased hemodynamic stress [9, 10]. HF with underlying HTN is associated with high mortality rates, with some trials, such as ALLHAT, showing up to 85% 10-year mortality [11].

Although the role of HTN in HF is well established, there is limited data on mortality trends due to HF in the population with underlying HTN. That's why we undertook this study to identify the trend of HF-related mortality in hypertensive patients and variations of this trend in different demographics and regions of the US. It will help identify populations at risk and aid policymakers and healthcare professionals, enabling prompt steps to be taken to lessen these disparities.

2 | Methods

2.1 | Study Design

The datasets analyzed during this study were generated from the Centers for Disease Control and Prevention Wide-Ranging Online Data for Epidemiologic Research (CDC-WONDER) Database [12], which is an extensive repository of death certificate data from all the states of the US and the District of Columbia. The multiple cause of death data was used to identify the individuals aged 65 years and above, with HTN as the underlying cause of death (UCD) and HF as the contributing cause of death. The data were retrieved using the International Classification of Diseases Tenth Revision (ICD-10) code I10-I15 for hypertensive diseases and I50 for HF. According to the US Department of Health and Human Services, the UCD of death is defined as the disease or injury that initiated the chain of events that directly led to death [13]. Similar codes for HF and HTN have been employed in earlier studies with a similar study design [4, 5, 14]. When HTN is mentioned as the UCD, it implies that HTN developed first and triggered the pathophysiological changes that ultimately resulted in death. In this scenario, where HTN is listed as the UCD and HF as the contributing cause of death, HTN is considered the root cause that led to the development of HF, which became the immediate cause of death. We listed HTN as the UCD and HF as the contributing cause of death to generate the datasets. The study was not deemed necessary for institutional review board approval, as the data are de-identified, government-issued, and publicly available. This study adheres to the reporting standards of the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines [15].

2.2 | Data Extraction

The data were extracted by population, gender, race or ethnicity, age groups, place of death, urban–rural classification, census regions, and states. Race or ethnicity was classified as Hispanic or Latino, Non-Hispanic (NH) Asian or Pacific Islander, NH American Indian or Alaska Native, NH Black or African American, and NH White. The place of death was categorized into medical facilities, the decedent's home, nursing homes or long-term care facilities, hospice centers, and others. The age groups were divided into 10-year intervals from 65 to 85+ years. The census regions were classified into the Northeast, the Midwest, the South, and the West. The National Center for Health Statistics Urban–Rural Classification Scheme was used to access the population by metropolitan (large central, large fringe, medium and small metropolitan) and non-metropolitan (micropolitan and non-core) areas [16].

2.3 | Statistical Analysis

The data are reported in AAMRs and crude death rates (CR). The AAMRs were determined by applying age-specific mortality rates to the age distribution 2000 US standard population, resulting in a weighted average for equitable comparisons of mortality rates across various populations or time periods [17]. CRs were calculated by dividing the number of deaths by the total population of each respective year. The AAMRs and CRs were used to analyze the deaths stratified by gender, race or ethnicity, census region, urban-rural classification, and state.

The Joinpoint Regression Program 5.0.2 [18] was used to calculate the Annual Percentage Changes (APCs) and Average Annual Percentage Changes (AAPCs) with 95% Confidence Intervals (CIs). This software analyzes the trends to determine the simplest joinpoint model. Beginning with the fewest joinpoints, it evaluates the statistical significance of adding more joinpoints up to a specified maximum limit, using Monte Carlo Permutation Tests [19]. To classify APCs as either increasing or decreasing, we used a two-tailed t-test to determine if the slope representing the change in mortality deviated significantly from zero. Additionally, to compare the trends between different groups, we utilized the pairwise comparison feature in Joinpoint, which tests the equality of the slopes between the groups, indicating whether the trends are parallel. This method followed the default procedure of Joinpoint, as described by Kim et al. [20]. Positive, non-overlapping CIs above zero indicate a significant increase, and negative, non-overlapping CIs below zero indicate a substantial decrease in rates. A p value of less than 0.05 was considered statistically significant.

3 | Results

A total of 259 079 (100%) HF-related deaths occurred in hypertensive older adults (aged ≥65 years) in the United States

TABLE 1 | Deaths, rates, and changes in heart failure mortality in hypertensive older adults (≥65 Years), 1999–2020.

Variable	Number of death	AAMRs (95% CI)	AAPCs (95% CI)
Overall	259 079 (100%)	27.72 (27.61–27.83)	5.5107[a] (4.5859–6.3462)
Sex			
Female	170 425 (65.78%)	28.57 (28.43–28.7)	5.2274[a] (4.3104–6.0687)
Male	88 654 (34.22%)	25.56 (25.39–25.73)	6.1482[a] (5.147–7.2589)
Census region			
Northeast	41 649 (16.08%)	21.44 (21.23–21.65)	5.8438[a] (4.9474–6.7164)
Midwest	58 504 (22.58%)	26.78 (26.57–27)	5.2072[a] (4.4136–6.4768)
South	91 021 (35.13%)	27.74 (27.56–27.92)	5.7772[a] (4.1007–7.4831)
West	67 905 (26.21%)	34.57 (34.31–34.83)	4.7784[a] (4.1428–5.6967)
Urbanization			
Metropolitan	207 634 (80.14%)	26.52 (26.38–26.67)	5.0871[a] (4.2346–6.1324)
Non-Metropolitan	51 445 (19.86%)	30.69 (30.43–30.96)	6.2246[a] (5.1735–7.2624)
Race and ethnicity			
NH Asian or Pacific Islander	5859 (2.26%)	19.42 (18.92–19.91)	3.0918[a] (2.347–4.3007)
NH Black or African American	32 366 (12.49%)	43.99 (43.51–44.47)	3.7360[a] (2.8562–4.6497)
NH White	205 750 (79.42%)	26.48 (26.37–26.6)	5.9159[a] (4.9532–6.8222)
Hispanic or Latino	13 592 (5.25%)	24.04 (23.63–24.44)	5.2662[a] (4.0446–7.7638)
Age groups[b]			
65–74 years	28 343 (10.94%)	5.55 (5.49–5.62)	4.9366[a] (3.8308–6.2636)
75–84 years	67 020 (25.87%)	22.45 (22.28–22.62)	5.0306[a] (4.2338–5.7609)
85+ years	163 716 (63.19%)	136.98 (136.32–137.65)	5.8372[a] (4.8573–6.7574)
States with the highest % increase			
Massachusetts	3224	13.66 (13.18–14.13)	3.7909[a] (1.6791–7.4048)
Tennessee	8294	46.02 (45.02–47.01)	8.1982[a] (6.4665–10.2826)
States with the lowest % increase			
Colorado	2618	21.51 (20.69–22.34)	2.0047[a] (0.7986–3.1479)
New Hampshire	939	22.34 (20.91–23.78)	0.7856 (−0.8884–2.5234)

Abbreviations: AAMRs, age-adjusted mortality rates; AAPC, average annual percentage change; CI, confidence interval.
[a]Average annual percentage change (AAPC) is significantly different from zero at alpha = 0.05.
[b]Crude mortality rates were used for age-group analysis.

from 1999 to 2020 (Table 1). Among these, 36.06% occurred within nursing homes/long-term care facilities, 24.46% in medical facilities, 4.08% in hospices, and 5.35% at the decedent's home (Tables S1–S6).

3.1 | Overall Trends for HF-Related Mortality in HTN

The overall AAMR for HF-related deaths during the study period was 27.72 (95% CI, 27.61–27.83). The AAMR increased from 11.27 in 1999 to 41.05 in 2020, with an average annual percentage increase of 5.51% (95% CI, 4.59–6.35), demonstrating an overall increasing trend. (Figure 1, Table 1). The overall AAMR increased from 1999 to 2001 with an APC increase of 36.55% (95% CI, 19.52–49.12). The mortality trend remained stable from 2001 to 2013, with a non-significant APC of 0.13% (95% CI, −1.09 to 0.99). Following this stability, the overall trend exhibited a significant rise from 2013 to 2020 with an APC increase of 7.22% (95% CI, 5.70–9.35) (Figure 1, Tables 1 and S7).

To account for the 2017 change in HTN diagnostic criteria, we further divided the study period into two timelines: 1999–2017 and 2017–2020. Between 1999 and 2017, the AAMRs increased from 11.27 in 1999 to 33.54 in 2017, with an APC of 5.23% (4.15 to 6.15, $p < 0.05$), indicating a steady rise. However, for 2017–2020, the AAMR increased from 33.54 in 2017 to 41.05 in 2020, with an APC of 7.22% (5.70–9.35, $p < 0.05$), reflecting a sharper rise in mortality following the change in diagnostic criteria [21].

