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Arterial Stiffness Is Greater in African Americans Than in Whites

Evidence From the Forsyth County, North Carolina, ARIC Cohort

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Background: Impairment of arterial dilation is thought to occur earlier than arterial wall thickening in the atherosclerotic process. In comparison with whites, African Americans reportedly have a generalized attenuation of their vasodilation mechanisms. We set out to evaluate arterial stiffness and its correlates by ethnicity, hypothesizing that African Americans would have stiffer common carotid arteries (ie, lower arterial distension for a given systolic pressure) than their white counterparts.

Methods: The study population included 268 African Americans and 2459 whites, who were aged 45 to 64 years at baseline examination in 1986 to 1989, free of coronary heart disease and stroke/transient ischemic attack, from Forsyth County, North Carolina. The β stiffness index and pulsatile arterial diameter change were derived from brachial blood pressure and from echo-tracked systolic and diastolic carotid arterial diameters.

Results: African Americans had stiffer carotid arteries than their white counterparts, with a right shift of the β stiffness index distribution. After adjustment for selected cardiovascular risk factors, the mean β stiffness index was 9% higher for African Americans (mean $\pm$ SEM: 11.3 $\pm$ 0.3) than for whites (mean $\pm$ SEM: 10.3 $\pm$ 0.1) among participants not taking antihypertensive medication. Socioeconomic status and comorbidities were differentially associated with arterial stiffness by ethnicity. Specifically, the association between these correlates and β stiffness index was stronger in African Americans than in whites.

Conclusions: This report on arterial mechanics in African Americans suggests that large artery stiffening either occurs earlier, or is more accelerated in African Americans than in whites in our sample, perhaps as a result of earlier exposure to multiple risk factors. This finding may have implications for hypertension prevention, as arterial stiffness is associated with the development of hypertension. Am J Hypertens 2004;17: 304–313 © 2004 American Journal of Hypertension, Ltd.

Key Words: Arterial stiffness, carotid artery, race/ethnicity, population-based, risk factors, hypertension prevention.

In the United States, African Americans have higher prevalence[1] and incidence[2] of hypertension and of end-organ damage than whites. These patterns have stimulated a large body of research to identify the determinants of this disproportionally higher burden of hypertension and its sequelae in African Americans. In the past, primarily due to technological limitations, greater attention was given to small artery (ie, increased peripheral vascular resistance) than to larger artery impairment as a hallmark of hypertension.[3] In the past two decades, the improvement of noninvasive, accurate, and reliable ultrasound techniques[4] has made it possible to quantitatively evaluate morphometric and functional aspects of large arteries.

Initially ultrasound studies focused on the investigation of arterial wall thickness as a marker of atherosclerosis.[5]

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Studies of the large arteries function were subsequently fostered by several findings. First, in epidemiologic studies systolic blood pressure (SBP), a major correlate of large artery elasticity, was a stronger predictor of cardiovascular events and death than diastolic blood pressure (DBP).[6,7] Second, large artery disease was shown to differ from small artery disease with respect to epidemiologic and pathophysiologic characteristics.[8] Finally, recent data suggest that impairment of arterial dilation may precede arterial wall thickening.[9]

The scarcity of data on arterial mechanics in African Americans,[10] their differential response to antihypertensive medication,[11] and the high toll they pay to hypertension led us to explore the stiffness of the common carotid artery (CCA) in African Americans in the Atherosclerosis Risk In Communities (ARIC) study. The main objectives were to address the following questions: 1) Do African Americans have stiffer elastic arteries than whites independently of age, sex, BP, body mass index, and artery diameter? 2) Do major cardiovascular risk factors other than age, sex, BP, body mass index, and arterial diameter offer a statistical explanation (and thereby insight into potential explanatory mechanisms) for a differential arterial stiffness by ethnicity? 3) Are these factors differentially associated with arterial stiffness within each ethnic group?

