Income, education, and the clustering of risk in cardiovascular disease in the US, 1999–2018: an observational study

Salma M. Abdalla,[a,b,*] Samuel B. Rosenberg,[b] Nason Maani,[c] Catalina Melendez Contreras,[b] Shui Yu,[d] and Sandro Galea[b]

[a]Global Health Department, Boston University School of Public Health, Boston, MA, USA
[b]Epidemiology Department, Boston University School of Public Health, Boston, MA, USA
[c]Global Health Policy Unit, School of Social and Political Science, University of Edinburgh, Edinburgh, UK
[d]New Balance Foundation Obesity Prevention Center, Boston Children's Hospital, Boston, MA, USA

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Summary

Background Health metrics in the United States (US) have lagged behind other high-income countries in recent decades, and show persistent gaps between socio-demographic groups. Top 20% income earners and college graduates have also increasingly diverged from the reminder of the population in various dimensions over the past few decades. This study described population patterns in cardiovascular diseases (CVD) by income and education over a twenty-year period.

Methods This analysis used nationally representative data from 10 cycles (1999–2018) of the National Health and Nutrition Examination Survey (NHANES). Participants were stratified by income and education into four groups: top 20% income earners, college graduates; top 20% income earners, non-college graduates; bottom 80% income earners, college graduates; and bottom 80% income earners, non-college graduates. For income, we created a binary variable (ratio > 5 cutoff) using NHANES income-to-poverty ratio variable to create a standardized measure of income. We calculated the age-standardized prevalence and odds ratios of four conditions: congestive heart failure (CHF), angina, heart attack, and stroke, for each income-education group.

Findings 49,704 participants reported data for both income and education. The age-standardized prevalence of CVD outcomes varied across the four groups. This was most significant when comparing the prevalence among the top 20% income, college graduate group to the bottom 80% income, non-college graduate group: CHF (0.5% vs. 3.0%), angina (1.4% vs. 2.8%), heart attack (1.7% vs. 3.9%), and stroke (1.1% vs. 3.4%). Compared to the top 20% income, college graduate group, the odds of all CVD conditions were significantly higher in the bottom 80% income groups (college graduates: odds ratios (ORs) 1.48–3.67; non-college graduates: ORs 2.36–6.52), as well as for CHF and heart attack in the top 20% income, non-college graduates (OR 3.11 [95% CI: 1.92, 5.06] and OR 1.92 [95% CI: 1.35, 2.73], respectively).

Interpretation Health gaps extend beyond extremes, with risk clustering favoring top 20% income earners with college degrees while most Americans are left behind. Future research should include longitudinal studies that focus on the mechanisms through which both income and education intersect to shape CVD outcomes in the US.

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Keywords: Cardiovascular disease; CVD; Income; Education; Social determinants of health

Introduction

Although the United States (US) has the highest spending on healthcare per capita among peer countries, health metrics have lagged behind other high-income countries in recent decades.[1,2] This poor health in the US is unevenly distributed, with persistent, and in some cases growing, gaps in health achievement among different socio-demographic groups.[3–5] Life expectancy among the richest 1% of Americans is now 10 years higher for both men and women compared to the poorest 1% of Americans.[1] However, gaps in health are not restricted to sociodemographic extremes. Recent

*Corresponding author. Global Health Department, School of Public Health, Boston University, 801 Massachusetts Avenue - Crosstown 304, Boston, MA 02118, USA.

E-mail address: s.abdalla@wustl.edu (S.M. Abdalla).

Research in context

Evidence before this study

We used PubMed to search for academic literature on income, education, and cardiovascular disease in the US on July 15, 2024. We used the following search terms: (cardiovascular* OR heart* OR CVD OR angina OR heart attack OR stroke OR congestive heart failure OR heart failure) AND (educat* OR college OR university) AND (income OR poverty) AND (adult*), and then added the term "AND (United States OR US OR USA OR American OR America)". A total of 4285 results, including articles, books and documents were obtained. Upon review of articles, we identified 34 as relevant.

The data highlight that over 70% of cardiovascular morbidity and mortality is associated with modifiable risk factors. In US adult populations, as well as other regions, significant inverse associations have been found between income, as well as educational attainment, and cardiovascular outcomes. Similarly, determinants of health such as employment, marital status, race/ethnicity, and health insurance have been independently studied and found to be associated to cardiovascular health outcomes. The literature also shows that interventions to decrease cardiovascular risk and improve cardiovascular health have had uneven effects across different population groups, sometimes leading to an increase in disparities.

Added value of this study

This study used data from a representative sample of nearly 50,000 American adults, from 10 cycles of the NHANES, to examine the interplay of income and education and cardiovascular outcomes between 1999 and 2018. It suggests that the top 20% income earners-college graduates, which represent a small proportion of US population, experience a clustering of advantageous socio-economic resources and needs, making them less likely to experience poor cardiovascular health compared to the majority of Americans.

Implications of all the available evidence

There is a socio-economic clustering of protective factors for cardiovascular health among a small group of Americans, despite ongoing efforts to narrow health disparities. This underscores the need for policies and interventions that address structural barriers to cardiovascular health equity. Future research should aim to identify the specific pathways through which income and education converge to shape cardiovascular health outcomes in the US, with an emphasis on developing and evaluating interventions that effectively mitigate disparities. Additionally, public health initiatives should integrate multi-sectoral approaches—spanning healthcare, education, labor, economic, and social policies—to ensure that cardiovascular health improvements benefit all Americans.

analyses show that trends in cardiovascular disease (CVD) outcomes—the leading cause of morbidity and mortality in the US—over the past two decades were markedly different between the top 20% income earners and the remainder of the US population.[6,7] These trends in CVD outcomes are coincident with widening in the income gap in the US population, with the income of the richest 20% diverging substantially from that of the remaining 80%.[6,7]

The widening gaps in CVD outcomes between the top 20% earners and the remainder of the population suggest that other foundational markers of health-promoting resources—that often co-vary with income—may also contribute to CVD, and overall, health gaps. Education is likely central in this regard. Educational attainment in the US is largely patterned by access to wealth and socioeconomic context.[8,9] Adults with higher educational attainment live longer and healthier lives, and conversely, adults with poor education live shorter lives in poorer health.[10] For example, one analysis showed that Americans with less than high school education were four times as likely to report poor health status compared to those with a post-secondary education.[11] There is also strong evidence of an inverse dose–response relationship between increasing years of education and prevalence of risky health behaviors as well as the probability of adverse health outcomes.[12,13] Risk factors for CVD are also strongly associated with education.[14] For example, a UK Biobank natural experiment found that on average, those who chose to stay in school after 15 were less likely to be diagnosed with hypertension and had lower arterial stiffness, compared to those who did not.[15]

The observations that there is a growing gap in CVD outcomes between the richest 20% and the remainder of the US population, and that this gap can contribute then to overall health disparities, suggest that it is important to understand underlying mechanisms, including by education.[6,7] We chose education strata that were meaningful to growing social status separation in the US. We stratified education by college graduation as there is growing evidence that this group, and the top 20% by income, are progressively divergent from the remainder of the population across many dimensions.[3,16–18]

This study thus aims to describe how income and education stratifications converge to explain the diverging trajectories and population patterns in CVD outcomes in recent decades in the US. In particular, the study aims to examine whether there are increasingly diverging trajectories in CVD outcomes between top 20% of income earners who have a college degree or more and the remainder of the US population over a twenty-year period in the US. This is a particularly important area of inquiry given the slowdown of national reductions in CVD morbidity and mortality over the past few decades.[7] Importantly, it is the group, top 20% earners and college graduates, that is largely responsible for decision-making that shapes the health of the entire US population.[19]

Methods

Data source and study population

We used data from the National Health and Nutrition Examination Survey (NHANES), a serial cross-sectional survey designed to assess health and nutrition status of people in the United States. Conducted by the National Center for Health Statistics, NHANES collects nationally representative samples each year and releases data in two-year cycles.[20] NHANES uses a stratified, multistage probability sampling approach to select participants representative of the civilian, non-institutionalized U.S. population. The NHANES website documents the sampling process.[21] The NHANES survey consists of two components: interviews and physical examinations. The interview process collects demographic, socioeconomic and health-related information, and a subset of participants receive physical examination that includes medical, dental and laboratory tests performed by trained medical personnel.[21] NHANES sampling strategy and large sample size enhance the precision of estimates. Moreover, we reported confidence interval (CI) widths throughout to provide a measure of the uncertainty associated with each estimate and provide insights around the sample size adequacy.

In this study, we used NHANES data from 1999 to 2018 for adults who were 20 years and older. We then constructed a weight variable combining ten survey cycles from 1999 to 2018 using the NHANES inverse probability medical weights. The inverse probability weights provided by NHANES adjusted for both unequal probability of sampling and nonresponse. Additionally, NHANES made post-stratification adjustments to match the U.S. civilian non-institutionalized population. Following NHANES guidelines, we developed a twenty-year survey weight by combining the four-year weight used in survey cycles 1 and 2 (1999–2002) with the two-year weights used in survey cycles 3 through 10 (2003–2018).[22] For the two-year prevalence, measurements used a two-year weight created through NHANES guidelines.[22] The bivariable and multivariable models spanning twenty years used the twenty-year medical weight.

