Race–Ethnic and Sex Differences in Left Ventricular Structure and Function: The Coronary Artery Risk Development in Young Adults (CARDIA) Study

Satoru Kishi, MD; Jared P. Reis, PhD; Bharath A. Venkatesh, PhD; Samuel S. Gidding, MD; Anderson C. Armstrong, MD; David R. Jacobs, Jr, PhD; Stephen Sidney, MD, MPH; Colin O. Wu, PhD; Nakela L. Cook, MD, MPH; Cora E. Lewis, MD, MSPH; Pamela J. Schreiner, PhD; Akihiro Isogawa, MD, PhD; Kiang Liu, PhD; João A. C. Lima, MD

Background—We investigated race–ethnic and sex-specific relationships of left ventricular (LV) structure and LV function in African American and white men and women at 43 to 55 years of age.

Methods and Results—The Coronary Artery Risk Development in Young Adults (CARDIA) Study enrolled African American and white adults, age 18 to 30 years, from 4 US field centers in 1985–1986 (Year-0) who have been followed prospectively. We included participants with echocardiographic assessment at the Year-25 examination (n=3320; 44% men, 46% African American). The end points of LV structure and function were assessed using conventional echocardiography and speckle-tracking echocardiography. In the multivariable models, we used, in addition to race–ethnic and gender terms, demographic (age, physical activity, and educational level) and cardiovascular risk variables (body mass index, systolic blood pressure, diastolic blood pressure, heart rate, presence of diabetes, use of antihypertensive medications, number of cigarettes/day) at Year-0 and -25 examinations as independent predictors of echocardiographic outcomes at the Year-25 examination (LV end-diastolic volume [LVEDV]/height, LV end-systolic volume [LVESV]/height, LV mass [LVM]/height, and LVM/LVEDV ratio for LV structural indices; LV ejection fraction [LVEF], Ell, and Ecc for systolic indices; and early diastolic and atrial ratio, mitral annulus early peak velocity, ratio of mitral early peak velocity/mitral annulus early peak velocity; ratio, left atrial volume/height, longitudinal peak early diastolic strain rate, and circumferential peak early diastolic strain rate for diastolic indices). Compared with women, African American and white men had greater LV volume and LV mass (P<0.05). For LV systolic function, African American men had the lowest LVEF as well as longitudinal (Ell) and circumferential (Ecc) strain indices among the 4 sex/race–ethnic groups (P<0.05). For LV diastolic function, African American men and women had larger left atrial volumes; African American men had the lowest values of Ell and Ecc for diastolic strain rate (P<0.05). These race/sex differences in LV structure and LV function persisted after adjustment.

Conclusions—African American men have greater LV size and lower LV systolic and diastolic function compared to African American women and to white men and women. The reasons for these racial-ethnic differences are partially but not completely explained by established cardiovascular risk factors. (J Am Heart Assoc. 2015;4:e001264 doi: 10.1161/JAHA.114.001264)

Key Words: echocardiography • left ventricular function • left ventricular mass • speckle-tracking echocardiography
Myocardial deformation assessed by speckle-tracking echocardiography (STE) may be an earlier indicator of cardiac dysfunction compared to traditional echocardiography measurements. Moreover, a detailed study of race–ethnic differences in cardiac function has not been performed in younger individuals. Two-dimensional (2D) STE, as well as tissue Doppler imaging, have evolved as novel tools to accurately quantify both global and regional myocardial function. Strain is a measure of deformation expressed as a fractional or percentage change from an object’s original dimension and has recently been used as an additional method to assess left ventricular (LV) function. 2D-STE is an angle-independent method for deformation assessment that enables strain measurement in the longitudinal, circumferential, and radial directions based on conventional echocardiographic images. The echocardiographic method has been validated for measurements of early subclinical cardiac dysfunction by assessing myocardial deformation against tagged magnetic resonance imaging and sonomicrometry.

In the MESA study, racial differences in regional LV systolic function in a large cohort study of adults have been previously reported. However, the association of sex and race ethnic-specific differences in younger adults among African Americans from a large community-based population has not been reported. Based on what is known about the earlier onset of clinical heart disease among African American men, we hypothesize that (1) white and female CARDIA participants will have better LV systolic and diastolic myocardial function, compared to African Americans and male participants, respectively; and (2) these differences in function are partially or completely explained by body size and exposure to cardiovascular risk factors. We propose to investigate such relationships in the CARDIA study, a large community-based population including African American and white men and women who have been followed for 25 years.

### Methods

#### Subjects

The CARDIA study is a National Institutes of Health/National Heart, Lung, and Blood Institute-sponsored multicenter study designed to investigate the development and determinants of coronary disease risk factors in young adults. Initially, 5115 African American and white men and women 18 to 30 years of age at the time of enrollment (1985–1986) were recruited and examined at 4 CARDIA Field Centers in Birmingham, Alabama; Chicago, Illinois; Minneapolis, Minnesota; and Oakland, California. Echocardiography was performed in the cohort in the follow-up Year-25 examination. The overall design and objectives of the CARDIA study have been presented elsewhere. The institutional review board at each of the study sites approved the study protocols, and written informed consent was obtained from all participants.

Of the 3499 participants attending the Year-25 examination, 3475 underwent echocardiography. For this study, we included 3474 participants with echocardiographic assessment at the CARDIA examinations for Year-25 (2010–2011). Of these, 1 changed sex, and 154 missed at least 1 of the clinical covariates used in the study. The remaining 3320 patients were included in our analytic cohort.

#### Echocardiography

Doppler echocardiography and 2D-guided M-mode echocardiography were performed with the Artida cardiac ultrasound scanner (Toshiba Medical Systems, Otawara, Japan) by trained sonographers using standardized protocols across all field centers. In a central laboratory, experienced sonographers made measurements from digitized images using a standard software off-line image-analysis system (Digisonics, Inc, Houston, TX). Using 2D-guided M-mode echocardiography, LV end-diastolic volume (LVEDV), LV end-systolic volume (LVESV), and left atrial volume (LAV) was measured from an apical 4-chamber view based on the American Society of Echocardiography (ASE). LVEDV, LVESV, LAV, and LV mass (LVM) were indexed to body height (LVEDV/ht, LVESV/ht, LAV/ht, and LVM/ht). Peak early diastolic velocity, peak late diastolic velocity, early diastolic and atrial ratio, isovolumetric relaxation time, and early peak diastolic mitral annular velocity (e') were measured from pulsed-Doppler echocardiographic recordings of transmitral flow. Using tissue Doppler imaging, e' was measured at the septal mitral annulus.

