ORIGINAL ARTICLE

Neighborhood Deprivation Predicts Heart Failure Risk in a Low-Income Population of Blacks and Whites in the Southeastern United States

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BACKGROUND: Recent data suggest that neighborhood socioeconomic environment predicts heart failure (HF) hospital readmissions. We investigated whether neighborhood deprivation predicts risk of incident HF beyond individual socioeconomic status in a low-income population.

METHODS AND RESULTS: Participants were 27 078 whites and blacks recruited during 2002 to 2009 in the SCCS (Southern Community Cohort Study), who had no history of HF and were using Centers for Medicare or Medicaid Services. Incident HF diagnoses through December 31, 2010, were ascertained using *International Classification of Diseases*, Ninth Revision, codes 428.x via linkage with Centers for Medicare or Medicaid Services research files. Participant residential information was geocoded and census tract determined by a spatial join to the US Census Bureau TIGER/Line Shapefiles. The neighborhood deprivation index was constructed using principal components analysis based on census tract-level socioeconomic variables. Cox models with Huber–White cluster sandwich estimator of variance were used to investigate the association between neighborhood deprivation index and HF risk. The study sample was predominantly middle aged (mean, 55.5 years), black (69%), female (63%), low income (70% earned <$15 000/y), and >50% of participants lived in the most deprived neighborhoods (third neighborhood deprivation index tertile). Over median follow-up of 5.2 years, 4300 participants were diagnosed with HF. After adjustment for demographic, lifestyle, and clinical factors, a 1 interquartile increase in neighborhood deprivation index was associated with a 12% increase in risk of HF (hazard ratio, 1.12; 95% confidence interval, 1.07–1.18), and 4.8% of the variance in HF risk (intraclass correlation coefficient, 4.8; 95% confidence interval, 3.6–6.4) was explained by neighborhood deprivation.

CONCLUSIONS: In this low-income population, scant neighborhood resources compound the risk of HF above and beyond individual socioeconomic status and traditional cardiovascular risk factors. Improvements in community resources may be a significant axis for curbing the burden of HF.

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WHAT IS KNOWN

- Prior evidence suggests a strong independent association between individual socioeconomic characteristics, such as income, education and occupation, and heart failure risk.
- Recent data suggest that neighborhood socioeconomic factors also play a significant role in predicting heart failure outcomes including heart failure admissions and readmissions.

WHAT THE STUDY ADDS

- Neighborhood socioeconomic factors significantly predict heart failure incidence independent of individual income, level of education, and traditional cardiovascular risk factors.
- These findings support the position of several cardiovascular societies suggesting that upstream interventions encompassing preventive measures and public policy, namely improvements in community-level resources particularly in areas with acute neighborhood deprivation, may have a wide-reaching population-level effect on the mitigation of adverse cardiovascular outcomes including heart failure.

Heart failure (HF) is a major public health problem, particularly in the southeastern United States which has been described as the heart failure belt.[1,2] This region has the highest prevalence of established HF risk factors (including coronary heart disease, high blood pressure, diabetes mellitus, and obesity) which themselves may be associated with socioeconomic characteristics that influence health outcomes. Although evidence from middle-class populations suggests that individual socioeconomic status (SES) contributes to HF risk,[3–6] recent data support that neighborhood factors may also predict HF readmissions independent of individual SES.[7] However, it is not known whether such neighborhood factors are independent predictors of other HF outcomes such as HF incidence among persons with already low individual SES.

The SCCS (Southern Community Cohort Study) is a prospective cohort study that recruited persons of low SES from 12 states in the southeastern United States. Within this cohort, we tested the hypothesis that neighborhood characteristics (defined by a composite deprivation index) predict the risk of incident HF beyond individual SES (defined by annual household income and highest level of education attained).

METHODS

Design and Study Population

The SCCS is an ongoing prospective investigation of the incidence of cancer and other chronic conditions, including differential patterns by race and sex, in a resource-limited underinsured population.[8] A total of 84 797 participants aged 40 to 79 were enrolled into the SCCS from 2002 to 2009.[9] Approximately 86% of participants were recruited at community health centers, which provide primary health and preventive care services for underserved populations, such that the cohort is made up of a segment of society underrepresented in previous cohort studies, particularly those investigating cardiovascular disease (CVD).[8,10] The remaining 14% were enrolled via mail-based sampling of the general population. Demographic, socioeconomic, lifestyle, and anthropometric data, as well as personal medical history, were ascertained at cohort enrollment via standardized computer-assisted personal interviews for community health centers participants, and via self-administered mailed questionnaire for participants recruited from the general population. Detailed description of SCCS methods has been previously published.[8,10,11] According to SCCS Guidelines for Data and Biospecimen Use (policy manual available online at www.southerncommunitystudy.org), the data that support the findings of this study are available from the corresponding author on reasonable request by qualified researchers trained in human subject confidentiality protocols and on approval by the SCCS Data and Biospecimen Use Committee.

