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Integrating the micropolitan and state-level disparities in mortality of coexisting congestive heart failure and atrial fibrillation in the United States: A 20-year-long analysis

Ayesha Aman^{1*}, **Arfa Akram¹**, **Bisma Akram¹**, **Eisha Tariq¹**, **Iffat Ambreen Magsi²**, **Areeba Aamir Ali Basaria³**, and **Aimen Hassan¹**

¹Department of Medicine, King Edward Medical University, Lahore, Punjab, Pakistan

²Department of Medicine, Shaheed Mohtarma Benazir Bhutto Medical College, Larkana, Sindh, Pakistan

³Department of Medicine, Dow Medical College, Karachi, Sindh, Pakistan

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Mihajlo Jakovljevic M.D. Ph.D. MAE

*Corresponding author:

Ayesha Aman
(ayesha34aman@gmail.com)

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Abstract

Congestive heart failure (CHF) and atrial fibrillation (AF) are major cardiovascular diseases, particularly among older adults. This study analyzes national mortality trends for CHF and AF in the United States from 1999 to 2020, focusing on demographic variations and addressing gaps in evidence regarding urbanization and state-level disparities. Data were extracted from the Centers for Disease Control and Prevention Wide-ranging Online Data for Epidemiologic Research Multiple Cause of Death Public Use database (1999–2020). Age-adjusted mortality rates (AAMRs) per 100,000 population were calculated for adults aged ≥ 25 years. Mortality rates were stratified by year, gender, ethnicity, urbanization, census region, and state. Annual percent changes (APCs) were analyzed using the Joinpoint Regression Program. Between 1999 and 2020, 744,565 deaths related to CHF and AF were reported among adults aged ≥ 25 years. Overall, AAMR increased from 11.43 (95% CI: 11.27–11.58) in 1999 to 20.72 (95% CI: 20.55–20.89) in 2020, with significant APCs of 1.78% (1999–2010) and 3.38% (2010–2020). Males consistently showed higher AAMR (17.62) than females (14.13). Whites had the highest AAMR (16.42), while Asian/Pacific Islanders had the lowest (6.72). Among urbanization categories, Micropolitan areas exhibited the highest AAMR (18.61), while Large Central Metro areas exhibited the lowest (13.32). By region, the West had the highest AAMR (17.55), and the Northeast had the lowest (14.14). Mortality varied by state, with Oregon showing the highest (AAMR 25.65) and Nevada the lowest (AAMR 8.61). Rising CHF and AF-related mortality rates warrant targeted public health interventions, particularly in high-burden groups. Addressing healthcare issues, providing access, promoting early detection, and implementing evidence-based management are critical to reducing mortality.

Keywords: Congestive heart failure; Atrial fibrillation; Mortality trends; CDC WONDER; Epidemiology

1. Introduction

Congestive heart failure (CHF) and atrial fibrillation (AF) are two of the most common and clinically significant cardiovascular diseases, particularly in individuals aged ≥ 25 (Carlisle *et al.*, 2019). They are major contributors to cardiovascular mortality and morbidity. Globally, the prevalence of CHF and AF in 2021 was reported to be over 56.50 million and 52.55 million cases, respectively (Roth *et al.*, 2023). In the United States (U.S.), approximately 6.7 million adults have CHF, and an estimated 10.55 million adults have AF (Abovich *et al.*, 2023; Noubiap *et al.*, 2024). By 2030, the number of people in the U.S. with AF is projected to reach 12.1 million, and the number with CHF is projected to reach 8.5 million (Colilla *et al.*, 2013; Heidenreich *et al.*, 2013). This rise reflects improved survival after myocardial infarction and other acute cardiovascular events, as well as an aging population (Steinberg *et al.*, 2004). Prevalence varies by age, sex, and geographical region.

Congestive heart failure is a complex clinical syndrome involving structural and functional cardiac impairments, mechanical disturbances, and failure of peripheral compensatory mechanisms (Singh *et al.*, 2025). It affects multiple organ systems, and the complexity of this syndrome is depicted by its variable clinical presentation. CHF is a chronic, progressive condition in which the heart fails to pump blood efficiently, resulting in reduced tissue perfusion and fluid accumulation in the lungs and peripheral tissues (Kokkinos *et al.*, 2000; Mercuro *et al.*, 2019). The core problem is reduced contractility, leading to decreased stroke volume, ejection fraction, and cardiac output (Ge *et al.*, 2019). Compensatory mechanisms, initially adaptive, later become deleterious. These include ventricular remodeling and neurohormonal activation—activation of the renin–angiotensin–aldosterone system, release of antidiuretic hormone, and activation of the sympathetic nervous system—causing vasoconstriction and fluid retention (Chatterjee *et al.*, 2005). Increased preload and afterload elevate myocardial stress, worsening contractility in a vicious cycle. Clinically, CHF manifests as pulmonary congestion and peripheral fluid retention, including edema and weight gain (Parmley *et al.*, 1985). Common etiologies include ischemic heart disease, cardiomyopathy, valvular disorders, and hypertension (Kobayashi *et al.*, 2020). CHF creates a highly arrhythmogenic substrate through extensive structural, neurohormonal, and ion channel remodeling, increasing the risk of life-threatening arrhythmia (Kurokawa & Abriel, 2009).

Atrial fibrillation, a supraventricular arrhythmia characterized by irregular and often rapid heartbeats, frequently coexists with CHF and worsens its clinical

course (Boyle & Shivkumar, 2008; Dries *et al.*, 1998). It is the most frequently encountered cardiac arrhythmia. During AF, atrial contraction is disorganized, resulting in irregular heart rate due to rapid, uncoordinated electrical impulses (Chorro *et al.*, 1990). On the electrocardiogram, P-waves are absent, replaced by fibrillatory waves (f-waves), and R-R intervals are irregular (Soliman *et al.*, 2019). AF is classified by duration as paroxysmal, persistent, long-standing persistent, and permanent types. Guiding treatment strategies, including rhythm control, stroke prevention, and symptom management. AF increases the risk of severe complications such as stroke and systemic embolism (Hammond-Haley *et al.*, 2018) because stagnant atrial blood promotes clot formation, which may embolize and cause complications. Consequently, anticoagulation is central to management (Khan & Lip, 2019). AF significantly reduces quality of life and functional status, causing fatigue, breathlessness, palpitations, leading to limited physical activity and psychological and emotional burden (Dorian *et al.*, 2000). AF is both a consequence and contributor to structural heart disease; once it is established, it acts in a complex cycle that further damages the myocardium.