We selected potential confounders to include in this paper using the modified disjunctive cause criterion.[23] Based on this approach, age, sex, race/ethnicity, marital status, citizenship status, and insurance status were retained as potential confounders. These variables were likely to influence both the exposures (income and educational level) and the outcome (CVD prevalence) through social, economic, and biological mechanisms. Clinical biomarker variables, including body mass index (BMI), systolic blood pressure (SBP), high-density lipoprotein (HDL), and low-density lipoprotein (LDL), were treated as intermediate variables that may mediate the relationship between income/education and CVD prevalence but can also potentially be confounders. We thus conducted two analyses: one excluding biomarker variables as potential mediators and another including them to estimate direct effects. We also considered the potential influence of unmeasured confounders, such as early-life socioeconomic conditions and parental education. However, the NHANES dataset does not include relevant proxies for these variables.

Demographic metrics, including income level and educational attainment

Demographic characteristics in our analyses included age (20–39 years old, 40–59 years old, or 60 years and older), sex (male or female), race/ethnicity (White non-Hispanic, Black non-Hispanic, Hispanic, or other non-Hispanic), marital status (married or not married), citizenship status (US citizen or non-US citizen) and insurance status (health insurance or no health insurance). In addition, we included survey cycle as a continuous variable.

We developed a variable to describe the combination of income and education, using two NHANES variables: income-to-poverty ratio and education level. Income-to-poverty ratio is a more accurate measurement of participant's socioeconomic status compared to crude family income because it represents the annual family income adjusted for family size and poverty threshold guidelines of specific survey year, as published by the Department of Health and Human Service (HHS).[24] Income-to-poverty ratio was treated as missing if a participant's family income was missing or if respondents reported their income as "<$20,000" or "≥$20,000". When income-to-poverty ratio was above 5, NHANES coded the ratio as 5 due to disclosure concerns. We dichotomized income-to-poverty ratio into greater than or equal to 5 or less than 5, which roughly represents the richest 20% and the remainder 80% of participants in our sample.

With the increasing level of educational attainment in the US over the past two decades, we created a binary education variable using completion of college (4-years college) as a cut-off. Participants who are still in college are classified by NHANES as having a high-school degree as the highest degree. We defined college graduate as having a college degree or more, and some college or less as non-college graduate.[25]

We then combined the income-to-poverty ratio and education level into a categorical variable representing combined income and education: top 20% income earners, college graduates; top 20% income earners, non-college graduates; bottom 80% income earners, college graduates; and bottom 80% income earners, non-college graduates.

Clinical biomarker health metrics and cardiovascular outcomes

NHANES collects biomarker information during the physical and laboratory examination process, which was measured in a subset of participants who completed the physical examination. NHANES provides BMI as a person's mass in kilograms divided by the square of their height in meters. For SBP, NHANES collects three consecutive measurements, with a fourth taken if a previous reading was incomplete. We defined mean SBP as the mean of three measurements. NHANES provides HDL and LDL in mg/dL. We created binary or categorical variables using these biomarker measurements. We defined obesity as a BMI greater than or equal to 30 kg/m^2, high systolic blood pressure as a mean SBP greater than or equal to 130 mmHg, low HDL as less than 40 mg/dL, and low LDL as less than 70 mg/dL, normal LDL as 70–159 mg/dL, and high LDL as greater than or equal to 160 mg/dL.[26–29] For this paper, we hypothesized that biomarkers can potentially operate as either confounders or mediators depending on the proposed causal pathway. To account for either possibility, we included regression models that exclude biomarkers as potential mediators as well as sensitivity analyses that include them as potential confounders.

CVD outcomes in this analysis consisted of self-reported variables extracted from NHANES interview section, where participants were asked if they were ever told by a healthcare professional that they had a cardiovascular condition, including a) congestive heart failure (CHF), b) angina/angina pectoris, c) heart attack, or d) stroke.

Statistical analysis

We used data from 1999 to 2018 to assess the relationship between the combination of income and education, and various health outcomes. First, we calculated twenty-year inverse probability weights using the method described in a preceding section. Second, we performed a descriptive analysis on the twenty-year sample to compare demographics, income and educational information, and clinical biomarkers within the four categories. Third, we calculated the age-standardized prevalence of cardiovascular outcomes using the 2000 Census population proportions provided by NHANES for both the twenty-year sample and for each survey cycle.[30] We compared the age-standardized prevalence of CHF, angina, heart attack, and stroke among participants across each of the four categories representing combined income and education. We calculated confidence intervals for proportions using the Korn and Graubard method, which account for age-adjustment and design effect, thereby accounting for the stratification, clustering, and unequal weighting present in complex survey design.[31–33] We performed chi-square tests with Rao-Scott correction to assess statistical significance.[34] We evaluated the chi-square tests to ensure that no expected cell count is less than 1 and no more than 20% of the expected cell counts are less than 5. We found no deviations from these assumptions.

Fourth, we analyzed the association between different demographic variables and the combination of income and education on each CVD outcome by running logistic regression models. Model 1 assessed the odds of each CVD outcome given the combination of income and education. Model 2 additionally controlled for demographic variables age, sex, race/ethnicity, marital status, citizenship status, health insurance status, and survey cycle. Model 3 additionally controlled for BMI, SBP, HDL, and LDL. To assess potential residual confounding due to the categorization of variables, we conducted a sensitivity analysis using linear regression, treating all variables that could be converted into continuous forms as continuous.

In all analyses, we treated participants who responded "refuse" or "don't know" to a specific question as missing. Our final sample consisted of participants above 20 years old who completed the physical examination with no missing data for the categorical variable representing combined income and education. In the main model, there were 1011 participants missing at least one predictor (2%). In the sensitivity analysis that adds the biomarker predictors to the model, there were 33,812 participants missing at least one predictor (71.0%), the majority of which was due to LDL variable, which was missing 26,796 responses. We have opted to not impute missing data for predictors due to low missingness (<5%) in the main model and high missingness in the sensitivity analyses with biomarkers, which can lead to less reliable results. Supplementary Fig. S1 is a flowchart describing the analysis inclusion criteria. We used R version 4.2.3 and the packages "data.table", "tidyverse", "survey", "srvyr", "treemapify", and "ggh4x".[35–42]

Ethical approval

Review and approval by an Institutional review board was not required for this study, as it involved a secondary analysis of publicly available data.

Role of the funding source

The funder had no involvement in the study's design, execution, data collection, management, analysis, or interpretation, nor in the preparation, review, approval of the manuscript, or the decision to submit it for publication.

Results

Participant characteristics

Of the 52,398 eligible participants aged 20 years or older who completed the physical examination, 49,704 participants had data for both income-to-poverty ratio and education (94.9%, unweighted) and were included in the analysis. Fig. 1 summarizes the frequency distribution and weighted percentage of the income and education variable. Over half of the top 20% income participants were college graduates (55.8%, 4746/8762; [95% Confidence Interval (CI): 53.7%, 57.9%]), while less than a fifth of the bottom 80% income participants were college graduates (18.7%, 6089/40,942; [95% CI: 17.7%, 19.8%]). Table 1 shows the frequency and weighted percentage of participants by income and education. A chi-squared test for each variable showed statistically significant differences between groups ($p < 0.001$). These characteristics are provided with age standardization in the Supplementary information (Supplementary Table S2).

Prevalence of cardiovascular outcomes, 1999–2018

Fig. 2 presents the age-standardized prevalence of the four cardiovascular outcomes across each two-year cycle of the sample. The prevalence of CHF remained relatively stable over survey cycles; the highest prevalence was 2.7% (171/5052; [95% CI: 1.9%, 3.6%]) in 2011–2012 and the lowest prevalence was 1.9% (156/5566; [95% CI: 1.4%, 2.5%]) in 2009–2010. Angina was more common in early survey cycles and less common in later survey cycles, peaking at 3.1% (205/4699; [95% CI: 2.1%, 4.4%]) in 2003–2004 and nadiring at 1.9% (140/5567; [95% CI: 1.4%, 2.5%]) in 2009–2010. Heart attack had the highest prevalence across almost all survey cycles, peaking at 3.8% (250/4706; [95% CI: 2.9%, 4.8%]) in 2003–2004. Stroke gradually increased in prevalence from 2.2% (160/4120; [95% CI: 1.8%, 2.8%]) in 1999–2000 to 3.2% (243/4766; [95% CI: 2.6%, 3.8%]) in 2017–2018. Supplementary Table S3 provides the prevalence of CVD outcomes by all study charateristics. Crude prevalence revealed a similar, albeit more fluctuating, pattern of results (Supplementary Fig. S2).

