Original Article

Association Between Living in Food Deserts and Cardiovascular Risk

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Background—Food deserts (FD), neighborhoods defined as low-income areas with low access to healthy food, are a public health concern. We evaluated the impact of living in FD on cardiovascular risk factors and subclinical cardiovascular disease (CVD) with the hypothesis that people living in FD will have an unfavorable CVD risk profile. We further assessed whether the impact of FD on these measures is driven by area income, individual household income, or area access to healthy food.

Methods and Results—We studied 1421 subjects residing in the Atlanta metropolitan area who participated in the META-Health study (Morehouse and Emory Team up to Eliminate Health Disparities; n=712) and the Predictive Health study (n=709). Participants' zip codes were entered into the United States Food Access Research Atlas for FD status. Demographic data, metabolic profiles, hs-CRP (high-sensitivity C-reactive protein) levels, oxidative stress markers (glutathione and cystine), and arterial stiffness were evaluated. Mean age was 49.4 years, 38.5% male and 36.6% black. Compared with those not living in FD, subjects living in FD (n=187, 13.2%) had a higher prevalence of hypertension and smoking, higher body mass index, fasting glucose, and 10-year risk for CVD. They also had higher hs-CRP (P=0.014), higher central augmentation index (P=0.015), and lower glutathione level (P=0.003), indicative of increased oxidative stress. Area income and individual income, rather than food access, were associated with CVD risk measures. In a multivariate analysis that included food access, area income and individual income, both low-income area and low individual household income, were independent predictors of a higher 10-year risk for CVD. Only low individual income was an independent predictor of higher hs-CRP and augmentation index.

Conclusions—Although living in FD is associated with a higher burden of cardiovascular risk factors and preclinical indices of CVD, these associations are mainly driven by area income and individual income rather than access to healthy food. (***Circ Cardiovasc Qual Outcomes*. 2017;10:e003532. DOI: 10.1161/CIRCOUTCOMES.116.003532.**)

Key Words: coronary disease ■ epidemiology ■ hypertension ■ prevalence ■ risk factors

Neighborhood environmental characteristics and socioeconomic status (SES) have been linked to health outcomes, especially cardiovascular disease (CVD).[1,2] These unfavorable environmental attributes also seem to impact lifestyle behaviors including physical activity and smoking.[2–4] It has long been suspected that the adverse effects of these environments are driven by low access to healthy food for neighborhood residents.[5,6] The Coronary Artery Risk Development in Young Adults study reported that an increased prevalence of convenience stores was associated with lower dietary quality, specifically in low-income subjects.[7] However, whether other aspects of the socioeconomic neighborhood environment also contribute to geographical differences in CVD health status, and the role played by individual SES, remain a subject of controversy.[1,2]

See Editorial by Ferdinand and Mahata

A food desert (FD) is defined by the US department of agriculture (USDA) as a location with both low access to healthy food and low income.[8] An estimated 23.5 million people live in FD across the United States,[8,9] and the White House Task Force on Childhood Obesity recognized FD as a major contributor to a poor dietary pattern and obesity.[10] Governmental programs and policies are currently focused on clearing FD areas by funding healthy food options and access.[11] However, the direct linkage between FD and health outcomes remains understudied.

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WHAT IS KNOWN

- Neighborhood characteristics and socioeconomic status have been linked to unfavorable cardiovascular risk profile and health outcomes.
- Previous literature suggested that adverse effects of the environment may be because of low access to healthy food.

WHAT THE STUDY ADDS

- The study demonstrates an association between living in food deserts and inflammation, oxidative stress, and arterial stiffness.
- We demonstrate that the higher prevalence of cardiovascular risk factor burden, oxidative stress, inflammation, and subclinical vascular disease is driven by individual income rather than food access.

The relationship between SES and cardiovascular risk can be studied in the general population by investigating risk factor prevalence and presence of subclinical vascular disease.[12] Vascular dysfunction often precedes CVD,[13] and previous studies have reported a higher pulse wave velocity (a measure of arterial stiffness) and intima–media thickness in black subjects with lower SES, even in adolescence.[14] Chronic inflammation, estimated by circulating hs-CRP (high-sensitivity C-reactive protein) levels, is an established risk factor for diabetes mellitus, hypertension, and CVD and is inversely related to SES.[15–17] Oxidative stress (OS) is an important initiating factor in the pathogenesis of subclinical and clinical CVD, but its relationship to neighborhood and environmental factors remains unknown.[18,19]

Few studies have examined the relationship between specific characteristics of disadvantaged neighborhoods, such as living in a FD and a comprehensive set of CVD risk factors and subclinical measures of vascular disease.[20] CVD and its risk factors are more prevalent in southeastern United States,[21,22] and there is a shift in concentration of cardiovascular mortality from the northeast to deep south.[23] Although the reasons are likely to be multifactorial, differences in racial distribution and social determinants seem to play a role. Whether neighborhood access to healthy foods is driving these disparities above and beyond income levels at the personal or neighborhood level remains poorly studied. Herein, we examined the association between living in areas of either low income or low access to healthy food, or both (FD) and the burden of cardiovascular risk factors, inflammation, OS, and subclinical vascular disease. Our hypothesis was that living in a FD would be associated with an unfavorable cardiovascular risk profile and subclinical vascular disease, independent of overall area SES and individual SES.