Congestive heart failure and AF both share several important risk factors and pathophysiological substrates, explaining their frequent coexistence and bidirectional relationship. Aging, hypertension, obesity, obstructive sleep apnea, and structural heart disease (e.g., valvular disorders, coronary artery disease, myocardial infarction) are among the risk factors for CHF and AF-related mortality in persons aged 25–85 and older (Del Gobbo *et al.*, 2015). Other contributing factors include smoking, diabetes mellitus, physical inactivity, excessive alcohol consumption, family history, and genetics. Hypertension is the most common risk factor; it causes pressure overload and left ventricular hypertrophy, leading to cardiac remodeling and fibrosis (Gumprecht *et al.*, 2019). Coronary artery disease causes myocardial injury and ischemia, leading to inflammation, fibrosis, and scarring, and consequently impaired cardiac function and increased risk of arrhythmias (Nguyen *et al.*, 2017). Diabetes is associated with microvascular damage, metabolic derangements, low-grade inflammation, and oxidative damage that causes myocardial dysfunction and fibrosis (Adameova & Dhalla, 2014). Obesity promotes adipose tissue deposition in the epicardium, systemic inflammation, and hemodynamic dysfunction, including volume and pressure overload, contributing to structural and electrical changes in the heart (Packer, 2018). Advanced age is a non-modifiable independent risk factor. Aging promotes both structural and electrical changes that increase susceptibility to both CHF and AF (Lin *et al.*, 2018). Renin–angiotensin–aldosterone system activation

and cardiac remodeling in CHF further elevate AF risk.

Congestive heart failure remains a major risk factor for AF development. AF acts as both a precipitating and worsening factor in CHF. The presence of AF in patients with CHF is associated with worsening hemodynamics, increased thromboembolic risk, and reduced response to medical treatments (Thihalolipavan & Morin, 2015). Conversely, CHF strongly promotes sustained AF induction through interstitial fibrosis that impairs local conduction, thereby causing AF (Li *et al.*, 1999). These overlapping pathophysiological pathways highlight the importance of investigating their combined impact on mortality. Both conditions, independently and synergistically, increase stroke risk, hospitalization rates, and all-cause mortality, making them major contributors to the cardiovascular disease burden in aging populations (Wang *et al.*, 2003). Symptom burden is greater when both conditions coexist than when either occurs alone. Complications include thromboembolic events, renal dysfunction, progressive heart failure, and sudden cardiac death (Diet & Erdmann, 2000; Odutayo *et al.*, 2016). CHF-specific consequences, such as reduced ejection fraction and fluid overload, increase the risk of pulmonary edema and cardiogenic shock (Ne *et al.*, 2019), whereas AF is highly associated with embolic stroke, cognitive impairment, and anticoagulation-related bleeding (Bula, 2024; Sankaranarayanan *et al.*, 2015). These effects are particularly pronounced in frail and elderly populations, leading to greater functional decline and reduced exercise tolerance.

Diagnostic challenges in CHF arise from non-specific symptoms such as breathlessness and fatigue, which overlap with other conditions like chronic obstructive pulmonary disease, as well as limitations of diagnostic tools such as chest radiography and electrocardiography. Similarly, AF may present with non-specific symptoms or remain asymptomatic and is often dismissed by patients as a normal consequence of aging, resulting in delayed diagnosis (Kotecha *et al.*, 2016). Therapeutic challenges in the management of coexisting CHF and AF stem from their complex interrelated pathophysiology. Each condition exacerbates the other, creating a loop that increases morbidity and mortality. Pharmacological constraints exist, as some antiarrhythmic medications commonly used for AF are contraindicated in CHF. Additional challenges include underutilization of evidence-based therapies, inadequate patient education, and polypharmacy, which increases pill burden and negatively affects medication adherence (Boyle & Shivkumar, 2008; Cesaro *et al.*, 2025). Despite therapeutic advances such as implantable cardioverter defibrillators, catheter ablation, and newer

anticoagulants, mortality remains high, particularly among vulnerable age and racial groups (Syed *et al.*, 2021). These challenges highlight the need for coordinated interdisciplinary management strategies.

Epidemiological data indicate that the prevalence of CHF and AF in the U.S. has increased over the past two decades, particularly among older persons, Black populations, and socioeconomically disadvantaged groups (Díaz-Toro *et al.*, 2015; Van Nuys *et al.*, 2018). However, population-level geographical disparities, including urbanization and state-level mortality differences, remain underexplored (Zuin *et al.*, 2024). Given the growing burden of multimorbidity, an integrated epidemiological assessment focusing on the coexistence of CHF and AF is needed. Understanding these trends is critical for identifying at-risk subgroups, informing health policy, improving clinical outcomes, and advancing equitable cardiovascular care. These conditions also impose a substantial economic burden on the U.S. healthcare system through increased medical expenditures and productivity losses. Synthesizing evidence can support clinicians, policymakers, and researchers in guideline development through improving patient stratification and management. Longitudinal analyses using Centers for Disease Control and Prevention Wide-ranging Online Data for Epidemiologic Research (CDC WONDER) data are essential for monitoring public health progress.

Using the CDC WONDER database, this study examines national trends in CHF- and AF-related mortality in the U.S. from 1999 to 2020, focusing on age-adjusted mortality rates (AAMRs), annual percentage changes (APCs), and disparities by age, gender, race/ethnicity, and geographic location. This analysis aims to support evidence-based interventions, guide resource allocation, and address healthcare disparities in the management of these interconnected cardiovascular disorders.