Methods

Study Population

The ARIC study included 15,792 participants, aged 45 to 64 years at enrollment, randomly selected from four U.S. locations: suburban Minneapolis, MN; Forsyth County, NC; Jackson, MS; and Washington County, MD.[5] To evaluate the ethnic differences in arterial stiffness free of confounding by study site, our analysis was restricted to the residents of Forsyth County, the only center that recruited sizable numbers of residents from both ethnic groups. Of the 4036 participants from this center, 2977 had pulsatile data. Additional exclusions were SBP $\leq$70 mm Hg or pulse pressure $\leq$0 mm Hg ($n = 3$) and symptomatic cardiovascular disease ($n = 247$). The final sample included 2727 participants, of whom 268 were African American and 1529 were women. The University of North Carolina Institutional Review Board approved the study and subjects gave written informed consent.

Study Variables

Outcome The pulsatile arterial diameter change (PADC) and the β index measured arterial stiffness (β). The β was derived from the echo-tracked systolic (SAD) and diastolic (DAD) CCA diameters, and from the oscillometrically (DINAMAP 1846-SX; Vital Signs Monitors, Tampa, FL) measured brachial BP. Details of the ultrasound method have been described elsewhere.[12] Supine BP, the average of all BP measures taken at 5-min intervals during the ultrasound examination, was modeled as actual BP and as ethnic-specific percentile rank. These data were used to compute PADC (PADC = SAD − DAD) and the β index.[13] Stiffer arteries are associated with smaller diameter changes for a given difference in pressure (ie, smaller PADC and larger β).

Exposure and Covariates Only participants classifying themselves as African American or white were included in this analysis. Age, body mass index, waist-to-hip ratio, education, household income, cigarette smoking, hypertension, and diabetes were self-reported. Fasting blood chemistries included cholesterol, triglycerides, HDL cholesterol, calculated LDL cholesterol, von Willebrand factor, fibrinogen, glucose, and insulin. Ultrasound measurements from the left CCA were used in this study, as they match the site of measurement of PADC. All procedures were in accordance with institutional guidelines.

Statistical Analyses

Graphic spline smoothing models found a linear relationship to be adequate for all variables except DBP, lifetime cigarette use, and triglycerides. The main association was evaluated by multiple regression modeling in the whole study population and in the subset of participants who were not using antihypertensive medication. Quadratic terms were included for curvilinear dose–response shapes.

To answer the second question, nested ethnicity inclusive (unstratified) models were fit, with additional covariates included in the full model one at a time, then aggregated based on the magnitude of the change of the estimate of interest. To answer the third question, we fitted the fullest model including all two-way interaction terms between ethnicity and all covariates to check which ones were modifiers, and then fitted the ethnicity-specific models. The nominal value for significance of main and interactive effect was set at 0.05 and 0.10, respectively. All analyses were carried out with the Statistical Analysis Software, version 6.12 (SAS Institute, Cary, NC).

Results

Population Characteristics

The four ethnicity–gender groups were of comparable age (Table 1). African Americans reported less formal education than their white counterparts. African-American women had the lowest household income; 40% of them earned less than $16,000 per year. The prevalence of hypertension and diabetes in African Americans was twice that of whites. African-American women had the largest mean body mass index values. African Americans had higher values for fasting blood glucose levels, considerably higher insulin levels, and markedly lower values for triglycerides.

Brachial artery hemodynamics and CCA dimensions also displayed a pattern of ethnic and sex differences (Table 2). Men had larger arterial diameter and wall thick-

Table 1. Demographic, socio-economic, behavioral, comorbidity anthropometric, and biological characteristics in the Forsyth County cohort by sex and ethnicity