Methods

Study Sample

We performed a cross-sectional analysis of data from subjects aged 20 to 79 years and residing in the Atlanta metropolitan area who were recruited into the META-Health study (Morehouse and Emory Team up to Eliminate Health Disparities; n=712) or the Predictive Health (PH) study (n=709).[24,25] The META-Health (MH) study recruited 753 community participants of whom 721 were eligible and enrolled. Only 712 subjects had valid addresses for determining area characteristics. The Predictive Health study (http://predictivehealth.emory.edu) recruited a cohort of university employees from Emory University and the Georgia Institute of Technology.[24,25] Seven hundred eleven subjects were enrolled in the study, and only 709 had valid addresses for neighborhood analysis. There was no significant difference between those who were included and those who were excluded from our analysis. Those with poorly controlled medical conditions, acute illness, recent hospitalization, or pregnant women were excluded. Detailed information on demographics and anthropometrics was collected. Hypertension, hypercholesterolemia, and diabetes mellitus were defined according to the Joint National Committee, Adult Treatment Panel III, and American Diabetes Association criteria, respectively.[26–28] The Atherosclerotic Cardiovascular Disease in Adults (ASCVD) scores were calculated to estimate the 10-year risk for coronary death or myocardial infarction.[29] Subjects signed an informed consent that was approved by the Emory and Georgia Tech institutional review board. Please see the Data Supplement for details.

Each participants' zip code was entered into the USDA Food Desert Research Atlas that determined their FD status.[8] A FD refers to a geographic location with both low income and low access to healthy foods. Low-income areas are defined according to criteria developed by the Department of Treasury's New Markets Tax Credit program as any area where poverty rate is ≥20% or where the median family income is ≤80% of the state-wide median family income. Areas with low access to healthy foods are defined as areas where a significant share of people live ≥1 mile away in urban areas or ≥10 miles in rural areas from supermarket, supercenter, or large grocery store.[8]

Laboratory Tests

Participants were instructed to fast for 12 hours before the study visit. Venous blood was collected, and levels of total cholesterol, low-density lipoprotein cholesterol, high-density lipoprotein cholesterol, and glucose were measured by spectrophotometry. Serum hs-CRP level was measured by immunonephelometry (Siemens/Dade Behring). Markers of OS included plasma levels of the amionthiols, glutathione, and cystine, which were measured using high-performance liquid chromatography as described previously.[19,30,31] Low levels of glutathione and high levels of cystine indicate higher OS. Of 1421 subjects enrolled in MH and PH studies, the following data were missing: hs-CRP (69 MH and 7 PH subjects), GSH (41 MH and 98 PH), and cystine (41 MH and 97 PH subjects) because of technical difficulties in sample drawing or processing. Pulse wave velocity (PWV; 295 MH and 24 PH subjects) and augmentation index (AI, 52 MH and 17 PH subjects) data were missing. Only available data were analyzed.

Vascular Function Testing

PWV and AI were estimated in the supine position after an overnight fast using the SphygmoCor device (AtCor Medical, Australia), which records sequential high-quality pressure waveforms at peripheral pulse sites using a high-fidelity tonometer, as described previously.[31–33] AI is a ratio calculated from blood pressure waveform as the percentage of central pulse pressure to the secondary systolic pressure rise caused by the overlap of the reflected pressure waves.[34] Details are available in the Data Supplement.

Statistical Methods

Continuous variables are presented as means±SD when normally distributed, skewed variables (cardiovascular risk scores and hs-CRP) as median (lower and upper quartiles), and categorical variables as proportions. Univariate group differences were compared using the χ^2 test for categorical variables and independent *t* tests for continuous variables. Nonparametric testing (Mann–Whitney) was used for comparing skewed variables, and these values were log transformed before analysis. Multiple linear regression was performed to determine the association of FD, area or personal income, and food access with OS measures and vascular function after adjusting for traditional CVD risk factors, including age, sex, race, smoking, hypertension, hyperlipidemia, diabetes mellitus, and body mass index. Interaction between food access, area, and personal income was performed. We intentionally adjusted for CVD risk factors because of baseline differences of risk factor burden between subjects living in different areas of FD. Individual income and education level were highly correlated in our sample. Therefore, we only adjusted for individual income to reduce multicollinearity. *P* values <0.05 were considered significant. Analyses were performed using SPSS, Inc (version 23).

Results

Subjects' Characteristics

Baseline demographic and clinical characteristics of the 1421 subjects are presented in Table 1. The sample was 38.5% male, 36.6% black, mean age 49.4±10.2 years. Education-level assessment revealed that 11% had a high school diploma or less, whereas 63.7% were college graduates. Annual household income in 11.2% was <$25 000, and 47.9% had income >$75 000 (Table 1).

FD Areas and Cardiovascular Risk

The distribution of FD in the Atlanta metro area according to the USDA Food Access Research Atlas is shown in Figure (A). Individuals living in FD areas (n=187, 13.2%) were predominantly black (52% versus 34%) with less college education and lower income compared with those who were not living in FD (Table 1). They also had an unfavorable cardiovascular risk profile with a higher prevalence of hypertension and smoking rates, higher body mass index and fasting blood glucose levels, and a higher ASCVD score (*P*=0.007). Moreover, they also had higher levels of hs-CRP, lower levels of glutathione, and higher AI compared with those living in non-FD areas (Table 1). These differences remained significant for glutathione and AI after adjustment for traditional risk factors (Tables 1 and 2).

