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Association of socioeconomic status with arterial stiffness in older African American and White adults: The ARIC study cohort

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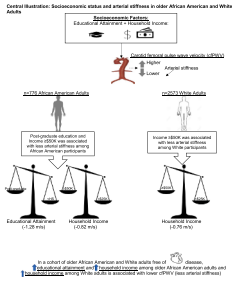
GRAPHICAL ABSTRACT



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ABSTRACT

Objective: To examine the cross-sectional associations of individual measures of SES—educational attainment and household income—and the joint effects of SES with PWV, as well as the SES-race interaction, in a cohort of older African American and White adults.

Methods: Data from the Atherosclerosis Risk in Communities (ARIC) Study were used to evaluate the cross-sectional associations of individual and joint SES [education and income] and carotid femoral pulse wave velocity (cfPWV), a subclinical marker of arterial stiffness, and the interaction of SES and race using adjusted multivariable linear regression models in a cohort of 3342 men and women aged 67–89 years free of CVD in 2011–2013.

Results: Participants were 64% female, 23% African American, mean cfPWV (12.3±3.5-African American and 11.6±3.9-White participants). Post-graduate education compared to less than high school was significantly associated with lower cfPWV (less stiffness) in African American (β = -1.28 m/s; 95% CI, -1.97, -0.59) but not in White (β = -0.69 m/s; 95% CI, -1.39, 0.01) participants. Income ≥$50K as compared to <$25K, was associated with lower cfPWV both in African American (β = -0.82 m/s; 95% CI, -1.42, -0.22) and White (β = -0.76 m/s; 95% CI, -1.19, -0.32) participants. The interaction of race and individual measures of SES on cfPWV in African American and White adults were not statistically significant (p-value >0.10).

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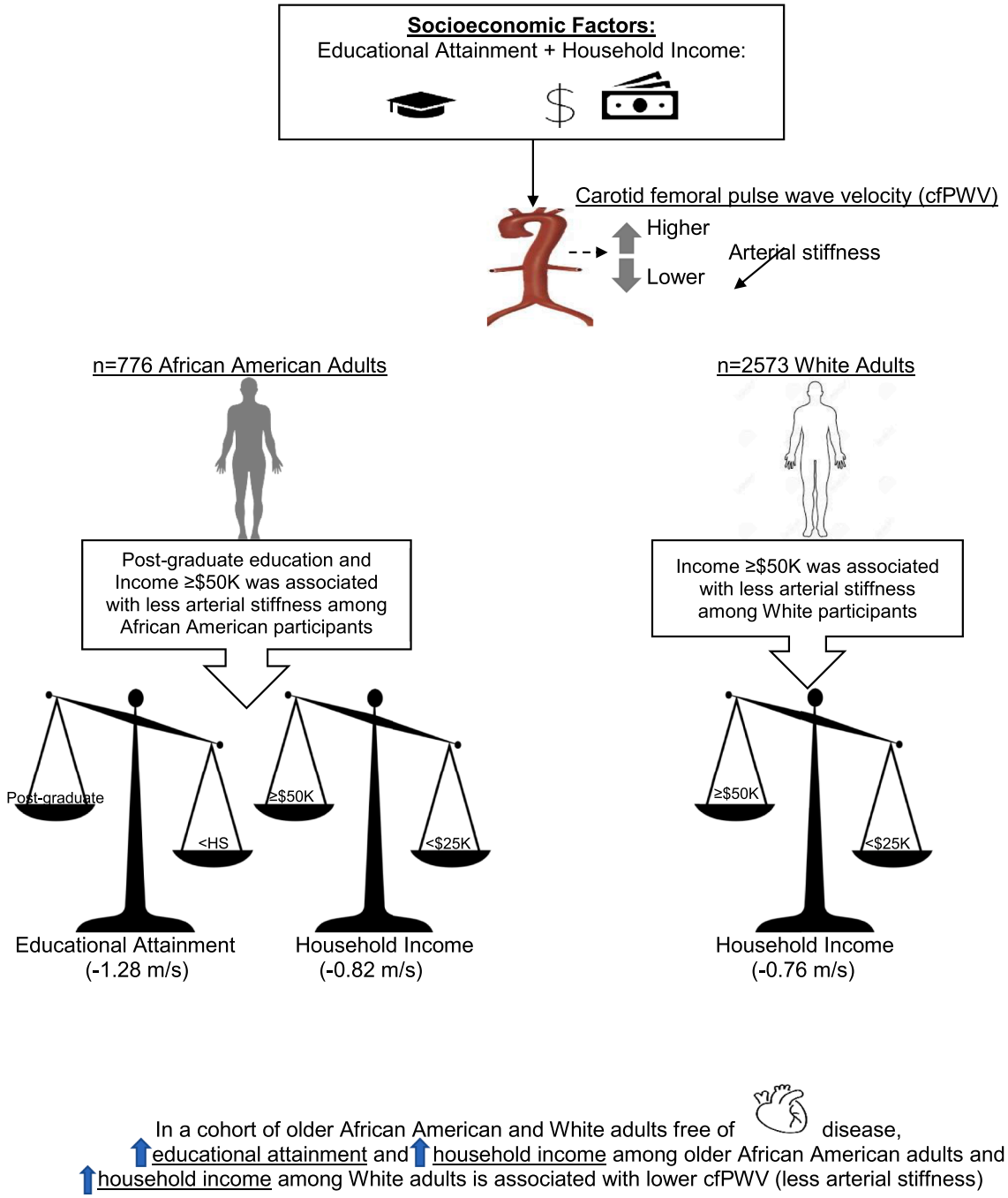
Conclusions: Higher SES was cross-sectionally associated with lower arterial stiffness in this cohort; the data did not support differences by race. Prospective studies of SES and cfPWV are needed to efficiently compare larger racially and regionally diverse populations with a wider range of socioeconomic profiles to better identify subgroup CVD risk.

Central Illustration

Socioeconomic status and arterial stiffness in older African American and White Adults

1. Introduction

Despite overall decreases in mortality from cardiovascular disease (CVD) observed in recent decades [1,2], important disparities exist that are patterned by race and socioeconomic status (SES) [3]. Low SES and African American race are associated with a greater burden of traditional CVD risk factors and higher blood pressure levels that may also



contribute to greater arterial stiffness, a subclinical marker of CVD [4,5]. However, the contribution of traditional CVD risk factors does not fully explain the racial and socioeconomic differences in arterial stiffness [6]. The well established SES-health gradient that increasing SES is associated with better health and longer life [7], has been shown to be stronger for White versus African American populations despite similar SES resources [8,9]. These differences may partially explain the enduring racial and ethnic disparities underlying CVD which have been suggested to peak during midlife [10–13]. Importantly, identifying racial and socioeconomic disparities at the subclinical level has important implications for the prevention of overt CVD, target organ damage, and longevity [14].