For the current analyses, we included 27 078 participants who were either ≥65 years old at cohort enrollment (n=7001) or <65 years at enrollment (n=20 077) and (1) reported being covered by Medicaid (which provides medical benefits to low-income adults and uninsured persons) or Medicare (the primary health insurance program for persons aged ≥65 and those with disabilities under age 65) on the baseline questionnaire; or (2) did not report Medicare or Medicaid on the baseline questionnaire but had a Centers for Medicare and Medicaid Services (CMS) claim within 90 days of being enrolled in SCCS.[2] The restriction to these groups increases the likelihood of participants having continuous coverage in Medicare or Medicaid from the time of SCCS enrollment to the end of the follow-up period (December 31, 2010), for the ascertainment of incident HF events. Analyses were restricted to self-reported African American or black and non-Hispanic white SCCS participants because too few persons in other racial groups were available for stable statistical analyses.

Census Tracts

Census tracts were used as proxies for neighborhoods in this study. Census tracts are small, relatively permanent statistical subdivisions of a county or equivalent entity that are updated by local participants before each decennial census as part of the US Census Bureau Participant Statistical Areas Program.[12] Prior literature suggests that census tracts were originally designed to be relatively homogenous in socioeconomic characteristics,[13] and if neighborhoods are considered to be spatially defined collections of people, infrastructures, and institutions influenced by common economic and environmental forces,[14] then census tracts could be regarded as a relevant proxy. More so, in addition to the relative socioeconomic homogeneity that may exist between persons living in a census tract, the latter may be able to capture disparities in social and physical attributes, between small geographic units, that are relevant to health outcomes.[13] Census tracts have also been widely used as the default proxy in prior studies investigating the association between neighborhood socioeconomic environment and cardiovascular outcomes.[7,15]

At the time of the SCCS baseline interview, study participants provided information on their residential address which was then geocoded by a multistage process incorporating both batch and interactive processes.[16] The census tract for the geocoded address was then determined by a spatial join to the US Census Bureau Topologically Integrated Geographic Encoding and Referencing (TIGER/Line) Shapefiles[17] using ESRI ArcMap 10.0 software (ESRI, Redlands, CA) that uses geographic information systems technology. Non-Post Office box addresses failing to geocode in ArcMap and Post Office box addresses (2.8% of all addresses) were submitted to the online-based EZ-Locate Client version 2.47 available from Tele Atlas at www.geocode.com using their USA_Geo_002 base map (Tele Atlas, 2006).[16] Overall, 99.96% of participants' addresses were geocoded. Details of the geocoding procedure for SCCS participants have been published elsewhere.[16] The 27 078 SCCS participants included in the current analyses resided in 4666 census tracts. Geocoding of SCCS participants' addresses and linkage to geographic information data sets such as census tract data allowed development of residence-specific metrics including the SCCS-derived deprivation index.

Neighborhood Deprivation Index

The SCCS-derived deprivation index is a clustering of social and economic indicators which reflect neighborhood deprivation and have been linked to adverse health outcomes. It was constructed using principal components analysis based on 11 census tract-level variables (from Census 2000) representing 4 main dimensions[18,19]: (1) social indicators: percentage of housing units with ≥1 occupant per room, percentage of occupied housing units with renter/owner costs >50% of income, and percent female-headed households with dependent children; (2) wealth and income: percentage of households with income <$30 000 per year, percentage of persons with income below the 1999 poverty status, percentage of households with public assistance income, percentage of households with no car, and median value of owner-occupied housing units; (3) education: percentage of persons aged ≥25 who did not graduate high school; and (4) occupation: percentage of males and females who are unemployed and percentage males in professional occupations.