#### Two-Dimensional STE Analysis

STE images for myocardial strain and strain rate measurements were analyzed in a 16-segment basis for LV midwall layer, using Wall Motion 2D Tracking software (Toshiba Medical Systems). Three cardiac cycles from each view were recorded for offline analyses. Strain was calculated as the change in segment length relative to its end-diastolic length from peak systolic values. Longitudinal strain and strain rate curves were assessed from 4-chamber views. Circumferential strain and strain rate were assessed from the short-axis view at midventricular level. Global strain values were calculated as the average of segmental peak strains. Global strain rate values were also calculated from the average of segmental peak values for each phase (in sec$^{-1}$). The STE image set in each view was excluded if more than 3 segments were improperly tracked. Excluded
cases for poor image quality for both the echo and STE measurements included 392 cases for longitudinal strain and strain rate assessed from the 4-chamber view and 353 cases for circumferential strain and strain rate assessed from the short-axis view. STE indices of systolic cardiac deformation at the Year-25 examination included 4-chamber longitudinal peak strain (Ell) and circumferential peak strain (Ecc), and 4-chamber longitudinal systolic strain rate (Ell_SRs), and circumferential systolic strain rate (Ecc_SRs). Diastolic STE indices were as follows: peak early diastolic strain rate in the 4-chamber longitudinal (Ell_SRe) and circumferential (Ecc_SRe).

**Covariates**

Standardized protocols were used to measure height, weight, heart rate, blood pressure, cholesterol, glucose, smoking, educational level, and physical activity at baseline and at the Year-25 examination. Sex and ethnicity were self-reported. Weight and height were measured with the use of a standard balance-beam scale. Weight was measured to the nearest 0.1 kg with the participants wearing light clothing. Height was measured to the nearest 0.5 cm without shoes. BMI was calculated as weight (kg) divided by height squared (m²). We used the average of the second and third of 3 blood pressure measurements performed at 1-minute intervals after the participant had been sitting quietly for 5 minutes in a quiet room. The presence of diabetes was assessed at each examination based on a combination of medication use for diabetes (Years-0 and -25), fasting plasma glucose ≥126 mg/dL (Years-0 and -25), 2-hour glucose ≥200 mg/dL (Year-25), or HbA1c ≥6.5% (Year-25). Information on demographic characteristics, smoking status, educational level, and medication use was collected at the time of clinical interview.

**Statistical Analysis**

Descriptive statistics were displayed using means and SDs for continuous variables. Categorical variables were present as numbers and percentages. Paired or unpaired t tests, χ² tests, F-tests, Bonferroni adjustment for multiple comparison, and Tukey-Kramer tests were used to compare the difference in prevalence of various risk factors among race-ethnicity and sex subgroups. LV structural parameters were defined as LVEDV/ht (height), LVESV/ht, LVM/ht, and LVM/LVEDV ratio; LV systolic function was defined as LV ejection fraction (LVEF), Ell, and Ecc; and LV diastolic function was defined as E/A ratio, e, LAV/ht, Ell_SRe, and Ecc_SRe. We conducted univariate linear regression analysis to assess the association of race/sex groups with LV structure and function. Multivariable linear regression models were used to assess the association of race/sex groups with LV structure and function. Model 1: LV structure or LV function=demographic variables (age)+BMI at Year-25; Model 2: LV structure or LV function=Model 1+Year-25 risk factors (systolic blood pressure [mm Hg], diastolic blood pressure [mm Hg], heart rate [bpm], presence of diabetes [yes/no], use of antihypertensive medications [years/no], number of cigarettes/day, physical activity [exercise unit], and educational level [years]); and Model 3: LV structure or LV function=Model 2+Year-0 risk factors (BMI, systolic blood pressure, diastolic blood pressure, heart rate, presence of diabetes, use of antihypertensive medications, number of cigarettes/day, physical activity, and educational level). BMI at Year-25 was included in Model 1 and Model 2. By including BMI at Year-0, Model 3 suggested that BMI at Year-0 could have additional influence on the current LV structural and functional parameters. The correlation between BMI at Year-0 and BMI at Year-25 was 0.69 (P<0.0001). On the potential collinearity between BMI at Year-0 and Year-25 for the LV structural and functional parameters, the variance inflation factor of the Year-0 and Year-25 was <10, suggesting that the collinearity between BMI at Year-0 and Year-25 was not too high (Table 1). Since BMI changed between Year-0 and Year-25 for many study participants, incorporating the BMI values at both time points in Model 3 provided additional information on the influence of BMI on the LV structural and functional parameters. A 2-sided P value of <0.05 was considered to be statistically significant. All statistical analyses were performed using JMP (version 10.0 for Windows, SAS Institute Inc, Cary, NC) and STATA (version 12.0, Stata Corp, College Station, TX).

**Results**

Descriptive statistics for the cohort (n=3320) at Years-0 and -25 are presented in Table 2. The study population was 43.6% male and 46.3% African American with a mean age of 50.2±3.6 at the Year-25 examination. BMI for all groups increased over 25 years with an increased prevalence of overweight and obesity. African American women had higher mean BMI, higher prevalence of hypertension, and lower educational level and physical activity compared with white women at Year-0. African Americans had higher mean BMI, higher prevalences of hypertension and diabetes, and lower educational level and physical activity at Year-25 compared to whites. The echocardiographic parameters at the Year-25 examination are shown in Table 2. African American men had the highest LVM/ht, LVEDV/ht, and LVESV/ht compared with other race/sex groups (Table 3). For LV systolic function, LVEF, Ell, Ecc, Ell_SRs, and Ecc_SRs in African American men were the lowest among all groups (Table 3). For LV diastolic function, e', Ell_SRe, and Ecc_SRe in African American men were also the lowest among all groups (Table 3).
Race–Ethnicity and Sex Variations in LV Size and Structure

Being an African American man was significantly associated with larger LV structural parameters (Table 4). BMI at Year-25 was a significant determinant of differences in LVEDV/ht and LVESV/ht comparing African American men and white women in Model 1 (Table 4). The differences remained consistent in Models 2 and 3. BMI, heart rate, education level, systolic and diastolic blood pressure, smoking, and antihypertensive medications at Year-25 attenuated the differences in LVM/ht between race–ethnicities in Model 2. Additionally, the magnitude of differences in LVM/ht remained after adjusting for Year-0 risk factors in Model 3. The LVM/LVEDV ratio was not different between women and men in univariate analyses. BMI, physical activity, diastolic blood pressure, antihypertensive medications at Year-25 and BMI, number of cigarettes per day, and diabetes at Year-0 attenuated the differences in the LVM/LVEDV ratio between race–ethnicities in Models 2 and 3.