2. Methodology

2.1. Data source and study design

This study employed a retrospective observational approach. Data were extracted from the CDC WONDER database. Mortality trends related to CHF and AF were evaluated over a 22-year period from 1999 to 2020. We used the Multiple Cause of Death Public Use dataset to retrieve mortality data for individuals aged 25 years and older (CDC, n.d.). We examined deaths in which CHF or AF was listed on the death certificate, either as the underlying cause of death or as a contributing cause. The International Statistical Classification of Diseases and Related Health Problems, 10th Revision (ICD-10), was used to identify CHF and AF on death certificates using codes I50 and I48, respectively. Similar ICD codes have been utilized

in prior studies for such analysis (Maqsood *et al.*, 2023). Institutional review board approval was not required because the data were retrieved from a government-provided, de-identified, publicly available dataset. The study followed the Strengthening the Reporting of Observational Studies in Epidemiology guidelines for reporting observational research.

2.2. Study population and data extraction

We included adults aged 25 years and older who died between January 1, 1999, and December 31, 2020, and whose death records mentioned CHF, AF, or both. Data extracted from all 50 U.S. states were stratified according to gender, race, census region, state, and urbanization. Census regions were classified into four categories: Northeast, Midwest, South, and West, as defined by the U.S. Census Bureau (Ingram *et al.*, 2014). Race and ethnicity were categorized as Hispanic or Latino, non-Hispanic (NH) White, NH Black or African American, NH American Indian or Alaska Native, and NH Asian or Pacific Islander, with Hispanic/Latino identity cutting across all four racial categories. Urbanization categories based on 2013 included Large Central Metro, Large Fringe Metro, Medium Metro, Small Metro, Micropolitan (Nonmetro), and Noncore (Nonmetro). To investigate age-related patterns, the population was divided into CDC-recommended ten-year age intervals: 25–34, 35–44, 45–54, 55–64, 65–74, 75–84, and 85 years and older. This approach ensured a sufficient sample size within each age group to support meaningful statistical analysis.

2.3. Statistics analysis

Age-adjusted mortality rates per 100,000 people were calculated using the direct standardization method, with the 2,000 U.S. standard population as the reference. To identify statistically significant changes in mortality trends over time, the Joinpoint Regression Program (version 5.3.0, National Cancer Institute [NCI]; NCI Joinpoint trend analysis software) was used to estimate APC values. 95% confidence interval (CI) for AAMRs was also calculated. The grid search method was applied to identify all possible join points in the data. Temporal trends were evaluated using log-linear regression models on raw data. Both permutation tests and parametric methods were employed. Statistical significance was defined as a two-tailed p -value < 0.05 , and 95% CIs were reported to indicate the precision of estimates.

In addition to overall temporal trends, subgroup analyses were conducted to evaluate patterns across age groups and regions, thereby distinguishing random variation from true changes in CHF- and AF-related mortality. This approach enabled assessment of both

gradual and abrupt changes in mortality trends, providing a comprehensive overview of national patterns over time.

3. Results

3.1. Overall trends

A total of 744,565 deaths were recorded from 1999 to 2020 (APC 2.54; 95% CI: 2.19–2.88, $p < 0.000001$) among adults aged 25 years and older due to CHF and AF. The overall AAMR in 1999 was 11.43 (95% CI: 11.27–11.58) and increased to 14.43 (95% CI: 14.27–14.59) by 2010, with an APC of 1.78 (95% CI: 1.23–2.32). There was then a steep rise in AAMR from 2010 to 2020, reaching 20.72 (95% CI: 20.55–20.89), with an APC of approximately 3.38 (95% CI: 2.88–3.88) (Figure 1). These trends are detailed in Tables 1 and S1.

3.2. Gender

Age-adjusted mortality rates for CHF and AF stratified by gender revealed consistently higher AAMRs in males (AAMR = 17.62; 95% CI: 17.56–17.68) than in females (AAMR = 14.13; 95% CI: 14.08–14.17).

3.2.1. Male

Age-adjusted mortality rate for men in 1999 was 12.21 (95% CI: 11.92–12.49), increasing to 15.17 (95% CI: 14.87–15.46) in 2005, with an APC of 3.17 (95% CI: 1.92–4.43). This was followed by little change through 2009, with an AAMR of 15.13 (95% CI: 14.85–15.40) and an APC of 0.61 (95% CI: –2.50–3.82). Subsequently, AAMR increased steadily to 24.83 (95% CI: 24.53–25.12) by 2020, with an APC of 4.29 (95% CI: 3.96–4.63).

3.2.2. Female

Among women, the AAMR increased significantly from 10.83 (95% CI: 10.64–11.02) in 1999 to 13.26 (95% CI: 13.06–13.46) in 2010, with an APC of 1.57 (95% CI: 0.96–2.18). Thereafter, AAMR continued to rise, reaching 17.64 (95% CI: 17.43–17.85) by 2020, with an APC of 2.51 (95% CI: 1.94–3.08) (Figure 1).

3.3. Race

When stratified by race, the AAMR for CHF and AF was highest among White patients (AAMR = 16.42; 95% CI: 16.39–16.46), followed by Black/African Americans (AAMR = 9.77; 95% CI: 9.67–9.87), American Indians (AAMR = 9.59; 95% CI: 9.21–9.98), Hispanic/Latinos (AAMR = 8.01; 95% CI: 7.91–8.12), and lowest among Asian/Pacific Islanders patients (AAMR = 6.72; 95% CI: 6.59–6.84).

The AAMR for White patients in 1999 was 11.89 (95% CI: 11.72–12.06), which increased to 15.20 (95% CI:

Table 1. Overall deaths and age-adjusted mortality rate related to congestive heart failure and atrial fibrillation in the United States (age ≥ 25 years), 1999 to 2020

	Total deaths	Overall AAMR per 100,000 deaths	95% confidence interval	
			Lower	Upper
Total	744,565	15.58	15.55	15.62
Gender				
Female	426,576	14.13	14.08	14.17
Male	317,989	17.62	17.56	17.68
Race				
American Indian or Alaska Native	2,541	9.59	9.21	9.98
Asian or Pacific Islander	10,880	6.72	6.59	6.84
Black or African American	39,715	9.77	9.67	9.87
White	691,429	16.42	16.39	16.46
Ethnicity				
Hispanic or Latino	23,958	8.01	7.91	8.12

Abbreviation: AAMR: Age-adjusted mortality rate.