Arterial stiffness, estimated most often from measures of aortic pulse wave velocity (PWV) [15], is acknowledged as a predictor of future CVD and all-cause mortality, independently of other cardiovascular risk factors [4,16]. Inconsistent SES patterns and differential vulnerabilities associated with arterial stiffness have been observed among higher versus lower SES African American adults that was not observed across SES strata among White adults [17,18], These findings have been attributed to the diminished return's hypothesis which specifies that the health differences between Black and White persons are greatest at the highest levels of SES [8,12]. Moreover, voluminous evidence suggest diminished returns' may be the result of systemic racism which creates unfair inequities across various sectors of society [9,10,19]. Due to the intersecting social identities associated with race and class for African American populations [20], researchers have argued that it is necessary to not only examine the main effects by which SES operates, but also test for SES-race interactions as they reflect the intersection of different systems of constraint and opportunity with respect to health [21–23].

The extent to which differential returns to individual SES (educational attainment and income) by race confers increased CVD risk, measured as higher arterial stiffness, among older African American and White adults, remains unclear. Motivated by the diminished returns hypothesis, we examined the cross-sectional associations of individual and joint measures of SES—educational attainment and household income—with PWV, as well as the SES-race interaction, in a cohort of older African American and White adults. Based on results from a previous study that showed greater arterial stiffness among higher SES Black versus White adults,[17] we hypothesized that higher SES would be associated with lower arterial stiffness, however, this association would be stronger for White versus Black adults.

2. Methods

2.1. Study population

The Atherosclerosis Risk In Communities (ARIC) Study is an ongoing community-based, longitudinal prospective cohort of 15,792 men and women, age 45–64 years at baseline, recruited from four US communities: Forsyth County, NC (African Americans and Whites); Jackson, MS (all African Americans); selected suburbs of Minneapolis, MN; and Washington County, MD. Recruitment began in 1987 with baseline

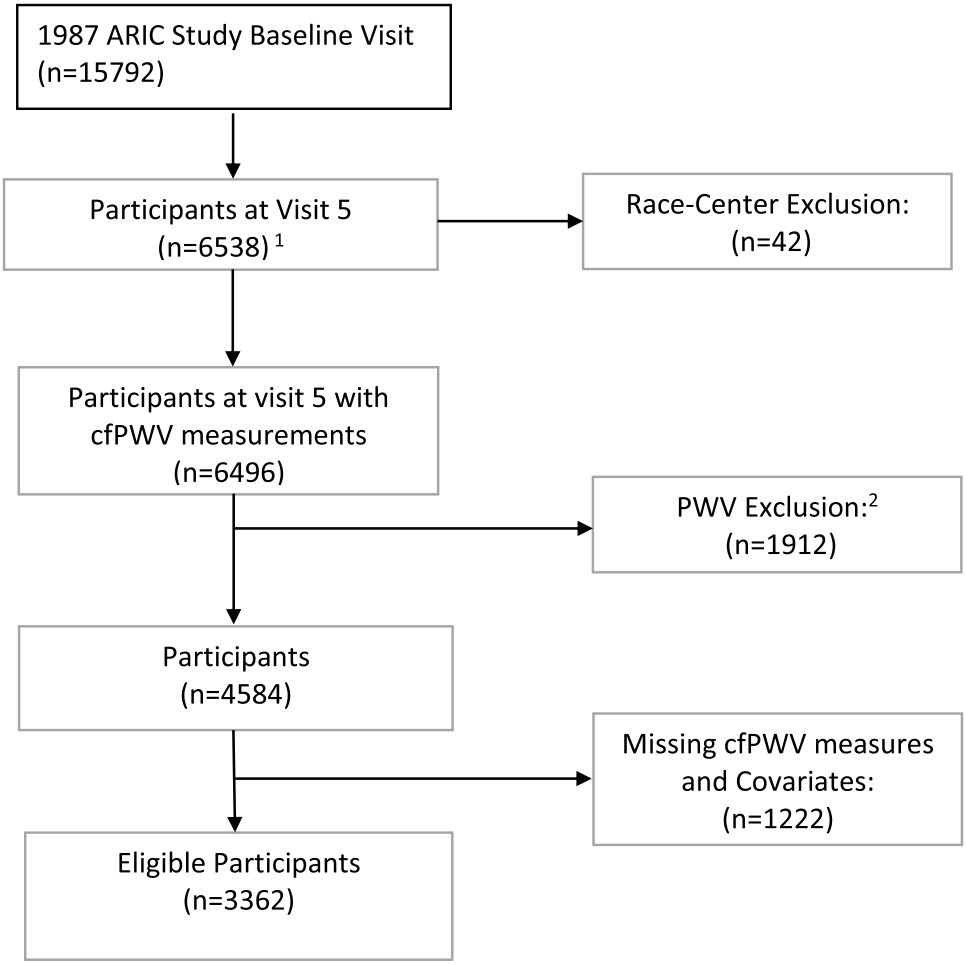


Fig. 1. Process of selection of study population.
Abbreviations: ARIC, Atherosclerosis Risk in Communities Study. [1]Participants in primary analysis; [2]Predefined factors that might affect the validity of PWV measurements.

screening occurring through 1989. Subsequent follow-up visits were conducted in 1990–1992 (visit 2), 1993–1995 (visit 3), 1996–1998 (visit 4), 2011–2013 (visit 5), 2016-2017 (visit 6), and 2018-2019 (visit 7). Additional information about the initial study design and objectives can be found elsewhere [24,25].

Pulse wave velocity (PWV) was measured at visit 5 (2011-2013) among 6538 participants, with 6496 participants with PWV measurements. Participants were excluded if they had missing information on SES variables [educational attainment (n = 11), median household income (n = 664)]; a history of prevalent coronary heart disease (n = 645), heart failure (n = 210), or stroke (n = 153); if they had any of the following: body mass index (BMI) $\geq$ 40kg/m^2 (n = 143); major arrhythmias (Minnesota code 8-1-3, 8-3-1, and 8-3-2) (n = 146), Minnesota code 8-1-2 with evidence of low quality PWV waveforms (n = 153), aortic stenosis (n = 28), aortic regurgitation (n = 24), aortic aneurysm (n = 82), self-reported aortic revascularization surgery (n = 54), and peripheral revascularization (n = 28) due to interference with PWV measurements [26]; or missing covariates of interest: BMI (n = 267), systolic (n = 35) and diastolic (n = 35) blood pressure, and current smoking status (n = 423). Further, participants who self-identified as non-African American or non-White (n = 18) were excluded from these analyses. Participants who self-identified as African American from the Maryland (n = 15) and Minnesota (n = 9) sites were also excluded due to the small sample size, leaving a final analytic sample of 3362 participants (Fig. 1. Flow diagram). Institutional Review Boards at each of the four sites approved the study, and written informed consent was obtained from all participants at each study visit.

2.2. Measures

2.2.1. Socioeconomic status

We included two individual socioeconomic status indicators: educational attainment and total combined annual family income. Educational attainment was characterized as highest level of education reported at visit 1 (1987–1989) and categorized into 4 categories: Less than High School (HS) (n = 389), HS (HS/GED, n = 1123), Some College and above (Vocational school and college, n = 1330) and Post-Graduate (Graduate school, n = 520). Total combined family income was self-reported at visit 5 (2011–2013) and was categorized as: <$25,000 ($n$ = 865); $25,000-<$50,000 (n = 1106); and $50,000 and above ($n$ = 1391).