Food Access, Area Income, Individual Income, and Cardiovascular Risk

The population was further classified on the basis of residing in neighborhoods and its access to healthy food and area income in addition to individual household income (Table 3; Figure [B and C]). Subjects living in neighborhoods with low access to healthy food were more often black, with lower education level, higher body mass index, and prevalence of hypertension compared with subjects living in favorable food access areas. Similar findings in addition to higher prevalence of diabetes mellitus, smoking, hyperlipidemia, and higher ASCVD score were observed in subjects living in low-income compared with high-income areas. The sample was further classified based on individual income defined as annual household income <$50 000. Similar differences in cardiovascular risk factors were observed in subjects with low compared with high individual income.

The differences in subclinical vascular disease was also examined in subjects based on their neighborhood characteristics and individual SES. There were no differences in the markers of inflammation, OS, or vascular stiffness in those living in

Table 1. Subjects' Characteristics by Food Desert Status

	Total	Food Desert	Non–food Desert	*P* Value
Sample, n	1421	187	1234	…
Age, y	49.4±10.2	49.1±8.8	49.4±10.5	0.68
Male sex, %	38.5	38.5	37.5	0.80
Black, %	36.6	51.9	34	**<0.001**
Education (% distribution)				**<0.001**
High school graduate or less	11	22.8	9.8	
Some college	20.1	33.3	19.3	
College graduate	63.7	43.9	70.9	
Income (% distribution)				**<0.001**
≤ $25 000	11.2	22.3	10.8	
$25 000–$50 000	16.2	27.4	16.2	
$50 000–$75 000	15.5	17.7	17.2	
>$75 000	47.9	32.6	55.8	
Hypertension	34.5	47.6	32.4	**<0.001**
Diabetes mellitus	8.9	11.3	8.6	0.22
Hyperlipidemia	51.4	54.3	51.5	0.47
Heart disease	3.4	5.5	3.2	0.13
Smoking	13.3	21.9	12.4	**<0.001**
Medication use, %				
Hypertension treatment	21.4	35.8	22.2	**<0.001**
Lipid treatment	51.4	14.6	16.6	0.52
Metabolic syndrome	27.2	30.6	28	0.46
BMI, mean, kg/m^2	28.9±7	30.6±8	28.6±7	**<0.001**
Systolic blood pressure, mm Hg	121.4±17	125.9±21	120.6±16	**<0.001**
Fasting blood glucose, mg/dL	91.7±22	94.8±33	91.2±20	**0.042**
Total cholesterol, mg/dL	196±38	199.5±42	196.3±38	0.29
LDL	114.5±33	118.3±37.1	113.9±33	0.1
HDL	60.8±18	59.1±16.5	61.3±18	0.12
Triglyceride	109.2±63	113.1±62.5	108.1±64	0.32
Cardiovascular risk estimation				
ASCVD (IQR)	3.0 (1.2–6.6)	4.1 (1.7–7.3)	2.8 (1.1–6.4)	**0.007**

(*Continued*)

Table 1. Continued

	Total	Food Desert	Non–food Desert	*P* Value
Inflammatory markers				
Hs-CRP mg/L (IQR)	1.6 (0.5–3.8)	2.2 (0.9–4.5)	1.5 (0.5–3.7)	**0.014**
Hs-CRP >2 mg/L, %	42.7	52.9	41.6	**0.005**
Oxidative stress markers, µmol/L				
Glutathione	1.65±0.63	1.51±0.58	1.67±0.64	**0.003**
Cystine	84.0±18.5	85.2±16.6	83.9±18.8	0.41
Vascular function				
Pulse wave velocity, m/s	7.33±1.52	7.50±1.79	7.30±1.48	0.18
Augmentation index at 75 bpm	21.29±10.7	23.09±11.3	21.00±10.6	**0.015**

Values shown are mean±SDs or number (%) for normally distributed variables or median (IQR) for non-normally distributed variables. Bold values indicate statistically significant difference (P<0.05). ASCVD indicates atherosclerotic cardiovascular disease in adults; BMI, body mass index; HDL, high-density lipoprotein; Hs-CRP, high-sensitivity C-reactive protein; IQR, interquartile range; and LDL, low-density lipoprotein.

low compared with good access to healthy foods (Tables 2 and 3). However, subjects living in low-income areas had a higher hs-CRP levels, lower glutathione levels, higher PWV, and AI compared with subjects residing in higher income areas (Table 3). The differences in hs-CRP and glutathione levels remained significant after adjustment for cardiovascular risk factors (Table 2). Low individual income was also associated with higher levels of hs-CRP, PWV, and AI and lower glutathione level, and the differences remained significant after adjustment for cardiovascular risk factors (Tables 2 and 3).

Relationship Between Cardiovascular Risk and Both Area Income and Food Access

Subjects were separated into 4 categories based on whether they were living in high-income areas with either good (n=356) or low access to healthy foods (n=597), or in low-income areas with either good (n=281) or low access to healthy food (FD, n=187; Figure I through V in the Data Supplement). Subjects living in low-income areas with low food access (FD) had no significant difference in ASCVD score, hs-CRP, PWV, cystine, or glutathione levels compared with subjects living in areas with low income and good food access areas. Only subjects living in low-income areas, irrespective of whether they had good or poor access to healthy food, had higher hs-CRP level and higher OS (low glutathione) when compared with subjects living in high-income areas, regardless of their food access (Figure I through V in the Data Supplement).