Race–Ethnicity and Sex Differences in LV Systolic Function

Being an African American man was significantly associated with worse LV systolic function (Table 4). There were significant differences in LVEF after adjustment for demographics and BMI in Model 1 (Table 4). BMI, age, and heart rate at Year-25 and BMI at Year-0 were significant determinants of attenuation of the differences in LVEF between race–ethnicities. However, men maintained lower LVEF than women after adjustments in Models 2 and 3. African American men had the least Ell and Ecc in Models 1 to 3 compared to white women. These sex/race–ethnic differences in Ell persisted after adjustment for risk factors at both Year-0 and 25. For Ecc, there were no differences between African American women and white women in univariate and multivariable analyses. The β-coefficient of systolic parameters for the African American men was almost 2.0 times larger than the β-coefficient for the white men.

**Table 1. Potential Collinearity Assessment Between BMI at Year-0 and Year-25 for the LV Structural and Functional Parameters**

| Model 1 | Structural indices | n | \( R^2 \) | Y-25 BMI | Y-0 BMI |
|---------|--------------------|---|-----------|----------|---------|
|         | LVEDV/height, mL/m | 3078 | 0.07 | 0.61 (0.04)* | 1.00 |
|         | LVM/height, g/m   | 2980 | 0.20 | 1.88 (0.07)* | 1.00 |
| Systolic indices | LVEF, % | 3077 | 0.001 | −0.03 (0.02) | 1.00 |
|         | Ell, % | 2908 | 0.04 | 0.07 (0.01)* | 1.00 |
| Diastolic indices | E/e’ ratio | 3239 | 0.06 | 0.08 (0.01)* | 1.00 |
|         | Ell_SRe, sec\(^{-1}\) | 2896 | 0.01 | −0.004 (0.001)* | 1.00 |

Model 1 is adjusted for BMI at Year-25. Model 2 is adjusted for BMI at Year-25 and Year-0. BMI indicates body mass index; E/e’, ratio of mitral early peak velocity/mitral annulus early peak velocity; Ell, longitudinal peak systolic strain; Ell_SRe, longitudinal peak early diastolic strain rate; LV, left ventricular; LVEDV, LV end-diastolic volume; LVEF, LV ejection fraction; LVM, LV mass; VIF, variance inflation factor.

*P <0.05.
Table 2. Participant Characteristics at the CARDIA Year-0 and Year-25 Examinations (n=3320)

| Variable                  | African American Men (n=616, 18.6%) | African American Women (n=920, 27.7%) | White Men (n=830, 25.0%) | White Women (n=954, 28.7%) |
|---------------------------|-------------------------------------|---------------------------------------|--------------------------|---------------------------|
|                           | Year-0 | Year-25 | Year-0 | Year-25 | Year-0 | Year-25 | Year-0 | Year-25 |
| Age, y                    | 24.3 (3.8)* | 24.6 (3.8)* | 25.6 (3.3) | 25.6 (3.4) | 26.3 (3.4) | 25.8 (3.4) | 25.6 (3.4) | 25.8 (3.4) |
| BMI, kg/m²                | 26.4 (6.8)* | 25.9 (6.4)* | 24.3 (3.5)* | 22.9 (4.1) | 22.6 (4.1) | 22.9 (4.1) | 22.9 (4.1) | 22.9 (4.1) |
| BSA, m²                   | 1.94 (0.18)* | 2.12 (0.24)* | 1.95 (0.16)* | 1.68 (0.15) | 1.68 (0.15) | 1.68 (0.15) | 1.68 (0.15) | 1.68 (0.15) |
| Heart rate, beats/min     | 63.9 (9.4)* | 67.1 (10.3)* | 67.0 (10.7)* | 71.9 (10.9) | 71.9 (10.9) | 71.9 (10.9) | 71.9 (10.9) | 71.9 (10.9) |
| SBP, mm Hg                | 115.4 (10.1)* | 126.0 (15.1)* | 123.3 (17.5)* | 114.2 (10.1)* | 119.2 (13.6)* | 104.5 (9.2) | 112.3 (14.4)* | 112.3 (14.4)* |
| DBP, mm Hg                | 70.2 (10.0)* | 75.4 (11.0)* | 78.2 (11.2)* | 70.8 (9.4)* | 70.8 (9.4)* | 73.9 (10.0)* | 70.0 (10.5)* | 70.0 (10.5)* |
| Hypertension, n (%)       | 23 (3.7) | 274 (44.5)* | 49 (3.5)* | 218 (26.3)* | 15 (1.6) | 186 (19.5)* | 162 (17.5)* | 162 (17.5)* |
| Diabetes, n (%)           | 0 (0) | 67.2 (10.7)* | 157 (17.1)* | 67.2 (10.7)* | 67.2 (10.7)* | 67.2 (10.7)* | 67.2 (10.7)* | 67.2 (10.7)* |
| Number of cigarettes, cig/day | 4.4 (7.0)* | 29.6 (6.2)* | 3.9 (7.0)* | 5.9 (10.0)* | 2.0 (6.1)* | 5.8 (9.4) | 1.2 (4.2)* | 1.2 (4.2)* |
| Using antihypertensive medication, n (%) | 9 (1.5) | 210 (34.1)* | 38 (4.1)* | 11 (1.3) | 166 (20.0)* | 10 (1.1) | 136 (14.3)* | 136 (14.3)* |
| Education level, y        | 13.1 (1.9)* | 17.3 (2.5)* | 14.3 (2.7)* | 14.9 (2.4) | 16.0 (2.5) | 16.0 (2.5) | 16.0 (2.5) | 16.0 (2.5) |
| Physical activity, EU     | 525 (345)* | 371 (295)* | 273 (223)* | 514 (295)* | 431 (287)* | 414 (267) | 343 (261)* | 343 (261)* |

BMI indicates body mass index; BSA, body surface area; CARDIA, Coronary Artery Risk Development in Young Adults; DBP, diastolic blood pressure; EU, exercise unit; SBP, systolic blood pressure.

*P<0.05: vs Year-0 among the same race/gender group.
†‡P<0.05: vs Year-25 white women.
‡P<0.05: vs Year-0 white women.

Race–Ethnicity and Sex Differences in LV Diastolic Function

Being an African American man was significantly associated with worse LV diastolic function (Table 4). BMI and age were significant determinants that attenuated the differences in E/A ratio among race and sex in Model 1 among conventional LV diastolic parameters, (Table 4). For the e', BMI, age, heart rate, education level, physical activity, diastolic blood pressure, diabetes, and antihypertensive medications at Year-25 attenuated the differences between race–ethnicities. The differences were still present after adjusting for Year-0 risk factors. BMI, heart rate, education level, physical activity, systolic and diastolic blood pressure at Year-25 and BMI, heart rate, educational level, physical activity, and systolic and diastolic blood pressure at Year-0 were significant attenuators of the differences between men and women among white CARDIA participants in Model 3. In STE parameters, age, diastolic blood pressure, and antihypertensive medications were significant determinants of attenuation of the differences in E/e' between African American men and white men. The differences remained after adjusting for Year-0 risk factors. The association of BMI at Year-25 as risk factor to LV structure and function was of a higher magnitude than BMI at Year-0 (Table 5).