3.2 | Stratification by Demographic Groups

3.2.1 | Gender Stratification

Overall, 65.78% of deaths occurred in females and 34.22% in males (Table 1). During the study period, older adult females had a higher AAMR (28.57) than older adult males (25.56). Despite having lower AAMRs than females, older adult males exhibited a more significant rise in mortality with an average

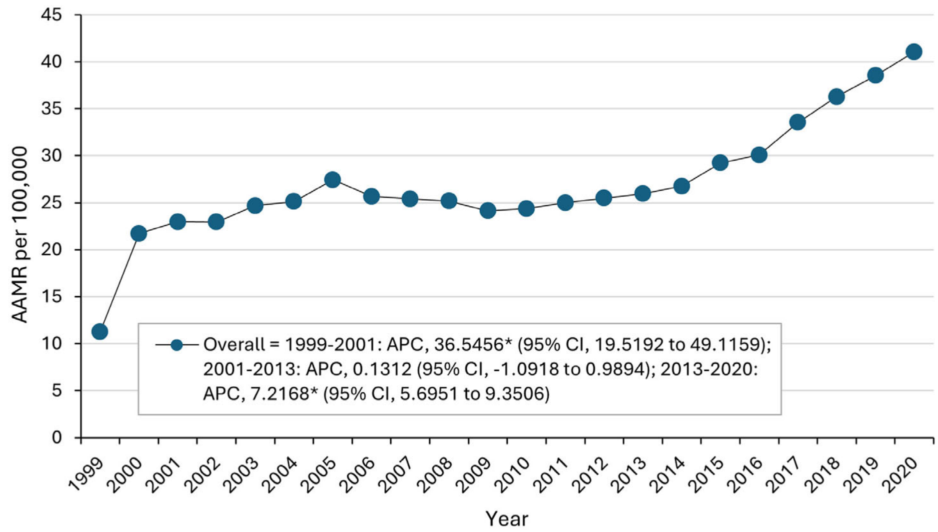

FIGURE 1 | Trends in the overall age-adjusted mortality rates (AAMRs) related to heart failure in hypertensive older adults in the United States, 1999–2020.

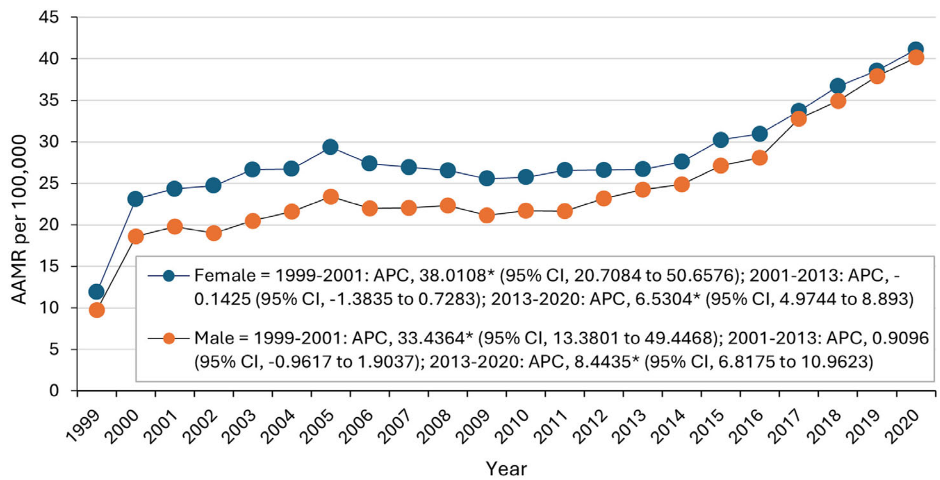

FIGURE 2 | Trends in sex-stratified age-adjusted mortality rates (AAMRs) related to heart failure in hypertensive older adults in the United States, 1999–2020.

annual percentage increase of 6.15% (95% CI, 5.15–7.26). In comparison, older females exhibited a lower increase of 5.23% (95% CI, 4.31–6.07) (Tables 1 and S7). The temporal trends and APCs over the study period for both sexes are illustrated in Figure 2.

The parallelism test rejected parallel trends between female and male AAMRs, indicating the trends were significantly different (p value < 0.05). However, the AAPC difference between the two groups was not statistically significant, with a value of −0.92% (−3.37 to 1.53), suggesting a 0.92% less rise in female AAPC than in male AAPC.

3.3 | Racial Stratification

From 1999 to 2020, the AAMR increased for all racial and ethnic groups. NH Blacks or African Americans had the highest AAMR (43.99) followed by NH whites (26.48), Hispanics or Latinos (24.04), and NH Asians or Pacific Islanders (19.42). Although NH African Americans had the highest AAMRs among all the racial groups, NH Whites experienced the most significant rise in mortality, with an average annual percentage increase of 5.92% (95% CI, 4.95–6.82), followed by Hispanics at 5.27% (95% CI, 4.04–7.76), NH African Americans at 3.74% (95%CI, 2.86–4.65). The NH Asians or Pacific Islanders experienced the lowest percentage increase in mortality of 3.09% (95% CI, 2.35–4.30) till the end of the study period (Tables 1 and S8). The temporal trends with APCs are illustrated in Figure 3.

The parallelism test rejected parallel trends between NH Asian or Pacific Islander and Hispanic or Latino, indicating significantly different trends (p value < 0.05). The AAPC difference between the two groups was not significant, with a value of −2.17% (−5.96 to 1.61). Similarly, for NH Black and NH White, the trends were significantly different, with a non-significant AAPC difference of −2.18% (−4.62 to 0.26), showing a 2.18% greater rise in NH White AAPC than in NH Black AAPC. NH Blacks also showed a significantly different trend from Hispanics or Latinos with a non-significant AAPC difference of −1.53% (−5.28 to 2.22). The

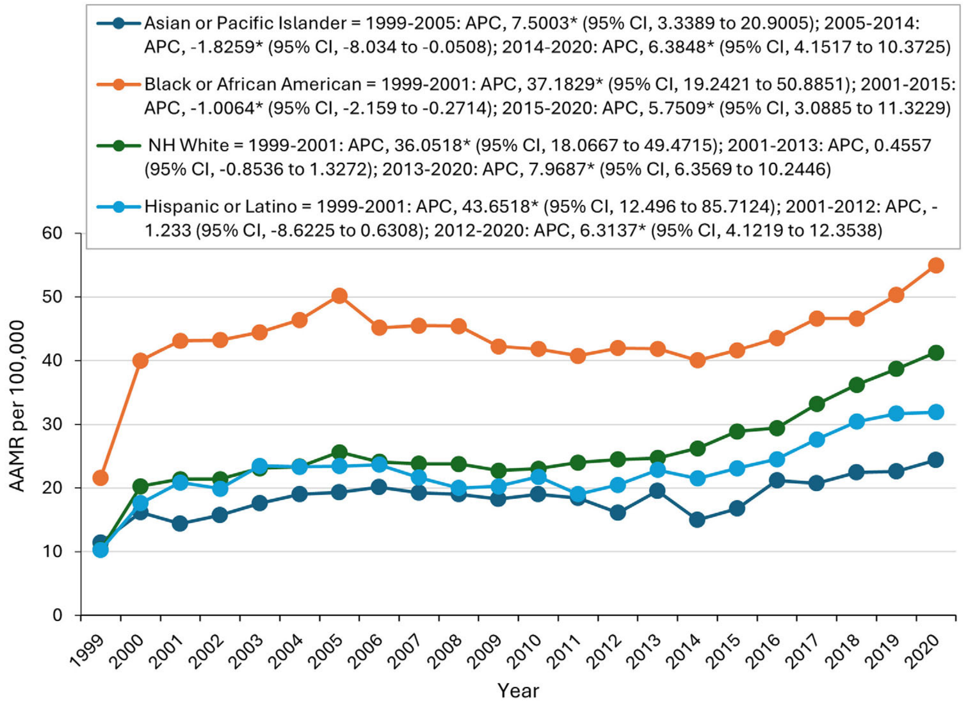

FIGURE 3 | Race and ethnicity-stratified trends in age-adjusted mortality rates (AAMRs) related to heart failure in hypertensive older adults in the United States, 1999–2020.

pairwise comparison revealed parallel trends for the other racial and ethnic groups.

3.4 | Ten-Year Age Groups

Crude mortality rates increased consistently with age, with the lowest rate in the 65–74 years age group (5.55) and the highest in those over 85 years age group (136.98). The 65–74 age group exhibited a slight annual increase in mortality of 4.94% (95% CI, 3.83–6.26), while the age group over 85 years experienced a significantly greater rise of 5.84% (95% CI: 4.86–6.76). This trend highlights the increased vulnerability of older individuals with HTN to HF-related deaths (Tables 1 and S11, Figure S3).

3.4.1 | Stratification by Geographic Region

On pairwise comparison, non-parallel trends were observed between the 65–74-year and 75–84-year age groups, with a relative non-significant AAPC difference of −0.09% (−2.77 to 2.58). The other age groups exhibited parallel trends with AAPC differences that were not statistically significant.