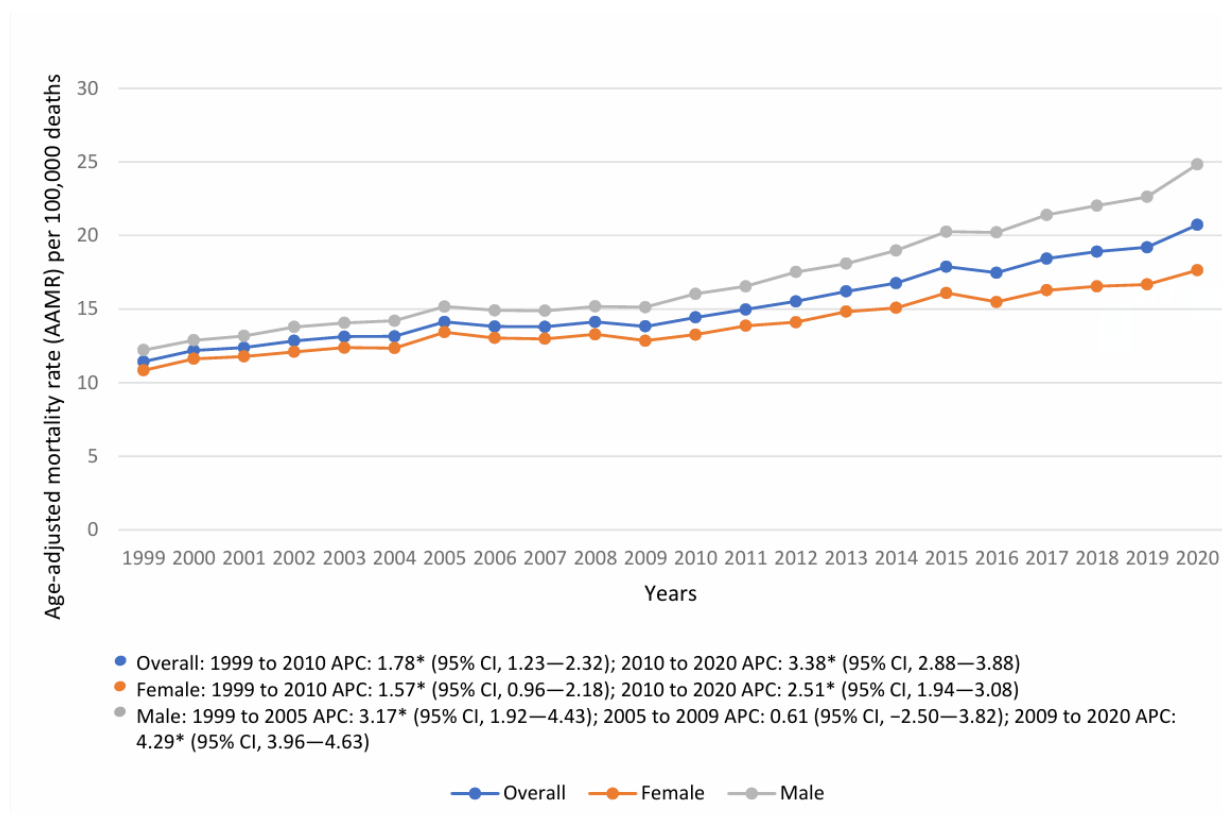


Figure 1. Overall and gender-stratified trends in congestive heart failure- and atrial fibrillation-related age-adjusted mortality rates per 100,000 deaths in the United States from 1999 to 2020. * indicates that the annual percent change (APC) is significantly different from zero at $\alpha = 0.05$.

15.03–15.38) by 2010 (APC = 1.86; 95% CI: 1.30–2.42) and further increased to 22.11 (95% CI: 21.92–22.3) in 2020 (APC = 3.56; 95% CI: 3.05–4.06), demonstrating a consistent upward trend. Among Hispanic/Latino patients, the AAMR increased from 5.57 (95% CI: 5–6.14) in 1999 to 10.85 (95% CI: 10.41–11.28) in 2020, with an APC of 2.99 (95% CI: 2.62–3.37). Similar increasing trends were observed among Black/African Americans, American Indians, and Asians (Figure 2 and Table S2).

3.4. Urbanization

Age-adjusted mortality rates for CHF and AF stratified by 2013 urbanization category showed the highest AAMR in Micropolitan (Nonmetro) areas (AAMR = 18.61; 95% CI: 18.49–18.74) and the lowest in Large Central Metro areas (AAMR = 13.32; 95% CI: 13.25–13.38). Increasing mortality trends were observed across all urbanization categories (Table S4).

3.4.1. Large Central Metro

In 1999, the AAMR in Large Central Metro was 10.14 (95% CI: 9.85–10.42), which increased to 12.29 (95% CI: 12–12.59) in 2005, with an APC of 2.97 (95% CI: 2.37–3.56). The AAMR then slightly decreased to 12.15 (95% CI: 11.87–12.44) in 2009 (APC = 0.02; 95% CI: –1.52–1.58), followed by a significant increase until 2015, reaching 15.23 (95% CI: 14.93–15.53) with an APC of 3.62 (95% CI: 2.97–4.48). After a decline through 2018 (APC = –0.11; 95% CI: –2.63–2.47), AAMR increased significantly through 2020, reaching 16.53 (95% CI: 16.23–16.82), with an APC of 4.17 (95% CI: 1.69–6.70).

3.4.2. Large Fringe Metro

In Large Fringe Metro areas, the AAMR increased from 11.06 (95% CI: 10.72–11.39) in 1999 to 12.38 (95% CI: 12.07–12.69) in 2009, with an APC of 1.09 (95% CI: 0.36–1.82). By 2020, the AAMR further increased to 19.57 (95%