Discussion

This study reports that differences in cardiac remodeling and myocardial function between women and men, as well as between African American and white individuals, are present by midlife and are partially derived from known cardiovascular risk factors and socioeconomic variables.

Race–Ethnicity and Sex Differences in LV Size and Structure

African American men have the highest values of LVM among the 4 race/sex groups in our study, after adjustment for demographics and cardiovascular risk factors at Year-25. Among middle-aged and elderly populations, race–ethnicity impacts cardiac remodeling after adjustment for risk factors, with African American men having higher LVM than white women in univariate analyses. However, BMI and heart rate at Year-25 attenuated the differences in Ecc_sRe between African American men and white men after adjustment for cardiovascular risk factors at Year-25. The differences remained after adjusting for Year-0 risk factors. The association of BMI at Year-25 as risk factor to LV structure and function was of a higher magnitude than BMI at Year-0 (Table 5).
individuals.17–20 In the MESA study, LVM and LV volume were greater in men than in women.21–23 In prospective analyses, variations of LV structure after adjusting for Year-0 risk factors yielded similar results to those found in the Year-25 cross-sectional relationships. In Year-0, the magnitude of risk factors in African American men was significantly greater compared with white women. Sex differences in LV structure were in agreement with previous studies.13,18,20,22,24 Both CARDIA and the Bogalusa Heart Study investigated the relation of LVM to risk factors in younger individuals using 5-year follow-up data in a biracial cohort.25,26 These reports indicated that high BMI and blood pressure have a marked impact on increasing LVM over 5 years in childhood and during young adulthood. More recently, Gidding et al reported that higher blood pressure, worsening obesity, tobacco use, and long-standing diabetes are associated with significant worsening of LV remodeling in the CARDIA cohort.27 This study suggests that exposure to cardiovascular risk factors attenuates but does not fully explain differences in LV structure by gender and race–ethnicity.

### Race–Ethnicity and Sex Differences in LV Systolic Function

This study shows greater differences among the 4 race/gender groups in myocardial strain than LVEF. Men have...
Table 4. Relationship of Race–Ethnicity and Sex Group to LV Structural and Functional Parameters at the Year-25 Examination

| Structural indices | \( n \) | \( R^2 \) | \( \beta \) (SE) | \( \beta \) (SE) | \( \beta \) (SE) | \( \beta \) (SE) |
|--------------------|--------|----------|----------------|----------------|----------------|----------------|
| LVEDV/height, mL/m |        |          |                |                |                |                |
| Unadjusted         | 3078   | 0.15     | 15.27 (0.79)\(^2\) | 3.93 (0.71)\(^2\) | 13.50 (0.73)\(^2\) | Ref |
| Model 1            | 3078   | 0.23     | 13.63 (0.77)\(^2\) | 0.54 (0.72)\(^2\) | 12.89 (0.69)\(^2\) | Ref |
| Model 2            | 3078   | 0.25     | 12.35 (0.84)\(^2\) | 0.09 (0.75)\(^2\) | 12.00 (0.75)\(^2\) | Ref |
| Model 3            | 3078   | 0.26     | 11.06 (0.91)\(^2\) | -0.18 (0.77)\(^2\) | 10.79 (0.80)\(^2\) | Ref |
| LVESV/height, mL/m |        |          |                |                |                |                |
| Unadjusted         | 3077   | 0.11     | 8.11 (0.50)\(^2\) | 1.51 (0.45)\(^2\) | 6.20 (0.46)\(^2\) | Ref |
| Model 1            | 3077   | 0.15     | 7.26 (0.50)\(^2\) | -0.31 (0.47)\(^2\) | 5.92 (0.45)\(^2\) | Ref |
| Model 2            | 3077   | 0.25     | 6.73 (0.55)\(^2\) | -0.45 (0.50)\(^2\) | 5.67 (0.50)\(^2\) | Ref |
| Model 3            | 3077   | 0.26     | 6.33 (0.60)\(^2\) | -0.51 (0.51)\(^2\) | 5.17 (0.53)\(^2\) | Ref |
| LVM/height, g/m    |        |          |                |                |                |                |
| Unadjusted         | 2980   | 0.15     | 30.88 (1.45)\(^2\) | 14.94 (1.29)\(^2\) | 21.68 (1.35)\(^2\) | Ref |
| Model 1            | 2980   | 0.33     | 26.30 (1.31)\(^2\) | 4.97 (1.21)\(^2\) | 20.11 (1.20)\(^2\) | Ref |
| Model 2            | 2980   | 0.37     | 19.50 (1.41)\(^2\) | -0.14 (1.25)\(^2\) | 17.35 (1.28)\(^2\) | Ref |
| Model 3            | 2980   | 0.39     | 18.15 (1.52)\(^2\) | -0.21 (1.27)\(^2\) | 15.46 (1.36)\(^2\) | Ref |
| LVM/LVEDV ratio\(^*\) |        |          |                |                |                |                |
| Unadjusted         | 2808   | 0.02     | 14.0 (3.00)\(^2\) | 15.00 (2.00)\(^2\) | 6.00 (3.00)\(^*\) | Ref |
| Model 1            | 2808   | 0.05     | 10.97 (2.75)\(^2\) | 5.02 (2.51)\(^*\) | Ref |
| Model 2            | 2808   | 0.07     | 2.45 (3.03)\(^2\) | 2.52 (2.74)\(^2\) | Ref |
| Model 3            | 2808   | 0.07     | 3.90 (3.31)\(^2\) | 2.30 (2.94)\(^2\) | Ref |
| Systolic indices   |        |          |                |                |                |                |
| LVEF, %            |        |          |                |                |                |                |
| Unadjusted         | 3077   | 0.02     | -2.51 (0.40)\(^2\) | 0.52 (0.34)\(^2\) | -1.17 (0.35)\(^*\) | Ref |
| Model 1            | 3077   | 0.03     | -2.25 (0.38)\(^2\) | 0.94 (0.36)\(^2\) | -1.11 (0.35)\(^*\) | Ref |
| Model 2            | 3077   | 0.04     | -2.31 (0.43)\(^2\) | 0.80 (0.38)\(^*\) | -1.25 (0.38)\(^*\) | Ref |
| Model 3            | 3077   | 0.04     | -2.48 (0.47)\(^2\) | 0.73 (0.39)\(^2\) | -1.23 (0.41)\(^*\) | Ref |
| Ell, %             |        |          |                |                |                |                |
| Unadjusted         | 2908   | 0.07     | 1.91 (0.13)\(^2\) | 1.11 (0.12)\(^2\) | 0.97 (0.12)\(^*\) | Ref |
| Model 1            | 2908   | 0.10     | 1.82 (0.13)\(^2\) | 0.82 (0.12)\(^2\) | 0.92 (0.12)\(^*\) | Ref |
| Model 2            | 2908   | 0.15     | 1.30 (0.14)\(^2\) | 0.50 (0.12)\(^2\) | 0.62 (0.12)\(^*\) | Ref |
| Model 3            | 2908   | 0.16     | 1.37 (0.15)\(^2\) | 0.50 (0.13)\(^2\) | 0.70 (0.13)\(^*\) | Ref |
| Ecc, %             |        |          |                |                |                |                |
| Unadjusted         | 2952   | 0.03     | 1.39 (0.15)\(^2\) | 0.25 (0.14)\(^2\) | 0.55 (0.14)\(^*\) | Ref |
| Model 1            | 2952   | 0.04     | 1.24 (0.15)\(^2\) | -0.01 (0.14)\(^2\) | 0.51 (0.14)\(^*\) | Ref |
| Model 2            | 2952   | 0.05     | 0.94 (0.17)\(^2\) | -0.12 (0.15)\(^2\) | 0.35 (0.15)\(^*\) | Ref |
| Model 3            | 2952   | 0.06     | 1.02 (0.19)\(^2\) | -0.26 (0.16)\(^2\) | 0.39 (0.16)\(^*\) | Ref |
| Diastolic indices  |        |          |                |                |                |                |
| E/A ratio          |        |          |                |                |                |                |
| Unadjusted         | 3266   | 0.01     | -0.04 (0.02)\(^2\) | -0.07 (0.02)\(^2\) | 0.02 (0.02)\(^2\) | Ref |