3.5 | Census Regions

Over the study period, the highest AAMR was observed in the Western region (34.57), followed by the South (27.74), the Midwest (26.78), and the Northeast (21.44). The AAMR for the Western and Midwestern regions remained stable from 1999 to 2001, followed by a sharp decline until 2012, with an upward trend re-emerging in 2020. A similar pattern was observed in the Southern and Northeastern regions. Notably, the Northeast had the most significant greatest annual percentage increase of 5.84% (95% CI, 4.95–6.72), while the West had the lowest of 4.78% (95% CI, 4.14–5.70). The annual mortality trend was also observed in the South with an AAPC of 5.78% (95% CI, 4.10–7.48) and the Midwest with an AAPC of 5.21% (95% CI, 4.41–6.48) (Tables 1 and S9). Figure 4 illustrates the temporal trends with APCs for all the census regions.

The parallelism test indicated significant non-parallel trends between the Northeast and the Midwest, with a non-significant AAPC difference of 0.64% (−2.17 to 3.45). The Northeast also exhibited a significant non-parallel trend with the South, with a relative AAPC increase of 0.07% (−2.85 to 2.98), which was non-significant. The remaining regions showed parallel trends with AAPC differences that were not statistically significant.

3.6 | State Wise Distribution

There were significant regional differences in AAMR across different states, with the AAMRs ranging from the lowest of 13.48 in Hawaii to the highest of 55.79 in Mississippi. States in the top 90th percentile included Mississippi, Tennessee, Oklahoma, Washington, South Dakota, and Iowa and had the AAMRs approximately two to three times higher than those in the bottom 10th percentile, which included Hawaii, Massachusetts, Connecticut, Pennsylvania, Delaware, and New Jersey (Figure 5). States with the highest percentage increase in AAMR included Massachusetts and Tennessee, with the highest percentage increase in AAMR of 879.09% and 771.69% from 1999 to 2020, respectively, while those with the lowest percentage increase in AAMR included Colorado (58.88%) and New Hampshire (23.40%) (Tables 1 and S12,

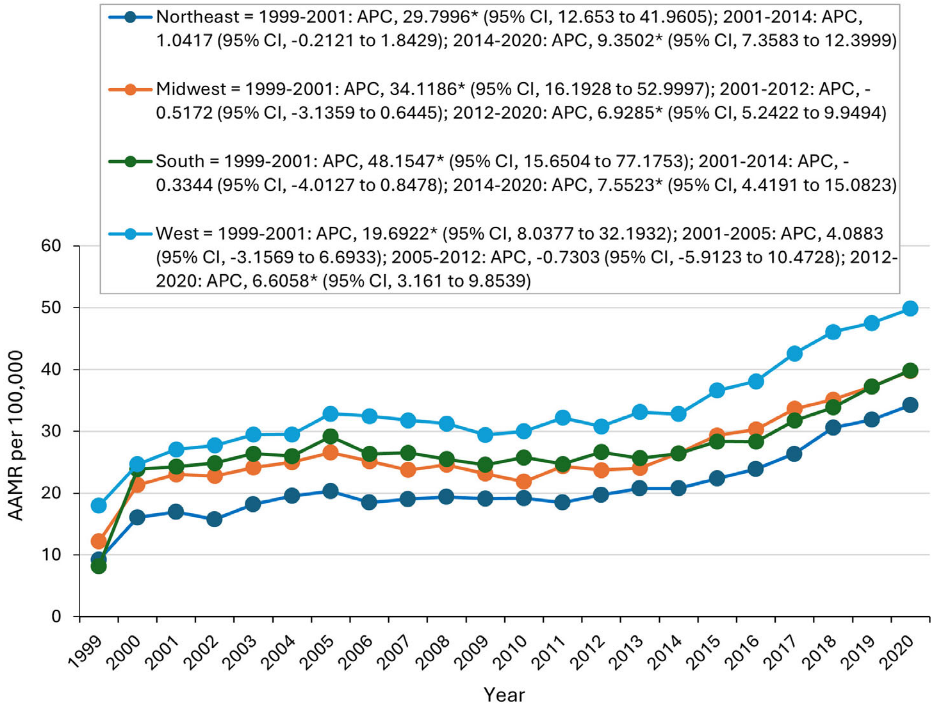

FIGURE 4 | Trends in age-adjusted mortality rates (AAMRs) related to heart failure in hypertensive older adults stratified by census regions in the United States, 1999–2020.

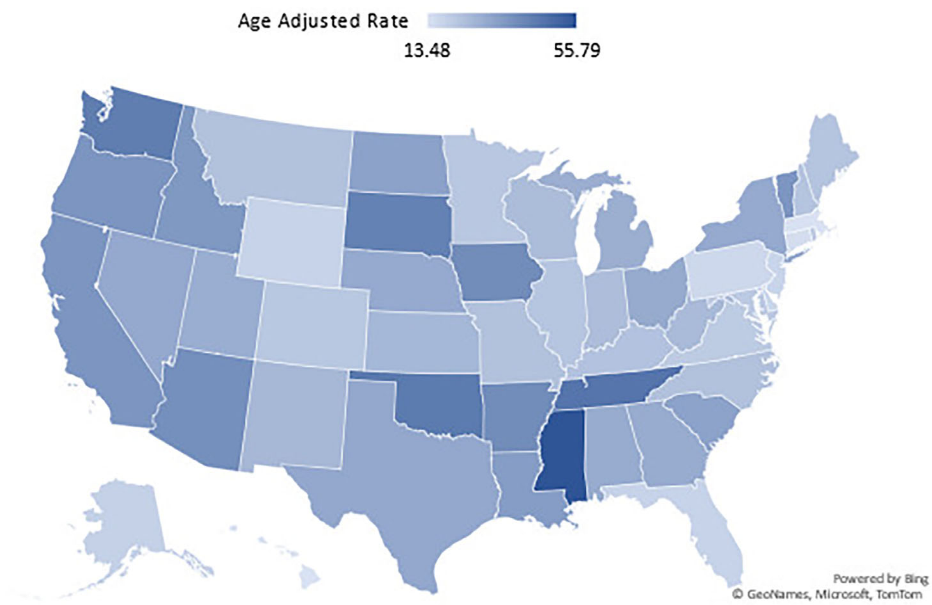

FIGURE 5 | Trends in age-adjusted mortality rates (AAMRs) related to heart failure in hypertensive older adults in the United States, mapped for each State of the United States, 1999–2020.

Figure S2). The percentage change in mortality for every state is provided in Table S13.

3.7 | Urbanization

Non-metropolitan areas showed a higher AAMR (30.69) than non-metropolitan areas (26.52), with an average annual percentage increase of 6.22% (95% CI: 5.17–7.26), also higher than the AAPC increase of non-metropolitan areas, which was 5.09% (95% CI: 4.23–6.13) (Tables 1 and S10, Figure S1). The parallelism test revealed parallel mortality trends between metropolitan areas and non-metropolitan areas, with a relative AAPC decline of −0.86% (−3.31 to 1.59) in metropolitan areas, which was not significant.

4 | Discussion

This study examines the 20-year mortality trends in older adults (65+ years) with pre-existing HTN, focusing on HF as the immediate cause of death between 1999 and 2020. Our analysis reveals notable disparities in HF-related mortality trends among hypertensive older adults, highlighting variations across various demographic groups and geographic regions. These findings can help inform health policies to mitigate current trends in HTN-related HF mortality and protect vulnerable populations. First, an overall increasing trend of HF-related mortality in HTN over the last two decades was observed. This pattern of progressive escalation was similar in both older men and women; however, females exhibited higher AAMRs than males. Second, the US Black population of our concerned age group displayed the highest mortality rates. Third, significant regional statistics included the highest AAMRs demonstrated by the Western region, with states such as Mississippi, Tennessee, Oklahoma, Washington, and South Dakota falling in the top 90th percentile. Additionally, non-metropolitan areas exhibited higher mortality rates than metropolitan areas.

With approximately 6.7 million people currently living with HF in the United States, this number is expected to rise to 8.7 million by 2030, 10.3 million by 2040, and 11.4 million by 2050, accompanied by a 24% lifetime risk of developing HF [22]. High BP has been established as one of the key risk factors [10], and one in two Americans have HTN [23]. Chronic HTN often culminates in HF if left unmanaged [24]. In a cohort study conducted by Levy et al., HTN preceded HF in 91% of newly diagnosed cases [25]. Almost four in 10 (39%) HF cases in men and nearly six in 10 (59%) cases in women were attributed to HTN [25]. At 80 years of age, the lifetime risk of HF was discovered to be around 20%, doubling for patients with BP of 160/100 mm Hg compared to those with 140/90 mm Hg [26]. In hypertensive patients, left ventricular (LV) diastolic dysfunction is often the first sign of heart disease [24]. Prolonged pressure overload leads to concentric LV hypertrophy, progressing to HF with preserved ejection fraction [24]. Alternatively, hypertensive heart disease can also precipitate dilated cardiomyopathy, characterized by both diastolic dysfunction and reduced ejection fraction, thereby leading to HF [24].