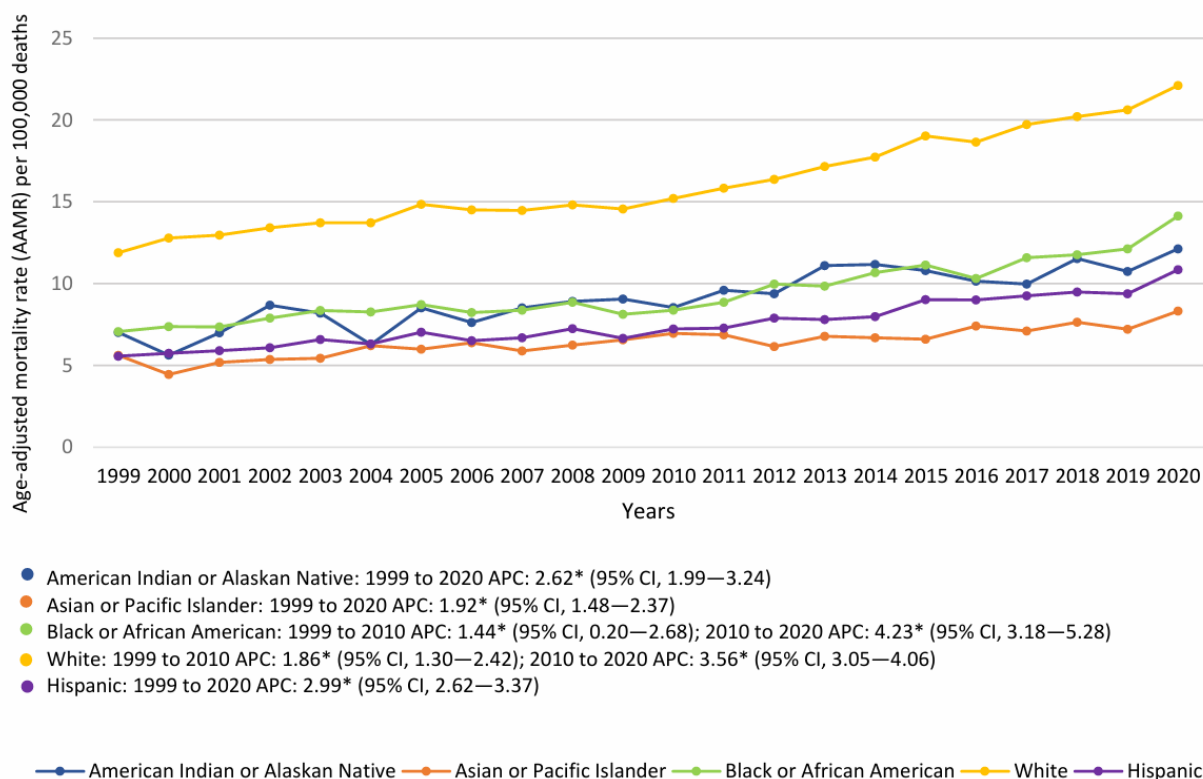


Figure 2. Race-stratified trends in congestive heart failure- and atrial fibrillation-related age-adjusted mortality rates per 100,000 deaths in the United States, 1999 to 2020. * indicates that the annual percent change (APC) is significantly different from zero at $\alpha = 0.05$.

CI: 19.23–19.91), with an APC of 3.63 (95% CI: 3.16–4.11).

3.4.3. Small Metro

In Small Metro areas, the AAMR increased from 12.64 (95% CI: 12.1–13.17) in 1999 to 23.76 (95% CI: 23.17–24.35) in 2020, with an APC of 2.82 (95% CI: 2.54–3.09).

3.4.4. Micropolitan (Nonmetro)

In Micropolitan (Nonmetro) areas, the AAMR increased from 13.2 (95% CI: 12.68–13.72) in 1999 to 16.73 (95% CI: 16.16–17.3) in 2005 (APC = 3.56; 95% CI: 1.98–5.16). This was followed by a modest increase through 2010 to 16.77 (95% CI: 16.22–17.32), with an APC of 0.39 (95% CI: –2.14–2.99). Subsequently, the AAMR rose sharply to 26.63 (95% CI: 25.99–27.27) in 2020 (APC = 4.50; 95% CI: 3.95–5.05).

3.4.5. Medium Metro and Noncore (Nonmetro)

Medium Metro and Noncore (Nonmetro) also showed increasing trends in AAMR. In Medium Metro, AAMR increased from 1999 to 2005 (APC = 3.82; 95% CI:

2.72–4.94), followed by a non-significant decline (APC = –0.10; 95% CI: –1.81–1.63). Subsequently, a sharp rise was observed during two different periods. From 2010 to 2015, there was an increase with an APC of 4.81 (95% CI: 3.22–6.42), and from 2015 to 2020, a slightly smaller increase in AAMR was demonstrated by an APC of 2.57 (95% CI: 1.64–3.51).

In Noncore (Nonmetro), there was a significant rise in AAMR from 1999 to 2013, with an APC of 2.43 (95% CI: 1.89–2.87). This was followed by a steep rise in mortality rate from 2013 to 2020, with an APC of 5.18 (95% CI: 3.97–6.42) (Figure 3).

3.5. Geographical region

3.5.1. State

The AAMR for CHF and AF stratified by state revealed that the highest mortality rate was observed in Oregon (AAMR = 25.65; 95% CI: 25.26–26.04), while the lowest was in Nevada (AAMR = 8.61; 95% CI: 8.28–8.94). Washington, Rhode Island, Vermont, and North Dakota were in the upper 90th percentile of CHF- and AF-related mortality