Overall prevalence of cardiovascular outcomes by income and education, 1999–2018

Fig. 3 presents the age-standardized prevalence of the four cardiovascular outcomes over the whole sample. Fewer than 1% of top 20% income, college graduate participants reported CHF (0.5%, 42/4746; [95% CI: 0.3%, 0.4%]), increasing in prevalence with each group: 1.5% (95/4016; [95% CI: 1.2%, 2.0%]) of top 20% income, non-college graduate participants, 1.6% (139/6089; [95% CI: 1.3%, 2.0%]) of bottom 80% income, college graduate participants, and 3.0% (1418/34,853;

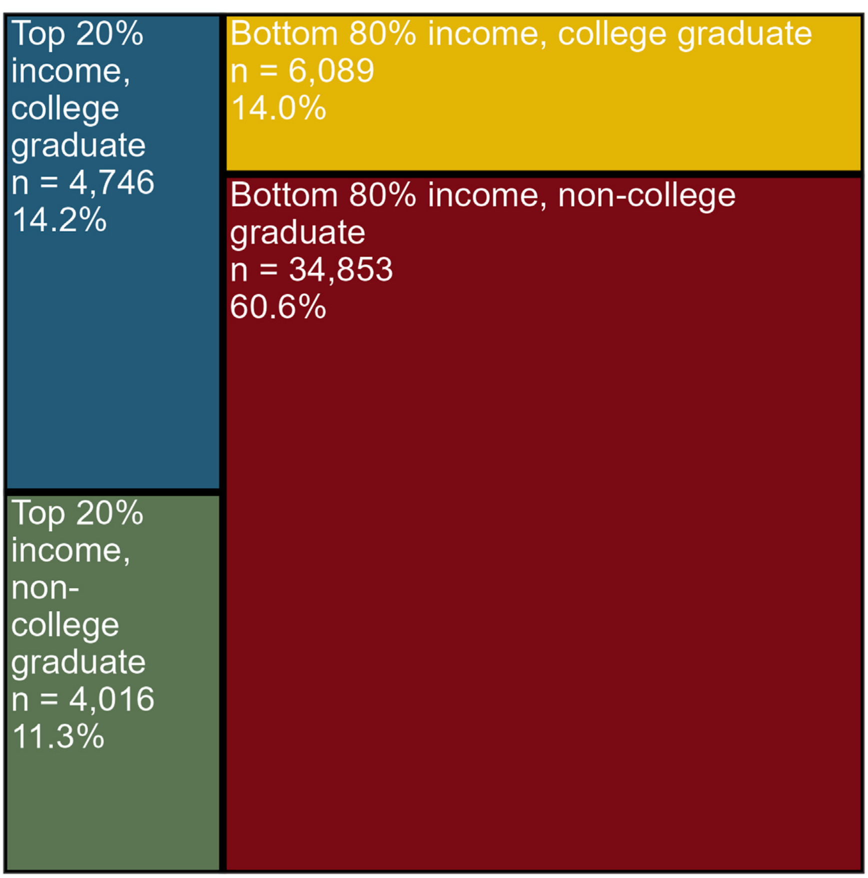

Fig. 1: **Characteristics of study participants, 1999–2018.**

	Top 20% income, college graduate		Top 20% income, non-college graduate		Bottom 80% income, college graduate		Bottom 80% income, non-college graduate		p-value
	No.	Weighted % [95% CI]	No.	Weighted % [95% CI]	No.	Weighted % [95% CI]	No.	Weighted % [95% CI]	
Overall (n = 49,704)	4746	14.2% [13.2%, 15.3%]	4016	11.3% [10.7%, 11.9%]	6089	14.0% [13.2%, 14.7%]	34,853	60.6% [59.0%, 62.1%]	
Characteristic									
Age, y									<0.0001
20–39	1497	30.4% [28.1%, 32.8%]	1014	25.5% [23.5%, 27.5%]	2436	42.8% [40.7%, 44.9%]	12,298	40.7% [39.6%, 41.7%]	
40–59	1918	47.2% [44.9%, 49.5%]	1693	51.6% [49.6%, 53.6%]	1916	35.8% [34.0%, 37.7%]	10,085	33.5% [32.6%, 34.4%]	
≥60	1331	22.4% [20.5%, 24.4%]	1309	22.9% [21.1%, 24.8%]	1737	21.4% [19.9%, 23.0%]	12,470	25.9% [25.0%, 26.8%]	
Sex									<0.0001
Male	2460	51.4% [50.3%, 52.6%]	2066	52.2% [50.7%, 53.7%]	2838	45.9% [44.4%, 47.4%]	16,614	47.1% [46.5%, 47.6%]	
Female	2286	48.6% [47.4%, 49.7%]	1950	47.8% [46.3%, 49.3%]	3251	54.1% [52.6%, 55.6%]	18,239	52.9% [52.4%, 53.5%]	
Race/ethnicity									<0.0001
White non-Hispanic	2948	83.9% [82.1%, 85.6%]	2391	82.6% [80.7%, 84.4%]	3101	72.4% [70.1%, 74.6%]	14,120	62.1% [59.3%, 64.8%]	
Black non-Hispanic	574	4.4% [3.7%, 5.2%]	752	7.1% [6.1%, 8.2%]	1091	9.0% [8.0%, 10.1%]	7893	13.8% [12.3%, 15.4%]	
Hispanic	384	3.4% [2.9%, 3.9%]	615	6.1% [5.2%, 7.1%]	803	7.9% [6.8%, 9.1%]	10,489	18.1% [16.0%, 20.3%]	
Asian non-Hispanic	617	3.9% [3.1%, 4.9%]	141	1.1% [0.9%, 1.4%]	742	4.7% [3.8%, 5.6%]	1087	1.5% [1.3%, 1.8%]	
Other non-Hispanic	223	4.4% [3.5%, 5.5%]	117	3.1% [2.3%, 4.0%]	352	6.0% [5.0%, 7.2%]	1264	4.5% [4.0%, 5.0%]	
Marital status									<0.0001
Married	3433	74.3% [72.2%, 76.3%]	2635	69.7% [67.6%, 71.8%]	3359	57.3% [55.0%, 59.5%]	16,420	49.0% [47.7%, 50.3%]	
Not married	1264	25.7% [23.7%, 27.8%]	1342	30.3% [28.2%, 32.4%]	2675	42.7% [40.5%, 45.0%]	18,094	51.0% [49.7%, 52.3%]	
Citizenship status									<0.0001
US citizenship	4429	95.8% [94.9%, 96.6%]	3839	97.3% [96.5%, 98.0%]	5341	91.6% [90.3%, 92.7%]	29,308	89.3% [88.3%, 90.4%]	
Non-US citizenship	314	4.2% [3.4%, 5.1%]	177	2.7% [2.0%, 3.5%]	745	8.4% [7.3%, 9.7%]	5488	10.7% [9.6%, 11.7%]	
Health insurance									<0.0001
Health insurance	4650	98.1% [97.4%, 98.6%]	3741	93.9% [92.6%, 95.1%]	5351	89.5% [88.3%, 90.6%]	25,889	75.6% [74.5%, 76.8%]	
No health insurance	95	1.9% [1.4%, 2.6%]	272	6.1% [4.9%, 7.4%]	733	10.5% [9.4%, 11.7%]	8928	24.4% [23.2%, 25.5%]	
Cardiovascular disease outcomes									
Congestive heart failure	42	0.5% [0.3%, 0.8%]	95	1.6% [1.2%, 2.0%]	139	1.7% [1.3%, 2.1%]	1418	3.1% [2.9%, 3.4%]	<0.0001
Angina	83	1.4% [1.0%, 1.9%]	101	2.1% [1.6%, 2.7%]	140	1.8% [1.4%, 2.3%]	1154	2.9% [2.7%, 3.2%]	<0.0001
Heart attack	111	1.8% [1.4%, 2.2%]	153	3.3% [2.6%, 4.2%]	201	2.2% [1.9%, 2.6%]	1744	4.0% [3.8%, 4.3%]	<0.0001
Stroke	70	1.1% [0.8%, 1.5%]	106	1.8% [1.4%, 2.3%]	174	2.3% [1.9%, 2.8%]	1629	3.5% [3.3%, 3.8%]	<0.0001

Estimates unweighted; percentages weighted with twenty-year NHANES interview weights. Observations were not age standardized. The Korn and Graubard method was used to calculate the 95% confidence interval. Significance estimated using a chi-squared test with Rao & Scott correction. Participants were missing marital status (N = 482), citizenship status (N = 63), health insurance (N = 45), congestive heart failure (N = 144), angina (N = 162), heart attack (N = 78), or stroke (N = 64).