In our analysis of the overall 20-year escalating trend, we report a gradual rise from 1999 to 2006, followed by a brief decline from 2006 to 2009. Rates resumed an upward trend post-2009. This observed pattern is attributable to a multifaceted array of factors. Enhanced diagnostic methodologies introduced between 1999 and 2006 likely facilitated improved detection of HF and increased reporting on death certificates, thereby contributing to the initial escalation. Such enhanced techniques included Impedance Cardiography, Doppler Echocardiography, and testing for B-type natriuretic peptide (BNP) serum levels for diagnosing HF [27–29]. The increased identification of HTN beyond the early 1990s was also made possible due to increased BP screening, with approximately 80% of Americans having their BP checked annually [30]. The widened availability of BP monitoring at home and Ambulatory Monitoring (ABP), along with encouragement for their use as supplementary sources of information in clinical practice, also made significant contributions [31]. Consequently, rates of BP control increased from 31.8% in 1999–2000 to 49.5% in 2007–2008 [32].

Following 2006, advancements in HF treatment and management strategies, as well as heightened public awareness initiatives around HTN, explain the subsequent decline in rates. HTN treatment rates increased from 59.8% to 74.7% between 1999–2000 and 2011–2012, and control rates also improved, rising from 32.2% to 51.2% [32]. Factors contributing to this improved control included health insurance coverage, frequent healthcare visits, and guideline-based cholesterol treatment [33]. As highlighted by Muntner et al., controlled BP was more likely to be achieved among those with private insurance (48.2%), Medicare (53.4%), or other government health insurance or Medicaid (43.2%), compared to patients without health insurance (24.2%) [32]. Key pharmacological advances in HF management, including Angiotensin receptor-neprilysin inhibitors (ARNI), sodium-glucose co-transporter inhibitors (SGLT2i), and glucagon-like peptide-1 agonists (GLP-1 RA) have provided new therapeutic options to improve patient outcomes [34]. These drugs offered new treatment options, improving patient outcomes. However, post-2009 mortality rates increased. The US BP control progress plateaued and subsequently declined during and after 2009 [32], indicating an increasing prevalence leading to worsening HTN outcomes as depicted in our study.

SGLT2 inhibitors and ARNIs significantly reduce the risk of HF events and improve left ventricular ejection fraction, underscoring their potential role in HF management [35, 36]. SGLT2 inhibitors were approved for HF in 2020, while ARNIs were approved in 2014. However, our analysis showed that post-2013, the HF mortality in hypertensive patients was on the rise. One potential reason for this could be the limited adoption of these new drugs. The Get with the Guidelines for HF (GWTG-HF) registry indicated that nearly 70% of patients hospitalized for HF with reduced ejection fraction (HFrEF) would be eligible for ARNIs [37]. In contrast, only 2.3% of patients hospitalized for HFrEF were prescribed ARNIs at the time of discharge within the first 12 months following FDA approval [38]. The underprescription of ARNIs and SGLT2 inhibitors remains an issue today, with the prevalence of ARNI use at 11% and SGLT2 inhibitor use at 6%. Furthermore, the utilization of ARNIs and SGLT2 inhibitors is notably lower among female patients, individuals older than 85, and patients with comorbid conditions such as diabetes, stroke, chronic kidney disease, and chronic obstructive pulmonary disease [39]. Additionally, other factors such as the increasing prevalence of comorbidities and lifestyle modifications, including continued smoking, increasing sedentary behavior, obesity, high blood cholesterol, and diabetes also contributed to the rise [40]. BP control rates declined following 2013 despite increasing awareness of HTN [41, 42]. This contributed to the adverse cardiovascular outcomes and elevated risk of HF development in hypertensive populations. Our results are also consistent with the data reported by HFSA (HF Society of America), which reports an increase in HF mortality rates since 2012, with a pronounced acceleration in 2020 [22]. Furthermore, our analysis revealed a sharper incline in AAMRs following the 2017 ACC/AHA Hypertension Clinical Guidelines. The revised criteria lowered the threshold for HTN diagnosis from 140/90 to 130/80 mm Hg [21]. This change likely led to more individuals being classified as hypertensive, contributing to the increased mortality rate.

HF-related AAMR in hypertensive patients exhibited a significant gender disparity, with older women demonstrating higher rates than older men. This contrasts the results reported by Siddiqi et al., where older men in the general US population exhibited higher mortality rates due to HF alone [42]. This can be explained based on the prevalence of HTN between the sexes. Previous studies have reported significant BP differences between genders in the US population, with 71.6% of males classified as normotensive compared to 69.7% of females [43]. The risk for developing HTN in normotensive males is two-fold compared to three-fold in normotensive females [25]. Additionally, recent studies report that females experience a much sharper increase in BP from the third decade of life, and consequently, the prevalence of HTN accelerates comparatively with age [44]. This is also consistent with an analysis of US HTN-related mortality, which found that older adult women displayed the highest AAMRs [45]. Women also face a 1.1-fold higher risk of developing cardiovascular disease per 10 mm Hg increase in systolic BP compared to men [46]. The cause lies in the fact that there are fundamental differences between men and women in the left ventricular response to chronic load alteration, with males more likely to develop eccentric left ventricular remodeling with stress and females develop more concentric remodeling, making females more susceptible to HF with preserved ejection and increasing the risk of mortality as compared to men [47]. Left ventricular chamber size increases in men with aging but remains stable in women [48]. The absence of chamber dilation may render the female heart more susceptible to impairments in systolic, diastolic, or chronotropic reserves [49].

Our results demonstrate pronounced differences in mortality rates across racial and ethnic groups. Older adult NH Blacks or African Americans (AAs) exhibited the highest AAMRs, followed by Non-Hispanic Whites and Hispanics or Latinos, while older adult NH Asians had the lowest. These results are consistent with the prevalence of HTN and HF in these racial groups. The National Health and Nutrition Examination Survey (NHANES) 2011–2012, conducted by the CDC, indicated that the highest prevalence of HTN in the US was among African American adults (42.1%), compared to non-Hispanic Whites (28.0%), Hispanics (26.0%), and non-Hispanic Asians (24.7%) [50]. Similarly, the prevalence of HF from 2013 to 2016 was the highest among African Americans at 5017 per 100 000 population, significantly higher than other racial groups. For non-Hispanic Whites, the prevalence during the same period was 2746 per 100 000 population [51]. The all-cause standardized cardiovascular disease (CVD) mortality rate was also the highest among Black adults at 484.7 (397.3–599.1) per 100 000, followed by White adults at 384.5 (338.3–441.6), Hispanic adults at 292.4 (217.8–402.7), and adults of other races/ethnicities at 255.1 (143.0–510.2) [52]. The diversity of underlying causes, pathophysiology, genetic predispositions, and sociocultural factors contributes to these variations in clinical outcomes. The US Black population has one of the highest prevalence rates of HTN worldwide [53], with HTN accounting for 30% of all deaths in this population [54]. The impact of HTN in NH AAs is also reported to be severe, with high prevalence and severity, earlier onset, and extensive organ damage [54]. Consequently, the AA population has a 50% higher frequency of HF and mortality [55], with hypertensive AAs being vulnerable to more severe left ventricular impairment [56]. Blacks also respond poorly to anti-hypertensive drugs such as Beta-blockers and ACE inhibitors [57]. The reasons for this lie in the differences in pathophysiology, including endothelial dysfunction, higher salt sensitivity, and lower plasma renin levels in the black community [58]. AAs also report a high prevalence of comorbidities such as obesity and diabetes mellitus [54] and low BP control rates [32, 59] in comparison with other ethnic groups.

NH Asians had the lowest AAMRs in our data. A study conducted by Yoon et al. found Asians to have the lowest HTN prevalence of 24.9% as compared to Blacks, Whites, and Hispanics (41.2%, 28.0%, and 25.9%, respectively) [60]. These discrepancies also parallel the trends in AAMR across racial groups reported in our study. The American Heart Association estimates that Asians have a lower risk of developing HTN (84.1%) compared to Blacks (92.7%), Whites (86.0%), and Hispanics (92.4%) [61]. Additionally, an investigation found nearly seven in 10 Asians with HTN to be taking proactive steps to manage their condition, with 67.8% receiving management, 64.3% adhering to medication, and 67.0% seeking information to improve their health [62]. Our results are also in line with the findings of Cheng et al., who reported a lower incidence and prevalence of HF in Asians compared with Black and White populations [63]. In our data, the NH white adult population displayed the second-highest AAMRs. Our results align with the conclusions drawn by Hicken et al., who reported the highest HTN prevalence in Blacks (49%) and the second highest in Whites (33%) within their study population [64].