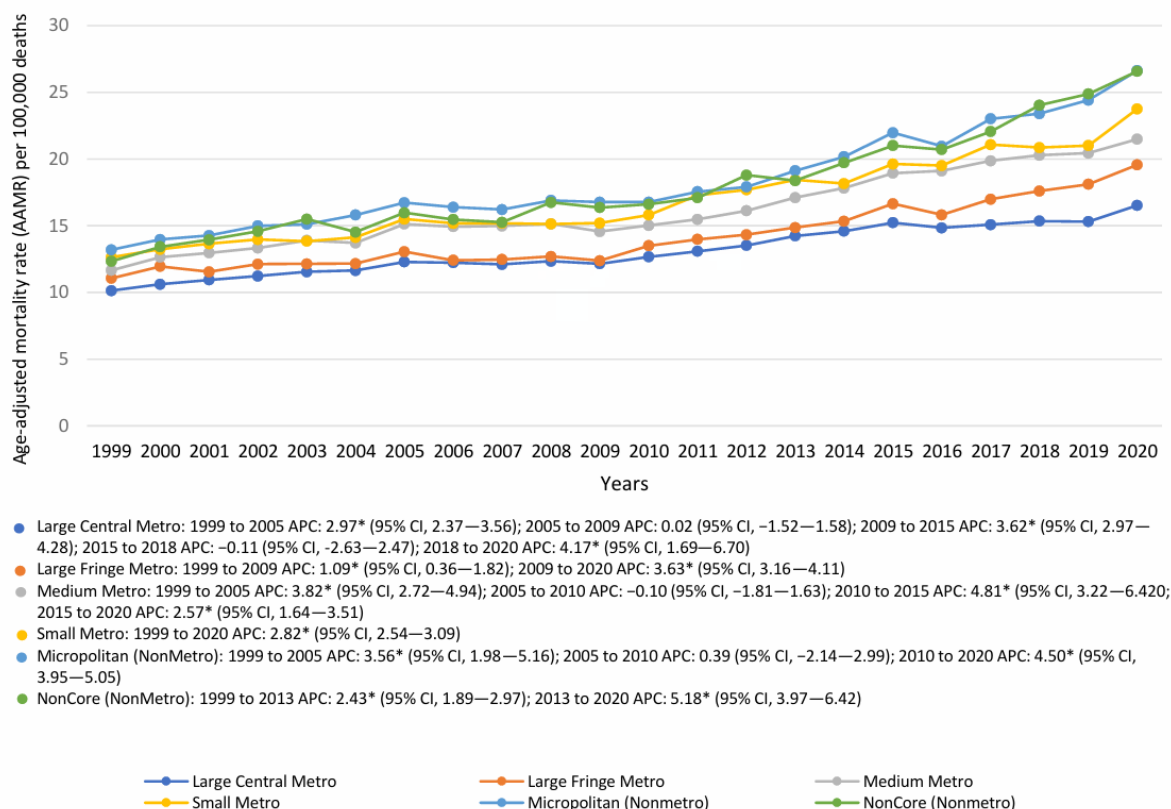


Figure 3. Urbanization-stratified trends in congestive heart failure- and atrial fibrillation-related age-adjusted mortality rates per 100,000 deaths in the United States, 1999–2020. * indicates that the annual percent change (APC) is significantly different from zero at $\alpha = 0.05$.

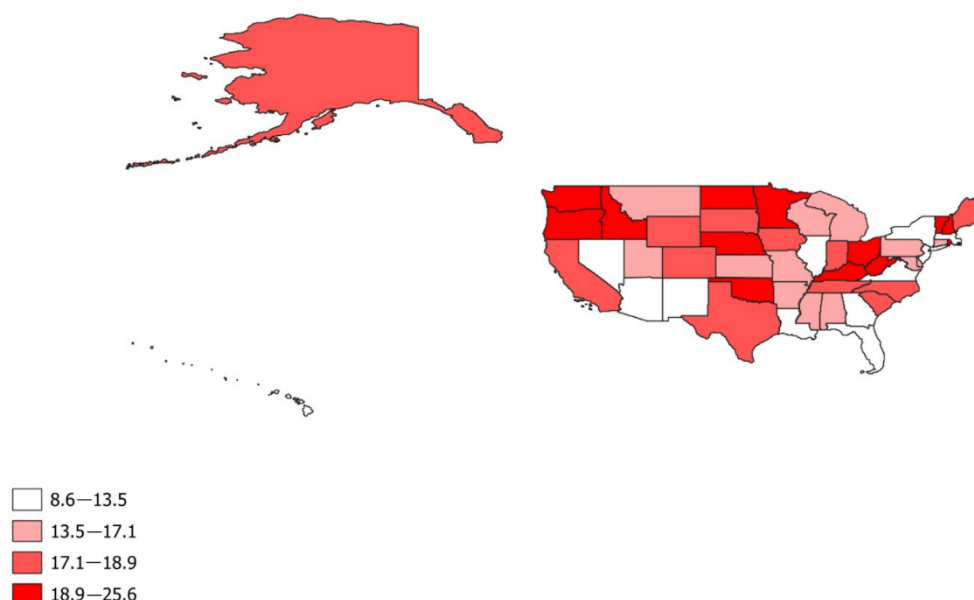


Figure 4. State-wise map showing states with the highest and lowest mortality, arranged by state-level age-adjusted mortality rate per 100,000 deaths in the United States, 1999–2020

rates, whereas Hawaii, Arizona, Florida, and the District of Columbia were in the lower 10th percentile (Figure 4, Table S3).

3.5.2. Census region

When stratified by census region, the highest AAMR for CHF and AF was reported in the West (AAMR = 17.55; 95% CI: 17.46–17.63), followed by the Midwest (AAMR = 16.78; 95% CI: 16.7–16.86), then South (AAMR = 14.36; 95% CI: 14.3–14.41), with the lowest observed in Northeast (AAMR = 14.14; 95% CI: 14.07–14.22) (Figure 5, Table S5).

4. Discussion

There is an increase in overall mortality trends in CHF and AF from 1999 to 2020, with two distinct phases: a moderate increase from 1999 to 2010 and a steeper increase from 2010 to 2020. Gender differences are noteworthy, with an increased mortality rate in males as compared to females. A higher mortality burden was noted in Whites compared to Asians and Pacific Islanders, indicating racial disparities. However, all racial groups showed increasing trends, with rates varying. Micropolitan areas showed higher AAMR compared to Central Metro. At the state level, mortality trends were highest in Oregon and lowest in Nevada. The West had the highest regional death burden, followed by the Midwest, South, and Northeast.

The overall increase in mortality rates suggests a growing disease burden despite medical advancements, indicating

a gap in the prevention, diagnosis, and management of CHF and AF (Iyngkaran *et al.*, 2018). When CHF and AF coexist, they tend to amplify each other's risks, leading to increased combined mortality (Horodinschi & Diaconu, 2021). Patients with concomitant CHF and AF face worse symptoms and prognosis (Hammond-Haley *et al.*, 2018). CHF and AF are age-associated diseases, and increasing age raises the risks of comorbidities, which contribute accordingly (Sarullo *et al.*, 2020). Suboptimal evidence-based management of CHF and AF, such as underuse of anticoagulants or late diagnosis, is an overriding factor in the increasing mortality trends (Koga *et al.*, 2022). The rising mortality trends underscore the need to strengthen primary prevention, address comorbidities, and enhance early disease detection.