Table 1: **Characteristics of study participants by combination of income and education, 1999–2018.**

[95% CI: 2.8%, 3.3%]) of bottom 80% income, non-college graduate participants. The top 20% income, college graduate group had the lowest prevalence of angina (1.4%, 83/4746; [95% CI: 1.0%, 1.8%]). The top 20% income, non-college graduate group had an angina prevalence of 2.0% (101/4016; [95% CI: 1.5%, 2.6%]). The prevalence for the bottom 80% income, college graduate group was 1.7% (140/6089; [95% CI: 1.3%, 2.2%]). The bottom 80% income, non-college graduate group had the highest prevalence of angina (2.8%, 1154/34,853; [95% CI: 2.6%, 3.1%]). The top 20% income, college graduate group had the lowest prevalence of heart attack, and the bottom 80% income, non-college graduate group had the highest (1.7%, 111/4746; [95% CI: 1.3%, 2.2%] and 3.9%, 1744/34,853; [95% CI: 3.6%, 4.1%], respectively). The top 20% income, non-college graduate group had a higher prevalence than the bottom 80% income, college graduate group (3.2%, 153/4016; [95% CI: 2.5%, 4.1%] and 2.1%, 201/6089; [95% CI: 1.8%, 2.5%], respectively). Stroke showed a similar pattern to CHF, with 1.1% (70/4746; [95% CI: 0.8%, 1.5%]) for top 20% income, college graduate, 1.7% (106/4016; [95% CI: 1.3%, 2.2%]) for top 20% income, non-college graduate, 2.2% (174/6089; [95% CI: 1.8%, 2.7%]) for bottom 80% income, college graduate, and 3.4% (1629/34,853; [95% CI: 3.2%, 3.6%]) for bottom 80% income, non-college graduate. The crude prevalence of cardiovascular outcomes by income and education reflects the age-standardized prevalence (Supplementary Fig. S3).

Odds ratios of cardiovascular outcomes by income and education, 1999–2018

Fig. 4 shows three models depicting the odds of each cardiovascular outcome given a combination of income and education, using the top 20% income, college

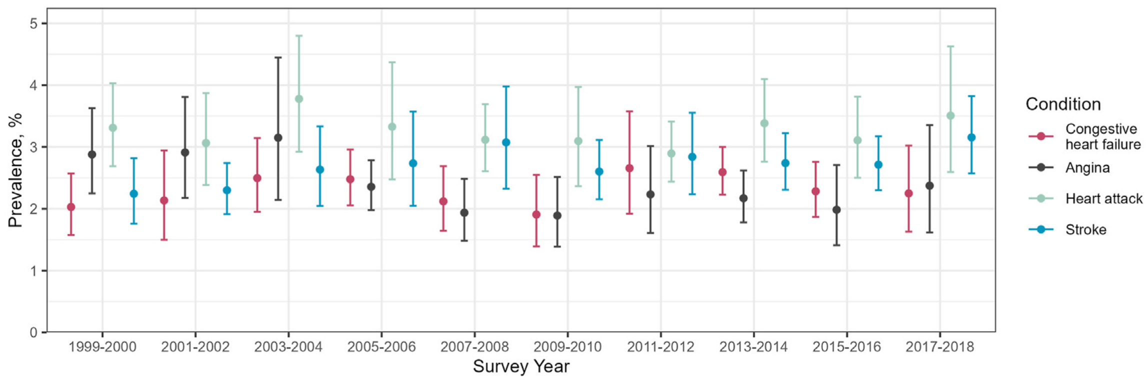

Fig. 2: **Age-standardized prevalence of cardiovascular outcomes by survey cycle, 1999–2018.** Weighted with NHANES two-year interview weights. Observations were age standardized. The Korn and Graubard method was used to calculate the 95% confidence interval. Error bars represent the 95% confidence interval. Participants were missing congestive heart failure (N = 144), angina (N = 162), heart attack (N = 78), or stroke (N = 64).

graduate group as the reference. Other groups had higher odds of each condition across all three models, except for the bottom 80% income, college graduate group for angina.

The bivariable model (Model 1) showed higher odds of CHF (Odds Ratio (OR): 3.17 [95% CI: 1.95, 5.15]), angina (OR: 1.49 [95% CI: 1.01, 2.18]), heart attack (OR: 1.91 [95% CI: 1.34, 2.71]), or stroke (OR: 1.57 [95% CI: 1.03, 2.41]) for the top 20% income, non-college graduate group. The bottom 80% income, college graduate group was more likely to have CHF (OR: 3.30 [95% CI: 2.10, 5.19]) or stroke (OR: 2.04 [95% CI: 1.38, 3.00]). The bottom 80% income, non-college graduate group was more likely to have experienced CHF (6.34 [95% CI: 4.17, 9.63]), angina (2.11 [95% CI: 1.56, 2.85]), heart attack (2.32 [95% CI: 1.80, 2.98]), or stroke (3.17 [95% CI: 2.32, 4.34]).

Table 2 displays the model controlling for demographics (Model 2 in Fig. 4). Generally, the odds of reporting CVD outcomes increased along top 20% income, college graduate; top 20% income, non-college graduate; bottom 80% income, college graduate; and bottom 80% income, non-college graduate. For CHF, compared to the top 20% income, college graduate group, the top 20% income, non-college graduate group had 3.11 [95% CI: 1.92, 5.06] times the odds, the bottom

Fig. 3: **Age-standardized prevalence of cardiovascular outcomes by combination of income and education, 1999–2018.** Weighted with NHANES twenty-year interview weights. Observations were age standardized. The Korn and Graubard method was used to calculate the 95% confidence interval. Error bars represent the 95% confidence interval. Participants were missing congestive heart failure (N = 144), angina (N = 162), heart attack (N = 78), or stroke (N = 64).

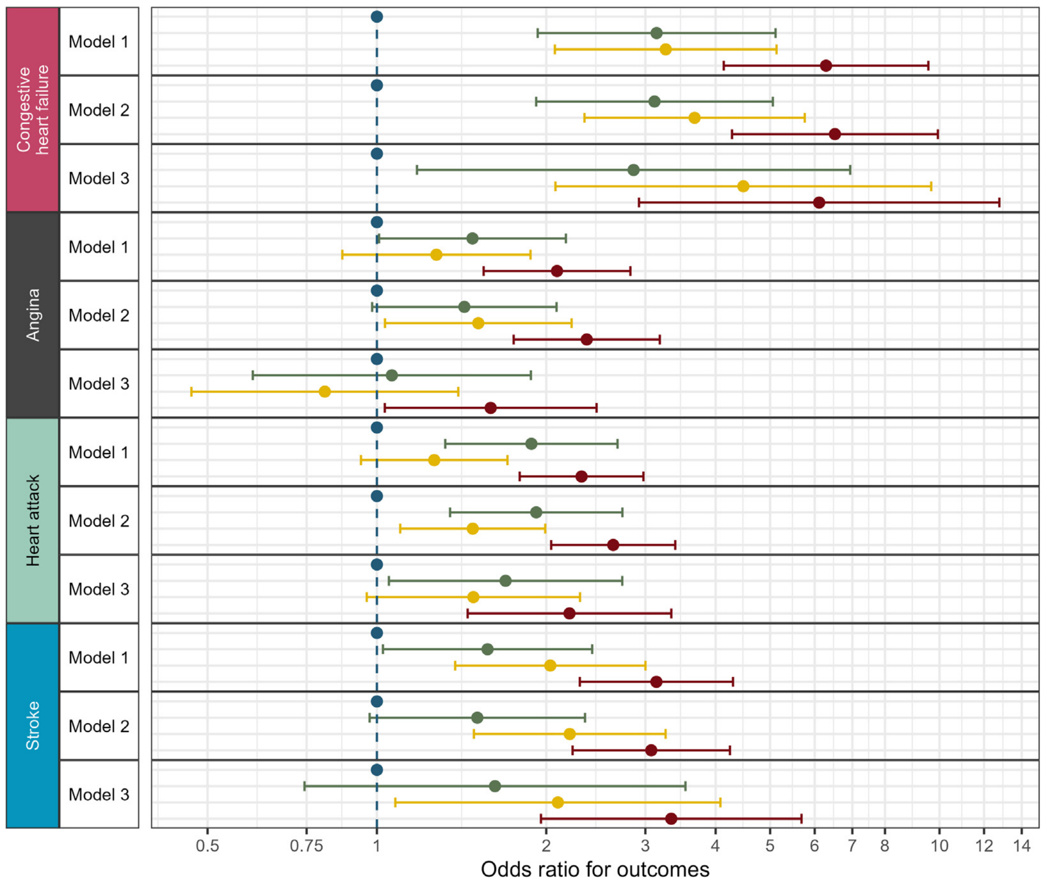

***Fig. 4:* Forest plot of age-standardized odds of each cardiovascular outcome for the combination of income and education across three models, 1999–2018.** Model 1 regresses the combination of income and education on each cardiovascular outcome. Model 2 controls for age, sex, race/ethnicity, marital status, citizenship status, health insurance, and survey cycle. Model 3 controls for the covariates presented in Model 2 and BMI, SBP, HDL, and LDL. Models 1 and 2 were weighted with NHANES twenty-year interview weights. Model 3 was weighted with NHANES twenty-year medical weights. Observations were age standardized. Error bars represent the 95% confidence interval. For Model 1, participants were missing congestive heart failure (N = 144), angina (N = 162), heart attack (N = 78), or stroke (N = 64). For Model 2, participants were missing marital status (N = 482), citizenship status (N = 63), health insurance (N = 45), congestive heart failure (N = 144), angina (N = 162), heart attack (N = 78), or stroke (N = 64). For Model 3, participants were missing marital status (N = 432), citizenship status (N = 59), health insurance (N = 40), BMI (N = 942), SBP (N = 4792), HDL (N = 6990), LDL (N = 26,796), congestive heart failure (N = 132), angina (N = 152), heart attack (N = 70), or stroke (N = 58).