Furthermore, we observed substantial regional variations in HF-associated mortality among hypertensive adults, with the highest burden in the western region and the lowest in the northeastern region. Our findings present a contemporary paradox that diverges from the existing body of literature. The southern regions exhibit the highest incidence of HTN in older adults, with the prevalence increasing by 0.6% from 2009 to 2017. The West, however, had a decline of 0.2% from 2009 to 2017 [65]. Notably, HTN-related mortality rates reveal a distinct geographic pattern, wherein the South is afflicted with the highest mortality rates, while the Northeast reports the lowest mortality rates [4]. In contrast, mortality rates attributed solely to HF among older adults also exhibit regional disparity, with the Midwest representing the highest mortality rates and the Northeast demonstrating the lowest [42]. The states in the top 90th percentile (Mississippi, Tennessee, Oklahoma, Washington, and South Dakota) had AAMRs roughly three times the AAMRs in the bottom 10th percentile (Hawaii, Massachusetts, and Connecticut). Mississippi had the highest AAMR attributed to HF, with 109.6 deaths per 100 000 population in 2017 [66]. Such high mortality rates in Mississippi are attributed to worse cardiovascular outcomes, further precipitated by a synergistic interplay of comorbidities, including hypertensive disorders, diabetes mellitus, obesity, and sedentary behavior, which collectively exacerbate the cardiovascular risk [66, 67]. Geographical differences in health outcomes are also moderated by the intersection of regional healthcare infrastructure disparities, environmental stressors such as climate variability, and divergent state-specific policies [66].

Our analysis revealed a significant contrast between non-metropolitan and metropolitan areas, with the former exhibiting higher rates, with an overall escalation in both metropolitan and non-metropolitan areas throughout the study period [68]. This aligns with previous reports of higher cardiovascular mortality rates in rural areas of the US compared to urban regions [69, 70]. This trajectory can be attributed to the disparate availability of healthcare resources, including the density of primary care physicians (PCPs) and cardiologists in urban areas, as well as the socioeconomic dichotomy between the populations of these two regions [42]. In a study conducted by Germak et al., rural counties displayed higher rates of hospital closures, and an 8.2% decrease in both PCPs and cardiologists within 6 years following a hospital closure [71]. It was also observed that rates of HTN management were lower among those without access to a healthcare facility (26.5%) than those with access (48.4%) [32]. The gap in healthcare outcomes is also vast, with rural communities displaying a 20% higher all-cause mortality rate than their urban counterparts [72]. In rural areas, there is a diminished utilization of emergency department services and hospitalizations [68], frequently associated with lower use of guideline-recommended therapies at discharge and shorter lengths of stay [73]. Furthermore, HF patients discharged from rural hospitals were less likely to be prescribed Cardiac resynchronization therapy (CRT) and key elements of guideline-directed medical therapy (GDMT), including angiotensin-converting enzyme inhibitor, angiotensin receptor blocker, and ARNI therapy [73]. This elevated the risk of hospital readmission, poor HTN management, accelerated disease progression, and increased mortality. Efforts to reduce rural-urban differences in HF-related mortality will require a combination of diverse public health and clinical interventions targeting the underlying cause [72].

To elucidate trends and disparities in HF mortality among hypertensive populations, examining Social Determinants of Health (SDOH) and their impact on health outcomes is also crucial [73]. SDOH encompasses a complex array of factors, including social, environmental, economic, and psychosocial structures that play a role in shaping health trajectories. These include issues such as substandard housing, neighborhood deprivation, food insecurity, limited access to recreational spaces, transportation barriers, racial and socioeconomic segregation, structural racism, and various psychological stressors. Together, they promote unhealthy behaviors leading to increased stress levels, sympathetic activity, and inflammation, which elevates the risk of HTN [73]. In the United States, 33% of the racial gap in unmanaged HTN between Black and White populations can be explained by SDOHs [74]. Overall, Black individuals are more susceptible to low-income conditions, limited education, disadvantaged neighborhoods, and residence in health professional shortage areas. Furthermore, restricted access to affordable, high-quality medical care, as well as external factors like environmental pollution, can heighten the prevalence of HTN [73]. Food insecurity, characterized by inconsistent or limited access to nutritious food, is linked to obesity, a major risk factor for HTN [75]. This connection is fueled by the consumption of high-calorie, processed foods during scarcity [76]. Additionally, numerous barriers prevent individuals from lower socioeconomic strata from engaging in regular physical activity. These include restricted access to recreational facilities, concerns about neighborhood safety, lack of personal motivation, and demanding time commitments [77, 78]. Psychological stressors such as social isolation or occupational strain have also been associated with raised BP in the United States [79, 80]. Moreover, the impact of SDOH can also lead to non-adherence to recommendations from a healthcare provider, including antihypertensive medication and a healthy lifestyle, which is correlated with an increased risk of CVDs, such as HF [81].

To address the trends in HTN-related HF mortality, it is crucial to establish collaborative efforts between healthcare providers, policymakers, and community leaders. Developing effective prevention and management strategies can help combat the rising trends, such as awareness campaigns focusing on HTN and its present-day causes, as well as cardiovascular risks, including HF [82].

Initiatives that promote healthy lifestyle choices, including physical activity, balanced diets, and stress reduction, should be supported to reduce predisposition to HTN [83]. Additionally, reducing salt intake, avoiding smoking, and limiting alcohol consumption can also play a vital role in the prevention and management of HTN [84]. Furthermore, culturally sensitive interventions for high-risk communities based on racial classifications should be implemented to ensure positive outcomes [85]. Health education classes promoting active self-management and social support should be introduced [86]. Efforts to improve healthcare infrastructure, especially in non-metropolitan areas, with improved access to healthcare services, medications, and healthcare professionals, are also essential for reversing the rising trends and disparities.

5 | Limitations

Several limitations merit consideration when interpreting the findings of this study. Firstly, in the reliance on International Classification of Disease (ICD) codes, there is a risk of omission or incomplete interpretation of mortality data of HF as a cause of death in hypertensive older US adults [87, 88]. Secondly, the database does not provide the data on the systolic and diastolic BP, SDOH, and crucial clinical variables that would facilitate a more nuanced characterization of HF in older hypertensive populations, including vital signs, degree of BP control, age at diagnosis, treatment compliance, ejection fraction, and echocardiographic data. Lastly, the absence of socioeconomic determinants of healthcare is a notable limitation.

6 | Conclusion

This study highlights a significant increase in HF-related mortality rates among older adults with underlying HTN over the past two decades, with an average annual percentage increase of 5.51% in mortality rates. Significant disparities were observed across gender, race and ethnicity, urban-rural areas, and geographic regions, with the most vulnerable being women, NH Blacks, the Western region, and non-metropolitan areas. Targeted healthcare measures are needed to mitigate the increasing mortality burden in vulnerable populations.

Author Contributions

Conceptualization: A.R.; Methodology: A.R.; Formal Analysis and Investigation: A.R.; Writing–Original Draft Preparation: M.K., M.A.A.S., F.M., and A.I.; Writing–Review and Editing: U.K. and A.R.; Supervision: U.K.

Acknowledgments

The authors have nothing to report.

Disclosure

The authors have no relevant financial or non-financial interests to disclose.

Consent and Ethics Statement

The research is based on de-identified data and does not apply to the consent of the participants and ethical approval.

Conflicts of Interest

The authors declare no conflicts of interest.

Study Participants

The research is based on de-identified human death certificate data from the CDC WONDER database, https://wonder.cdc.gov/mcd.html.

References

1. S. S. Martin, A. W. Aday, Z. I. Almarzooq, et al., "2024 Heart Disease and Stroke Statistics: A Report of US and Global Data From the American Heart Association," *Circulation* 149, no. 8 (2024): E347–E913, https://doi.org/10.1161/CIR.0000000000001209.

2. Hypertension, accessed November 27, 2024, https://www.who.int/news-room/fact-sheets/detail/hypertension.

3. K. T. Mills, A. Stefanescu, and J. He, "The Global Epidemiology of Hypertension," *Nature Reviews Nephrology* 16, no. 4 (2020): 223–237, https://doi.org/10.1038/s41581-019-0244-2.

4. S. J. Forrester, E. V. Dolmatova, and K. K. Griendling, "An Acceleration in Hypertension-Related Mortality for Middle-Aged and Older Americans, 1999–2016: An Observational Study," *PLOS ONE* 15, no. 1 (2020): e0225207, https://doi.org/10.1371/JOURNAL.PONE.0225207.

5. V. Jain, A. M. K. Minhas, A. A. Morris, et al., "Demographic and Regional Trends of Heart Failure-Related Mortality in Young Adults in the US, 1999–2019," *JAMA Cardiology* 7, no. 9 (2022): 900–904, https://doi.org/10.1001/JAMACARDIO.2022.2213.