Continued
Race and Sex Differences in LV Structure and Function  
Kishi et al

Table 4. Continued

| Model | \(n\) | \(r^2\) | African American Men | African American Women | White Men | White Women |
|-------|-------|---------|----------------------|-----------------------|-----------|-------------|
|       |       |         | \(\beta (SE)\)       | \(\beta (SE)\)        | \(\beta (SE)\) | \(\beta (SE)\) |
| Model 1 | 3266  | 0.08    | -0.03 (0.02)         | -0.04 (0.02)         | 0.03 (0.02) | Ref         |
| Model 2 | 3266  | 0.21    | 0.04 (0.02)*         | 0.02 (0.02)          | 0.05 (0.02) | Ref         |
| Model 3 | 3266  | 0.21    | 0.03 (0.02)          | 0.02 (0.02)          | 0.05 (0.02) | Ref         |

\(e', \text{cm/s}\)

| Unadjusted | 3264  | 0.03    | -1.10 (0.12)\(^2\)  | -0.70 (0.11)\(^2\)  | -0.55 (0.11)\(^2\) | Ref         |
| Model 1    | 3264  | 0.12    | -1.14 (0.12)\(^2\)  | -0.58 (0.11)\(^2\)  | -0.53 (0.11)\(^2\) | Ref         |
| Model 2    | 3264  | 0.21    | -0.50 (0.13)\(^2\)  | -0.12 (0.11)         | -0.21 (0.12) | Ref         |
| Model 3    | 3264  | 0.23    | -0.67 (0.13)\(^2\)  | -0.15 (0.12)         | -0.36 (0.12)\(^2\) | Ref         |

| E/e' ratio |

| Unadjusted | 3239  | 0.05    | 0.51 (0.14)\(^2\)  | 1.02 (0.13)\(^2\)  | -0.37 (0.13)\(^2\) | Ref         |
| Model 1    | 3239  | 0.10    | 0.49 (0.14)\(^2\)  | 0.80 (0.13)\(^2\)  | -0.40 (0.13)\(^2\) | Ref         |
| Model 2    | 3239  | 0.17    | -0.29 (0.15)        | 0.29 (0.14)*        | -0.82 (0.14)\(^2\) | Ref         |
| Model 3    | 3239  | 0.18    | -0.08 (0.17)        | 0.37 (0.15)\(^2\)  | -0.68 (0.15)\(^2\) | Ref         |

| LA volume/height, mL/m |

| Unadjusted | 3280  | 0.04    | 4.34 (0.46)\(^2\)  | 3.94 (0.41)\(^2\)  | 2.69 (0.42)\(^2\) | Ref         |
| Model 1    | 3280  | 0.16    | 3.41 (0.43)\(^2\)  | 1.60 (0.40)\(^2\)  | 2.35 (0.39)\(^2\) | Ref         |
| Model 2    | 3280  | 0.20    | 2.82 (0.47)\(^2\)  | 1.36 (0.42)\(^2\)  | 2.07 (0.42)\(^2\) | Ref         |
| Model 3    | 3280  | 0.22    | 1.96 (0.51)\(^2\)  | 1.34 (0.43)\(^2\)  | 1.19 (0.45)\(^2\) | Ref         |

| Ell_SRe, sec\(^{-1}\) |

| Unadjusted | 2896  | 0.06    | -0.17 (0.01)\(^2\)  | -0.09 (0.01)\(^2\)  | -0.12 (0.01)\(^2\) | Ref         |
| Model 1    | 2896  | 0.09    | -0.18 (0.01)\(^2\)  | -0.08 (0.01)\(^2\)  | -0.12 (0.01)\(^2\) | Ref         |
| Model 2    | 2896  | 0.12    | -0.13 (0.02)\(^2\)  | -0.05 (0.01)\(^2\)  | -0.09 (0.01)\(^2\) | Ref         |
| Model 3    | 2896  | 0.12    | -0.12 (0.02)\(^2\)  | -0.05 (0.01)\(^2\)  | -0.08 (0.01)\(^2\) | Ref         |

| Ecc_SRe, sec\(^{-1}\) |

| Unadjusted | 2947  | 0.02    | -0.13 (0.02)\(^2\)  | -0.02 (0.02)        | -0.06 (0.02)\(^2\) | Ref         |
| Model 1    | 2947  | 0.02    | -0.12 (0.02)\(^2\)  | -0.01 (0.02)        | -0.06 (0.02)\(^2\) | Ref         |
| Model 2    | 2947  | 0.03    | -0.10 (0.02)\(^2\)  | 0.002 (0.02)        | -0.04 (0.02)\(^2\) | Ref         |
| Model 3    | 2947  | 0.03    | -0.09 (0.02)\(^2\)  | 0.0002 (0.02)       | -0.03 (0.02)        | Ref         |

Model 1 is adjusted for age and BMI at Year-25. Model 2 is further adjusted for Model 1 + Year-25 risk factors (educational level, physical activity, heart rate, presence of diabetes, systolic blood pressure, diastolic blood pressure, use of antihypertensive medications, and number of cigarettes/day). Model 3 is further adjusted for Model 2 + Year-0 risk factors (BMI, educational level, physical activity, heart rate, presence of diabetes, systolic blood pressure, diastolic blood pressure, use of antihypertensive medications, and number of cigarettes/day). BMI indicates body mass index; E/A, early diastolic and atrial ratio; E/e', ratio of mitral early peak velocity/mitral annulus early peak velocity; e', mitral annulus early peak velocity; Ecc, circumferential peak systolic strain; Ecc_SRe, circumferential peak early diastolic strain rate; Ell, longitudinal peak systolic strain; Ell_SRe, longitudinal peak early diastolic strain rate; LA, left atrial; LV, left ventricular; LVEDV, LV end-diastolic volume; LVEF, left ventricular ejection fraction; LVESV, LV end-systolic volume; LVM, LV mass.