In the original description of the neighborhood deprivation index (NDI) by Messer et al,[18] the first principal component was retained, as it explained over 67% of the variance with component loadings ranging between 0.2 and 0.4, suggesting similar contribution of each of the component variables to the first principal component. In the SCCS, the first principal component explained most of the variability (over 60%) in the component measures as well, as such it was retained for the construction of the NDI in the SCCS.[19]

Individual Socioeconomic Variables and Other Covariates

SCCS participants reported their highest level of education attained and the range of their total household income for the year before enrollment. History of tobacco smoking, alcohol use, and total amount of moderate and vigorous exercise was equally self-reported. The presence of traditional cardiovascular risk factors at baseline was based on a self-reported history of physician-diagnosed hypertension, diabetes mellitus, high cholesterol, myocardial infarction and stroke, as well as self-reported use of medications for these conditions. Many of the questions on the SCCS questionnaire were adapted from questionnaires used and validated in other settings; a series of independent validation studies using biomarkers, repeat interviews, or medical records have demonstrated the reliability of the questionnaire within the SCCS population for variables such as smoking status, self-reported diseases including diabetes mellitus, height, and weight.[8]

Outcome Ascertainment

HF events were ascertained via linkage of the SCCS cohort with CMS Research Identifiable Files.[2] Incident HF was defined as the first occurrence of a medical claim with an *International Classification of Diseases*, Ninth Revision, discharge code of 428.x within the Medicare institutional (Medicare Provider Analysis and Review which includes inpatient, outpatient, and skilled nursing facility base files), Part B carrier (includes noninstitutional physician services and durable medical equipment), or outpatient-based claims files or the Medicaid Analytic Extract Inpatient and Other Services claims files, from the date of SCCS enrollment through December 31, 2010. Detailed description of the CMS research files is published elsewhere.[20] Death (including date of death) was ascertained via linkage of the cohort with the Social Security Administration vital status service for epidemiological researchers and the National Death Index through December 31, 2010, and death was used as a censoring variable during data analysis.

Statistical Analysis

Among the 27 078 participants, 260 (0.96%) had missing values for NDI and were therefore excluded from these analyses. Descriptive statistics were computed for all study participants overall and by tertiles of deprivation index. Tertile cut points were based on the distribution of NDI at the census tract level (not individuals) for the census tracts (n=4666) covered by the population (n=26 818) included in the final analysis. Tertile 1 represents the least deprived census tracts (ie, the neighborhoods with the highest socioeconomic level), whereas tertile 3 represents the most deprived. The inequality in the number of individuals per tertile of NDI is explained in part by the wide variation in the number of persons per census tract (mean=6; range: 1–243) and that census tracts with higher deprivation tended to have more individuals per census tract, that is, more persons lived in the most socioeconomically disadvantaged neighborhoods.

Modeling Hierarchical Data

For the current analyses, the data were organized in a hierarchical fashion with individual participants (level 1 units) nested within census tracts (level 2 units). Given the nested structure of the data, the nonindependence of the data points within each census tract, and the limitations of a multilevel modeling approach in this setting (unbalanced data with many small clusters), we used a Cox proportional hazards model that accounts for nonindependence using the Huber–White cluster sandwich estimator of variance.[21] The intraclass correlation coefficient was computed using the latent variable approach.[22] Elaborate formulae for the intraclass correlation coefficient and the cluster sandwich estimator are provided in the Data Supplement.

Deprivation Index and HF Incidence

To investigate HF incidence, duration of follow-up was computed from date of enrollment into the SCCS until the date of the first diagnosis of HF, date of death, or December 31, 2010, whichever occurred first. Age-standardized incidence rates of HF for each NDI tertile were computed using the overall age distribution of the study sample as reference.

Multivariable-adjusted Cox analyses were used to model a flexible association between NDI (modeled using restricted cubic splines with 4 knots) and HF accounting for nonlinearity and nonadditivity of effects by race. The log relative hazard of incident HF was computed from the fully adjusted model for observed values of deprivation index while holding the values of covariates at their referent values and plotted (on the *y* axis) against NDI (on the *x* axis) by race. For each categorical and dichotomous covariate, the referent value used in the computation of log relative hazard (Xβ) was the modal category, whereas for each continuous covariate, the referent value was the median. The covariates included in the full model were age at enrollment (restricted cubic splines with 4 knots), race (white/black), NDI×race interaction terms (linear and nonlinear), sex, cigarette smoking (never, former, current <19.5 pack-years, current ≥19.5 pack-years, 19.5 being the median pack-years among current smokers), alcohol intake (linear), total metabolic equivalent-hours of moderate or greater exercise (linear and quadratic term), body mass index (restricted cubic splines with 4 knots), history of diabetes mellitus, hypertension, high cholesterol, myocardial infarction/coronary artery bypass graft or stroke (all yes/no), as well as annual household income (<$15 000; $15 000–$24 999; ≥$25 000), and education (<high school, high school/vocational training/junior college, ≥college degree) to investigate the potential mediating effects of individual SES. The criteria for selecting relevant covariates and choosing their functional form are provided in the Data Supplement.