2.2.2. Outcome

Arterial stiffness was estimated from measurements of carotid femoral PWV (cfPWV) performed during visit 5 (2011-2013) by trained technicians using an automated waveform analyzer VP-1000 Plus (Omron, Kyoto, Japan) following a standardized protocol, with faster cfPWV indicating higher arterial stiffness [27]. Participants were supine for 5–10 min prior to the measurement. Carotid and femoral arterial pressure waveforms were acquired by applanation tonometry sensors on the left common carotid artery and left common femoral artery. Pulse wave velocity was calculated as the distance between the suprasternal notch to carotid minus the carotid to femoral distance divided by transit time [26]. Distance for cfPWV was measured with a segmometer (Rosscraft, Surrey, Canada). The validity and reliability of the automated waveform analyzer for measuring PWV among healthy adults have been described previously [26]. For the purposes of these analyses, cfPWV was modeled as a continuous variable in meters/second.

Quality control procedures regarding PWV assessment included central training and recertification, quarterly equipment calibration, and ongoing quality control reviews on a random sample of 40 records per month stratified by center with feedback provided to technicians [28]. Approximately 78% of records were considered optimal quality, 17% were good quality, 3% were acceptable, and none were poor or unacceptable [28].

Table 1
Characteristics of study participants by Education and Race, ARIC Study, 2011-2013.

	African American (N = 776)				**White (N = 2573)**			
M(SD) or N[%]	<HS 191 [24]	HS 173 [22]	Some college or college 239 [30]	Post-graduate 186 [24]	<HS 198 [8]	HS 950 [37]	Some college or college 1091 [42]	Post-graduate 334 [13]
Age, yrs	75 (5)	74 (5)	73 (4.3)	74 (4.7)	78 (5.5)	76 (5.1)	76 (5.3)	75 (5.1)
Sex								
Females	136 [71]	129 [75]	152 [64]	135 [73]	132 [67]	658 [69]	664 [61]	130 [39]
Site								
Forsyth Co., NC	6 [3]	9 [5]	24 [10]	6 [3]	24 [12]	217 [23]	284 [26]	104 [31]
Jackson, MS	185 [97]	164 [95]	215 [90]	180 [97]	-	-	-	-
Minneapolis suburbs, MN	-	-	-	-	25 [13]	318 [33]	560 [51]	149 [45]
Washington Co., MD	-	-	-	-	149 [75]	415 [44]	247 [23]	81 [24]
Income								
<$25K	156 [82]	117 [68]	104 [44]	19 [10]	105 [53]	220 [23]	134 [12]	10 [3]
$25K-<$50K	23 [12]	44 [25]	70 [29]	59 [32]	65 [33]	417 [44]	368 [34]	60 [18]
≥$50K	12 [6]	12 [7]	65 [27]	108 [58]	28 [14]	313 [33]	589 [54]	264 [79]
Lifestyle								
Alcohol drinker	27 [14]	25 [15]	57 [24]	68 [37]	58 [29]	491 [52]	767 [70]	255 [76]
Current smoker	19 [10]	11 [6]	14 [6]	4 [2]	12 [6]	57 [6]	67 [6]	13 [4]
CV risk factors								
Diabetes	86 [45]	79 [46]	93 [40]	54 [29]	71 [36]	261 [28]	222 [21]	54 [16]
BP meds	156 [83]	151 [88]	192 [80]	132 [71]	127 [64]	561 [59]	582 [54]	158 [48]
Cholesterol meds,	93 [49]	87 [51]	125 [53]	86 [47]	112 [57]	507 [54]	496 [46]	160 [48]
BMI, (kg/m^2)	30 (4.8)	29 (4.9)	29 (4.7)	29 (4.2)	29 (5.7)	28 (5.2)	28 (5.1)	28 (5)
SBP, mmHg	135 (19)	136 (19)	134 (18.2)	131 (16)	131 (19.6)	130 (17.4)	129 (18)	127 (16.6)
DBP, mmHg	70 (9.7)	70 (10.6)	70 (10.1)	70 (9.6)	64 (11)	65 (10.4)	66 (10.4)	66 (10.6)
HDL-C, mg/dl	53 (13.5)	55 (13.5)	54 (13.6)	57 (14.3)	48 (12.2)	52 (13.6)	53 (14.7)	52 (13.8)
Total cholesterol, mg/dl	186 (38)	186 (40.2)	187 (44.2)	189 (36.1)	176 (42.9)	182 (43)	180 (42.4)	180 (40.5)
cf-PWV, m/s	13 (3.7)	12.4 (3.5)	12.3 (3.5)	11.4 (3.2)	12.1 (3.2)	12 (4.6)	11.4 (3.4)	11.1 (3)

Mean(SD) or N[%]; **Abbreviations:** ARIC-Atherosclerosis Risk In Communities; BMI-body mass index; cf-PWV-central femoral pulse wave velocity; DBP-diastolic blood pressure; HDL-C-high density lipoprotein cholesterol; HS-High School; MD-Maryland; MS-Mississippi; MN-Minnesota; NC-North Carolina; SBP-Systolic blood pressure;

Table 2
Characteristics of study participants by Income and Race, ARIC, 2011-2013.

	African American (N = 789)			White (N = 2573)		
M(SD) or N [%]	< $25K 396 [50]	$25K-<$50K 196 [25]	≥$50K 197 [25]	< $25K 469 [18]	$25K-<$50K 910 [35]	≥$50K 1194 [46]
Age, yrs	75 (4.9)	73 (4.4)	73 (4.6)	77 (5.2)	75 (4.9)	74 (4.6)
Sex						
Females	303 [77]	141 [72]	108 [55]	353 [72]	593 [65]	638 [53]
Site						
Forsyth Co., NC	17 [4]	21 [11]	7 [4]	91 [19]	206 [23]	332 [28]
Jackson, MS	379 [96]	175 [89]	190 [96]	-	-	-
Minneapolis suburbs, MN	-	-	-	134 [29]	349 [38]	569 [48]
Washington Co., MD	-	-	-	244 [52]	355 [39]	293 [25]
Education						
<HS	156 [40]	23 [12]	12 [6]	105 [22]	65 [7]	28 [2]
HS	117 [30]	44 [22]	12 [6]	220 [47]	417 [46]	313 [26]
Some college or college	104 [26]	70 [36]	65 [33]	134 [29]	368 [40]	589 [49]
Post-graduate	19 [5]	59 [30]	108 [55]	10 [2]	60 [7]	264 [22]
Lifestyle						
Current alcohol	64 [16]	45 [23]	68 [35]	199 [42]	500 [55]	872 [73]
Current smoker	31 [8]	10 [5]	7 [4]	36 [8]	38 [4]	75 [6]
CV risk factors						
Diabetes	173 [44]	71 [36]	68 [35]	150 [32]	216 [24]	242 [20]
BP meds	333 [85]	161 [82]	137 [70]	272 [58]	533 [59]	623 [53]
Cholesterol meds	194 [49]	100 [52]	97 [50]	240 [51]	451 [50]	584 [49]
BMI, (kg/m^2)	29.5 (4.9)	29 (4.3)	29 (4.5)	28 (4.7)	27 (4.3)	27 (4.2)
SBP, mmHg	135 (19.4)	133 (18.1)	132 (15.5)	131 (18.7)	130 (17.5)	127 (16.2)
DBP, mmHg	69 (10.2)	70 (9.8)	71 (9.6)	64 (10.2)	66 (9.8)	66 (10.2)
Total cholesterol, mg/dl	186 (39.2)	191 (43.1)	185 (38.2)	52 (13.5)	54 (14.2)	54 (13.8)
HDL-C, mg/dl	54 (13.3)	56 (14.7)	54 (13.5)	190 (41.4)	190 (41.5)	187 (39)
cf-PWV, m/s	13.0 (3.7)	12.0 (3.2)	12.0 (3.2)	12.2 (4.3)	12.0 (3.7)	11.1 (3.8)