Parameter	Overall	Women		Men	
		African Americans	Whites	African Americans	Whites
n (%)	2727 (100)	168 (6.2)	1361 (49.9)	100 (3.7)	1098 (40.3)
Demographics					
Age (y)	56.7 ± 5.9	56.8 ± 5.8	56.9 ± 6.0	56.4 ± 6.2	56.5 ± 5.8
Socioeconomic factors (%)					
Education					
<High school	14.5	19.6	13.6†	26.0	13.8‡
High school graduate	42.7	37.7	49.0	37.0	35.9
>High school	42.8	41.7	37.3	37.0	50.3
Household income					
<$16,000	13.0	40.3	14.1§	21.7	6.7§
$16,000–$35,000	32.6	37.2	34.5	42.2	28.7
$35,000+	54.3	22.5	51.4	36.1	64.6
Behavioral factors					
Smoking status (%)					
Current	26.4	33.9	25.5*	46.5	24.7§
Former	35.2	22.6	26.2	27.3	49.1
Never	38.3	43.5	48.3	26.3	26.2
Cigarettes (pack-years)	16.6 ± 21.8	9.0 ± 12.9*	11.6 ± 17.7	21.8 ± 23.5	23.5 ± 24.9
Comorbidity factors (%)					
Hypertension	28.3	55.4	23.2§	51.0	28.4§
Diabetes	10.4	18.0	7.7§	24.2	11.4‡
Antihypertensive medication use	17.9	41.7	14.6§	33.0	17.0§
Anthropometric characteristics					
Body mass index (kg/m^2)	26.1 ± 4.4	28.8 ± 5.6	25.3 ± 4.6§	26.8 ± 4.6	26.6 ± 3.5
Waist-to-hip ratio	0.910 ± 0.083	0.899 ± 0.074	0.866 ± 0.081§	0.945 ± 0.049	0.963 ± 0.051‡
Biological risk factors					
Fasting glucose (mmol/L)	6.0 ± 1.9	6.6 ± 3.0	5.8 ± 1.7§	6.8 ± 3.0	6.1 ± 1.7‡
Fasting insulin (μU/mL)	12.0 ± 23.7	20.4 ± 60.5	9.7 ± 12.9§	22.4 ± 67.1	12.6 ± 14.1§
HDL cholesterol (mmol/L)	1.3 ± 0.5	1.5 ± 0.4	1.5 ± 0.5	1.2 ± 0.4	1.1 ± 0.3§
LDL cholesterol (mmol/L)	3.4 ± 0.9	3.3 ± 1.0	3.3 ± 1.0	3.4 ± 1.1	3.4 ± 0.9
Triglycerides (mmol/L)	1.5 ± 1.1	1.1 ± 0.5	1.5 ± 0.9§	1.3 ± 0.7	1.7 ± 1.3†
Total cholesterol (mmol/L)	5.4 ± 1.0	5.3 ± 1.0	5.5 ± 1.0*	5.2 ± 1.1	5.2 ± 1.0
Fibrinogen (μmol/L)	8.7 ± 1.8	9.6 ± 1.9	8.7 ± 1.8§	9.0 ± 1.7	8.5 ± 1.8†
von Willebrand factor (%)	111.5 ± 43.3	129.8 ± 54.4	121.6 ± 46.8§	109.7 ± 41.9	110.0 ± 42.1†

Data are mean ± SD unless otherwise specified (%).
* $P = .050–.070$; † $P = .049–.010$; ‡ $P = .009–.001$; § $P < .0001$.

Table 2. Common carotid artery dimensions and brachial artery hemodynamic parameters in the Forsyth County cohort by sex and ethnicity