In further analyses, multivariable Cox models assuming linearity of effects (with NDI modeled as a rescaled continuous variable using the interquartile range [IQR]) were used to estimate the effect of a 1 IQR increase in deprivation index on HF incidence while adjusting for the aforementioned covariates in a sequential fashion (models 1–3). Hazard ratios (HRs) for a 1 IQR increase in NDI compare the hazard of the event occurring for a typical person in the middle of the upper half (the 75th percentile) of the distribution of NDI to the hazard of the event for a typical person in the middle of the lower half (25th percentile) of the distribution. Knots were placed at quantiles of covariate distributions, equally spaced in sample size.[21]

We conducted a sensitivity analysis excluding HF cases diagnosed within 2 years of follow-up to limit the possibility that HF cases occurring soon after enrollment may not have been influenced by baseline values of NDI.

Model assumptions were verified using Schoenfeld residuals and log (−log) plots.

All analyses were performed using STATA (version 12.1; Stata Corp, College Station, TX) and the rms package for R version 3.1.1 (R Core Team 2014).[21,23]

Ethical Approval

Participants enrolled in SCCS provided written informed consent, and protocols were approved by the Institutional Review Boards of Vanderbilt University Medical Center and Meharry Medical College.

RESULTS

Characteristics of the Study Population

Baseline characteristics of the 26 818 included participants are shown in Table 1, overall and by tertiles of NDI. The mean (SD) age of participants at cohort enrollment was 55.5 (10.4) years, 62.7% were women, 69.0% were black, 69.9% had annual household income <$15 000, 38.6% had less than a high school education, and 44.8% were obese (body mass index≥30 kg/m^2). The mean (SD) NDI was 0.85 (1.21) with a range of −2.4 to 6.0 (increasing values of deprivation index represent increasing levels of neighborhood deprivation or decreasing levels of neighborhood SES). There was a modest negative correlation between NDI and annual household income (Spearman rank correlation coefficient, ρ=−0.23) and education (ρ=−0.17). Compared with persons living in the least socioeconomically deprived neighborhoods (tertile 1), participants living in the most deprived neighborhoods (tertile 3) were more likely to be younger, black, and obese, have less than a high school education, earn <$15 000 a year, and be current smokers. They were also more likely to report a history of diabetes mellitus and hypertension at baseline.

Deprivation Index and HF Incidence

Over a median (25th, 75th percentile) follow-up time of 5.2 (3.2, 6.8) years, 4300 participants (16%) developed incident HF. SCCS participants in the third NDI tertile had the highest age-standardized HF incidence rate, 37.9 per 1000 person-years, compared with 28.4 per 1000 person-years and 33.9 per 1000 person-years for persons in tertiles 1 and 2, respectively.

The figure shows a graph of the log relative hazard (Xβ) of HF plotted against NDI. Among whites, the log relative hazard of HF rises sharply with increasing NDI, then levels off after an NDI of ≈0.5. Among blacks on the other hand, the curve has a more gradual slope and it plateaus at higher values of deprivation index (≈2.0).

Table 2 shows the risk of incident HF associated with NDI adjusted for relevant covariates in a sequential fashion (models 1–3). Overall, after adjustment for age, sex, and race, a 1 IQR increase in NDI was associated with

Table 1. Baseline Characteristics of SCCS Participants Receiving Medicare or Medicaid During Follow-Up Between 2002 and 2010, Overall and by Tertile* of Deprivation Index