Mean(SD) or N[%]; **Income:** K denotes $1000 USD; **Abbreviations:** ARIC-Atherosclerosis Risk In Communities; BMI-body mass index; cf-PWV-central femoral pulse wave velocity; DBP-diastolic blood pressure; HDL-high density lipoprotein; MD-Maryland; MS-Mississippi; MN-Minnesota; NC-North Carolina; SBP-Systolic blood pressure;

2.2.3. Covariates

Sex, race, and educational attainment were assessed at ARIC study baseline [25]. Additional covaraites considered in this analysis were ascertained at visit 5 (2011–2013). Age, race, sex, current alcohol consumption, and current smoking status, defined as current or ever smoked, were self-reported. Body mass index (BMI) was calculated as measured weight in kilograms divided by height in meters squared. Systolic blood pressure (SBP) and diastolic blood pressures (DBP) were obtained by taking the averages of the second and third of three blood pressure measurements. HTN was defined as SBP ≥ 140 mm Hg and DBP ≥ 90 mm Hg or antihypertensive medication use. Diabetes mellitus was defined as: a fasting blood glucose level ≥126 mg/dL, non-fasting blood glucose ≥200 mg/dL, use of hypoglycemic medication(s), or a self-reported physician's diagnosis. Circulating total cholesterol and high-density lipoprotein (HDL-C) were measured in collected plasma samples using standard procedures [29].

Table 3
Association of socioeconomic status and Joint effects of SES on Carotid Femoral Pulse Wave Velocity, ARIC, 2011-2013 Overall *N* = **3362**.

	Model 1 N=3362		Model 2 N=3307		Model 3 N=3290	
	β	*95% CI*	*β*	*95% CI*	*β*	*95% CI*
Education						
<HS (Ref)						
HS	-0.03	-0.47, 0.42	0.03	-0.42, 0.48	0.03	-0.40, 0.47
≥Some college	-0.29	-0.73, 0.16	-0.10	-0.55, 0.35	-0.05	-0.49, 0.39
Post-graduate	-0.94	-1.44, -0.44	-0.63	-1.14, -0.12	-0.45	-0.95, 0.04
Income*						
<$25K (ref)						
$25K-<$50K	-0.56	-0.91, -0.22	-0.45	-0.80, -0.10	-0.45	-0.78, -0.11
$≥$50K	-0.82	-1.16, -0.47	-0.64	-1.00, -0.29	-0.53	-0.88, -0.19
Joint SES score						
2 (low education, low income)	*Ref*					
3	-0.13	-0.71, 0.44	-0.09	-0.67, 0.49	-0.05	-0.61, 0.51
4	-0.36	-0.90, 0.18	-0.26	-0.80, 0.28	-0.21	-0.73, 0.32
5	-0.27	-0.82, 0.28	-0.12	-0.67, 0.43	-0.07	-0.60, 0.47
6	-0.90	-1.45, -0.34	-0.65	-1.22, -0.09	-0.48	-1.03, 0.07
7 (high education, high income)	-1.28	-1.89, -0.67	-0.96	-1.58, -0.33	-0.74	-1.35, -0.14

Model 1-linear regression model adjusted for age, site, sex, race; Model 2-Model 1 + CV risk factors (HDL, total cholesterol, BMI, smoking, alcohol), lipid lowering medications, diabetes; Model 3-Model 2 + BP, BP medications

2.3. Statistical analysis

Characteristics of the study population are presented as the mean and standard deviation for continuous variables and proportions for categorical variables overall and by educational attainment, annual household income, and race. Normality of distributions was tested using the Kolmogorov-Smirnov criterion. To develop the joint effects SES variable, we summed the education (range 1–4) and income (range 1–3) categories without weights, resulting in a combined SES score with ranges 2 (lowest education and income) through 7 (highest education and income). Associations of individual and joint SES with cfPWV were examined separately in the minimally and fully adjusted models, both in the overall cohort and separately by race using multivariable linear regression analyses. For the overall analyses, *model 1* adjusted for age, sex (male or female), race/ethnicity (African American or White), and ARIC race-center variable; *model 2* added HDL-C, total cholesterol, BMI, smoking (yes or no), current alcohol use (yes or no), lipid lowering medication use (yes or no), and diabetes (yes or no); and *model 3* added SBP, DBP and BP medication use (yes or no). To test whether the association between SES indicators and arterial stiffness differed by race, we included interaction terms between educational attainment and race and income and race. Interaction effects of race and individual SES measures on cfPWV were tested for significance based on the Wald Chi-square statistic. Statistical analyses were performed using SAS 9.4 (Cary, NC) and STATA, version 16 (StataCorp LP, College Station, Texas).

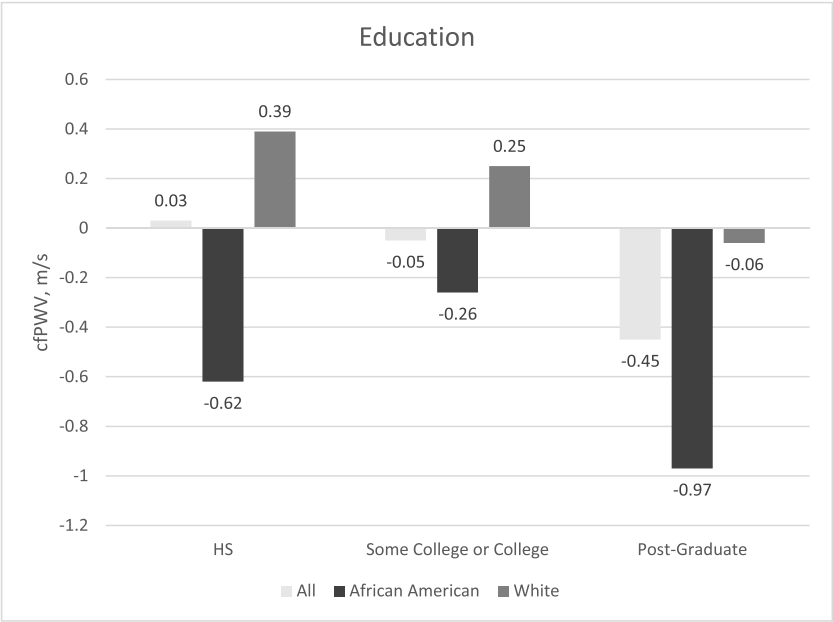


Fig. 2. Adjusted Beta's of education for the overall cohort, black, and white participants.
Legend: Light bar represents overall sample, Dark bar-African American participants, Gray bar-White participants. Abbreviation: <HS-less than high school, cfPWV-carotid femoral pulse wave velocity.