80% income, college graduate group had 3.67 [95% CI: 2.34, 5.76] times the odds, and the bottom 80% income, non-college graduate group had 6.52 [95% CI: 4.28, 9.93] times the odds. Angina had a similar trend. Compared to the top 20% income, college graduate group, the bottom 80% income, college graduate group had 1.51 [95% CI: 1.03, 2.22] times the odds of angina and the bottom 80% income, non-college graduate group had 2.36 [95% CI: 1.75, 3.18] times the odds. This trend remained for stroke, with half-over the odds for the top 20% income, non-college graduate group, twice the odds for the bottom 80% income, college graduate group (OR: 2.20 [95% CI: 1.49, 3.26]), and thrice the odds for the bottom 80% income, non-college graduate group (OR: 3.07 [95% CI: 2.23, 4.24]), compared to the top 20% income, college graduate group. The trend was different for heart attack. Compared to the top 20% income, college graduate group, the top 20% income, non-college graduate group had higher odds of heart attack (OR: 1.92 [95% CI: 1.35, 2.73]), but the bottom 80% income, college graduate group had 1.48 [95% CI: 1.10, 1.99] times the odds of heart attack. The bottom 80% income, non-college graduate group had 2.63 [95% CI: 2.04, 3.39] times the odds of heart attack compared to the top 20% income, college graduate group.

In the model controlling for demographics and biomarkers (Model 3), the top 20% income, non-college graduate group was more likely to have experienced CHF (OR: 2.86 [95% CI: 1.18, 6.94]) or heart attack (OR: 1.69 [95% CI: 1.05, 2.73]). The bottom 80%

	Congestive heart failure		Angina		Heart attack		Stroke	
	Odds ratios [95% CI]	p-value	Odds ratios [95% CI]	p-value	Odds ratios [95% CI]	p-value	Odds ratios [95% CI]	p-value
Characteristic								
Age, y								
20–39	Reference [1]		Reference [1]		Reference [1]		Reference [1]	
40–59	6.36 [4.58, 8.85]	<0.0001	7.32 [5.08, 10.5]	<0.0001	8.92 [6.63, 12.0]	<0.0001	5.27 [3.84, 7.24]	<0.0001
≥60	26.6 [18.7, 37.8]	<0.0001	23.4 [16.3, 33.7]	<0.0001	33.8 [25.1, 45.4]	<0.0001	19.4 [14.8, 25.4]	<0.0001
Sex								
Male	Reference [1]		Reference [1]		Reference [1]		Reference [1]	
Female	0.66 [0.58, 0.75]	<0.0001	0.67 [0.59, 0.77]	<0.0001	0.42 [0.37, 0.47]	<0.0001	1.03 [0.90, 1.17]	0.66
Race/ethnicity								
White non-Hispanic	Reference [1]		Reference [1]		Reference [1]		Reference [1]	
Black non-Hispanic	1.31 [1.13, 1.52]	0.00040	0.59 [0.49, 0.72]	<0.0001	0.81 [0.70, 0.93]	0.0033	1.39 [1.21, 1.59]	<0.0001
Hispanic	0.80 [0.64, 0.99]	0.042	0.79 [0.65, 0.95]	0.013	0.71 [0.59, 0.86]	0.00049	0.83 [0.68, 1.02]	0.074
Asian non-Hispanic	0.60 [0.42, 0.87]	0.0076	0.55 [0.32, 0.95]	0.031	0.60 [0.42, 0.88]	0.0084	0.66 [0.46, 0.95]	0.025
Other non-Hispanic	1.15 [0.77, 1.72]	0.50	1.15 [0.75, 1.76]	0.52	1.33 [0.98, 1.81]	0.071	1.70 [1.25, 2.30]	0.00079
Not married vs. married	1.41 [1.24, 1.61]	<0.0001	1.12 [0.95, 1.32]	0.19	1.41 [1.24, 1.59]	<0.0001	1.35 [1.18, 1.54]	<0.0001
Non-US citizenship vs. US citizenship	0.67 [0.49, 0.92]	0.013	0.49 [0.34, 0.69]	<0.0001	0.50 [0.31, 0.79]	0.0031	0.58 [0.41, 0.82]	0.0023
No health insurance vs. health insurance	0.63 [0.47, 0.84]	0.0018	0.79 [0.58, 1.07]	0.13	0.83 [0.65, 1.06]	0.14	0.77 [0.62, 0.94]	0.013
Income and education								
Top 20% income, college graduate	Reference [1]		Reference [1]		Reference [1]		Reference [1]	
Top 20% income, non-college graduate	3.11 [1.92, 5.06]	<0.0001	1.43 [0.98, 2.09]	0.063	1.92 [1.35, 2.73]	0.00036	1.51 [0.97, 2.34]	0.067
Bottom 80% income, college graduate	3.67 [2.34, 5.76]	<0.0001	1.51 [1.03, 2.22]	0.033	1.48 [1.10, 1.99]	0.010	2.20 [1.49, 3.26]	0.00011
Bottom 80% income, non-college graduate	6.52 [4.28, 9.93]	<0.0001	2.36 [1.75, 3.18]	<0.0001	2.63 [2.04, 3.39]	<0.0001	3.07 [2.23, 4.24]	<0.0001
Survey cycle	1.00 [0.97, 1.02]	0.70	0.94 [0.91, 0.97]	0.00040	0.98 [0.96, 1.00]	0.10	1.01 [0.99, 1.03]	0.40

Odds ratios weighted using NHANES twenty-year interview weights. Observations were age standardized. Participants were excluded if missing marital status (N = 482), citizenship status (N = 63), or health insurance (N = 45). Each model excluded participants if they were missing congestive heart failure (N = 144), angina (N = 162), heart attack (N = 78), or stroke (N = 64).

Table 2: **Odds ratios of cardiovascular outcomes, 1999–2018.**

income, college graduate group had higher odds of CHF (OR: 4.48 [95% CI: 2.08, 9.67]) or stroke (OR: 2.10 [95% CI: 1.08, 4.08]). The bottom 80% income, non-college graduate group was more likely to have experienced CHF (OR: 6.11 [95% CI: 2.92, 12.8]), angina (OR: 1.59 [95% CI: 1.03, 2.46]), heart attack (OR: 2.20 [95% CI: 1.45, 3.34]), or stroke (OR: 3.34 [95% CI: 1.96, 5.69]). Supplementary Table S5 describes the physical examination subsample. Supplementary Table S6 presents the full version of Model 3.

Discussion

Two main observations emerge from this assessment of CVD outcomes among US adult population between 1999 and 2018. First, there is a substantial clustering of protective factors and lower adverse CVD outcomes among a small segment of Americans. Second, it is the accumulation of favorable socio-economic resources that is likely contributing to better health among a small proportion of Americans, rather than any one socio-economic indicator alone.

This work suggests that the top 20% income, college graduate group had the lowest prevalence of CVD risk factors, including low HDL and high BMI, and lowest prevalence of adverse CVD outcomes among all groups in the analysis. In contrast, nearly a tenth of the bottom 80% income, non-college graduate group reported a history of having at least one of the four adverse CVD outcomes studied. The strength of the association varied by outcome, potentially due to the underlying pathophysiology, risk factors, and treatments associated with each CVD outcome. The association was strongest for CHF compared to other outcomes, which can potentially be because CHF is a chronic condition that develops over time. CHF is often the final event that could have been prevented or well managed by access to resources. Many factors contribute to the development and progression of CHF such as health literacy, access to healthier behaviors, existing comorbidities, and access to healthcare, which are often linked to income and education.[43,44] The weaker association for more acute outcomes such as heart attack can be due to higher mortality rates among lower income populations, which in turn can lead to reporting only by the surviving population.[45,46]

There is growing literature that examines the concept of risk clusters among populations experiencing multiple forms of inequality.[47] For example, Caspi et al., found that around one fifth of a birth-cohort study in

New Zealand accounted for clustering of risks around health ranging from 40% of excess obesity to 57% of hospital overnight stays and 78% of prescriptions filled and that childhood risks predicted being part of this segment of the population.[48] Richmond-Rakerd et al., found that a small segment of the population (around 10%) accounted for the highest burden and clustering of need across different social and economic sectors, including poor health, in New Zealand and Denmark.[49] Our study contributes to this body of work examining the clustering of favorable socio-economic resources and low risk of CVD that is concentrated among a small minority of the population. This study highlights that clustering of risk and need around CVD in the US is not a minority concern, but rather one that affects most Americans.