\*P<0.05; \†P<0.01; \‡P<0.001: vs white women as the referent group among race–ethnicity and sex groups.

\‡LVM/LVEDV was multiplied by 100.

lower LVEF than women after adjusting for risk factors and other potential confounders. However, exposure to cardiovascular risk factors (BMI, heart rate, and age) attenuates the race–ethnic differences in LVEF, but not between women and men. Sex differences found in our study were consistent with previous evaluations.\(^{13,23}\) There were significant differences in Ell among the 4 race/sex groups, even after adjusting for risk factors and potential confounders. African American men had the lowest level for longitudinal and circumferential strains. Conversely, white women had the largest magnitude of myocardial systolic strain. In the MESA study, using tagged magnetic resonance imaging, African American groups had the lowest Ecc compared to 3 other racial/ethnic groups, consistent with our findings.\(^{11}\) The
proportion of the variance explained by cardiovascular risk factors at both Year-0 and Year-25 in Ell ($R^2=0.16$) was higher than in LVEF ($R^2=0.04$). Our findings suggest that LV systolic parameters are affected by still unknown cardiovascular risk factors potentially including genetic and environmental factors. In addition, LVEF is a poor indication of early LV systolic dysfunction or cardiovascular risk compared to STE parameters.28

### Table 5. Relationship of BMI to LV Structural and Functional Parameters at the Year-25 Examination

|                  | n   | $R^2$ | Year-25 BMI $\beta$ (SE)* | Year-0 BMI $\beta$ (SE)* |
|------------------|-----|-------|---------------------------|--------------------------|
| **Structural indices** |     |       |                           |                          |
| LVEDV/height, mL/m |     |       |                           |                          |
| Model 1          | 3078| 0.23  | 0.68 (0.04)*              |                          |
| Model 2          | 3078| 0.25  | 0.73 (0.04)*              |                          |
| Model 3          | 3078| 0.27  | 0.52 (0.06)*              | 0.42 (0.08)*             |
| LVM/height, g/m  |     |       |                           |                          |
| Model 1          | 2980| 0.33  | 1.89 (0.07)*              |                          |
| Model 2          | 2980| 0.37  | 1.76 (0.07)*              |                          |
| Model 3          | 2980| 0.39  | 1.27 (0.09)*              | 1.04 (0.13)*             |
| **Systolic indices** |     |       |                           |                          |
| LVEF, %          |     |       |                           |                          |
| Model 1          | 3077| 0.03  | −0.05 (0.02)*             |                          |
| Model 2          | 3077| 0.04  | −0.06 (0.02)*             |                          |
| Model 3          | 3077| 0.04  | −0.01 (0.03)              | −0.10 (0.04)             |
| Ell, %           |     |       |                           |                          |
| Model 1          | 2908| 0.10  | 0.06 (0.01)*              |                          |
| Model 2          | 2908| 0.15  | 0.04 (0.01)*              |                          |
| Model 3          | 2908| 0.16  | 0.04 (0.01)*              | −0.01 (0.01)             |
| **Diastolic indices** |     |       |                           |                          |
| E/e’ ratio       |     |       |                           |                          |
| Unadjusted       | 3239| 0.05  |                           |                          |
| Model 1          | 3239| 0.10  | 0.06 (0.01)*              |                          |
| Model 2          | 3239| 0.17  | 0.05 (0.01)*              |                          |
| Model 3          | 3239| 0.18  | 0.05 (0.01)*              | −0.003 (0.01)            |
| Ell_SRe, sec$^{-1}$ |     |       |                           |                          |
| Unadjusted       | 2896| 0.06  |                           |                          |
| Model 1          | 2896| 0.09  | −0.01 (0.001)*            |                          |
| Model 2          | 2896| 0.12  | −0.001 (0.001)*           |                          |
| Model 3          | 2896| 0.12  | −0.0003 (0.001)           | −0.003 (0.001)           |

Model 1 is adjusted for race–ethnicity and sex group, age, and BMI at Year-25. Model 2 is further adjusted for Model 1 + Year-25 risk factors (educational level, physical activity, heart rate, presence of diabetes, systolic blood pressure, diastolic blood pressure, use of antihypertensive medications, and number of cigarettes/day). Model 3 is further adjusted for Model 2 + Year-0 risk factors (BMI, educational level, physical activity, heart rate, presence of diabetes, systolic blood pressure, diastolic blood pressure, use of antihypertensive medications, and number of cigarettes/day). BMI indicates body mass index; E/e’, ratio of mitral early peak velocity/mitral annulus early peak velocity; Ell, longitudinal peak systolic strain; Ell_SRe, longitudinal peak early diastolic strain rate; LV, left ventricular; LVEDV, LV end-diastolic volume; LVEF, left ventricular ejection fraction; LVM, LV mass.

*P<0.05.

### Race–Ethnicity and Sex Differences in LV Diastolic Function

In conventional Doppler and novel STE diastolic measures, African American men had lower LV diastolic function compared to African American women and white men and women. The contribution of cardiovascular risk factors was higher in African American men and women than in white men...
and women at the Year-25 examination. LV diastolic dysfunction may reflect chronic exposure to cardiovascular risk factors such as diabetes, hypertension, and increased BMI.\(^2^9\) However, racial differences in diastolic dysfunction are not entirely explained by cardiovascular risk factors. LV diastolic as well as systolic function may be affected by genetic as well as environmental factors over the human life course.\(^3^0,3^1\) The MESA study, which included participants aged 45 to 84 years, showed that racial/ethnic differences in myocardial dysfunction remained significant, adjusting for cardiovascular risk factors and socioeconomic variables.\(^1^1\) In an older population (Cardiac Abnormalities and Brain Lesions study), no race-ethnic differences in LV diastolic function were observed.\(^3^2\) This could have resulted from progression of atherosclerosis and adverse LV remodeling among all race-ethnic and sex groups or due to attrition among the group of African American male Cardiac Abnormalities and Brain Lesions study participants.