Table 4
Association of socioeconomic status and Joint effects of SES on Carotid Femoral Pulse Wave Velocity in African American Adults, ARIC Study, 2011-2013.

	Model 1 N=789		Model 2 N=765		Model 3 N=763	
	β	***95% CI***	***β***	***95% CI***	***β***	***95% CI***
Education						
<HS (Ref)						
HS	-0.40	-1.10, 0.30	-0.44	-1.15, 0.26	-0.62	-1.28, 0.05
≥Some college	-0.23	-0.88, 0.43	-0.20	-0.87, 0.46	-0.26	-0.89, 0.38
Post-graduate	-1.29	-1.98, -0.60	-1.14	-1.86, -0.43	-0.97	-1.65, -0.29
Income*						
<$25K (ref)						
$25K-<$50K	-0.90	-1.49, -0.31	-0.79	-1.39, -0.19	-0.69	-1.26, -0.13
$≥$50K	-0.86	-1.46, -0.27	-0.74	-1.35, -0.13	-0.57	-1.15, 0.01
Joint SESscore						
2 (low education, low income)						
3	-0.72	-1.49, 0.06	-0.71	-1.48, 0.07	-0.60	-1.34, 0.14
4	0.03	-0.72, 0.79	0.07	-0.70, 0.83	-0.02	-0.74, 0.71
5	-0.48	-1.34, 0.38	-0.52	-1.39, 0.36	-0.57	-1.40, 0.27
6	-1.39	-2.19, -0.58	-1.24	-2.06, -0.42	-0.90	-1.68, -0.11
7 (high education, high income)	-1.34	-2.18, -0.50	-1.16	-2.02, -0.29	-1.00	-1.83, -0.18

Model 1- linear regression model adjusted for age, site, sex; Model 2-Model 1 + CV risk factors (HDL, total cholesterol, BMI, smoking, alcohol), lipid lowering medications, diabetes; Model 3-Model 2 + BP, BP medications.

Table 5
Association of socioeconomic status and Joint effects of SES on Carotid Femoral Pulse Wave Velocity in Whites, ARIC Study, 2011-2013.

	Model 1 N=2573		Model 2 N=2540		Model 3 N=2525	
	β	***95% CI***	***β***	***95% CI***	***β***	***95% CI***
Education						
<HS (Ref)						
HS	0.16	-0.43, 0.76	0.30	-0.30, 0.89	0.39	-0.19, 0.97
≥Some college	-0.17	-0.78, 0.43	0.11	-0.50, 0.72	0.25	-0.35, 0.84
Post-graduate	-0.68	-1.38, 0.01	-0.28	-1.00, 0.43	-0.06	-0.76, 0.63
Income*						
<$25K (ref)						
$25K-<$50K	-0.42	-0.85, 0.01	0.68	0.04, 1.32	-0.35	-0.77, 0.07
$≥$50K	-0.74	-1.17, -0.31	-0.14	-0.88, 0.60	-0.48	-0.90, -0.05
Joint SES score						
2 (low education, low income)						
3	0.31	-0.54, 1.16	-0.46, 1.25	0.36	0.45	-0.38, 1.28
4	-0.27	-1.07, 0.53	-0.92, 0.69	0.77	0.01	-0.77, 0.80
5	-0.03	-0.83, 0.77	-0.60, 1.02	0.62	0.31	-0.48, 1.10
6	-0.60	-1.42, 0.22	-1.10, 0.56	0.52	-0.10	-0.90, 0.71
7 (high education, high income)	-1.08	-1.97, -0.19	-1.58, 0.25	0.15	-0.39	-1.28, 0.50

Model 1- linear regression model adjusted for age, site, sex; Model 2-Model 1 + CV risk factors (HDL, total cholesterol, BMI, smoking, alcohol), lipid lowering medications, diabetes; Model 3-Model 2 + BP, BP medications.

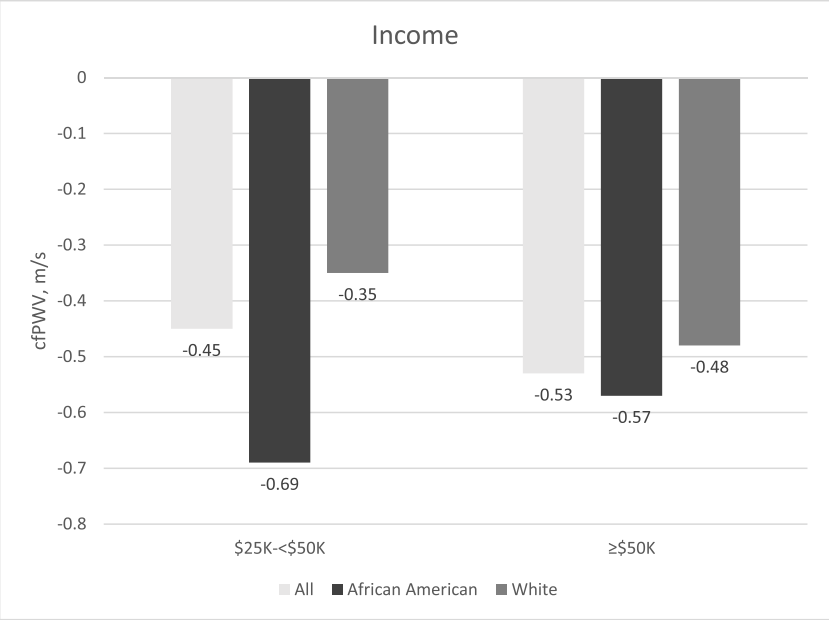


Fig. 3. Adjusted Beta's of income among the overall cohort, black, and white participants.
Legend: Light bar represents overall sample, Dark bar-African American participants, Gray bar-White participants. Abbreviation: <$25K, less than 25,000 dollars annually; $25K-<$50K, $25,000-less than $50,000; and ≥$50K-greater than or equal to $50,000.

Table 6
Main and Interaction effects between education, income, and race on PWV, ARIC Study, 2011-2013.

	Model 1 N=3362			Model 2 N=3307			Model 3 N=3290		
	β	*95% CI*	*p*-value	*β*	95% CI	*p*-value	*β*	95% CI	*p*-value
Education									
<HS	1.30	0.55, 2.05	0.001	1.07	0.32, 1.82	0.01	0.94	0.21, 1.67	0.01
HS	0.86	0.09, 1.63	0.03	0.60	-0.17, 1.38	0.13	0.30	-0.45, 1.05	0.44
≥Some college	1.01	0.30, 1.72	0.01	0.83	0.11, 1.55	0.02	0.65	-0.04, 1.35	0.07
Post-graduate	Ref			-			-		
Interaction									
Education X race			0.29			0.27			0.11
Income									
<$25K	0.74	0.10, 1.38	0.02	0.68	0.04, 1.32	0.04	0.50	-0.12, 1.12	0.12
$25K-<$50K	-0.20	-0.94, 0.53	0.59	-0.14	-0.88, 0.60	0.71	-0.25	-0.96, 0.47	0.50
$50K ≥	ref								
Interaction									
Income X race			0.30			0.37			0.46

Model 1-linear regression model adjusted for age, site, sex; Model 2-Model 1 + CV risk factors (HDL, total cholesterol, BMI, smoking, alcohol), lipid lowering medications, diabetes; Model 3-Model 2 + BP, BP medications.