In our study, males consistently showed increased mortality trends compared to females, highlighting under-recognized gender-based physiological differences. Men tend to have reduced ejection fraction and develop CHF at a younger age, whereas women are more likely to have heart failure with preserved ejection fraction (HFpEF), which is associated with lower mortality (DeVore *et al.*, 2022). Women with HFpEF require lower doses of medications for better outcomes compared to men (Regitz-Zagrosek *et al.*, 2020). Women with AF and CHF also have different clinical presentations, thromboembolic risks, and management strategies compared to men (Veenis *et al.*, 2021). Women are less likely to receive invasive rhythm control therapies for AF, reflecting under-recognition of

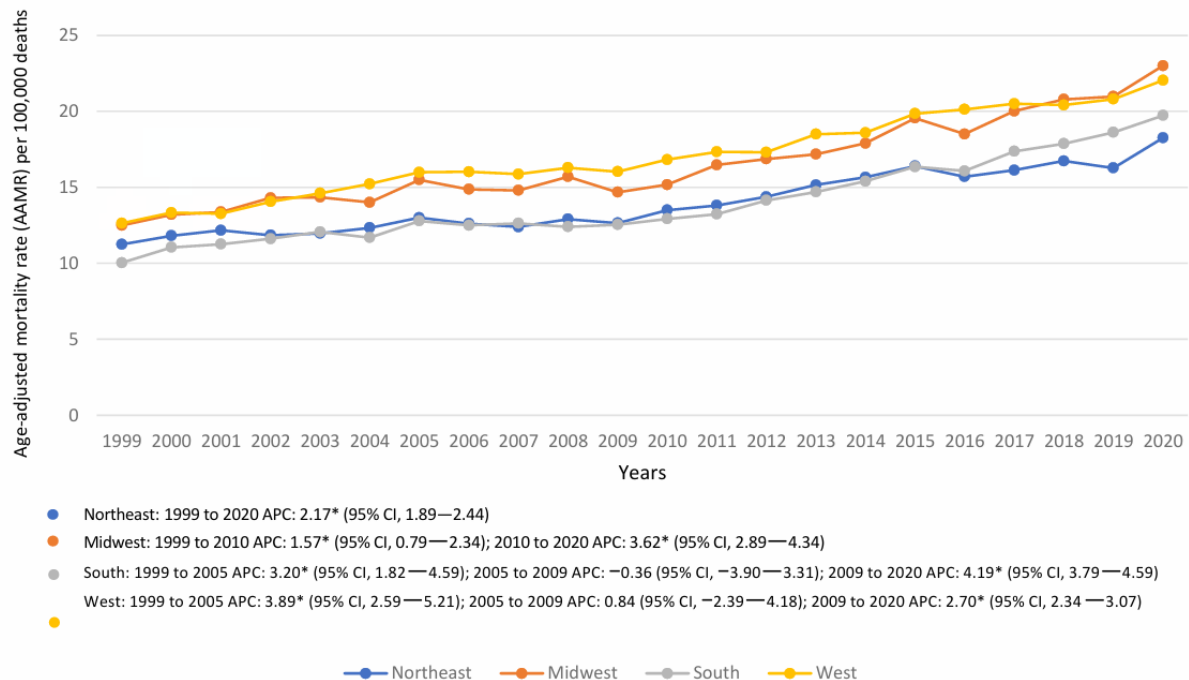


Figure 5. Region-stratified trends in congestive heart failure- and atrial fibrillation-related age-adjusted mortality rates per 100,000 deaths in the United States, 1999–2020. * indicates that the annual percent change (APC) is significantly different from zero at $\alpha = 0.05$.

cardiovascular diseases in women due to differences in healthcare-seeking behavior between genders (Ball *et al.*, 2013). Under-representation of women in cardiovascular disease trials further contributes to this disparity and raises concerns regarding the under-recognition and under-treatment of these conditions in women (Schnabel *et al.*, 2017). Hormonal and autonomic sex-based differences may also play a role. This calls for gender-specific strategies in the prevention, diagnosis, and management of CHF and AF, as well as inclusive research involving both genders.

Significant differences in the mortality rates were observed among racial and ethnic groups, with the highest trends in Whites, and the lowest in Asians/Pacific Islanders, although increasing trends were observed across all races (Matthews *et al.*, 2024). Persistent disparities may be attributed to structural barriers such as healthcare access, income inequality, and insurance gaps. Although White patients generally have better access to healthcare and lower exposure to some risk factors, comorbidities, and genetic predisposition contribute to higher mortality rates. A specific gene variant in the White population predisposes them to AF more than the Black race and other ethnic groups (Jensen *et al.*, 2013). The rising incidence in Whites also reflects lifestyle-related comorbidities such as obesity

and an aging population, which are significant risk factors for AF and CHF (Roberts *et al.*, 2016). Lower mortality in Asians/Pacific Islanders may be partially explained by underdiagnosis and under-representation despite a higher prevalence of risk factors (Gupta *et al.*, 2022). This underscores the need to address the social determinants of health. Biological predisposition further explains complex mortality trends in different races, such as higher CHF incidence but lower mortality in the Black population (Gill *et al.*, 2011). Although the White population carries the highest mortality burden, increasing trends across all racial groups highlight the need for equity-based interventions.

The highest mortality rates were observed in the micropolitan areas, whereas the lowest were found in large central metropolitan areas. Rural populations bear a disproportionately higher burden of CHF- and AF-related mortality (Tandon *et al.*, 2020). This may be due to limited access to cardiovascular specialists, suboptimal preventive care, and delayed diagnosis in noncore areas (Kotit, 2023). The higher costs of CHF and AF management, combined with higher poverty rates and low literacy rates, contribute to increased disease prevalence (Jiang *et al.*, 2022). Rural patients are also less likely to receive guideline-directed therapy (Joynt *et al.*, 2011), partly due to limited access

to specialized care in these noncore areas (Matsuo *et al.*, 2021). Lifestyle differences between rural and urban areas and a higher prevalence of comorbidities in rural areas further contribute to increased mortality trends of CHF and AF in rural areas (Annie *et al.*, 2020).