This analysis suggests that considering income and education together can help provide more insight into the burden of CVD in the US than examining either factor independently. Several studies have shown how different socio-economic factors contribute to the burden of CVD.[50–58] Moreover, previous research has largely shown that income and education both play a role in CVD risk factors and clinical outcomes.[5,59–73] For example, Abdalla et al., documented the worsening of CVD biomarkers and diagnoses among the poorest 80% of the US population while CVD outcomes remained the same or improved among the richest 20% of Americans in a twenty-year period.[6,74] Hamad and colleagues showed that higher educational attainment was consistently associated with improvements in HDL, depression, and smoking.[75] Kubota et al., found that, regardless of other socioeconomic factors, educational attainment was inversely associated with lifetime risks of CVD.[76] Conversely, Johnson et al. found that the protective role of educational attainment was not equal across different races and ethnicities.[47] In addition, Lewis et al., found that for younger Americans, low income was associated with higher incidence of coronary heart disease regardless of educational level.[77] Similarly, a meta-analysis by Khaing et al., suggested a higher risk for four CVD outcomes in populations with low and medium education (less than university) as well as low and medium income across different high-income nations.[78] Our results align with the growing literature that shows how multiple socio-economic factors can interact to prevent or produce adverse outcomes. For example, Zhang et al. examined CVD incidence and mortality and found that the people in the low socioeconomic status group—defined as a latent variable of family income, educational attainment, employment status, and health insurance— had 2.4 times the hazard ratio of all-cause mortality compared to the high socioeconomic status group.[79] Our work adds to literature by highlighting that the accumulation of favorable socio-economic resources like high income and educational attainment can act synergistically to prevent poor CVD outcomes, likely contributing to more better cardiovascular health than either factor on its own.

This study is not without limitations. First, there may be self-reporting bias. However, previous analyses have shown that self-reported CVD outcomes in NHANES and other surveys can be useful for measuring population prevalence of cardiovascular disease in US.[80–82] Other surveys have suggested low sensitivity among certain populations like older adults and populations with limited English proficiency.[83–85] Second, our results may be influenced by survival bias, particularly among participants from disadvantaged backgrounds, diluting the true prevalence of cardiovascular disease in the US. For example, between 1999 and 2019, cardiovascular mortality occurred at 1.32 times the rate for Black women compared to White women and 1.33 times the rate for Black men compared to White men.[86] These rate ratios were even larger for younger populations.[86] Thus, our results may represent a low-end estimate of the true CVD outcomes disparity that may exist. Third, the race/ethnicity categories we selected may not fully represent the diversity of the American population over time. For example, there are notable key differences in the social determinants of cardiometabolic disease within Asian subpopulations.[87] This limitation reflects systemic issues in measuring health inequities by race/ethnicity in both NHANES and the United States Census, although oversampling in recent years has reduced the magnitude of this limitation.[22] Fourth, it is plausible that a different stratification of income and education can yield a clustering of benefit or risk that differs in magnitude or the percentage of population it represents. However, we chose strata that were meaningful to growing social status separation in the US. We stratified income by the top 20% of earners and education by college graduation because there is growing evidence that these are two groups are increasingly divergent from the remainder of the population across multiple dimensions.[3,16–18] These are also the two groups that largely control decision-making spaces in the US.[19,88,89] Fifth, this study maybe subject to the potential limitations of observational studies including reverse causality, unmeasured confounding, or overadjustment bias. In particular, early-life socioeconomic conditions and parental education are potential unmeasured confounders that do not have reliable proxies in the NHANES dataset. Six, this study did not involve a formal sample size calculation. However, the use of NHANES, with its nationally representative sample and large population size, mitigates this limitation to some extent. Additionally, the reporting of confidence intervals for all estimates allows readers to assess the precision of the findings and interpret them accordingly. Lastly, this study used information from 10 NHANES cycles with a cutoff date before the Covid-19 pandemic began. There is mounting literature highlighting the economic effect the pandemic has had on the population, particularly among poor households and vulnerable populations.[90,91] This might have affected and exacerbated the disparities highlighted in our study.

This study demonstrates that the accumulation of favorable socio-economic resources preventing poor CVD outcomes is concentrated in a small proportion of the population. Health gaps are not just a feature of differences between extremes, for example gaps between the richest 1% and the poorest 1%. Rather, this analysis shows that most Americans are left behind in health, while a few who lead decision-making in the US experience better health outcomes. Despite efforts to narrow health gaps, these observations highlight the challenge of improving the well-being of the majority. Foundational assets that can promote health must be at the center of such efforts. Future research should include longitudinal studies that focus on the mechanisms through which both income and education shape CVD outcomes in the US as well as more nuanced categories of income and education to allow for a more comprehensive evaluation of the socioeconomic graduates in CVD health.

Contributors
SMA and SG were awarded the funding to conduct this study and collaborated on the conceptualization, design, and supervision of the study. SBR and SY had access to the data. SY cleaned and compiled the dataset from NHANES. SBR conducted data curation, formal statistical analysis, and visualizations. SMA and SBR wrote the manuscript draft. NM, CMC, and SG critically reviewed the manuscript. All authors revised and approved the final version of the manuscript and Supplementary material.

Data sharing statement
All data was publicly available for download from the National Center for Health Statistics (https://wwwn.cdc.gov/nchs/nhanes/default.aspx).

Artificial intelligence (AI) use
ChatGPT-4o was used for grammar review.

Declaration of interests
The authors declare no competing interests.

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Appendix A. Supplementary data
Supplementary data related to this article can be found at https://doi.org/10.1016/j.lana.2025.101039.

References
1 Chetty R, Stepner M, Abraham S, et al. The association between income and life expectancy in the United States, 2001-2014. *JAMA*. 2016;315(16):1750–1766. https://doi.org/10.1001/jama.2016.4226.
2 Tikkanen R, Abrams M. *U.S. Health care from a global perspective, 2019: higher spending, worse outcomes?* The Commonwealth Fund; 2020. https://doi.org/10.26099/7avy-fc29.
3 Bor J, Cohen GH, Galea S. Population health in an era of rising income inequality: USA, 1980-2015. *Lancet*. 2017;389(10077):1475–1490. https://doi.org/10.1016/S0140-6736(17)30571-8.
4 Brownell NK, Ziaeian B, Jackson NJ, Richards AK. Trends in income inequities in cardiovascular health among US adults, 1988–2018. *Circulation*. 2024;17(5):e010111. https://doi.org/10.1161/CIRCOUTCOMES.123.010111.
5 Odutayo A, Gill P, Shepherd S, et al. Income disparities in absolute cardiovascular risk and cardiovascular risk factors in the United States, 1999-2014. *JAMA Cardiol*. 2017;2(7):782–790. https://doi.org/10.1001/jamacardio.2017.1658.
6 Abdalla SM, Yu S, Galea S. Trends in cardiovascular disease prevalence by income level in the United States. *JAMA Netw Open*. 2020;3(9):e2018150. https://doi.org/10.1001/jamanetworkopen.2020.18150.
7 Mehta NK, Abrams LR, Myrskylä M. US life expectancy stalls due to cardiovascular disease, not drug deaths. *Proc Natl Acad Sci USA*. 2020;117(13):6998–7000. https://doi.org/10.1073/pnas.1920391117.
8 Jez SJ. The differential impact of wealth versus income in the college-going process. *Res High Educ*. 2014;55(7):710–734. https://doi.org/10.1007/s11162-014-9332-0.
9 Bhatia A, Miller C. *Explore how income influences attendance at 139 top colleges - the New York times*. The New York Times; 2023. https://www.nytimes.com/interactive/2023/09/11/upshot/college-income-lookup.html. Accessed March 8, 2024.
10 Hahn RA, Truman BI. Education improves public health and promotes health equity. *Int J Health Serv*. 2015;45(4):657–678. https://doi.org/10.1177/0020731415585986.
11 Prus SG. Comparing social determinants of self-rated health across the United States and Canada. *Soc Sci Med*. 2011;73(1):50–59. https://doi.org/10.1016/j.socscimed.2011.04.010.
12 Zajacova A, Lawrence EM. The relationship between education and health: reducing disparities through a contextual approach. *Annu Rev Public Health*. 2018;39:273–289. https://doi.org/10.1146/annurev-publhealth-031816-044628.
13 Cutler DM, Lleras-Muney A. Understanding differences in health behaviors by education. *J Health Econ*. 2010;29(1):1–28. https://doi.org/10.1016/j.jhealeco.2009.10.003.
14 Winkleby MA, Jatulis DE, Frank E, Fortmann SP. Socioeconomic status and health: how education, income, and occupation contribute to risk factors for cardiovascular disease. *Am J Public Health*. 1992;82(6):816–820. https://doi.org/10.2105/ajph.82.6.816.
15 Davies NM, Dickson M, Davey Smith G, van den Berg GJ, Windmeijer F. The causal effects of education on health outcomes in the UK Biobank. *Nat Hum Behav*. 2018;2(2):117–125. https://doi.org/10.1038/s41562-017-0279-y.
16 Bureau UC. Income and poverty in the United States: 2015. Census.gov. https://www.census.gov/library/publications/2016/demo/p60-256.html. Accessed March 9, 2024.
17 Perry M. *Explaining US income inequality by household demographics, 2018 update*. American Enterprise Institute - AEI; 2019. https://www.aei.org/carpe-diem/explaining-us-income-inequality-by-household-demographics-2018-update/. Accessed July 20, 2024.
18 Nelson L. *16 ways college graduates are different*. Vox; 2019. https://www.vox.com/2014/4/25/18077072/college-graduates. Accessed March 9, 2024.
19 Galea S, Abdalla SM. COVID-19 pandemic, unemployment, and civil unrest: underlying deep racial and socioeconomic divides. *JAMA*. 2020;324(3):227–228. https://doi.org/10.1001/jama.2020.11132.
20 Johnson CL, Dohrmann SM, Burt VL, Mohadjer LK. National health and nutrition examination survey: sample design, 2011-2014. *Vital Health Stat*. 2014;2(162):1–33.
21 National Center for Health Statistics. *About the national health and nutrition examination survey*. Centers for Disease Control and Prevention; 2023. https://www.cdc.gov/nchs/nhanes/about_nhanes.htm. Accessed August 31, 2023.
22 National Center for Health Statistics. Weighting. Centers for disease control and prevention. https://wwwn.cdc.gov/nchs/nhanes/tutorials/weighting.aspx. Accessed August 31, 2023.
23 VanderWeele TJ. Principles of confounder selection. *Eur J Epidemiol*. 2019;34(3):211–219. https://doi.org/10.1007/s10654-019-00494-6.
24 National Center for Health Statistics. *Data documentation, codebook, and frequencies*; 2017. https://wwwn.cdc.gov/Nchs/Nhanes/2015-2016/DEMO_I.htm. Accessed August 31, 2023.
25 Hanson M. *College graduation Statistics*. Education Data Initiative; 2023. https://educationdata.org/number-of-college-graduates/. Accessed October 2, 2023.
26 CDC. Adult obesity facts. *Obesity*; 2024. https://www.cdc.gov/obesity/php/data-research/adult-obesity-facts.html. Accessed July 22, 2024.
27 Whelton PK, Carey RM, Aronow WS, 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: a report of the American college of cardiology/American heart association task force on clinical