	Deprivation Index			
	Overall	Tertile 1	Tertile 2	Tertile 3
Deprivation index (range)	0.85 (−2.4 to 6.0)	−0.76 (−2.4 to −0.3)	0.03 (−0.3 to 0.4)	1.61 (0.4 to 6.0)
Census tracts, n	4666	1556	1555	1555
Participants, n	26818	4256	6478	16084
Age, y (SD)	55.5 (10.4)	58.1 (10.7)	56.8 (10.4)	54.2 (10.1)
Women, %	62.7	60.0	64.6	62.6
Blacks, %	69.0	37.3	49.8	85.2
Education, %				
<High school	38.6	25.5	36.4	42.9
HS/Junior college/VT	53.1	57.0	55.0	51.3
≥College degree	8.3	17.5	8.6	5.8
Annual income, %				
<$15 000	69.9	53.3	65.0	76.2
$15 000–$24 999	17.9	18.2	20.6	16.8
≥$25 000	12.2	28.5	14.4	7.0
Smoking, %				
Never	34.7	34.6	36.6	33.9
Former	25.2	32.7	28.4	22.0
Current	40.1	32.7	35.0	44.2
Alcohol intake, %				
0 drink per day	55.0	53.6	62.1	52.5
>0–2 drinks per day	33.1	36.8	29.8	33.5
>2 drinks per day	11.9	9.6	8.1	14.0
Physical exercise†, MET-h/d, (SD)	0.87 (2.3)	1.13 (2.6)	0.77 (2.1)	0.85 (2.3)
BMI, kg/m² (SD)	30.4 (7.8)	29.9 (7.4)	30.7 (7.7)	30.4 (7.9)
BMI categories, %				
Underweight, BMI <18.5	1.7	1.4	1.6	1.8
Lean, BMI 18.5–<25.0	24.0	24.6	21.3	24.9
Overweight, BMI 25–<30.0	29.5	32.5	30.4	28.4
Obese, BMI ≥30.0	44.8	41.5	46.7	45.0
Diabetes mellitus, %	26.5	24.5	28.1	26.4
Hypertension, %	62.5	58.4	63.4	63.3
High cholesterol, %	39.5	45.3	44.3	35.9
History of MI, %	8.6	10.0	10.1	7.6
History of stroke, %	9.6	9.4	9.9	9.5

Other than for stroke (P=0.66), all comparisons between tertiles of neighborhood deprivation index (NDI) were significant (P<0.0001). BMI indicates body mass index; HS, high school; MI, myocardial infarction; SCCS, Southern Community Cohort Study; and VT, vocational training.

*Tertile cut points were based on the distribution of NDI at the census tract level (not individuals). The third tertile is the most deprived, whereas tertile 1 is the least deprived. The inequality in the number of individuals per tertile of NDI is explained in part by the significant variation in the number of persons per census tract and the fact that census tracts with higher deprivation had more individuals per census tract.

†Physical exercise=total moderate and vigorous exercise.

a 14% increase in the risk of HF (HR, 1.14; 95% confidence interval [CI], 1.09–1.19). Subsequent adjustment for lifestyle and clinical factors was associated with a minimal change in the point estimate (HR, 1.15; 95% CI, 1.09–1.20). In the full model, further adjustment for income and education showed only a modest attenuation of the strength of the association; namely, a 1 IQR increase in NDI was associated with a 12% increase in the risk of HF (HR, 1.12; 95% CI, 1.07–1.18). The intraclass correlation coefficient was 4.8% (95% CI,

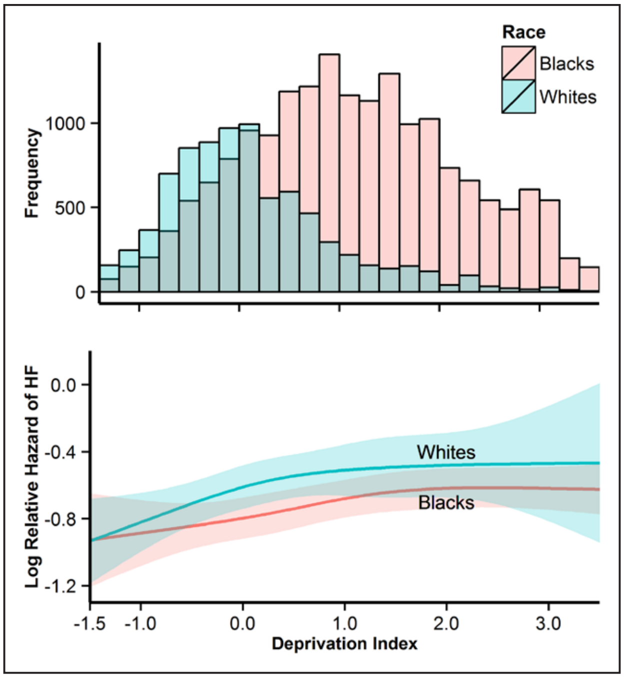

Figure. Plot of log relative hazard (Xβ) of incident heart failure (HF) versus deprivation index by race.
The *y* axis shows the log relative hazard of incident HF computed from the fully adjusted model for observed values of deprivation index while holding the values of covariates at their referent values. The curves display the trend in HF risk with increasing levels of neighborhood deprivation (on the *x* axis) while simultaneously holding the covariate values constant. For both blacks and whites, HF risk increases with increasing deprivation index, but the curve for whites seems steeper before both eventually plateau. The overlaid histogram shows the distribution of deprivation index.