Parameter	Overall	Women		Men	
		African Americans	Whites	African Americans	Whites
n (%)	2727 (100)	168 (6.2)	1361 (49.9)	100 (3.7)	1098 (40.3)
Common carotid artery characteristics					
Diastolic arterial diameter (mm)	7.483 ± 0.855	7.403 ± 0.871	7.111 ± 0.733‡	7.983 ± 0.799	7.912 ± 0.772
Systolic arterial diameter (mm)	7.879 ± 0.884	7.756 ± 0.895	7.505 ± 0.757‡	8.367 ± 0.802	8.317 ± 0.813
Pulsatile arterial diameter change# (mm)	0.396 ± 0.124	0.353 ± 0.117	0.395 ± 0.115‡	0.384 ± 0.141	0.405 ± 0.132
Distension ratio#	0.05 ± 0.02	0.048 ± 0.016	0.056 ± 0.017‡	0.049 ± 0.019	0.051 ± 0.016
Left far wall thickness (mm)	0.647 ± 0.159	0.671 ± 0.165	0.615 ± 0.144‡	0.737 ± 0.176	0.675 ± 0.164†
Wall-to-radius ratio	0.170 ± 0.040	0.177 ± 0.040	0.169 ± 0.037*	0.181 ± 0.044	0.167 ± 0.039†
β index (adventitial diameter)	10.73 ± 4.05	12.85 ± 5.25	10.76 ± 4.00‡	11.60 ± 4.70	10.29 ± 3.60†
β index (internal diameter)	7.34 ± 2.43	8.49 ± 2.99	7.44 ± 3.50‡	7.43 ± 2.49	7.03 ± 2.10†
Brachial artery hemodynamics					
Systolic blood pressure (mm Hg)	120.5 ± 17.9	131.1 ± 22.5	116.2 ± 17.0‡	132.8 ± 21.8	123.1 ± 15.9‡
Diastolic blood pressure (mm Hg)	71.3 ± 9.7	74.7 ± 10.6	66.7 ± 8.3‡	80.2 ± 10.5	75.7 ± 8.1‡
Pulse pressure (mm Hg)	49.2 ± 13.2	56.4 ± 16.5	49.4 ± 13.5‡	52.6 ± 14.9	47.4 ± 11.5‡
Mean arterial pressure (mm Hg)	87.7 ± 11.4	93.5 ± 13.6	83.2 ± 10.1‡	97.7 ± 13.5	91.5 ± 9.9‡
Heart rate (beat/min)	65.8 ± 10.0	66.7 ± 10.8	67.4 ± 9.7	63.8 ± 9.9	63.9 ± 9.8

Data are mean ± SD.

Pulsatile arterial diameter change = systolic arterial diameter (SAD) − diastolic arterial diameter (DAD); distension ratio (strain) = (SAD−DAD)/DAD.

* $P = .050–.070$; † $P = .0009–.0001$; ‡ $P < .0001$.

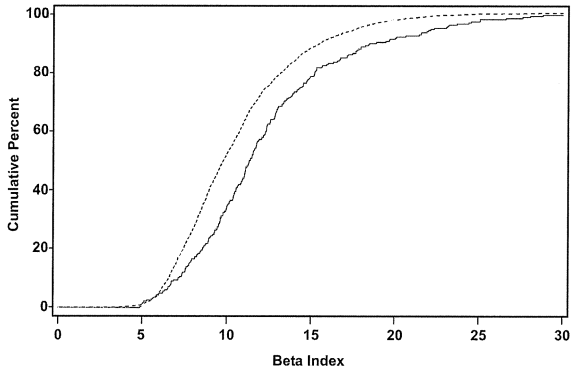

FIG. 1. Unadjusted cumulative distribution curve. The **solid line** represents African Americans and the **dashed line** represents whites.

ness, but the wall-to-radius ratio was slightly greater for African Americans than for whites because of their larger intima-media thickness (IMT). All BP components were greater for African Americans than for whites. African Americans had stiffer CCA as expressed by the cumulative distribution curve (Fig. 1; Kolmogorov-Smirnov test $P <$ .001). The ethnic difference remained significant after performing a Welch corrected t test to account for the ethnic differential in variances ($P <$ .001). The unadjusted between-group difference was 1.9 (1.4, 2.4) for β and −35 (−50, −19) microns for PADC.

Regression Analysis

Association Overall, African Americans had statistically significantly stiffer CCA than their white counterparts after adjustment for age, SBP and DBP, DAD, and body mass index (Table 3). Adjusted mean PADC was lower by 7% and adjusted mean β greater by 12% for the former compared with the latter. After exclusion of those receiving antihypertensive therapy, the ethnic difference was reduced to 6% and 9% for PADC and β, respectively. Women had stiffer arteries than men, with sex differences in adjusted mean β and PADC of a similar magnitude as ethnic differences.