practice guidelines. *Hypertension*. 2018;71(6):e13–e115. https://doi.org/10.1161/HYP.0000000000000065.
28 CDC. About cholesterol. *Cholesterol*; 2024. https://www.cdc.gov/cholesterol/about/index.html. Accessed July 22, 2024.
29 Liu Y, Liu F, Zhang L, et al. Association between low density lipoprotein cholesterol and all-cause mortality: results from the NHANES 1999–2014. *Sci Rep*. 2021;11(1):22111. https://doi.org/10.1038/s41598-021-01738-w.
30 National Center for Health Statistics. Sample code. Centers for disease control and prevention. https://wwwn.cdc.gov/nchs/nhanes/tutorials/samplecode.aspx. Accessed August 31, 2023.
31 National Center for Health Statistics. *Reliability of estimates*. Centers for Disease Control and Prevention; 2024. https://wwwn.cdc.gov/nchs/nhanes/tutorials/reliabilityofestimates.aspx. Accessed February 23, 2024.
32 Graubard BI, Korn EL. Survey inference for subpopulations. *Am J Epidemiol*. 1996;144(1):102–106. https://doi.org/10.1093/oxfordjournals.aje.a008847.
33 Korn E, Graubard B. Confidence intervals for proportions with small expected number of positive counts estimated from survey data. *Surv Methodol*. 1998;24:193–201.
34 Rao JNK, Scott AJ. On chi-squared tests for multiway contingency tables with cell proportions estimated from survey data. *Ann Statist*. 1984;12(1). https://doi.org/10.1214/aos/1176346391.
35 R Core Team. *R: a language and environment for statistical computing*. R Foundation for Statistical Computing; 2021. https://www.R-project.org/.
36 Dowle M, Srinivasan A. *data.table: extension of 'data.frame'*; 2021. https://CRAN.R-project.org/package=data.table.
37 Wickham H, Averick M, Bryan J, et al. Welcome to the tidyverse. *J Open Source Softw*. 2019;4(43):1686. https://doi.org/10.21105/joss.01686.
38 Lumley T. *survey: analysis of complex survey samples*. 2020. Published online.
39 Lumley T. Analysis of complex survey samples. *J Stat Software*. 2004;9(1):1–19.
40 Ellis GF, Schneider B. *Srvyr: 'Dplyr'-like syntax for summary Statistics of survey data*; 2022. https://CRAN.R-project.org/package=srvyr.
41 Wilkins D. *treemapify: draw Treemaps in "ggplot2."*; 2023. Published online https://CRAN.R-project.org/package=treemapify.
42 van den Brand T. *ggh4x: hacks for "ggplot2"*; 2024. Published online https://CRAN.R-project.org/package=ggh4x.
43 Bozkurt B, Ahmad T, Alexander KM, et al. Heart failure epidemiology and outcomes Statistics: a report of the heart failure society of America. *J Card Fail*. 2023;29(10):1412–1451. https://doi.org/10.1016/j.cardfail.2023.07.006.
44 Shahu A, Okunrintemi V, Tibuakuu M, et al. Income disparity and utilization of cardiovascular preventive care services among U.S. adults. *Am J Prevent Cardiol*. 2021;8:100286. https://doi.org/10.1016/j.ajpc.2021.100286.
45 Ritchey MD, Wall HK, George MG, Wright JS. US trends in premature heart disease mortality over the past 50 years: where do we go from here? *Trends Cardiovasc Med*. 2020;30(6):364–374. https://doi.org/10.1016/j.tcm.2019.09.005.
46 Tetzlaff J, Geyer S, Westhoff-Bleck M, Sperlich S, Epping J, Tetzlaff F. Social inequalities in mild and severe myocardial infarction: how large is the gap in health expectancies? *BMC Public Health*. 2021;21(1):259. https://doi.org/10.1186/s12889-021-10236-7.
47 Johnson AE, Herbert BM, Stokes N, Brooks MM, Needham BL, Magnani JW. Educational attainment, race, and ethnicity as predictors for ideal cardiovascular health: from the national health and nutrition examination survey. *J Am Heart Assoc*. 2022;11(2): e023438. https://doi.org/10.1161/JAHA.121.023438.
48 Caspi A, Houts RM, Belsky DW, et al. Childhood forecasting of a small segment of the population with large economic burden. *Nat Hum Behav*. 2016;1:5. https://doi.org/10.1038/s41562-016-0005.
49 Richmond-Rakerd LS, D'Souza S, Andersen SH, et al. Clustering of health, crime and social-welfare inequality in 4 million citizens from 2 nations. *Nat Hum Behav*. 2020;4(3):255–264. https://doi.org/10.1038/s41562-019-0810-4.
50 Shen R, Zhao N, Wang J, et al. Association between socioeconomic status and arteriosclerotic cardiovascular disease risk and cause-specific and all-cause mortality: data from the 2005–2018 National Health and Nutrition Examination Survey. *Front Public Health*. 2022;10:1017271. https://doi.org/10.3389/fpubh.2022.1017271.
51 Patel N, Kalra R, Bhargava A, Arora G, Arora P. Ideal cardiovascular health among American adults after the economic recession of 2008–2009: insights from NHANES. *Am J Med*. 2019;132(10):1182–1190.e5. https://doi.org/10.1016/j.amjmed.2019.06.004.
52 He J, Zhu Z, Bundy JD, Dorans KS, Chen J, Hamm LL. Trends in cardiovascular risk factors in US adults by race and ethnicity and socioeconomic status, 1999-2018. *JAMA*. 2021;326(13):1286–1298. https://doi.org/10.1001/jama.2021.15187.
53 Marmot MG, Shipley MJ, Hemingway H, Head J, Brunner EJ. Biological and behavioural explanations of social inequalities in coronary heart disease: the Whitehall II study. *Diabetologia*. 2008;51(11):1980–1988. https://doi.org/10.1007/s00125-008-1144-3.
54 Schultz WM, Kelli HM, Lisko JC, et al. Socioeconomic status and cardiovascular outcomes: challenges and interventions. *Circulation*. 2018;137(20):2166–2178. https://doi.org/10.1161/CIRCULATIONAHA.117.029652.
55 Wang T, Li Y, Zheng X. Association of socioeconomic status with cardiovascular disease and cardiovascular risk factors: a systematic review and meta-analysis. *Z Gesundh Wiss*. 2023:1–15. https://doi.org/10.1007/s10389-023-01825-4. Published online.
56 Pinheiro LC, Reshetnyak E, Sterling MR, Levitan EB, Safford MM, Goyal P. Multiple vulnerabilities to health disparities and incident heart failure hospitalization in the REGARDS study. *Circulation*. 2020;13(8):e006438. https://doi.org/10.1161/CIRCOUTCOMES.119.006438.
57 Ditah CM, Rahman E, Agbor VN, et al. Disparities and drivers of early age at diagnosis of congestive heart failure in the USA. *Int J Cardiol*. 2019;293:143–147. https://doi.org/10.1016/j.ijcard.2019.06.001.
58 Reshetnyak E, Ntamatungiro M, Pinheiro LC, et al. Impact of multiple social determinants of health on incident stroke. *Stroke*. 2020;51(8):2445–2453. https://doi.org/10.1161/STROKEAHA.120.028530.
59 Minhas AMK, Jain V, Li M, et al. Family income and cardiovascular disease risk in American adults. *Sci Rep*. 2023;13(1):279. https://doi.org/10.1038/s41598-023-27474-x.
60 Lemstra M, Rogers M, Moraros J. Income and heart disease: neglected risk factor. *Can Fam Phys*. 2015;61(8):698–704.
61 Cathro C, Brenn T, Chen S. Education level and self-reported cardiovascular disease in Norway—the tromsø study, 1994–2016. *Int J Environ Res Public Health*. 2023;20(11):5958. https://doi.org/10.3390/ijerph20115958.
62 Dégano IR, Marrugat J, Grau M, et al. The association between education and cardiovascular disease incidence is mediated by hypertension, diabetes, and body mass index. *Sci Rep*. 2017;7(1): 12370. https://doi.org/10.1038/s41598-017-10775-3.
63 Diez-Roux AV, Link BG, Northridge ME. A multilevel analysis of income inequality and cardiovascular disease risk factors. *Soc Sci Med*. 2000;50(5):673–687. https://doi.org/10.1016/s0277-9536(99)00320-2.
64 Nguyen RT, Khan SU, Valero-Elizondo J, Cainzos-Achirica M, Nasir K. Association of income status with stroke in non-elderly adults in the United States, 2012-2018. *Curr Probl Cardiol*. 2023;48(8):101235. https://doi.org/10.1016/j.cpcardiol.2022.101235.
65 Hu L, Ji J, Li Y, Liu B, Zhang Y. Quantile regression forests to identify determinants of neighborhood stroke prevalence in 500 cities in the USA: implications for neighborhoods with high prevalence. *J Urban Health*. 2021;98(2):259–270. https://doi.org/10.1007/s11524-020-00478-y.
66 Diez-Roux AV, Northridge ME, Morabia A, Bassett MT, Shea S. Prevalence and social correlates of cardiovascular disease risk factors in Harlem. *Am J Public Health*. 1999;89(3):302–307.
67 Fernandes TG, Bando DH, Alencar AP, Benseñor IM, Lotufo PA. Income inequalities and stroke mortality trends in Sao Paulo, Brazil, 1996-2011. *Int J Stroke*. 2015;10(SA100):34–37. https://doi.org/10.1111/ijs.12526.
68 Liang Y, Liu F, Yin H, et al. Trends in unhealthy lifestyle factors in US NHANES respondents with cardiovascular disease for the period between 1999 and 2018. *Front Cardiovasc Med*. 2023;10. https://doi.org/10.3389/fcvm.2023.1169036.
69 Min Y, Anugu P, Butler KR, et al. Cardiovascular disease burden and socioeconomic correlates: findings from the jackson heart study. *J Am Heart Assoc*. 2017;6(8):e004416. https://doi.org/10.1161/JAHA.116.004416.
70 Valero-Elizondo J, Hong JC, Spatz ES, et al. Persistent socioeconomic disparities in cardiovascular risk factors and health in the United States: medical Expenditure Panel Survey 2002-2013. *Atherosclerosis*. 2018;269:301–305. https://doi.org/10.1016/j.atherosclerosis.2017.12.014.