3.6–6.4), suggesting that 4.8% of the variance in HF risk was explained by neighborhood deprivation.

In the race-stratified analysis, the findings from the most parsimonious model (model 1) were suggestive of a significant heterogeneity of effects by race (HR, 1.34; 95% CI, 1.21–1.47 among whites, and HR, 1.09; 95% CI, 1.04–1.15 among blacks, *P* for interaction=0.0005). In the full models, the point estimates were less disparate between both racial groups: there was a 20% increase in risk (HR, 1.20; 95% CI, 1.07–1.34) of HF per 1 IQR increase in NDI among whites and a 10% increase among blacks (HR, 1.10; 95% CI, 1.04–1.17).

In sensitivity analyses excluding HF cases diagnosed within 2 years of follow-up (1752 cases excluded, leaving 2548 cases for the analysis), the effect estimates were similar, with an HR of 1.13 (95% CI, 1.06–1.20) for the overall cohort (n=25 066) in fully adjusted models.

Table 2. Hazard Ratios and 95% Confidence Intervals for Incident Heart Failure per 1 Interquartile Range Increase in Deprivation Index, Overall and by Race

	Overall (n=26 818)	Whites (n=8303)	Blacks (n=18 515)
Model 1	1.14 (1.09–1.19)	1.34 (1.21–1.47)	1.09 (1.04–1.15)
Model 2	1.15 (1.09–1.20)	1.27 (1.14–1.41)	1.12 (1.06–1.18)
Model 3	1.12 (1.07–1.18)	1.20 (1.07–1.34)	1.10 (1.04–1.17)

Model 1: includes deprivation index, age (restricted cubic splines with 4 knots), race, and sex. Model 2: model 1+smoking (never, former, current <19.5 pack-years, current ≥19.5 pack-years), alcohol intake (linear) and total physical activity in MET-h (linear+quadratic)+body mass index (restricted cubic splines with 4 knots), diabetes mellitus, hypertension, high cholesterol, history of myocardial infarction, and history of stroke (all yes/no). Model 3: model 2+annual household income (<$15 000, $15 000–$24 999, ≥$25 000) and education (<high school, high school/vocational training/junior college, ≥college). *P* value for deprivation index×race interaction=0.0005 (model 1). Intraclass correlation coefficient=4.8% (95% confidence interval, 3.6–6.4).

DISCUSSION

We investigated the association between NDI and HF incidence in a large population of low-income blacks and whites from the southeastern United States. Our main findings were (1) persons living in the most socioeconomically deprived neighborhoods seem to have a greater burden of CVD risk factors and (2) higher levels of neighborhood socioeconomic deprivation are significantly associated with an increase in HF risk independent of individual SES and traditional CVD risk factors.

The existing literature provides evidence of a strong independent association between individual socioeconomic characteristics, such as income, education and occupation, and HF risk.[3–6] In addition, recent data suggest that neighborhood SES also plays a significant role in predicting HF outcomes including HF admissions and readmissions,[7,24] but evidence for the association with HF incidence has been scant. The current investigation demonstrates an independent association between increasing neighborhood deprivation and increased risk of HF with a non-negligible proportion of the variance (≈5%) of HF incidence in this population explained by neighborhood socioeconomic factors. Furthermore, the dose–response curve indicates increasing HF risk with increasing levels of neighborhood deprivation in both blacks and whites before the curve plateaus. Neighborhood factors have been shown to predict the incidence of coronary heart disease[15,22] and we now extend this to HF. Further, given that our study was conducted within a population with relatively low individual SES, underrepresented in previous studies, it is particularly noteworthy to find that concurrent neighborhood socioeconomic deprivation further compounds the risk of HF in this population.