6. G. Lippi and F. Sanchis-Gomar, "Global Epidemiology and Future Trends of Heart Failure," *AME Medical Journal* 5, no. 15 (2020), https://doi.org/10.21037/AMJ.2020.03.03/COIF.

7. D. Z. L. Chan, A. J. Kerr, and R. N. Doughty, "Temporal Trends in the Burden of Heart Failure," *Internal Medicine Journal* 51, no. 8 (2021): 1212–1218, https://doi.org/10.1111/IMJ.15253.

8. A. Kasiakogias, E. A. Rosei, M. Camafort, et al., "Hypertension and Heart Failure With Preserved Ejection Fraction: Position Paper by the European Society of Hypertension," *Journal of Hypertension* 39, no. 8 (2021): 1522–1545, https://doi.org/10.1097/HJH.0000000000002910.

9. J. Hartupee and D. L. Mann, "Neurohormonal Activation in Heart Failure With Reduced Ejection Fraction," *Nature Reviews Cardiology* 14, no. 1 (2017): 30–38, https://doi.org/10.1038/NRCARDIO.2016.163.

10. K. E. Di Palo and N. J. Barone, "Hypertension and Heart Failure: Prevention, Targets, and Treatment," *Heart Failure Clinics* 16, no. 1 (2020): 99–106, https://doi.org/10.1016/J.HFC.2019.09.001.

11. L. B. Piller, S. Baraniuk, L. M. Simpson, et al., "Long-Term Follow-Up of Participants With Heart Failure in the Antihypertensive and Lipid-Lowering Treatment to Prevent Heart Attack Trial (ALLHAT)," *Circulation* 124, no. 17 (2011): 1811–1818, https://doi.org/10.1161/CIRCULATIONAHA.110.012575.

12. Multiple Cause of Death, 1999–2020 Request, accessed September 10, 2024, https://wonder.cdc.gov/mcd-icd10.html.

13. E. G. Brooks and K. D. Reed, "Principles and Pitfalls: A Guide to Death Certification," *Clinical Medicine & Research* 13, no. 2 (2015): 74–82, https://doi.org/10.3121/CMR.2015.1276.

14. T. J. Siddiqi, A. M. Khan Minhas, S. J. Greene, et al., "Trends in Heart Failure–Related Mortality Among Older Adults in the United States From 1999–2019," *JACC: Heart Failure* 10, no. 11 (2022): 851–859, https://doi.org/10.1016/J.JCHF.2022.06.012.

15. E. von Elm, D. G. Altman, M. Egger, S. J. Pocock, P. C. Gøtzsche, and J. P. Vandenbroucke, "The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) Statement: Guidelines for Reporting Observational Studies," *Journal of Clinical Epidemiology* 61, no. 4 (2008): 344–349, https://doi.org/10.1016/j.jclinepi.2007.11.008.

16. D. D. Ingram and S. J. Franco, "2013 NCHS Urban-Rural Classification Scheme for Counties," *Vital and Health Statistics. Series 2, Data Evaluation and Methods Research* no. 166 (2014): 1–73.

17. R. N. Anderson and H. M. Rosenberg, "Age Standardization of Death Rates: Implementation of the Year 2000 Standard," *National Vital Statistics Reports* 47, no. 3 (1998): 1–16. 20.

18. *Joinpoint Regression Program, Version 5.0.2 – May 2023; Statistical Methodology and Applications Branch, Surveillance Research Program* (National Cancer Institute).

19. H. J. Kim, M. P. Fay, E. J. Feuer, and D. N. Midthune, "Permutation Tests for Joinpoint Regression With Applications to Cancer Rates," *Statistics in Medicine* 19, no. 3 (2000): 335–351, https://doi.org/10.1002/(sici)1097-0258(20000215)19:3⟨335::aid-sim336⟩3.0.co;2-z.

20. H. Kim, M. P. Fay, B. Yu, M. J. Barrett, and E. J. Feuer, "Comparability of Segmented Line Regression Models," *Biometrics* 60, no. 4 (2004): 1005–1014, https://doi.org/10.1111/j.0006-341x.2004.00256.x.

21. P. K. Whelton, R. M. Carey, W. S. Aronow, et al., "2017 ACC/AHA/AAPA/ABC/ACPM/AGS/APhA/ASH/ASPC/NMA/PCNA Guideline for the Prevention, Detection, Evaluation, and Management of High Blood Pressure in Adults: Executive Summary: A Report of the American College of Cardiology/American Heart Association Task Force on Clinical Practice Guidelines," *Hypertension* 71, no. 6 (2017): 1269–1324, https://doi.org/10.1161/hyp.0000000000000066.

22. B. Bozkurt, T. Ahmad, K. Alexander, et al., "HF STATS 2024: Heart Failure Epidemiology and Outcomes Statistics an Updated 2024 Report From the Heart Failure Society of America," *Journal of Cardiac Failure* (2024), https://doi.org/10.1016/j.cardfail.2024.07.001.

23. Estimated Hypertension Prevalence, Treatment, and Control Among U.S. Adults | Million Hearts, accessed November 29, 2024, https://millionhearts.hhs.gov/data-reports/hypertension-prevalence.html.

24. F. H. Messerli, S. F. Rimoldi, and S. Bangalore, "The Transition From Hypertension to Heart Failure: Contemporary Update," *JACC: Heart Failure* 5, no. 8 (2017): 543–551, https://doi.org/10.1016/J.JCHF.2017.04.012.

25. D. Levy, M. G. Larson, R. S. Vasan, W. B. Kannel, and K. K. L. Ho, "The Progression From Hypertension to Congestive Heart Failure," *Jama* 275, no. 20 (1996): 1557–1562, https://doi.org/10.1001/JAMA.1996.03530440037034.

26. D. M. Lloyd-Jones, M. G. Larson, E. P. Leip, et al., "Lifetime Risk for Developing Congestive Heart Failure: The Framingham Heart Study," *Circulation* 106, no. 24 (2002): 3068–3072, https://doi.org/10.1161/01.CIR.0000039105.49749.6F.

27. M. H. Drazner, B. Thompson, P. B. Rosenberg, et al., "Comparison of Impedance Cardiography With Invasive Hemodynamic Measurements in Patients With Heart Failure Secondary to Ischemic or Nonischemic Cardiomyopathy," *American Journal of Cardiology* 89, no. 8 (2002): 993–995, https://doi.org/10.1016/S0002-9149(02)02257-9.

28. C. M. Yu, J. E. Sanderson, T. H. Marwick, and J. K. Oh, "Tissue Doppler Imaging a New Prognosticator for Cardiovascular Diseases," *Journal of the American College of Cardiology* 49, no. 19 (2007): 1903–1914, https://doi.org/10.1016/J.JACC.2007.01.078.

29. Q. Dao, P. Krishnaswamy, R. Kazanegra, et al., "Utility of B-Type Natriuretic Peptide in the Diagnosis of Congestive Heart Failure in an Urgent-Care Setting," *Journal of the American College of Cardiology* 37, no. 2 (2001): 379–385, https://doi.org/10.1016/S0735-1097(00)01156-6.

30. C. Vallbona and V. Pavlik, "Advances in the Community Control of Hypertension," *Journal of Hypertension* 10 (1992): S59–S59, https://doi.org/10.1097/00004872-199212007-00006.

31. G. S. Stergiou, I. I. Skeva, N. M. Baibas, C. B. Kalkana, L. G. Roussias, and T. D. Mountokalakis, "Diagnosis of Hypertension Using Home or Ambulatory Blood Pressure Monitoring: Comparison With the Conventional Strategy Based on Repeated Clinic Blood Pressure Measurements," *Journal of Hypertension* 18, no. 12 (2000): 1745–1751, https://doi.org/10.1097/00004872-200018120-00007.

32. P. Muntner, S. T. Hardy, L. J. Fine, et al., "Trends in Blood Pressure Control Among US Adults With Hypertension, 1999–2000 to 2017–2018," *Jama* 324, no. 12 (2020): 1, https://doi.org/10.1001/JAMA.2020.14545.

33. B. M. Egan, J. Li, F. N. Hutchison, and K. C. Ferdinand, "Hypertension in the United States, 1999 to 2012: Progress Toward Healthy People 2020 Goals," *Circulation* 130, no. 19 (2014): 1692–1699, https://doi.org/10.1161/CIRCULATIONAHA.114.010676.

34. R. Devadoss, G. Dhillon, P. Sharma, R. K. Verma, R. Munjal, and R. Kashyap, "Heartfelt Breakthroughs: Elevating Quality of Life With Cutting-Edge Advances in Heart Failure Treatment," *Journal of Cardiovascular Development and Disease* 11, no. 1 (2024): 15, https://doi.org/10.3390/JCDD11010015.