3. Results

3.1. Participant characteristics

Participant characteristics, by educational attainment are shown in Table 1. Participants with lower education were slightly older, less likely to consume alcohol, and had a worse overall cardiovascular risk profile in both Whites and African American adults. Characteristics of the cohort by income and race are shown in Table 2. Participants with lower income were more likely to be older and female, less likely to drink alcohol, likely to be current smokers, and had a higher prevalence of cardiovascular risk factors.

3.2. Associations of educational attainment and annual household income with cfPWV

The association between educational attainment, income, and cfPWV for the overall sample is shown in Table 3 (Fig. 2). Compared to less than a HS education, a post-graduate education was associated with lower cfPWV in the minimally adjusted model 1, (β = -0.94 m/s, *95%* CI = -1.44, -0.44). Subsequent adjustment for CV risk factors in model 2 attenuated this association (β = -0.63 m/s, *95%* CI = -1.14, -0.12). Adjustment for BP and BP medications in model 3 further attenuated this association to a no longer statistically significant estimate. High income was inversely associated with cfPWV. Compared to participants with income <$25,000, those with income of $25,000-<$50,000 and ≥$50,000 had lower cfPWV [-0.56 m/s (95% CI = -0.91, -0.22) and -0.82 m/s (*95%* CI = -1.16, -0.47), respectively]. Following adjustments for CV risk factors in model 2 and additionally for BP and BP medications in the fully adjusted model 3, these associations remained unchanged among those earning $25,000-<$50,000 and slightly attenuated for those earning ≥$50,000. The joint effects of possessing both high educational attainment and income, compared to low education and low income, were robust and associated with lower cfPWV in the minimally [-1.28 m/s (95% CI=-1.89, -0.67) and fully [-0.74 m/s (*95%* CI = -1.35, -0.14)] adjusted models.

Race-stratified models are shown in Tables 4 and 5, (Fig. 3). Post-graduate versus less than high school education was associated with a

-1.29 m/s (*95*% CI = -1.98, -0.60) lower cfPWV in the minimally adjusted model among African American participants. These associations were reduced but remained significant after adjusting for CV risk factors (model 2) and BP and BP medications (model 3). Income of $25,000-<$50,000 and ≥$50,000 was associated with a lower cfPWV in the minimally adjusted models for African American participants [(-0.90 m/s (*95*% CI = -1.49, -0.31) and (-0.86 m/s (*95*% CI = -1.46, -0.27)], respectively (Table 4). In the fully adjusted model 3, associations for both income categories were attenuated, yet remained significant only among those earning $25,000-<$50,000 (-0.69 m/s (95% CI = -1.26, -0.13) while approaching significance among those earning ≥$50,000. The joint effects of both high educational attainment and income on arterial stiffness was strong for African American participants in both the minimally, joint SES score of 6 (-1.39 m/s (*95*% CI = -2.19, -0.58), joint SES score of *7* (-1.34 m/s (*95*% CI = -2.18, -0.50), and fully adjusted models. Among White participants, a post-graduate compared to less than high school education had a non-significant and weaker influence on cfPWV (Table 5; -0.68 m/s, *95*% CI = -1.38, 0.01). The analyses between income and cfPWV for White participants shows participants earning ≥$50,000 versus those earning <$25,000 had a -0.74 m/s (*95*% CI = -1.17, -0.31) lower cfPWV (Table 5; model 1). After adjustment for CV risk factors, these associations were attenuated but remained significant (Models 2 and 3). There was a significant and stronger association between the joint effects of higher SES and arterial stiffness among White participants in the highest SES group [joint SES score 7, -1.08 m/s (95%CI = -1.97, -0.19) in the minimally adjusted model]; however, upon adjusting for additional CVD risk factors, this association was reduced and no longer significant. Although race stratified results suggested associations might differ by race, formal tests of interaction between race and SES measures with cfPWV were not statistically significant (p>.10) (Table 6).

4. Discussion

In this cross-sectional cohort study of 3362 older African American and White adults free of CVD, we found inverse associations between household annual income and educational attainment with arterial stiffness, as measured by cfPWV. Our study hypothesis that higher SES would be associated with lower arterial stiffness with this association stronger among White versus African American participants was partially supported with the observation that high educational attainment and high household income were associated with lower arterial stiffness overall. Although interactions between race and SES with arterial stiffness was not significant, the association between high SES and arterial stiffness was stronger among African American versus White participants.

Few contemporary studies have assessed the disparities between race and subclinical CVD outcomes of arterial stiffness across SES strata among older adults. Din-Dzietham et al. [18] found that African American persons with a HS or above (versus less than a HS) education had greater arterial stiffness and a more recent study by Wendell et al. [17] also found that among early to late midlife African American participants with higher (versus lower) SES had greater arterial stiffness. Notably, neither study observed these patterns among White participants. Nevertheless, our study findings were in the expected direction of the SES-health gradient that possessing either higher education and/or income was associated with lower arterial stiffness for both African American and White participants [30,31]. A possible explanation for our findings is that the diminished returns hypothesis has a larger impact at the higher end of the SES distribution [12,32]. Recent findings from Spikes et. al in a cohort of African American women from a wide range of SES backgrounds only observed differences in daytime SBP among women making less than $35,000 compared to women earning more than $35,000, with very similar BPs between women earning, $35, 000-$49,999, $50,000-$74,999, and more than $75,000 [33]. The limited number of African American participants with a high income and/or a post-graduate education in the ARIC population could limit our ability to observe this pattern.

Similar to a prior analysis of the ARIC cohort [18], we also did not observe a statistically significant association between education and arterial stiffness for White participants despite prior findings suggesting stronger health effects of education for White versus African American adults [34,35]. However, we did observe the expected SES-health association of higher income linked to lower arterial stiffness. One potential factor that may underlie and explain the greater impact that income versus education has on arterial stiffness may be due to resource substitution which suggests that the more resources advantaged groups have, the less critical is each individual resource with respect to the individual's well-being [34]. Moreover, potential mediators of education quality, neighborhood of residence, and differential pay based on region that influence income and health, could be instrumental and may mitigate the effects of lower education on arterial stiffness in White populations [7,35]; yet further study is warranted to examine these relationships.

The combined effect of both education and income was found to be stronger and associated with lower arterial stiffness for the overall cohort and African American versus White participants. Specifically, participants with the highest educational attainment and income (versus those with the lowest) had lower arterial stiffness. Attainment of higher education and income generates access to an array of social resources and social capital that foster better health, including better wage earning jobs, access to health care, health literacy, health promotion, and healthier food choices [3,31].