The NDI used for this study was a composite obtained from 11 neighborhood-level (census tract) variables representing 4 dimensions (wealth and income, education, occupation, and social indicators). As an aggregate measure, it represents a construct—neighborhood socioeconomic deprivation—which goes above and beyond its specific components and could be construed as a summary indicator of the area-level socioeconomic context and other correlates.[13] In addition, prior literature suggests that the underlying causal effects being investigated when using neighborhood deprivation indices as proxies are not only the literal effects of neighborhood socioeconomic deprivation but also the effect of the social and physical attributes which neighborhood socioeconomic context is reflective of in part.[13] However, the specific mechanistic pathways or causal intermediaries underpinning the independent link (above and beyond individual-level SES) between the neighborhood socioeconomic environment and HF risk remain currently uncertain. We advance a few plausible hypotheses (based on previous studies investigating the role of neighborhood socioeconomic environment on other health outcomes including coronary artery disease, HF readmissions, and mortality[7,15,25]) that need to be investigated further in future studies. Previous data suggest that the availability of community-level resources including but not limited to exercise facilities, healthy food outlets, and institutional resources (including healthcare facilities) vary considerably across neighborhoods.[13,26,27] In the geographic area inhabited by the participants in the current investigation, if food deserts are more preponderant in the most deprived neighborhoods, that could reduce access to healthier food choices and potentially increase the consumption of high-calorie foods and foods with high sodium content. Also, the combination of fewer physical activity resources, unaffordable gym memberships, and higher crime rate may predispose persons living in these communities to reduced physical activity and sedentariness. The combined influence of poor nutritional habits and physical inactivity could explain the higher rates of obesity that have been observed in poverty-dense counties in the United States.[28,29] The high rates of obesity are paralleled by high prevalence of obesity-related comorbid conditions including diabetes mellitus and high blood pressure (possibly abetted in part by the consumption of foods with high salt content) which further compound the risk of HF in these communities.

In the current cohort, compared with the neighborhoods with the highest socioeconomic position, the more deprived neighborhoods each had higher prevalence of obesity, hypertension, and diabetes mellitus at baseline and this may have contributed to the observed trend of increasing HF risk with worsening deprivation. Nevertheless, after adjustment for all these factors, a strong independent association between neighborhood deprivation and HF risk persisted, which could not be explained by mediation via CVD risk factors or individual SES. This suggests that some of the correlates of neighborhood socioeconomic deprivation may be less tangible and harder to measure. Some authors have hypothesized that persons living in deprived neighborhoods may be at higher risk of unfavorable societal stressors like noise, air pollution, and violence which may culminate in chronic psychological stress and predispose individuals to adverse health outcomes including HF.[15,30] Marked institutional deficiencies in resource-limited settings are usually mirrored by reduced access to quality education, occupational opportunities, and health facilities. These could expose individuals in these communities to reduced scholarship, income, and logistics and hence curtail individual ability to seek preventative care, self-management, and adherence to recommended treatment guidelines (evidence-based lifestyle strategies and multifactorial medical management approaches) for conditions such as diabetes mellitus and hypertension—predisposing them to elevated risk of HF.

The current study has a few noteworthy limitations. Persons <65 who do not use Medicaid were not included in this study, and given that these persons may have higher individual-level SES than the participants included in this study, the findings of this study may not be generalizable to young or middle-aged adults with higher individual-level SES. However, neighborhood socioeconomic environment has been shown to be associated with other cardiovascular outcomes (including coronary heart disease and HF readmissions)[7,15] in cohorts recruiting mostly middle-class participants (with higher utilization of private health insurance) like the ARIC study (Atherosclerosis Risk in Communities) or the Telemonitoring to Improve Heart Failure Outcomes trial. Hence, it is plausible that the association with incident HF could have equally been observed among persons not using CMS services. Some authors consider a neighborhood to be a spatially defined collection of people, infrastructures, and institutions influenced by common environmental, sociocultural, and economic forces.[31] The extent to which a census tract is a rational proxy for neighborhood remains uncertain. However, census tracts are a well-defined statistical and geographic entity which cover a contiguous area with long-term boundaries and harbor a population with relatively homogenous socioeconomic characteristics.[13] Thus, using them as proxies for neighborhoods seems reasonable for the purpose of investigating the health outcomes of a population with shared socioeconomic environment. More so, they have been extensively used in prior studies investigating the association between neighborhood socioeconomic context and health outcomes.[7,15,25] The fact that we relied essentially on baseline neighborhood data and were unable to include early-life neighborhood information or consider any potential change of address of study participants during the study is another potential limitation. However, we assumed that any potential movements of participants may be to similarly deprived neighborhoods given that most participants were of low individual-level SES. Most of our covariate data (past history of myocardial infarction, stroke, hypertension, diabetes mellitus, and high cholesterol) were based on self-report of a physician diagnosis and use of medications. Although self-report could be susceptible to recall and misclassification bias, these methods have been validated in the Southern Community Cohort Study (SCCS) and other epidemiological studies.[8] Several of the questions on the SCCS questionnaire were adapted from questionnaires that were validated in other settings; a series of independent validation studies using biomarkers, repeat interviews, or medical records have demonstrated the reliability of the questionnaire within the SCCS population for variables such as smoking status and self-reported diseases including diabetes mellitus.[8] HF was ascertained by linking our baseline SCCS data with CMS Research Identifiable Files using *International Classification of Diseases*, Ninth Revision, codes 428.x, rather than independent physician adjudication. Nonetheless, the diagnosis codes algorithm for identification of HF used in this study has been previously validated and used in other cohorts.[32–34] A review of the detection of HF in administrative claims data that included studies conducted among Medicare beneficiaries reported positive predictive values mostly over 90%.[32]