35. U. Khan, A. M. Amin, A. M. Taha, et al., "The Effect of Sodium-Glucose Co-Transporter 2 Inhibitors on Clinical Outcomes After Acute Myocardial Infarction: A Systematic Review and Meta-Analysis of Randomized Controlled Trials," *Future Cardiology* 21, no. 3 (2025): 177–190, https://doi.org/10.1080/14796678.2025.2464449.

36. J. Gao, C. Zhao, W. Z. Zhang, S. Liu, H. Xin, and Z. X. Lian, "Efficacy and Safety Profile of Angiotensin Receptor Neprilysin Inhibitors in the Management of Heart Failure: A Systematic Review and Meta-Analysis of Randomized Controlled Trials," *Heart Failure Reviews* 28, no. 4 (2022): 905–923, https://doi.org/10.1007/s10741-022-10273-3.

37. K. S. Parikh, S. J. Lippmann, M. Greiner, et al., "Scope of Sacubitril/Valsartan Eligibility After Heart Failure Hospitalization," *Circulation* 135, no. 21 (2017): 2077–2080, https://doi.org/10.1161/circulationaha.117.027773.

38. N. Luo, G. C. Fonarow, S. J. Lippmann, et al., "Early Adoption of Sacubitril/Valsartan for Patients With Heart Failure With Reduced Ejection Fraction," *JACC Heart Failure* 5, no. 4 (2017): 305–309, https://doi.org/10.1016/j.jchf.2016.12.018.

39. A. Alonso, A. A. Morris, A. I. Naimi, et al., "Use of Sodium-Glucose Cotransporter-2 Inhibitors and Angiotensin Receptor-Neprilysin Inhibitors in Patients With Atrial Fibrillation and Heart Failure From 2021 to 2022: An Analysis of Real-World Data," *Journal of the American Heart Association* 13, no. 6 (2024): e032783, https://doi.org/10.1161/jaha.123.032783.

40. V. L. Roger, A. S. Go, D. M. Lloyd-Jones, et al., "Heart Disease and Stroke Statistics–2011 Update: A Report From the American Heart Association," *Circulation* 123, no. 4 (2011): e18–e209, https://doi.org/10.1161/CIR.0B013E3182009701.

41. J. Li, J. Zhang, V. K. Somers, N. Covassin, L. Zhang, and H. Xu, "Trends and Disparities in Treatment and Control of Atherosclerotic Cardiovascular Disease in US Adults, 1999 to 2018," *Journal of the American Heart Association: Cardiovascular and Cerebrovascular Disease* 13, no. 9 (2024): e032527, https://doi.org/10.1161/JAHA.123.032527.

42. B. Zhou, G. Danaei, G. A. Stevens, et al., "Long-Term and Recent Trends in Hypertension Awareness, Treatment, and Control in 12 High-Income Countries: An Analysis of 123 Nationally Representative Surveys," *Lancet* 394, no. 10199 (2019): 639, https://doi.org/10.1016/S0140-6736(19)31145-6.

43. J. D. Wright, J. P. Hughes, Y. Ostchega, S. S. Yoon, and T. Nwankwo, "Mean Systolic and Diastolic Blood Pressure in Adults Aged 18 and Over in the United States, 2001–2008," *National Health Statistics Reports* no. 35 (2011): 1–22. 24.

44. P. J. Connelly, G. Currie, and C. Delles, "Sex Differences in the Prevalence, Outcomes and Management of Hypertension," *Current Hypertension Reports* 24, no. 6 (2022): 185, https://doi.org/10.1007/S11906-022-01183-8.

45. K. M. Flegal, D. Kruszon-Moran, M. D. Carroll, C. D. Fryar, and C. L. Ogden, "Trends in Obesity Among Adults in the United States, 2005 to 2014," *Jama* 315, no. 21 (2016): 2284–2291, https://doi.org/10.1001/JAMA.2016.6458.

46. Y. C. Wei, N. I. George, C. W. Chang, and K. A. Hicks, "Assessing Sex Differences in the Risk of Cardiovascular Disease and Mortality per Increment in Systolic Blood Pressure: A Systematic Review and Meta-Analysis of Follow-Up Studies in the United States," *PLOS ONE* 12, no. 1 (2017): e0170218, https://doi.org/10.1371/JOURNAL.PONE.0170218.

47. D. C. Scantlebury and B. A. Borlaug, "Why Are Women More Likely Than Men to Develop Heart Failure With Preserved Ejection Fraction?," *Current Opinion in Cardiology* 26, no. 6 (2011): 562–568, https://doi.org/10.1097/HCO.0B013E32834B7FAF.

48. A. M. Grandi, A. Venco, F. Barzizza, F. Scalise, P. Pantaleo, and G. Finardi, "Influence of Age and Sex on Left Ventricular Anatomy and Function in Normals," *Cardiology* 81, no. 1 (1992): 8–13, https://doi.org/10.1159/000175770.

49. J. L. Fleg, F. O'Connor, G. Gerstenblith, et al., "Impact of Age on the Cardiovascular Response to Dynamic Upright Exercise in Healthy Men and Women," *Journal of Applied Physiology (1985)* 78, no. 3 (1995): 890–900, https://doi.org/10.1152/JAPPL.1995.78.3.890.

50. D. T. Lackland, "Racial Differences in Hypertension: Implications for High Blood Pressure Management," *American Journal of the Medical Sciences* 348, no. 2 (2014): 135–138, https://doi.org/10.1097/maj.0000000000000308.

51. L. Rethy, L. C. Petito, T. H. T. Vu, et al., "Trends in the Prevalence of Self-Reported Heart Failure by Race/Ethnicity and Age From 2001 to 2016," *JAMA Cardiology* 5, no. 12 (2020): 1425, https://doi.org/10.1001/jamacardio.2020.3654.

52. J. He, J. D. Bundy, S. Geng, et al., "Social, Behavioral, and Metabolic Risk Factors and Racial Disparities in Cardiovascular Disease Mortality in U.S. Adults," *Annals of Internal Medicine* 176, no. 9 (2023): 1200–1208, https://doi.org/10.7326/m23-0507.

53. E. J. Roccella, "The Sixth Report of the Joint National Committee on Prevention, Detection, Evaluation, and Treatment of High Blood Pressure," *Archives of Internal Medicine* 157, no. 21 (1997): 2413–2446, https://doi.org/10.1001/ARCHINTE.157.21.2413.

54. J. M. Flack, K. C. Ferdinand, and S. A. Nasser, "Epidemiology of Hypertension and Cardiovascular Disease in African Americans," *Journal of Clinical Hypertension* 5, no. 1 (2007): 5, https://doi.org/10.1111/J.1524-6175.2003.02152.X.

55. D. P. Ferdinand, S. Nedunchezhian, and K. C. Ferdinand, "Hypertension in African Americans: Advances in Community Outreach and Public Health Approaches," *Progress in Cardiovascular Diseases* 63, no. 1 (2020): 40–45, https://doi.org/10.1016/J.PCAD.2019.12.005.

56. C. W. Yancy and M. Strong, "The Natural History, Epidemiology, and Prognosis of Heart Failure in African Americans," *Congestive Heart Failure (Greenwich, Conn.)* 10, no. 1 (2004): 15–18, https://doi.org/10.1111/J.1527-5299.2004.02026.X.

57. J. Lindhorst, N. Alexander, J. Blignaut, and B. Rayner, "Differences in Hypertension Between Blacks and Whites: An Overview," *Cardiovascular Journal of Africa* 18, no. 4 (2007): 241, Accessed November 30, 2024, https://pmc.ncbi.nlm.nih.gov/articles/PMC4170224/.

58. S. I. Richardson, B. I. Freedman, D. H. Ellison, and C. J. Rodriguez, "Salt Sensitivity: A Review With a Focus on non-Hispanic Blacks and Hispanics," *Journal of the American Society of Hypertension* 7, no. 2 (2013): 170–179, https://doi.org/10.1016/J.JASH.2013.01.003.

59. R. Aggarwal, N. Chiu, R. K. Wadhera, et al., "Racial/Ethnic Disparities in Hypertension Prevalence, Awareness, Treatment, and Control in the United States, 2013 to 2018," *Hypertension* 78, no. 6 (2021): 1719–1726, https://doi.org/10.1161/HYPERTENSIONAHA.121.17570/SUPPL_FILE/HYP_HYPE-2021-17570-T_SUPP1.PDF.

60. S. S. Yoon, M. D. Carroll, and C. D. Fryar, "Hypertension Prevalence and Control Among Adults: United States, 2011–2014," *NCHS Data Brief* no. 220 (2015). Hyattsville, MD: National Center for Health Statistics.

61. D. Mozaffarian, E. J. Benjamin, A. S. Go, et al., "Heart Disease and Stroke Statistics-2016 Update: A Report From the American Heart Association," *Circulation* 133, no. 4 (2016): e38–e48, https://doi.org/10.1161/CIR.0000000000000350.