Our study has several strengths. This study was performed using data from a large and well-characterized community-based cohort of older African American and White adults free of CVD that represent different geographic regions of the United States. We took advantage of the availability of cfPWV data, which is recognized as the gold standard measure of arterial stiffness, a robust and independent predictor of CVD [36,37]. Among our elderly cohort free of CVD, arterial stiffness measurements were within the expected range given the participants age, which is a robust risk factor for the development of arterial stiffness [38, 39]. Although the predictive value of arterial stiffness for CV events is considered higher in younger adults (<50 years) [38], our findings are still useful for risk stratification. A 1 m/s or 1-SD increase in PWV is associated with future CVD events and mortality [15,38,40]. A significant limitation is that our study had a relatively small number of African American participants, almost all of whom were from one field center, and a limited number of White participants in the lowest income categories, and African American participants in the highest income categories. These factors impacted our ability to conduct meaningful subgroup analyses and fully disentangle the influences of race versus region. Additionally, we were unable to disentangle the effects of race and education quality, specifically for the southern geographic region, since schools were segregated at the time of the participants' childhood, thereby making comparisons ineffectual. Despite the attainment of higher SES among African Americans participants, we were also unable to measure other factors associated with the effects of an underprivilege environment that may be associated with subclinical CVD such as race-related stress. Further studies are needed to compare larger racially and regionally diverse populations with a wider range of socioeconomic profiles to characterize the effects of SES resources between African American and White adults [41]. The mean age of our cohort was 75 (4.9) years, which may limit the amount of variability in PWV measures since SES-related disparities in health are more likely to decrease in late life as a result of selective mortality [42]. Third, our study was cross-sectional, therefore, temporal ordering could not be established. SES is a dynamic and complex measure that extends beyond traditional measures of education and income [43,44]; however other measures of individual SES such as wealth are not available in this cohort. Lastly, these findings may not be generalizable to other ethnic minority groups or younger adults.

4.1. Implications and conclusions

The current study has important clinical implications. Arterial stiffening is an objective preclinical marker, that confers CVD risk. Utilization of this measure in risk stratification may inform timely monitoring and assessment for blood pressure changes as well as initiate treatment modalities earlier to prevent hypertension-mediated CV outcomes. In summary we demonstrated that higher education and income was negatively associated with arterial stiffness in this overall cohort of older adults and within race strata. The joint effects of education and income were more robust among African American versus White participants and associated with lower arterial stiffness. Further detailed examinations into the social contextual and cultural contributions of subclinical CVD merits additional study in larger populations representing regional as well as racial and ethnic diversity.

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Statement of authorship

manuscript contributions made to the paper by each of the authors (Study conceptualization: **Telisa Spikes, Alvaro Alonso, Tené T. Lewis**. study design-**Telisa Spikes, Alvaro Alonso, Tené T. Lewis, B. Gwen Windham & Anna Kucharska-Newton**: conducted the analysis-**Telisa Spikes, Aniqa Alam, Alvaro Alonso**, wrote the paper-**Telisa Spikes**, provided final review- **Alvaro Alonso, Tené T. Lewis, B. Gwen Windham & Anna Kucharska-Newton**)

Author disclosures

No disclosures to declare.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

[1] Van Dyke ME, Greer S, Odom E, Schieb LJ, Vaughan AS, Kramer MR, et al. Heart disease death rates among blacks and whites aged ≥35 Years—United States, 1968-2015. Morb Mortal Wkly Rep 2018;67(5):1–11.
[2] 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 2019;10(25):1–11. https://doi.org/10.1016/j.tcm.2019.09.005.
[3] Bell CN, Thorpe RJ, Bowie JV, LaVeist TA. Race disparities in cardiovascular disease risk factors within socieconomic status strata. Ann Epidemiol 2017;28(3):147–52. https://doi.org/10.1016/j.annepidem.2017.12.007.
[4] Schutte AE, Kruger R, Gafane-Matemane LF, Breet Y, Strauss-Kruger M, Cruickshank JK. Ethnicity and arterial stiffness. Arter Thromb Vasc Biol 2020;40:1044–154. https://doi.org/10.1161/ATVBAHA.120.313133.
[5] Goel A, Maroules CD, Mitchell GF, Peshock R, Ayers CR, Vongpatanasin W, et al. Ethnic difference in proximal aortic stiffness: an observation from the dallas heart study. JACC Cardiovasc Imaging 2017;10(1):54–61. https://doi.org/10.1016/j.jcmg.2016.07.012.
[6] Baldo M, Cunha R, Ribeiro A, Lotufo P, Chor D, Barreto S, et al. Racial differences in arterial stiffness are mainly determined by blood pressure levels: results from the ELSA-Brasil study. J Am Heart Assoc 2017;6(e005477):1–11. https://doi.org/10.1161/JAHA.117.005477.
[7] Zajacova A, Lawrence EM. The relationship between education and health: reducing disparities through a contextual approach. Annu Rev Public Health 2018;39:273–89. https://doi.org/10.1146/annurev-publhealth-031816-044628.
[8] Farmer MM, Ferraro KF. Are racial disparities in health conditional on socioeconomic status? Soc Sci Med 2005;60(1):191–204. https://doi.org/10.1016/j.socscimed.2004.04.026.
[9] Brown TH, Richardson LJ, Hargrove TW, Thomas CS. Using multiple-hierarchy stratification and life course approaches to understand health inequalities: the intersecting consequences of race, gender, SES, and age. J Health Soc Behav 2016;57(2):200–22. https://doi.org/10.1177/0022146516645165.
[10] Assari S. Unequal gain of equal resources across racial groups. Int J Health Policy Manag 2017;7(1):1–9. https://doi.org/10.15171/ijhpm.2017.90.
[11] Assari S. The benefits of higher income in protecting against chronic medical conditions are smaller for African Americans than whites. Healthcare 2018;6(1):1–11. https://doi.org/10.3390/2Fhealthcare6010002 (Basel).
[12] Assari S. Health disparities due to diminished return among black Americans: public policy solutions. Social Issues Policy Rev 2018;12(1):112–45.
[13] Assari S, Cobb S, Saqib M, Bazargan M. Diminished returns of educational attainment on heart disease among black Americans. Open Cardiovasc Med J 2020;14:5–12. https://doi.org/10.2174/1874192402014010005.
[14] Terentes-Printzios D, Vlachopoulos C, Xaplanteris P, Loakeimidis N, Aznaouridis K, Baou K, et al. Cardiovascular risk factors accelerate progression of vascular aging in the general population results from the CRAVE study (Cardiovascular risk factors affecting vascular age). Hypertension 2017;70:1057–64. https://doi.org/10.1161/HYPERTENSIONAHA.117.09633.
[15] DeLoach SS, Townsend RR. Vascular stiffness: its measurement and significance for epidemiologic and outcome studies. Clin J Am Soc Nephrol 2008;3(1):184–92. https://doi.org/10.2215/CJN.03340807.
[16] Mozos I, Malainer C, Horbanczuk J, Gug C, Stoian D, Luca CT, et al. Inflammatory markers for arterial stiffness in cardiovascular diseases. Front Immunol 2017;8:1–16. https://doi.org/10.3389/fimmu.2017.01058.
[17] Wendell C, Waldstein SR, Evans MK, Zonderman A. Distributions of subclinical cardiovascular disease in a socioeconomically and racially diverse sample. Stroke 2017;48(4):850–6. https://doi.org/10.1161/STROKEAHA.116.015267.
[18] Din-Dzietham R, Couper D, Evans G, Arnett DK, Jones D. Arterial stiffness is greater in African Americans than in whites. Am J Hypertens 2004;17:304–13. https://doi.org/10.1016/j.amjhyper.2003.12.004.
[19] Yearby R, Clark B, Figueroa JF. Structural racism in historical and modern US health care policy. Health Aff 2022;41(2):187–94. https://doi.org/10.1377/hlthaff.2021.01466.
[20] Williams D, Lawrence J, Davis B. Racism and health: evidence and needed research. Annu Rev Public Health 2019;40(1):105–25. https://doi.org/10.1146/annurev-pubhealth-040218-043750.
[21] Kessler RC, Neighbors HW. A new perspective on the relationships among race, social class, and psychological distress. J Health Soc Behav 1986;27(2):107–15.
[22] Williams D, Priest N, Anderson N. Understanding associations between race, socioeconomic status and health: patterns and prospects. Health Psychol 2016;35(4):407–11. https://doi.org/10.1037/2Fhea0000242.
[23] Ciciurkaite G. Race/ethnicity, gender and the SES gradient in BMI: the diminishing returns of SES for racial/ethnic minorities. Sociol Health Illn 2020;43(8):1754–73. https://doi.org/10.1111/1467-9566.13267.
[24] Wright JD, Folsom AR, Coresh J, Sharrett AR, Couper D, Wagenknecht LE, et al. The ARIC (Atherosclerosis risk in communities) study: JACC focus seminar 3/8. J Am Coll Cardiol 2021;77(23):2939–59. https://doi.org/10.1016/j.jacc.2021.04.035.
[25] The ARIC investigators the atherosclerosis in communities (ARIC) study: desgn and objectives. Am J Epidemiol 1989;129(4):687–702.
[26] Meyer ML, Tanaka H, Palta P, Patel MD, Camplain R, Couper D, et al. Repeatability of central and peripheral pulse wae velocity measures: the atherosclerosis risk in communities (ARIC) study. Am J Hypertens 2016;29(4):470–5. https://doi.org/10.1093/ajh/hpv127.
[27] Cortez-Cooper M, Supak JA, Tanaka H. A new device for automatic measurements of arterial stiffness and ankle-brachial index. Am J Cardiol 2003;91(A9):1519–22.
[28] Meyer ML, Tanaka H, Plata P, Cheng S, Gouskova N, Aguilar D, et al. Correlates of segmental pulse wave velocity in older adults: the atherosclerosis risk in communities (ARIC) study. Am J Hypertens 2016;29(1):114–22.
[29] ARIC. ARIC manual 2 home and field center procedures ARIV visit 5 and NCS study protocol. Updated March 7, 2013. Accessed May 2, 2022, 2022. https://sites.cscc.unc.edu/aric/sites/default/files/public/manuals/Manual%202%20Home%20and%20Field%20Center%20Procedures.pdf.
[30] Schultz W, Kelli H, Lisko J, Varghese T, Shen J, Pratik S, et al. Socioeconomic status and cardiovascular outcomes: challenges and interventions. Circulation 2018;137(20):2166–78. https://doi.org/10.1161/CIRCULATIONAHA.117.029652.