Our study leverages data from a large biracial cohort with a sizable number of low-income participants living in resource-limited settings and who are traditionally underrepresented in previous cohorts investigating HF outcomes. Thus, it provided the unique opportunity to investigate the role of neighborhood factors on HF risk in a sample of people already having scant individual resources. The ability to perform geocoding of participant residential information and linkage to geographic information data sets such as census tract data allowed development of residence-specific metrics including the SCCS-derived deprivation index which we were able to use as a proxy for neighborhood SES. The large number of level 2 units (census tracts) covered by the study participants allowed for stable statistical analyses and provided some credence to the representativeness of the whole SCCS cohort by the subsample used for the current analysis.

In conclusion, we found that neighborhood socioeconomic factors significantly predict HF incidence independent of individual income and education level and traditional CVD risk factors. The American Heart Association and other cardiovascular societies recognize that improvements in cardiovascular health require strategies that target the entire spectrum of the healthcare system including public policy, prevention, acute care, chronic care, and rehabilitation. However, the more upstream measures which focus on public policy and prevention may have the greatest potential to mitigate the burden of CVD and improve human health. Areas with the most acute socioeconomic deprivation are most likely at the highest risk for CVD (including HF) and CVD mortality and hence may benefit most from such improvements in public health policies including, but not limited to, improvements in community-level resources.

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DISCLOSURES

None.

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FOOTNOTES

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Neighborhood Deprivation Predicts Heart Failure Risk in a Low-Income Population of Blacks and Whites in the Southeastern United States

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Supplemental Material

Supplementary Appendix 1. Huber-White Cluster Sandwich Estimator of Variance in Cox Models.

We utilized a Cox proportional hazards model that accounts for non-independence using the Huber-White cluster sandwich estimator of variance, H_c [1] whose general formula for linear and nonlinear models is given below:

$$H_c = I^{-1}(b)[\sum_{i=1}^{c}\{(\sum_{j=1}^{n_i} U_{ij})(\sum_{j=1}^{n_i} U_{ij})'\}]I^{-1}(b),$$

where *I* is the information matrix (the second derivative of the log likelihood, log *L*) [1] and *U* is the score statistic – the first derivative of log *L*. In the specific case of the Cox model, the cluster sandwich estimator, H_c uses special score residuals for *U* (the score vector) given there are no per-observation score contributions. [1, 2]

Supplementary Appendix 2. Estimating the intra-class correlation coefficient using the latent variable approach

The latent variable approach uses the closed-form solution of the intra-class correlation coefficient (ICC) in the multi-level logistic model to make an approximate estimation of the ICC in the multi-level Cox proportional hazards model.

$$ICC = \frac{\tau_{00}}{\tau_{00} + \pi^2/3},$$ where τ_{00} = group-level variance.[3]

Supplementary Appendix 3: Covariate selection and spending degrees of freedom

The selection of variables to be included in the multivariable models was based on the hypothesized relationships between the baseline covariates in question, deprivation index and the outcomes of interest (HF incidence and post-HF death). The functional form of the covariates (i.e. degrees of freedom spent) and deprivation index was based on a priori knowledge and the rank correlations between the covariate and the outcomes.

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