Relationship Between Cardiovascular Risk and Both Individual Income and Food Access

Subjects were separated into 4 categories based on whether they were living in areas with good or poor access to healthy food and whether they had high versus low individual income (Table I and Figure I through V in the Data Supplement). There were no significant differences in cardiovascular risk factors, CVD risk estimation, inflammation, arterial stiffness, and OS between subjects with low individual income living in areas with poor or good access to healthy food. Similarly, no differences in these measures were observed in subjects with high individual income living in varying food access areas. Thus, individuals with high income living in areas with low access to healthy food had lower risk factor burden and ASCVD scores (P=0.001), lower hs-CRP levels (P=0.004), and higher glutathione levels (P=0.005) compared with subjects with lower income living in similar low access area (Figure I through V in the Data Supplement). These data indicate that individual income and not food access was a more important contributor to CVD risk.

Relationship Between Cardiovascular Risk and Both Individual Income and Area Income

The distribution of risk factors, biomarkers, and vascular function was also studied to distinguish the effects of individual versus the area income levels (Table II and Figure I throgh V in the Data Supplement). Subjects with low individual income living in low-income areas were more likely to be black with lower educational level, higher prevalence of diabetes mellitus and smoking, higher hs-CRP levels (P=0.05), higher cardiovascular risk (ASCVD P<0.001), and lower glutathione level (P=0.041) compared with individuals with higher individual income living in low-income areas. Similarly, subjects with low individual income living in high-income areas were more often black with poor education levels, higher ASCVD score, higher Hs-CRP levels, and lower glutathione levels compared with those with high income living in similar high-income areas (Figure I through V in the Data Supplement).

Relationship Between Cardiovascular Risk and Individual Income, Area Income, and Food Access

Multivariate analyses were performed after adjustment for traditional cardiovascular risk factors to investigate which of these SES and neighborhood factors were associated with CVD risk markers. When individual income, area income, and food access were entered into the same model, independent predictors of higher ASCVD risk score were both low individual and low neighborhood income. Only low individual income was an independent predictor of both hs-CRP and AI after adjusting for CVD risk factors. Finally, area income (P=0.031) was also an independent predictor of OS (Table 4). Thus, the major predictors of increased CVD risk were individual and neighborhood income, whereas food access and living in FD were not independent predictors of CVD risk. There was no significant interaction between area income, individual income, and food access with ASCVD risk score, OS, and inflammation. The data were unchanged when adjusted for study cohort.

Discussion

In a community-based population from the southeastern United States, we demonstrate the clinical impact of living in FD and its components on cardiovascular risk and subclinical vascular disease. We found that subjects living in FD not