[31] Havranek E, Mujahid M, Barr D, Blair I, Cohen M, Cruz-Flores S, et al. Social determinants of risk and outcomes for cardiovascular disease. Circulation 2015; 132:873–98. https://doi.org/10.1161/CIR.0000000000000228.
[32] Bell CN, Sacks TK, Tobin CTS, Thorpe RJ. Racial non-equivalence of socioeconomic status and self-rated health among African Americans and Whites. Soc Sci Med Popul Health 2020;10(100561):1–9. https://doi.org/10.1016/j.ssmph.2020.100561.
[33] Spikes T, Murden R, McKinnon II, Bromfield SG, Van Dyke ME, Moore RH, et al. Association of net worth and ambulatory blood pressure in early middle-aged African American Women. JAMA Netw Open 2022;5(2):1–13. https://doi.org/10.1001/jamanetworkopen.2022.0331.
[34] Ross CE, Mirowsky J. Sex differences in the effect of education on depression: resource multiplication or resource substitution? Soc Sci Med 2006;63:1400–13. https://doi.org/10.1016/j.socscimed.2006.03.013.
[35] Assari S. Perceived neighborhood safety better predicts risk of mortality for whites than blacks. J Rac Ethnic Disparities 2016:1–21. https://doi.org/10.1007/s40615-016-0297-x.
[36] Laurent S, Cockcroft J, Van Bortel L, Boutouyrie P, Giannattasio C, Hayoz D, et al. European network for non-invasive investigation of large arteries. Expert consensus document on arterial stiffness: methodological issues and clinical applications. Eur Heart J 2006;27:2588–605. https://doi.org/10.1093/eurheartj/ehl254.
[37] Lagrand WK, Visser CA, Hermens WT, Niessen HWM, Verheugt FWA, Wolbink G-J, et al. C-reactive protein as a cardiovascular risk factor. Circulation 1999;100(1): 96–102. https://doi.org/10.1161/01.CIR.100.1.96.
[38] Laurent S, Boutouyrie P. Arterial stiffness and hypertension in the elderly. Front Cardiovasc Med 2020:7544302. https://doi.org/10.3389/fcvm.2020.544302.
[39] Laurent S, Boutouyrie P, Cunha GP, Lacolley P, Nilsson PM. Concept of extremes in vascular aging from early vascular aging to supernormal vascular aging. Hypertension 2019;74:218–28. https://doi.org/10.1161/HYPERTENSIONAHA.119.12655.
[40] Kim H-L, Kim S-H. Pulse wave velocity in atherosclerosis. Front Cardiovasc Med 2019;6(1-13):41. https://doi.org/10.3389/fcvm.2019.00041.
[41] Pearson J. Can't buy me whiteness new lessons from the Titanic on race, ethnicity, and health. Du Bois Rev 2008;5(1):27–48. https://doi.org/10.1017/S1742058X0808003X.
[42] George LK. The life course perspective. In: Gu D, Dupre M, editors. Encyclopedia of gerontology and population aging. Cham: Springer; 2019. p. 1–9.
[43] Cubbin C, Pollack C, Flaherty B, Hayward M, Sania A, Vallone D, et al. Assessing alternative measures of wealth in health research. Am J Public Health 2011;101 (5):939–47. https://doi.org/10.2105/AJPH.2010.194175.
[44] Braverman P, Gottlieb L. The social determinants of health: it's time to consider the causes of the causes. Public Health Rep 2014;129(2):19–31. https://doi.org/10.1177/2F003335491412915206.