Explanatory Regression Modeling Beyond age, sex, body mass index, SBP, DBP, and DAD, which were included in the reference model, hypertension, diabetes, and income further explained the ethnic difference in arterial stiffness, which was reduced to 10.2% ($P <$ .0001). Even when all the "established" cardiovascular disease risk factors were included in the model, there remained a significant ethnic difference in arterial stiffness (12.1%, $P <$ .0001). The pattern of association of ethnicity with PADC followed that of the β (data not shown).

Ethnicity-Specific Correlates of Arterial Stiffness In the reference model, the two-way interaction terms between ethnicity and IMT on the one hand, and DAD on the other (P = .08 for both terms) were statistically significant. However, in the fullest unstratified model, these interactions were no longer significant. The DAD and IMT are important factors to explore as they reflect the vascular remodeling process.[14] In this fullest model, education, income, hypertension, diabetes, and triglycerides were differentially associated with arterial stiffness by ethnicity (P for interaction $<$ .10 for all; Table 4). The ethnic-specific models showed that mean β, in relation to socioeconomic status and comorbidity variables, was greater in African Americans than in whites (Table 4). Most of the factors were statistically independent correlates of arterial stiffness in both groups.

Discussion

In this study—restricted to ARIC participants from Forsyth, North Carolina—African Americans had stiffer CCA than whites. This difference, observed in participants without symptomatic atherosclerosis and not taking antihypertensive medications, and persistent after correction for unequal variances, was in part explained by age, BP, body mass index, and DAD, but remained statistically significant after adjustment for these factors. Adjustment for hypertension, diabetes, and income further reduced the ethnic difference. The final adjusted mean β was roughly 9% higher and PADC 6% lower for African Americans not taking antihypertensive medication than for their white counterparts. Correlates of arterial stiffening were not identical in these ethnic groups. To our knowledge, this is the first report of such findings.

Few studies have reported on β and PADC values in African Americans, and none are population-based or can serve as comparison to the ones reported here. Our values for mean β [SD] derived from the internal diameter for whites are in the same range as those observed in small-scale studies in women (9.8 [4.1]) and men (8.1 [2.3]) in their sixth decade, in Sweden.[15] The only study describing the age distribution of β derived from the adventitial diameter, as was done for our study, was published on Japanese examinees.[16] The CCA mean β (SD) was 11.3 (2.0) among men and women ≥60 years old. Several studies have assessed ethnic differences in arterial stiffness using pulse wave velocity (PWV)[10,17] or pulse wave analysis of the radial[18,19] or brachial artery.[20] Three studies found stiffer arteries in African Americans than in whites, although the results were not adjusted for confounding factors.[10,18,20] In Ferreira's study,[10] hypertensive Brazilian-born male soldiers of African descent had greater mean PWV (stiffer aorta) than their white counterparts, whereas normotensive African Americans had lower values than their white counterparts. However, the slope of increase of aortic stiffness with SBP was steeper for Africans than for whites along the entire range of observed BP. In Prisant's study,[18] in contrast, the data suggested that small arteries were stiffer among normotensive African Americans compared with their white counterparts, but not among untreated or controlled hypertensives. Greater arterial stiffness was also observed among the

Table 3. Least-squares mean pulsatile arterial diameter change and β index ($\pm$SE) in Forsyth cohort for ethnic and sex groups