**Clinical Implications**

A previous CARDIA study showed that African American ethnicity had a strong relationship with subsequent development of HF over a 20-year follow-up period.\(^5\) Furthermore, the MESA study also reported that the risk of developing HF was greater among African Americans compared with whites.\(^4\) LV volume enlargement, higher LVM, lower LVEF, and worse conventional LV diastolic dysfunction were associated with the development of HF. Global systolic and diastolic strain parameters have recently been reported as predictors of incident HF.\(^7,3^3\) Our findings suggest that African American men have echocardiographic abnormalities that may represent antecedents of subsequent HF.\(^5\) Risk-factor control to forestall LV functional deterioration should begin at an early age with a particular emphasis on achieving these factor controls among African American men.

**Study Limitations**

Observed race/sex differences in LV structure and function may reflect exposure to genetic and environmental factors that have yet to be identified. Additionally, our study suggests that both types of determinants may be implicated in different cardiac remodeling pathways starting early in life, as suggested in other studies.

**Conclusions**

In this biracial community-based population of middle-aged adults, our findings indicate race/sex differences in LV structure and function. African American men have greater LV mass and reduced LV systolic and diastolic function among the 4 race/sex groups analyzed in this study before and after adjustment for cardiovascular risk factors. These racial-ethnic and sex differences are only partially explained by age, BMI, heart rate, blood pressure, and diabetes.

**Acknowledgments**

The Coronary Artery Risk Development in Young Adults Study (CARDIA) is supported by contracts HHSN268201300025C, HHSN268201300026C, HHSN268201300027C, HHSN268201300028C, HHSN268201300029C, and HHSN26820090004C from the National Heart, Lung, and Blood Institute (NHLBI), the Intramural Research Program of the National Institute on Aging (NIA), and an intra-agency agreement between NIA and NHLBI (AG0005).

**Disclosures**

None.

**References**

1. Hunt SA, Abraham WT, Chin MH, Feldman AM, Francis GS, Ganiats TG, Jessup M, Konstam MA, Mancini DM, Michi K, Oates JA, Rahko PS, Silver MA, Stevenson LW, Yancy CW. 2009. Focused update incorporated into the ACC/AHA 2005 guidelines for the diagnosis and management of heart failure in adults: a report of the American College of Cardiology Foundation/American Heart Association Task Force on Practice Guidelines Developed in Collaboration With the International Society for Heart and Lung Transplantation. J Am Coll Cardiol. 2009;53:e1–e90.
2. Chen J, Dharmarajan K, Wang Y, Krumholz HM. National trends in heart failure hospital stay rates, 2001 to 2009. J Am Coll Cardiol. 2013;61:1078–1088.
3. Chen J, Normand SLT, Wang Y, Krumholz HM. National and regional trends in heart failure hospitalization and mortality rates for Medicare beneficiaries, 1999–2008. JAMA. 2011;306:1669–1678.
4. Bahrami H, Kronmal R, Bluemke DA, Olson J, Shea S, Liu K, Burke GL, Lima JAC. Differences in the incidence of congestive heart failure by ethnicity: the Multi-Ethnic Study of Atherosclerosis. Arch Intern Med. 2008;168:2138–2145.
5. Bibbins-Domingo K, Fletcher MJ, Lin F, Vittinghoff E, Gardin JM, Arynchyn A, Lewis CE, Williams OD, Hulley SB. Racial differences in incident heart failure among young adults. N Engl J Med. 2009;360:1179–1190.
6. Stanton T, Leano R, Marwick TH. Prediction of all-cause mortality from global longitudinal speckle strain: comparison with ejection fraction and wall motion scoring. Circ Cardiovasc Imaging. 2009;2:356–364.
7. Cho GY, Marwick TH, Kim HS, Kim MK, Hong KS, Oh DJ. Global 2-dimensional strain as a new prognosticator in patients with heart failure. J Am Coll Cardiol. 2009;54:618–624.
8. Edwardsen T, Detrano R, Rosen BD, Carr JJ, Liu K, Lai S, Shea S, Pan L, Bluemke DA, Lima JAC. Coronary artery atherosclerosis is related to reduced regional left ventricular function in individuals without history of clinical cardiovascular disease: the Multiethnic Study of Atherosclerosis. Arterioscler Thromb Vasc Biol. 2006;26:206–211.
9. Geyer H, Caracciolo G, Abe H, Wilansky S, Carerj S, Gentile F, Nesser HJ, Khandheria B, Narula J, Sengupta PP. Assessment of myocardial mechanics using speckle tracking echocardiography: fundamentals and clinical applications. J Am Soc Echocardiogr. 2010;23:351–369.
10. Helle-Valle T, Crosby J, Edwardsen T, Lyseggen E, Amundsen BH, Smith HI, Rosen BD, Lima JA, Torp H, Ilenh H, Smiseth OA. New noninvasive method for assessment of left ventricular rotation: speckle tracking echocardiography. Circulation. 2005;112:3149–3156.
11. Fernandes VR, Cheng S, Cheng YJ, Rosen B, Agarwal S, McClelland RL, Bluemke DA, Lima JA. Racial and ethnic differences in subclinical myocardial function: the Multi-Ethnic Study of Atherosclerosis. Heart. 2011;97:405–410.
12. Friedman GD, Cutter GR, Donahue RP, Hughes GH, Hulley SB, Jacobs DR Jr, Liu K, Savage PJ. CARDIA: study design, recruitment, and some characteristics of the examined subjects. J Clin Epidemiol. 1988;41:1105–1116.
13. Lang RM, Bierig M, Devereux RB, Flachskampf FA, Foster E, Pellikka PA, Picard MH, Roman MJ, Seward J, Shanewise JS, Solomon SD, Spencer KT, Sutton MS, Stewart WJ. Recommendations for chamber quantification: a report from the American Society of Echocardiography’s Guidelines and Standards Committee and the Chamber Quantification Writing Group, developed in conjunction with the European Association of Echocardiography, a branch of the European Society of Cardiology. J Am Soc Echocardiogr. 2005;18:1440–1463.

14. Naghsh SF, Appleton CP, Gillebert TC, Marino PN, Oh JK, Smiseth OA, Waggner AD, Flachskampf FA, Pellikka PA, Evangelista A. Recommendations for the evaluation of left ventricular diastolic function by echocardiography. J Am Soc Echocardiogr. 2009;22:107–133.