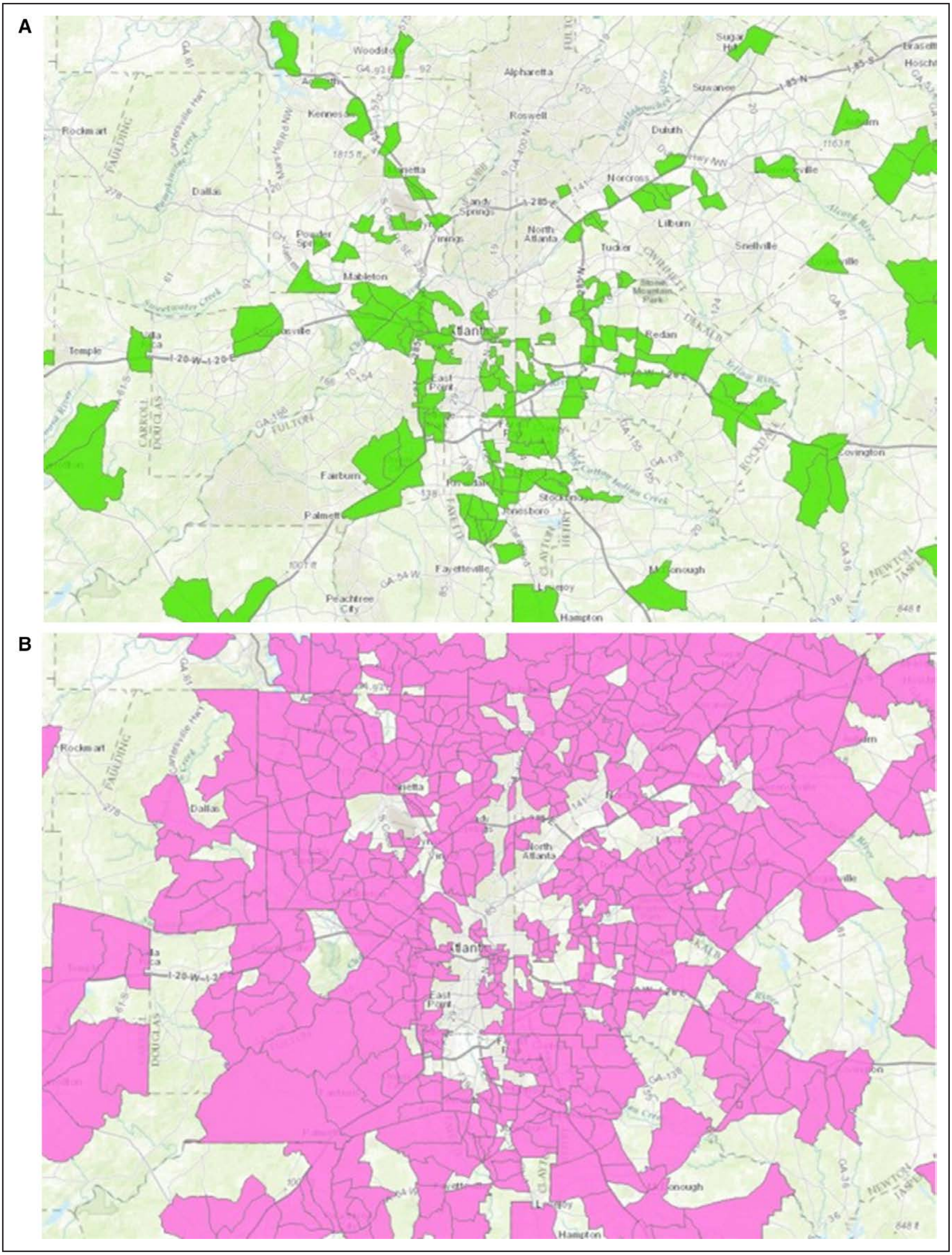

Figure. Distribution of (**A**) food deserts, (**B**) areas with low access to healthy food, and (**C**) low-income areas in the Atlanta metropolitan region according to the US Department of Agriculture Food Access Research Atlas.

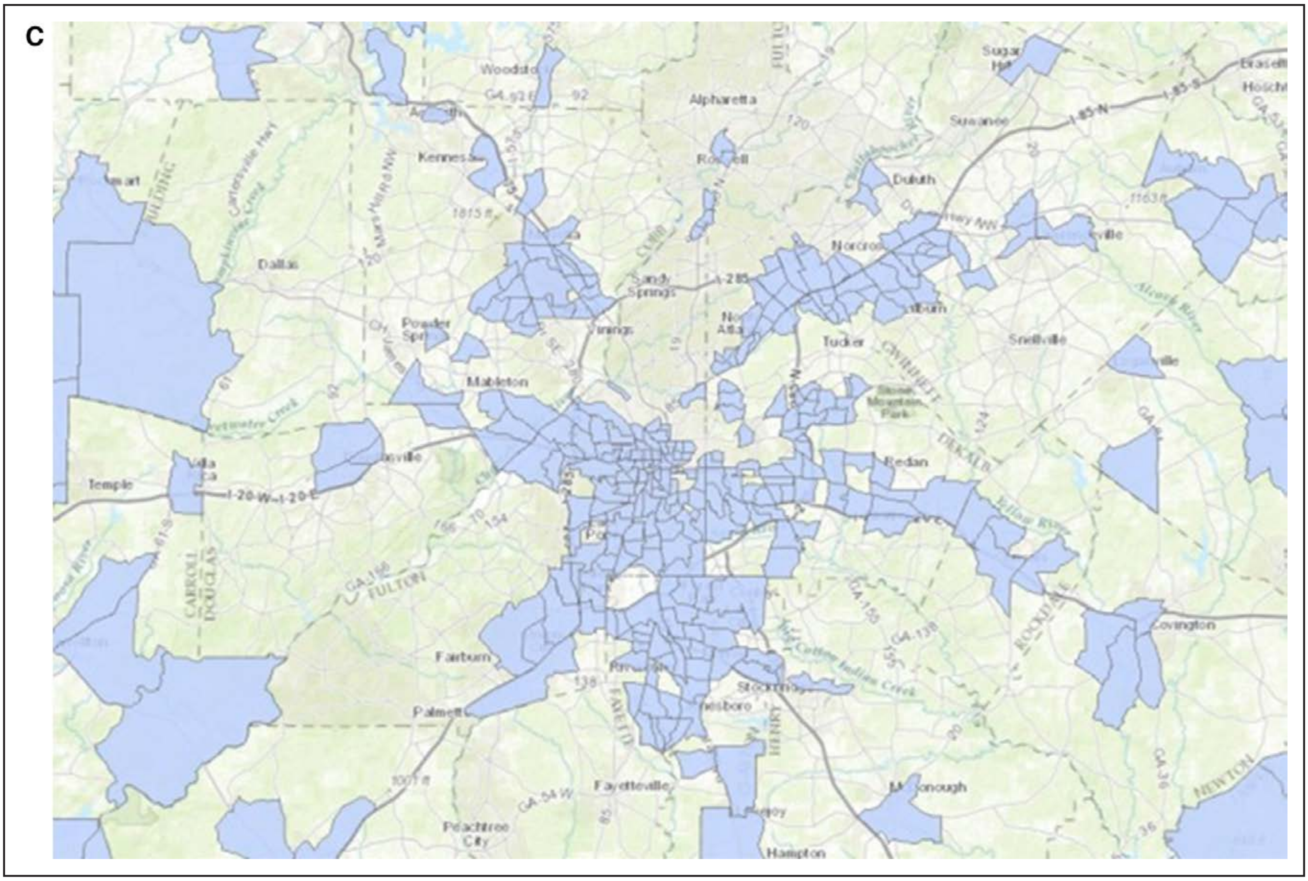

Figure Continued.

only had an unfavorable cardiovascular risk profile but also had increased systemic OS, inflammation, and arterial stiffness. Further investigation of individual components of FD showed that its associations with unfavorable health profile were driven by area income rather than food access. Moreover, individual household income showed the most robust impact on the various measures of CVD risk and subclinical vascular disease.