Parameter	*n*	Mean Pulsatile Arterial Diameter Change ± SEM* (microns)			Mean β Index ± SEM*		
		Crude	Absolute BP†	Percentiles BP‡	Crude	Absolute BP†	Percentiles BP‡
Total population							
African Americans	268	365 ± 8	379 ± 7	373 ± 7	12.5 ± 0.2	11.5 ± 0.2	12.0 ± 0.2
Whites	2459	399 ± 2	399 ± 2	399 ± 2	10.5 ± 0.1	10.6 ± 0.1	10.6 ± 0.1
Ethnic difference‖ (%)		−10	−5	−7	16	8	12
P value for difference = 0		.0001	.007	.006	.0001	.0001	.0001
Women	1529	391 ± 3	385 ± 3	387 ± 3	11.0 ± 0.1	11.0 ± 0.1	11.1 ± 0.1
Men	1198	403 ± 4	410 ± 4	408 ± 4	10.4 ± 0.1	10.4 ± 0.1	10.3 ± 0.1
Sex difference‖ (%)		−3	−7	−5	5	6	7
P value for difference = 0		.0001	.0001	.0001	.0004	.0001	.0001
Participants with self-report of antihypertensive medication excluded							
African Americans	165	373 ± 10	381 ± 9	377 ± 9	11.4 ± 0.3	10.9 ± 0.3	11.3 ± 0.3
Whites	2071	401 ± 3	401 ± 2	401 ± 2	10.3 ± 0.1	10.3 ± 0.1	10.3 ± 0.1
Ethnic difference‖ (%)		−8	−5	−6	11	6	9
P value for difference = 0		.003	.03	.009	.002	.03	.0001
Women	1259	392 ± 3	390 ± 4	392 ± 4	10.6 ± 0.1	10.6 ± 0.1	10.6 ± 0.1
Men	977	409 ± 4	411 ± 4	409 ± 4	10.1 ± 0.1	10.1 ± 0.1	10.0 ± 0.1
Sex difference‖ (%)		−4	−5	−4	5	5	6
P value for difference = 0		.001	.0003	.003	.001	.008	.0007

* Estimates obtained in the multiple regression model performed with PROC GLM in SAS and based on the least-squares means with coefficients across classification effects proportional to observed margins. All estimates represent main effects for ethnicity and sex.

† Model included ethnicity, sex, age, diastolic diameter, systolic blood pressure, diastolic blood pressure linear and squared, body-mass-index, all continuous.

‡ Same model as in previous model† but blood pressure components are ethnicity-specific percentiles.

‖ Ethnic/sex difference = (mean β index/PADC for African Americans − mean β index/PADC for whites)/mean β index/PADC for African Americans.

Table 4. Correlates β index within ethnic groups*

Parameter	Ethnicity-specific Models: African Americans (n = 268) Regression Coefficient ± SEM†	African Americans (n = 268) *P* Value for Coefficient = 0	Whites (n = 2459) Regression Coefficient ± SEM†	Whites (n = 2459) *P* Value for Coefficient = 0	Ethnicity-inclusive Model *P* Value for Interaction = 0
Model R^2 (*P* value for variance explained = 0)	0.32 ($P < .0001$)		0.28 ($P < .0001$)		
Age (y)	0.15 ± 0.05	.004	0.14 ± 0.01	.0001	
Diastolic arterial diameter (mm)	0.71 ± 0.38	.06	0.49 ± 0.10	.0001	
Systolic blood pressure (mm Hg)	0.04 ± 0.01	.005	0.05 ± 0.003	.0001	
Diastolic blood pressure (mm Hg)‡	−0.03 ± 0.01	.01	−0.03 ± 0.003	.0001	
Diastolic blood pressure^2 (mm^2 Hg)‡	0.0006 ± 0.0003	.09	0.0003 ± 0.00009	.0004	
Insulin (μU/mL)	0.009 ± 0.005	.06	0.006 ± 0.006	.32	
HDL cholesterol (mmol/L)	0.55 ± 0.77	.48	0.08 ± 0.20	.68	
LDL (mmol/L)§	0.11 ± 0.05	.03	0.02 ± 0.02	.30	
Triglycerides (mmol/L)‡,§	−0.16 ± 0.13	.22	0.13 ± 0.04	.002	.04
Body mass index (kg/m^2)	0.12 ± 0.07	.05	0.07 ± 0.02	.0002	
Waist-to-hip ratio	1.17 ± 5.24	.82	1.05 ± 1.18	.37	
	Mean β index ± SEM†	***P* value for difference = 0**	**Mean beta index ± SEM†**	***P* value for difference = 0**	
Sex					
Women	12.6 ± 0.4	.35	10.9 ± 0.1	.0001	
Men	11.9 ± 0.6		10.0 ± 0.1		
Smoking					
Never/former	12.4 ± 0.3	.49	10.6 ± 0.1	.0001	
Current	12.0 ± 0.4		10.0 ± 0.1		
Hypertension					
No	11.7 ± 0.4	.08	10.4 ± 0.1	.004	.05
Yes	12.8 ± 0.4		10.9 ± 0.1		
Diabetes					
No	12.0 ± 0.3	.07	10.5 ± 0.1	.58	.10
Yes	13.4 ± 0.8		10.7 ± 0.2		
Income					
$5,000–$15,999	13.4 ± 0.5	.03	10.8 ± 0.2		
$16,000–$34,999	12.2 ± 0.4		10.6 ± 0.1	.07	.01
$35,000+	11.3 ± 0.6		10.4 ± 0.1		
Education					
<High school	11.7 ± 0.6	.05	10.7 ± 0.2		
High school graduate	11.9 ± 0.4		10.3 ± 0.1	.24	.03
>High school	13.2 ± 0.5		10.6 ± 0.1		