71 Beckman AL, Herrin J, Nasir K, Desai NR, Spatz ES. Trends in cardiovascular health of US adults by income, 2005-2014. *JAMA Cardiol*. 2017;2(7):814–816. https://doi.org/10.1001/jamacardio.2017.1654.
72 Martinson ML. Income inequality in health at all ages: a comparison of the United States and england. *Am J Public Health*. 2012;102(11):2049–2056. https://doi.org/10.2105/AJPH.2012.300929.
73 Magnani JW, Ning H, Wilkins JT, Lloyd-Jones DM, Allen NB. Educational attainment and lifetime risk of cardiovascular disease. *JAMA Cardiol*. 2024;9(1):45–54. https://doi.org/10.1001/jamacardio.2023.3990.
74 Abdalla SM, Yu S, Galea S. Trends of biomarkers of cardiovascular disease in the United States by income: disparities between the richest 20% and the poorest 80%,1999–2018. *SSM Popul Health*. 2021;13:100745. https://doi.org/10.1016/j.ssmph.2021.100745.
75 Hamad R, Nguyen TT, Bhattacharya J, Glymour MM, Rehkopf DH. Educational attainment and cardiovascular disease in the United States: a quasi-experimental instrumental variables analysis. *PLoS Med*. 2019;16(6):e1002834. https://doi.org/10.1371/journal.pmed.1002834.
76 Kubota Y, Heiss G, MacLehose RF, Roetker NS, Folsom AR. Association of educational attainment with lifetime risk of cardiovascular disease: the atherosclerosis risk in communities study. *JAMA Intern Med*. 2017;177(8):1165–1172. https://doi.org/10.1001/jamainternmed.2017.1877.
77 Lewis MW, Khodneva Y, Redmond N, et al. The impact of the combination of income and education on the incidence of coronary heart disease in the prospective Reasons for Geographic and Racial Differences in Stroke (REGARDS) cohort study. *BMC Public Health*. 2015;15(1):1312. https://doi.org/10.1186/s12889-015-2630-4.
78 Khaing W, Vallibhakara SA, Attia J, McEvoy M, Thakkinstian A. Effects of education and income on cardiovascular outcomes: a systematic review and meta-analysis. *Eur J Prev Cardiol*. 2017;24(10):1032–1042. https://doi.org/10.1177/2047487317705916.
79 Zhang YB, Chen C, Pan XF, et al. Associations of healthy lifestyle and socioeconomic status with mortality and incident cardiovascular disease: two prospective cohort studies. *BMJ*. 2021;14:n604. https://doi.org/10.1136/bmj.n604. Published online April.
80 Lopez-Jimenez F, Batsis JA, Roger VL, Brekke L, Ting HH, Somers VK. Trends in 10-year predicted risk of cardiovascular disease in the United States, 1976 to 2004. *Circ Cardiovasc Qual Outcomes*. 2009;2(5):443–450. https://doi.org/10.1161/CIRCOUTCOMES.108.847202.
81 Machón M, Arriola L, Larrañaga N, et al. Validity of self-reported prevalent cases of stroke and acute myocardial infarction in the Spanish cohort of the EPIC study. *J Epidemiol Community Health*. 2013;67(1):71–75. https://doi.org/10.1136/jech-2011-200104.
82 Engstad T, Bonaa KH, Viitanen M. Validity of self-reported stroke : the tromso study. *Stroke*. 2000;31(7):1602–1607. https://doi.org/10.1161/01.str.31.7.1602.
83 Camplain R, Kucharska-Newton A, Loehr L, et al. Accuracy of self-reported heart failure. The atherosclerosis risk in communities (ARIC) study. *J Card Fail*. 2017;23(11):802–808. https://doi.org/10.1016/j.cardfail.2017.09.002.
84 Gure TR, McCammon RJ, Cigolle CT, Koelling TM, Blaum CS, Langa KM. Predictors of self-report of heart failure in a population-based survey of older adults. *Circ Cardiovasc Qual Outcomes*. 2012;5(3):396–402. https://doi.org/10.1161/CIRCOUTCOMES.111.963116.
85 Herbert BM, Johnson AE, Paasche-Orlow MK, Brooks MM, Magnani JW. Disparities in reporting a history of cardiovascular disease among adults with limited English proficiency and angina. *JAMA Netw Open*. 2021;4(12):e2138780. https://doi.org/10.1001/jamanetworkopen.2021.38780.
86 Kyalwazi AN, Loccoh EC, Brewer LC, et al. Disparities in cardiovascular mortality between Black and white adults in the United States, 1999 to 2019. *Circulation*. 2022;146(3):211–228. https://doi.org/10.1161/CIRCULATIONAHA.122.060199.
87 Min LY, Islam RB, Gandrakota N, Shah MK. The social determinants of health associated with cardiometabolic diseases among Asian American subgroups: a systematic review. *BMC Health Serv Res*. 2022;22(1):257. https://doi.org/10.1186/s12913-022-07646-7.
88 Evers-Hillstrom K. *Majority of lawmakers in 116th Congress are millionaires*. OpenSecrets News; 2020. https://www.opensecrets.org/news/2020/04/majority-of-lawmakers-millionaires/. Accessed April 23, 2024.
89 Schaeffer K. *The changing face of Congress in 8 charts*. Pew Research Center; 2023. https://www.pewresearch.org/short-reads/2023/02/07/the-changing-face-of-congress/. Accessed March 9, 2024.
90 COVID-19 leaves a legacy of rising poverty and widening inequality. World Bank Blogs. https://blogs.worldbank.org/en/developmenttalk/covid-19-leaves-legacy-rising-poverty-and-widening-inequality. Accessed July 22, 2024.
91 *Tracking the COVID-19 economy's effects on food, housing, and employment hardships | center on budget and policy priorities*; 2020. https://www.cbpp.org/research/poverty-and-inequality/tracking-the-covid-19-recessions-effects-on-food-housing-and. Accessed July 22, 2024.