Subclinical measures of vascular risk include measures of systemic inflammation, OS, and subclinical vascular disease,

Table 2. Estimated Adjusted Differences in Markers of Inflammation, Oxidative Stress, and Vascular Function According to the Status of Food Deserts, Food Access, Area Income, and Individual Income

	Estimated Difference (96% Confidence Interval)			
	Food Desert vs Non–food Desert	Low Food Access vs Good Food Access	Low-Income Area vs High-Income Area	Low Individual Income vs High Individual Income
Inflammatory markers				
Hs-CRP, %	5 (−11.8 to 25.2)	−6.6 (−16.9 to 5.1)	13.8 (1 to 29.3)*	20.7 (5.1 to 38.7)*
Oxidative stress markers, μmol/L				
Glutathione	−0.12 (−0.22 to −0.02)*	0.003 (−0.07 to 0.07)	−0.10 (−0.18 to −0.03)*	−0.10 (−0.18 to −0.02)*
Cystine	0.377 (−2.49 to 3.25)	−0.57 (−2.53 to 1.40)	−0.49 (−2.60 to 1.63)	−0.74 (−1.54 to 3.03)
Vascular function				
Pulse wave velocity, m/s	−0.02 (−0.29 to 0.25)	0.09 (−0.08 to 0.25)	0.06 (−0.12 to 0.25)	0.19 (−0.02 to 0.40)
Augmentation index at 75 bpm	1.47 (0.12 to 2.83)*	−0.47 (−1.39 to 0.46)	0.43 (−0.59 to 1.45)	1.89 (0.80 to 2.99)*
Cardiovascular risk estimation				
ASCVD, %	14 (6.4 to 22.1)*	0.5 (−4.2 to 5.3)	10.2 (4.5 to 16.2)*	15.1 (8.7 to 22.1)*

Percent difference was reported for Hs-CRP. Multivariate analysis after adjustment for age, sex, race, hypertension, hyperlipidemia, diabetes mellitus, smoking, body mass index, and heart disease. ASCVD indicates atherosclerotic cardiovascular disease in adults; and Hs-CRP, high-sensitivity C-reactive protein.

*$P<0.05$.

Table 3. Subjects' Characteristics by Food Access, Area, and Individual Income

	Low Food Access	Good Food Access	*P* Value	Low-Income Area	High-Income Area	*P* Value	Low Individual Income	High Individual Income	*P* Value
Sample, n	784	637		468	953		398	923	…
Age, y	49.1±10	49.7±10.5	0.35	49.± 10	49.6±10.4	0.38	48.6±10.5	49.8±9.9	0.05
Male sex, %	35.3	40.5	**0.05**	37.0	38.0	0.73	39	35	0.19
Black, %	39.5	32.3	**0.006**	51.7	28.6	**<0.001**	39	27	**<0.001**
Education (% distribution)			**0.019**			**<0.001**			**<0.001**
High school graduate or less	12.6	10		19.8	7.4		31	3	
Some college	23.2	18.6		30.4	16.7		37	14	
College graduate	64.1	71.3		49.8	75.9		32	82	
Income (% distribution)			0.66			**<0.001**			…
≤$25 000	12	12.7		22.0	7.6		…	…	
$25 000–$50 000	18.7	16.5		25.8	13.7		…	…	
$50 000–$75 000	17.7	16.7		18.6	16.6		…	…	
>$75 000	51.5	54.1		33.6	62.1		…	…	
Hypertension	37.5	30.5	**0.006**	41.4	30.9	**<0.001**	42	32	**<0.001**
Diabetes mellitus	8.6	9.3	0.65	11.4	7.7	**0.029**	14	7	**<0.001**
Hyperlipidemia	53.1	50.3	0.30	56.6	49.5	**0.015**	57	50	**0.04**
Heart disease	3.1	4.1	0.31	5.7	2.5	**0.005**	5	3	0.12
Smoking	13.9	13.4	0.81	20.6	10.3	**<0.001**	28	7	**<0.001**
Medication use, %									
Hypertension treatment	25.4	23	0.17	30.9	20.7	**<0.001**	29	22	**0.02**
Lipid treatment	15.7	17.3	0.45	16.1	16.5	0.94	17	16	0.53
Metabolic syndrome	30	26.3	0.15	30.1	27.4	0.31	28	29	0.67
BMI, mean, kg/m^2	29.4±7.3	28.3±6.7	**0.002**	29.9±7.7	28.4±6.7	**<0.001**	30.6±8.3	28.2±6.2	**<0.001**
Systolic blood pressure, mm Hg	122.1±17.7	120.3±16.2	**0.05**	123.3±19.4	120.3±15.7	**0.002**	124.3±20.2	120.2±15.9	**<0.001**
Fasting blood glucose, mg/dL	91.7±24.2	91.6±19.9	0.89	92.7±25.7	91.1±20.5	0.21	94.3±27.8	90.8±19.8	**0.012**
Total cholesterol, mg/dL	198.3±38	194.9±38.2	0.10	195.5±40.1	197.3±37.1	0.39	195.1±40.6	197.9±37.1	**0.002**
LDL	116.4±34	112.3±33	0.23	114.7±36	114.4±32	0.89	115.5±35.6	114.7±32.4	0.23
HDL	60.4±18	61.7±18	0.18	60.1±18	61.4±18	0.20	58.7±16.9	62.1±18.1	0.68
Triglyceride	109.9±62	107.3±65	0.45	107.3±59	109.4±66	0.57	108.2±58	108.3±64.5	**0.002**
Cardiovascular risk estimation									
ASCVD (IQR)	2.9 (1.2–6.5)	3.1 (1.1–6.5)	0.72	4.5 (1.8–8.0)	2.8 (1.2–6.4)	**<0.001**	5.1 (1.95–8.1)	2.6 (1–5.9)	**<0.001**
Inflammatory markers									
Hs-CRP, mg/L (IQR)	1.6 (0.5–4.0)	1.6 (0.5–3.6)	0.73	2.1 (0.8–4.9)	1.5 (0.5–3.4)	**<0.001**	2.2 (0.8–5.6)	1.5 (0.5–3.4)	**<0.001**
Hs-CRP >2 mg/L, %	43.3	42.8	0.84	51.3	39.1	**<0.001**	51.9	39.9	**<0.001**
Oxidative stress markers, µmol/L									
Glutathione	1.64±0.61	1.66±0.61	0.61	1.56±0.60	1.69±0.65	**<0.001**	1.5±0.6	1.7±0.6	**<0.01**
Cystine	83.9±18.4	84.3±18.4	0.47	84.3±18.5	84.0±18.9	0.69	84.8±19.1	83.7±18.5	0.37
Vascular function									
Pulse wave velocity, m/s	7.35±1.54	7.29±1.50	0.49	7.51±1.8	7.25±1.4	**<0.001**	7.5±1.7	7.2±1.4	**0.014**
Augmentation index at 75 bpm	21.35±10.8	21.20±10.5	0.81	22.0±11.5	20.9±10.2	**0.001**	22.4±12	20.9±9.9	**0.018**