* Ethnicity-specific regression models. See footnote to Table 3 for statistical procedure.

† Each variable is adjusted for the others.

‡ Variables with a quadratic fit centered to their mean to decrease colinearity.

§ Estimates derived from ethnicity-inclusive model, based on main and interaction term coefficient, using option ESTIMATE of Proc GLM.

African-American young adults enrolled in the Bogalusa study,[20] but not among the elderly participants in the Cardiovascular Health Study.[17] At the pathophysiologic level, attenuation of endothelium-dependent as well as endothelium-independent vasodilation, the potential underlying mechanism for arterial stiffening, has been described in normotensive and hypertensive African Americans by many investigators.[21,22] In our study, women had stiffer CCA than men after control for several variables, whereas the opposite was observed in the Bogalusa younger study population. Sex differences in arterial dynamics have been related to body height,[23] and estrogen effect,[24] and the age-related switch of the sex difference has been described by other researchers[25] and attributed to a hormonal effect.

A concern with these results is whether the observed ethnic differences in arterial stiffness merely reflect ethnic differences in the hypertension course. Adjusting for hypertension reduced the ethnic difference the most but might not have totally accounted for the confounding effect of medication. These antihypertensive medications have a direct variable effect on arterial stiffness and access and responsiveness to treatment vary by ethnicity. Our analyses in the subset not taking antihypertensive medication mitigated this concern, as a statistically significant 9% ethnic difference in arterial stiffness persisted. Although we adjust for level of risk factors at the time of examination, a residual confounding by duration of exposure to risk factors may have persisted, as African Americans more often exhibit multiple risk factors.

Some of the limitations of our study include potential selection bias, the substitution of static brachial pressure for dynamic carotid pressure, and residual and latent confounding. These are outlined.

There are several ways that selection bias may have affected our estimates of ethnic differences in arterial stiffness. Response rates differed by ethnicity. Furthermore, we were able to obtain technically optimal pulsatile data on only a subset of participants. Last, the exclusion of prevalent coronary heart disease, stroke, and transient ischemic attack may have differentially removed white and African American participants because of ethnic differences in risk, in access to medical care, and in the expression, recognition, and reporting of clinical symptoms.