These disparities can be controlled by improving access to cardiovascular healthcare facilities in rural areas through telemedicine, mobile cardiology units, and the establishment of referral centers and heart failure clinics. Community-based screening programs for hypertension, diabetes, and other cardiovascular risk factors, including pulse checks and electrocardiogram monitoring, should be prioritized in rural areas. Awareness campaigns targeting knowledge gaps and underutilization of healthcare facilities should be initiated. Improving emergency care services and health infrastructure in rural areas is an important step toward reducing disparities between rural and urban areas, as delays in emergency and critical care for AF and CHF are more common in rural areas, which contribute to worse outcomes. Furthermore, community-level programs promoting physical activity, dietary and lifestyle modification, blood pressure control, and smoking cessation should be implemented. Socioeconomic determinants such as poverty, lower literacy, and inadequate insurance coverage are important contributors to the higher mortality rates and must be addressed through policies promoting education and healthcare affordability.

Substantial interstate variation highlights differences in healthcare systems, risk factor prevalence, and health infrastructure (Kamin Mukaz *et al.*, 2022). Western and Midwestern states dominate the upper mortality percentiles, likely due to limited access to healthcare and specialist shortages in these regions (Jones & Armanios, 2020). Regional variation in social determinants of health (Jafri *et al.*, 2024), local environment, cultural patterns, and healthcare-seeking behaviors also shape the mortality trends (Enyeji *et al.*, 2023). Lifestyle factors such as diet, smoking, obesity, and physical activity also influence CHF and AF mortality (Youmans *et al.*, 2019). These findings call for tailored public health strategies targeting high-burden areas and vulnerable populations, as well as further research into understudied regions and populations (Patel *et al.*, 2014).

Several public health policies and preventive strategies are needed to curb the nationwide rise in CHF- and AF-related mortality in the U.S. Policies to prevent the development of cardiovascular risk factors, such as hypertension, diabetes, obesity, sedentary lifestyle, and chronic kidney disease, are essential. Population-level interventions, including promoting a heart-healthy diet, regulating salt content

in processed foods, and improving food labeling, are important. Policies promoting cardiovascular health from early life, including school-based physical activity and sports programs and workplace wellness initiatives, may reduce lifetime risk of cardiovascular death. Integration of public health databases with electronic health record systems could guide policy development. Strengthening national surveillance systems enables the efficient tracking of CHF- and AF-related incidence, hospitalizations, deaths, and trends. Educational and health literacy campaigns on early symptoms of heart failure and cardiac disease, and emphasizing the importance of long-term medication adherence, are critical to improving public health awareness at a national level and also enhancing earlier patient engagement and management. Non-adherence to heart failure and anticoagulation medications is also a major contributor to CHF- and AF-related mortality. Medication adherence and drug affordability policies, including policies to cover drug costs and promote generic availability, may further reduce the rising mortality. Taking into consideration desired outcomes such as reduced readmissions, optimized medication usage, and mortality reduction when designing policies may help align healthcare systems toward prioritizing preventive cardiovascular care.

This study is based on a large national dataset spanning over two decades, providing a structured and comprehensive overview of long-term mortality patterns. The use of AAMR and APC enables standardized comparisons across populations. Mortality rates were analyzed across gender, race, urbanization, and regional stratifications, emphasizing disparities that may otherwise be overlooked. Visual data representations enhance interpretability. Focusing on CHF and AF—two highly prevalent and fatal cardiovascular conditions—underscores the clinical and public health relevance of the findings. This study explores state-level differences by highlighting the highest- and lowest-mortality states, as well as metropolitan and micropolitan comparisons, which have remained unexplored in previous work. It restricts the focus to CHF rather than a broader heart failure category, thereby affecting overall cohort composition. The study places greater emphasis on disparities in healthcare access and public health policy implications, providing new insights and building upon the work of Zuin *et al.* (2024).

Several limitations should be acknowledged. As a retrospective study based on death certificate data and ICD coding, it may be subject to misclassification and reporting biases that affect the accuracy of mortality estimates. The lack of clinical details, such as treatment history and comorbidities, limits causal inference. Regional

variation in diagnostic and reporting practices may affect generalizability. Lifestyle and environmental factors were not included, limiting the assessment of known contributors to disease risk and outcomes.

5. Conclusion

Despite these limitations, this study depicts a clear upward trend in mortality in CHF- and AF-related mortality across the U.S. White Americans had the highest mortality rates. Despite the disparities, all racial groups have demonstrated increasing mortality. Males showed higher mortality than females, and rural areas had higher mortality rates than urban areas. West had the highest mortality, and mortality rates varied among states. The study, through a comprehensive, in-depth analysis, has discussed possible reasons for the disparities in mortality trends from CHF and AF in different groups. The steep rise in mortality in recent years underscores the urgent need for targeted public health policies involving the mass population and individual high-risk groups. The rise in mortality, which could pose a significant burden on healthcare for clinicians and cardiologists, demands immediate attention. The study also suggests several measures and important steps to slow the steep rise in CHF- and AF-related mortality in the U.S. It highlights a significant cardiovascular health issue that warrants urgent attention from health experts. The findings of this study may prove beneficial for public health professionals and physicians by informing interventions and guiding policy-making.

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Conflict of interest

The authors have no conflict of interest.

Author contributions

Conceptualization: Ayesha Aman

Data curation: Ayesha Aman, Arfa Akram, Bisma Akram

Formal analysis: Ayesha Aman, Arfa Akram, Bisma Akram, Eisha Tariq

Investigation: Iffat Ambreen Magsi, Aimen Hassan

Methodology: Ayesha Aman, Arfa Akram, Iffat Ambreen Magsi, Aimen Hassan

Software: Eisha Tariq, Areeba Aamir Ali Basaria

Supervision: Ayesha Aman

Visualization: Bisma Akram, Areeba Aamir Ali Basaria

Writing-original draft: Ayesha Aman, Arfa Akram, Bisma Akram, Eisha Tariq, Iffat Ambreen Magsi, Areeba Aamir Ali Basaria

Writing-review & editing: Aimen Hassan

Ethics approval and consent to participate

Institutional Review Board approval and informed consent were not required, as the data utilized were obtained from a government-provided, de-identified, publicly available dataset.

Consent for publication

Informed consent was not required for this study, as there was no direct human participation and the data were obtained from a government-provided, de-identified, publicly available dataset.

Availability of data

The data for this study are included in this article and its supplementary information files.

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