High income is defined as annual income >$50 000. Low income is defined as annual income <$50 000. Values shown are mean±SDs or number (%) for normally distributed variables or median (IQR) for non-normally distributed variables. Bold values indicate statistically significant difference ($P<0.05$). ASCVD indicates atherosclerotic cardiovascular disease in adults; BMI, body mass index; CVD, cardiovascular disease; HDL, high-density lipoprotein; Hs-CRP, high-sensitivity C-reactive protein; IQR, interquartile range; and LDL, low-density lipoprotein.

Table 4. Multivariate Analysis of Area Characteristics/Individual Income and Measures of Inflammation, Arterial Stiffness, Glutathione, and Cardiovascular Disease Risk

	LogCRP, β (CI)	AI, β (CI)	PWV, m/s, β (CI)	Glutathione, β (CI)	Cystine, β (CI)	LogASCVD, β (CI)
Model 1						
Low individual income	0.16 (0.01 to 0.30)*	1.56 (0.51 to 2.75)*	0.14 (−0.08 to 0.35)	−0.08 (−0.16 to 0.005)	0.94 (−1.42 to 3.30)	0.29 (0.17 to 0.41)*
Low-income area	0.10 (−0.04 to 0.24)	0.30 (−0.78 to 1.38)	0.14 (−0.07 to 0.34)	−0.09 (−0.17 to −0.008)*	−0.42 (−2.74 to 1.90)	0.14 (0.02 to 0.25)*
Low food access	−0.04 (−0.16 to 0.09)	−0.40 (−1.37 to 0.56)	0.09 (0.09 to 0.26)	−0.01 (−0.09 to 0.06)	−0.83 (−2.94 to 1.28)	−0.01 (−0.11 to 0.09)
Model 2						
Interaction term: (individual income × area income)†	−0.14 (−0.42 to 0.13)	0.59 (−1.58 to 2.77)	−0.25 (−0.67 to 0.18)	0.05 (−0.11 to 0.21)	−4.35 (−8.94 to 0.25)	0.04 (−0.08 to 0.15)
Model 3						
Interaction term: (individual income × food access)‡	0.011 (−0.26 to 0.28)	2.7 (0.56 to 4.74)*	0.14 (−0.26 to 0.55)	−0.06 (−0.21 to 0.10)	3.79 (−0.65 to 8.22)	−0.04 (−0.15 to 0.08)
Model 4						
Interaction term: (area income × food access)§	0.002 (−0.26 to 0.26)	3.02 (0.99 to 5.05)*	−0.27 (−0.66 to 0.12)	−0.09 (−0.24 to 0.06)	2.54 (−1.86 to 6.95)	0.10 (0.0 to 0.21)

Multivariate analyses controlling age, sex, race, hypertension, hyperlipidemia, diabetes mellitus, smoking, BMI, and heart disease except for ASCVD. Standardized β coefficient displayed with *P* value. AI indicates augmentation index; ASCVD, atherosclerotic cardiovascular disease in adults; BMI, body mass index; CRP, C-reactive protein; and PWV, pulse wave velocity.

*Statistically significant difference ($P<0.05$).