The important issue of substituting brachial for carotid BP stems from the site-specificity of arterial behavior, which calls to measure both dimensions and pressure at the same site.[26] Thus, one assumption we make is that brachial BP measured noninvasively by an oscillometric device is an acceptable approximation of the CCA intra-arterial pressure. Brachial BP correlates very well with intracarotid pressure, although it is higher by 10% to 15%,[27] as a result of the amplification phenomenon.[26] Self-calibrating automated devices also yield slightly higher values of SBP and lower DBP and consequently, larger pulse pressure than the auscultatory method,[28] although its high levels of repeatability rule out the well-known observer differences in BP measurement and possible differences by ethnicity of the examinee. However, because the BP measurement error does *not* vary by ethnicity,[29] adjusting for pulse pressure removes, in a similar fashion for African Americans and whites, that part of the effect on arterial stiffness that is due to pulse pressure. The ethnic difference remained significant after such adjustment.

Beta index was directly associated with education among African Americans ($P = .05$), but not among whites, and strongly and inversely associated with income ($P = .01$) in the former. This differential association by ethnicity may reflect the incommensurability of socioeconomic status variables.[30] The unexpected stiffer CCA in African Americans with higher education may be the result of the small sample size in the higher education–lowest income level group (data not shown). The small sample size prevented us from exploring this discrepancy termed social incongruity by Dressler,[31] and reported by other investigators.[32] The potential residual confounding by incomplete control of socioeconomic status factors in models including socioeconomic status, which would act by inflating the ethnic difference in arterial stiffness,[30] was addressed by not including socioeconomic status in the reference model and by stratifying regression analyses by ethnicity. Finally, the observed difference may also be related to latent confounding by unmeasured variables, such as markers of vasodilation, more specific vessel structure variables, and parameters of kidney function.

Also to be mentioned as limitations of these findings, the cross-sectional design is open to temporal ambiguity; thus the explanatory variables merely suggest antecedent factors, to be confirmed or refuted in prospective studies. Furthermore, the "generalizability" of the results is of concern as we used a single center to evaluate the ethnic differences in arterial stiffness.

Despite these limitations, these results are important. Although ethnicity, as an epidemiologic exposure variable, is a blunt instrument to measure population differences in arterial stiffness, as it applies to several dimensions (eg, historic, cultural, socioeconomic, and genetic) and defines populations with large within-group heterogeneity,[33] the magnitude of the observed ethnic difference in β is meaningful. It is of the same order as that observed between patients with angiographically normal coronaries ($\beta \pm$ SD: 9.2 ± 2.2) and those with angiographically significant coronary artery disease ($\beta \pm$ SD: 11.6 ± 3.2),[34] and between baseline values for ARIC participants who 6 years later developed hypertension ($\beta \pm$ SD: 11.9 ± 4.7) versus those who did not ($\beta \pm$ SD: 10.3 ± 3.8).[35] In addition, factors that differentially correlated with arterial stiffness by ethnicity were factors whose environmental contribution to their variance is reportedly greater than the genetic component (eg, income, education, hypertension, diabetes, and triglycerides).[36,37] Therefore, we submit that environmental—modifiable—factors, particularly socioeconomic status, may contribute

to the observed greater arterial stiffness in African Americans compared with whites. Prospective studies will elucidate the temporal and causal interplay between these factors and arterial stiffness. Because arterial stiffness is an early and reversible stage of the atherosclerotic process and predicts incident hypertension,[35] monitoring of this subclinical sign, along with BP,[38] in people at risk[39,40] and modulation of the modifying factors may prevent initiation or progression of this early stage of disease and thus has the potential to reduce ethnic cardiovascular disease disparities.

In conclusion, this is the first population-based report showing that African Americans who are free of clinical manifestations of atherosclerosis have significantly stiffer CCA than their white counterparts, after adjustment for major cardiovascular disease risk factors. The cross-sectional design does not allow us to conclude whether arterial disease occurs earlier or is more severe in African Americans compared with whites. Correlates for arterial stiffening that statistically differ by ethnicity are mostly environmental factors or factors with an important environmental etiologic component (eg, socioeconomic status, hypertension, diabetes, and lipids). These results bear their importance in the context of hypertension prevention.

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