62. M. Y. Jung, S. Lee, S. B. Thomas, and H. S. Juon, "Hypertension Prevalence, Treatment, and Related Behaviors Among Asian Americans: An Examination by Method of Measurement and Disaggregated Subgroups," *Journal of Racial and Ethnic Health Disparities* 6, no. 3 (2019): 584, https://doi.org/10.1007/S40615-018-00557-6.

63. Y. Cheng, A. N. Poon, Y. Ling, et al., "Heart Failure Among Asian American Subpopulations," *JAMA Network Open* 7, no. 9 (2024): e2435672, https://doi.org/10.1001/JAMANETWORKOPEN.2024.35672.

64. M. T. Hicken, H. Lee, J. Morenoff, J. S. House, and D. R. Williams, "Racial/Ethnic Disparities in Hypertension Prevalence: Reconsidering the Role of Chronic Stress," *American Journal of Public Health* 104, no. 1 (2014): 117, https://doi.org/10.2105/AJPH.2013.301395.

65. J. Uddin, S. Zhu, G. Malla, et al., "Regional and Rural-Urban Patterns in the Prevalence of Diagnosed Hypertension Among Older U.S. Adults With Diabetes, 2005–2017," *BMC Public Health* 24, no. 1 (2024): 1–11, https://doi.org/10.1186/S12889-024-18802-5/TABLES/2.

66. P. A. Glynn, R. Molsberry, K. Harrington, et al., "Geographic Variation in Trends and Disparities in Heart Failure Mortality in the United States, 1999 to 2017," *Journal of the American Heart Association* 10, no. 9 (2021): e020541, https://doi.org/10.1161/JAHA.120.020541.

67. L. Liu, X. Yin, M. Chen, H. Jia, H. J. Eisen, and A. Hofman, "Geographic Variation in Heart Failure Mortality and Its Association With Hypertension, Diabetes, and Behavioral-Related Risk Factors in 1,723 Counties of the United States," *Frontiers in Public Health* 6 (2018): 132, https://doi.org/10.3389/FPUBH.2018.00132/PDF.

68. S. M. Manemann, J. S. Sauver, C. Henning-Smith, et al., "Rurality, Death, and Healthcare Utilization in Heart Failure in the Community," *Journal of the American Heart Association: Cardiovascular and Cerebrovascular Disease* 10, no. 4 (2021): e018026, https://doi.org/10.1161/JAHA.120.018026.

69. M. C. Garcia, M. Faul, G. Massetti, et al., "Reducing Potentially Excess Deaths From the Five Leading Causes of Death in the Rural United States," *MMWR Surveillance Summaries* 66, no. 2 (2017): 1–7, https://doi.org/10.15585/MMWR.SS6602A1.

70. S. H. Cross, M. R. Mehra, D. L. Bhatt, et al., "Rural-Urban Differences in Cardiovascular Mortality in the US, 1999–2017," *Jama* 323, no. 18 (2020): 1852–1854, https://doi.org/10.1001/JAMA.2020.2047.

71. H. D. Germack, R. Kandrack, and G. R. Martsolf, "When Rural Hospitals Close, the Physician Workforce Goes," *Health Affairs (Project Hope)* 38, no. 12 (2019): 2086–2094, https://doi.org/10.1377/HLTHAFF.2019.00916.

72. J. B. Pierce, N. S. Shah, L. C. Petito, et al., "Trends in Heart Failure-Related Cardiovascular Mortality in Rural Versus Urban United States Counties, 2011–2018: A Cross-Sectional Study," *PLOS ONE* 16, no. 3 (2021): e0246813, https://doi.org/10.1371/JOURNAL.PONE.0246813.

73. A. Chaturvedi, A. Zhu, N. V. Gadela, D. Prabhakaran, and T. H. Jafar, "Social Determinants of Health and Disparities in Hypertension and Cardiovascular Diseases," *Hypertension* 81, no. 3 (2023): 387–399, https://doi.org/10.1161/hypertensionaha.123.21354.

74. O. P. Akinyelure, B. C. Jaeger, S. Oparil, et al., "Social Determinants of Health and Uncontrolled Blood Pressure in a National Cohort of Black and White US Adults: The REGARDS Study," *Hypertension* 80, no. 7 (2023): 1403–1413, https://doi.org/10.1161/hypertensionaha.122.20219.

75. D. Carvajal-Aldaz, G. Cucalon, and C. Ordonez, "Food Insecurity as a Risk Factor for Obesity: A Review," *Frontiers in Nutrition* 9 (2022): 1012734, https://doi.org/10.3389/fnut.2022.1012734.

76. A. Crimarco, M. J. Landry, and C. D. Gardner, "Ultra-Processed Foods, Weight Gain, and Co-Morbidity Risk," *Current Obesity Reports* 11, no. 3 (2021): 80–92, https://doi.org/10.1007/s13679-021-00460-y.

77. M. A. Beenackers, C. B. Kamphuis, K. Giskes, et al., "Socioeconomic Inequalities in Occupational, Leisure-Time, and Transport Related Physical Activity Among European Adults: A Systematic Review," *International Journal of Behavioral Nutrition and Physical Activity* 9, no. 1 (2012): 116, https://doi.org/10.1186/1479-5868-9-116.

78. R. Stalsberg and A. V. Pedersen, "Effects of Socioeconomic Status on the Physical Activity in Adolescents: A Systematic Review of the Evidence," *Scandinavian Journal of Medicine and Science in Sports* 20, no. 3 (2010): 368–383, https://doi.org/10.1111/j.1600-0838.2009.01047.x.

79. L. Yang, Y. Luo, L. He, et al., "Shift Work and the Risk of Cardiometabolic Multimorbidity Among Patients With Hypertension: A Prospective Cohort Study of UK Biobank," *Journal of the American Heart Association* 11, no. 17 (2022): e025936, https://doi.org/10.1161/jaha.122.025936.

80. Y. C. Yang, T. Li, and Y. Ji, "Impact of Social Integration on Metabolic Functions: Evidence From a Nationally Representative Longitudinal Study of US Older Adults," *BMC Public Health* 13, no. 1 (2013): 1210, https://doi.org/10.1186/1471-2458-13-1210.

81. E. Adinkrah, M. Bazargan, C. Wisseh, and S. Assari, "Adherence to Hypertension Medications and Lifestyle Recommendations Among Underserved African American Middle-Aged and Older Adults," *International Journal of Environmental Research and Public Health* 17, no. 18 (2020): 6538, https://doi.org/10.3390/ijerph17186538.

82. J. B. Pierce, U. Ikeaba, A. E. Peters, et al., "Quality of Care and Outcomes Among Patients Hospitalized for Heart Failure in Rural vs Urban US Hospitals: The Get With the Guidelines–Heart Failure Registry," *JAMA Cardiology* 8, no. 4 (2023): 376, https://doi.org/10.1001/JAMACARDIO.2023.0241.

83. M. A. Oto, O. Ergene, L. Tokgözoğlu, et al., "Impact of a Mass Media Campaign to Increase Public Awareness of Hypertension," *Turk Kardiyol Dern Ars* 39, no. 5 (2011): 355–364, https://doi.org/10.5543/TKDA.2011.01570.

84. T. Ojangba, S. Boamah, Y. Miao, et al., "Comprehensive Effects of Lifestyle Reform, Adherence, and Related Factors on Hypertension Control: A Review," *Journal of Clinical Hypertension* 25, no. 6 (2023): 509, https://doi.org/10.1111/JCH.14653.

85. K. Foti, D. Wang, L. J. Appel, and E. Selvin, "Hypertension Awareness, Treatment, and Control in US Adults: Trends in the Hypertension Control Cascade by Population Subgroup (National Health and Nutrition Examination Survey, 1999–2016)," *American Journal of Epidemiology* 188, no. 12 (2019): 2165, https://doi.org/10.1093/AJE/KWZ177.

86. P. Connell, C. Wolfe, and C. McKevitt, "Preventing Stroke: A Narrative Review of Community Interventions for Improving Hypertension Control in Black Adults," *Health & Social Care in the Community* 16, no. 2 (2008): 165–187, https://doi.org/10.1111/J.1365-2524.2007.00737.X.

87. M. L. Snyder, S. A. Love, P. D. Sorlie, et al., "Redistribution of Heart Failure as the Cause of Death: The Atherosclerosis Risk in Communities Study," *Population Health Metrics* 12, no. 1 (2014): 1–8, https://doi.org/10.1186/1478-7954-12-10/FIGURES/4.

88. S. A. Coady, P. D. Sorlie, L. S. Cooper, A. R. Folsom, W. D. Rosamond, and D. E. Conwill, "Validation of Death Certificate Diagnosis for Coronary Heart Disease: The Atherosclerosis Risk in Communities (ARIC) Study," *Journal of Clinical Epidemiology* 54, no. 1 (2001): 40–50, https://doi.org/10.1016/S0895-4356(00)00272-9.

Supporting Information

Additional supporting information can be found online in the Supporting Information section.