†Model 2 included variables in model 1+the interaction term.

‡Model 3 included model 1+the interaction term.

§Model 4 included model 1+the interaction term.

including arterial stiffness. These measures estimate activation of pathophysiologic processes that lead to initiation and progression of CVD and are independently predictive of adverse long-term outcomes.[19] Similarly, measures of subclinical vascular disease integrate the injury from risk factors on the vascular wall and are also predictive of future adverse outcomes.[13,35,36] In this study, we not only demonstrate that CVD risk scores are higher in individuals living in low-income neighborhoods or with lower personal income but also show that these factors were significantly associated with inflammation, OS, and arterial stiffness.

Food Deserts

The present study is the first to report the relationship between living in FD (defined as both low income and access to healthy food areas by the USDA), cardiovascular risk factors, and subclinical vascular disease. Previous studies have focused on select neighborhood characteristics and SES in addition to composite scores of neighborhood features.[2,37] For example, areas with poor food quality, low access to healthy foods, or more fast-food restaurants are associated with obesity and diabetes mellitus risks.[38,39] A recent study showed that although living in FDs was associated with decreased fruit and vegetable intake and higher systolic blood pressure, low individual income rather than FDs was associated with higher odds of chronic kidney disease.[40] Novel findings of our study are the relationships between FD and subclinical CVD measured as vascular dysfunction, inflammation, and OS, and the fact that these are driven by income rather than access to healthy foods.[13,19]

Food Access

There is controversy on the cardiovascular health effects of food access.[41,42] In the Atherosclerosis Risk in Communities study, increased prevalence of convenience stores was associated with a higher incidence of obesity but not diabetes mellitus, hypertension, or dyslipidemia.[43] However, other studies did not confirm these findings.[38,44] We found that living in areas with low access to healthy food was not associated with a higher CVD risk, inflammation, OS, or arterial stiffness compared with subjects living in areas with good access to healthy food. Thus, food access by itself, measured by proximity to supermarkets, might not contribute to increased cardiovascular risk, and the relative cost of higher quality food rather than access may be a major barrier to healthy lifestyle and choices.[6,45]

Area and Individual Income

The relationship between SES and CVD risk is well established.[2,37,46–48] There is striking geographical variation in the distribution of cardiovascular risk factors and CVD mortality in the United States.[49] Neighborhood SES, deprivation, lack of cohesion, decreased access to recreational resources, lack of public space, and safety are some of the factors that can affect these outcomes.[1] The income status of neighborhoods can also influence the diversity of food resources, prices, and, thus, food access.[50,51] Our analyses showed that the income status of areas is an independent determinant of cardiovascular risk and subclinical vascular disease.

Our study also showed that it was the individual income, rather than the neighborhood income or food access, that was associated with higher risk of developing CVD, inflammation, and OS. Thus, people with high individual income who lived in low-income areas had lower CVD risk and inflammation compared with subjects with lower individual income who lived in similar area. Moreover, people with high individual income who lived in an area with poor food access had better cardiovascular profile than those with lower individual income who lived in similar area. It seems that the adverse association of FD with health is partly driven by the area income and most importantly by individual income status, rather than access to food. There are several initiatives that promote healthy food access by providing incentives for individuals with low income. Georgia provides incentives for participants in the Supplemental Nutrition Assistance Program to increase the value of Supplemental Nutrition Assistance Program benefits if healthy food is purchased at farmers' markets. However, few farmers' markets are located in FDs and few accept Supplemental Nutrition Assistance Program in Georgia.[52] Providing support services for eligible low-income families may overcome some of the adverse health outcomes driven by low SES. A recent report by the Center for Disease Control and Prevention showed that enrollment in Supplemental Nutrition Assistance Program for Women, Infants, and Children decreased the prevalence of childhood obesity among low-income families.[53]

The study also demonstrated that residents living in disadvantaged areas including FD, low income, and low-access areas had a higher proportion of black residents. Black neighborhoods have been reported to have more fast-food restaurants,[54] fewer supermarkets,[55] fewer healthy options, lower levels of social cohesion, and worse walking environments.[56] Our data shows that blacks also formed a higher proportion of those with low income, a key driver of increased CVD risk.

Limitations and Strengths

Our study has several strengths. It investigates the relationship between components of FD and cardiovascular risk factors in a region of United States where there is tremendous racial and regional disparity in the incidence of CVD. It investigates the health impact of socioeconomic and neighborhood features on subclinical CVD, including inflammation, OS, and arterial stiffness. Limitations include its cross-sectional nature where causality between income and living in FD and subclinical vascular disease cannot be established. Second, our study was conducted in a single urban area in southeastern United States and may not be generalizable to other regions. Third, geographic locations and characteristics can change with time. However, a recent update by the USDA showed relatively small change in low-income and low-access neighborhoods between 2010 and 2015 data.[57] Previous studies also showed that individuals usually move into neighborhoods with similar SES across their life course.[58,59]

Conclusions and Implications

People living in FD had a higher prevalence of cardiovascular risk factors, inflammation, OS, and arterial stiffness. These associations are largely driven by area and individual income rather than access to healthy food. The implications of our findings are that at least in urban areas, risk of CVD seems to be associated less with access to healthy food and more with socioeconomic factors. This understanding may help to better tailor resources to affected communities and improve utilization of public health resources.

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Disclosures

None.

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