15. Kishi S, Armstrong AC, Gidding SS, Colangelo LA, Venkatesh BA, Jacobs J, David R, Carr JJ, Terry JS, Liu K, Goff D, David C, Lima JAC. Association of obesity in early adulthood and middle age with incipient left ventricular dysfunction and structural remodeling: the Coronary Artery Risk Development in Young Adults (CARDIA) study. JACC Heart Fail. 2014;2:500–508.

16. Jacobs DR Jr, Hahn LP, Haskell WL, Pirie P, Sidney S. Validity and reliability of short physical activity history. CARDIA and the Minnesota Heart Health Program. J Cardiopulm Rehabil. 1989;9:448–459.

17. Drazner MH, Peshock RM, Cooper RS, Klassen C, Kazi F, Willett D, Victor RG. Left ventricular hypertrophy is more prevalent in blacks than whites in the general population—the Dallas Heart Study. Hypertension. 2005;46:124–129.

18. Gardin JM, Siscovick D, Anton-Culver H, Jacobs J, Smith VE, Klopfenstein HS, Drazner MH, Dries DL, Peshock RM, Cooper RS, Klassen C, Kazi F, Willett D, Victor RG. Left ventricular hypertrophy is more prevalent in blacks than whites in the general population—the Dallas Heart Study. Hypertension. 2005;46:124–129.

19. Kizer JR, Amett DK, Bella JN, Paranicas M, Rao DC, Province MA, Oberman A, Kizer JR, Amett DK, Bella JN, Paranicas M, Rao DC, Province MA, Oberman A, Kizer JR, Amett DK, Bella JN, Paranicas M, Rao DC, Province MA, Oberman A. Kizer JR, Amett DK, Bella JN, Paranicas M, Rao DC, Province MA, Oberman A. Kizer JR, Amett DK, Bella JN, Paranicas M, Rao DC, Province MA, Oberman A. Kizer JR, Amett DK, Bella JN, Paranicas M, Rao DC, Province MA, Oberman A. Kizer JR, Amett DK, Bella JN, Paranicas M, Rao DC, Province MA, Oberman A.

20. Gardin JM, Wagenknecht LE, Anton-Culver H, Flack J, Gidding S, Kurosaki T, Wong ND, Manolio TA. Relationship of cardiovascular risk factors to echocardiographic left ventricular mass in healthy young black and white adult men and women: the CARDIA study. Circulation. 1995;91:1739–1748.

21. Kizer JR, Amett DK, Bella JN, Paranicas M, Rao DC, Province MA, Oberman A, Kitzman DW, Hopkins PN, Liu JE, Devereux RB. Differences in left ventricular structure between black and white hypertensive adults: the Hypertension Genetic Epidemiology Network Study. Circulation. 2004;43:1182–1188.

22. Gardin JM, Wagenknecht LE, Anton-Culver H, Flack J, Gidding S, Kurosaki T, Wong ND, Manolio TA. Relationship of cardiovascular risk factors to echocardiographic left ventricular mass in healthy young black and white adult men and women: the CARDIA study. Circulation. 1995;91:1739–1748.

23. Natori S, Lai S, Finn JP, Gomes AS, Hundley WG, Jerosch-Herold M, Pearson G, Edelman RR, Levy D, Manning WJ. Gender differences and normal left ventricular anatomy in an adult population free of hypertension. A cardiovascular magnetic resonance study of the Framingham Heart Study Offspring cohort. J Am Coll Cardiol. 2002;39:1055–1060.

24. Gardin JM, Brunner D, Scheinert P, Xie X, Reid CL, Ruth K, Bild DE, Gidding SS. Demographics and correlates of five-year change in echocardiographic left ventricular mass in young black and white adult men and women: the Coronary Artery Risk Development in Young Adults (CARDIA) study. J Am Coll Cardiol. 2002;40:529–535.

25. Urbina EM, Gidding SS, Bao W, Pickoff AS, Berduski S, Berenson GS. Effect of body size, ponderosity, and blood pressure on left ventricular growth in children and young adults in the Bogalusa Heart Study. Circulation. 1995;91:2400–2406.

26. Gidding SS, Liu K, Colangelo LA, Cook NL, Goff DC, Glasser SP, Gardin JM, Lima JA. Longitudinal determinants of left ventricular mass and geometry: the CARDIA study. Circ Cardiovasc Imaging. 2013;6:769–775.

27. Wong ND, Gardin JM, Kurosaki T, Anton-Culver H, Sidney S, Roseman J, Gidding S. Echocardiographic left ventricular systolic function and volumes in young adults: distribution and factors influencing variability. Am Heart J. 1995;129:571–577.

28. Russo C, Jin Z, Homma S, Rundek T, Elkind MS, Sacco RL, Di Tullio MR. Effect of obesity and overweight on left ventricular diastolic function: a community-based study in an elderly cohort. J Am Coll Cardiol. 2011;57:1368–1374.

29. Schocken DD, Benjamin EJ, Fonarow GC, Krumholz HM, Levy D, Mensah GA, Narula J, Shor ES, Young JB, Hong Y. Prevention of heart failure: a scientific statement from the American Heart Association Councils on Epidemiology and Prevention, Clinical Cardioiology, Cardiovascular Nursing, and High Blood Pressure Research; Quality of Care and Outcomes Research Interdisciplinary Working Group; and Functional Genomics and Translational Biology Interdisciplinary Working Group. Circulation. 2008;117:2544–2565.

30. Greenland P, Alpert JS, Beller GA, Benjamin EJ, Budoff MJ, Fayad ZA, Foster E, Hlatky MA, Hodgson JM, Kushner FG, Lauer MS, Shaw LJ, Smith SC Jr, Taylor AJ, Weintraub WS, Wenger NK. 2010 ACCF/AHA guideline for assessment of cardiovascular risk in asymptomatic adults: a Report of the American College of Cardiology Foundation/American Heart Association Task Force on Practice Guidelines Developed in Collaboration With the American Society of Echocardiography, American Society of Nuclear Cardiology, Society of Atherosclerosis Imaging and Prevention, Society for Cardiovascular Angiography and Interventions, Society of Cardiovascular Computed Tomography, and Society for Cardiovascular Magnetic Resonance. J Am Coll Cardiol. 2010;56:e50–e103.

31. Russo C, Jin Z, Homma S, Rundek T, Elkind MS, Sacco RL, Di Tullio MR. Race/ethnic disparities in left ventricular diastolic function in a triethnic community cohort. Am Heart J. 2010;160:152–158.

32. Choi EY, Rosen BD, Fernandes VR, Yan RT, Yoneyama K, Donekal S, Opdahl A, Almeida AL, Wu CO, Gomes AS, Bluemke DA, Lima JA. Prognostic value of myocardial circumferential strain for incident heart failure and cardiovascular events in asymptomatic individuals: the Multi-Ethnic Study of Atherosclerosis. Eur Heart J. 2013;34:2354–2361.