Scientific Contributions

Growth of Left Ventricular Mass in African American and European American Youth

Caroline Dekkers, Frank A. Treiber, Gaston Kapuku, Edwin J.C.G. van den Oord, Harold Snieder

Abstract—Increased left ventricular mass has been established as a strong risk factor for cardiovascular morbidity and mortality. To evaluate growth of left ventricular mass from childhood into early adulthood and its possible sociodemographic, anthropometric, and hemodynamic moderators, individual growth curves across age of left ventricular mass were created for 687 African American and European American males and females with a maximum of 10 annual assessments (age, 8.2 to 27.5 years). African Americans and males had significantly greater left ventricular mass ($P < 0.001$) than did European Americans and females, respectively. Males also showed a larger rate of change in left ventricle mass than did girls ($P < 0.001$). The ethnicity and gender effects on left ventricular mass only became apparent in early adolescence, and they persisted when controlling for socioeconomic status and anthropometric and hemodynamic variables. Body mass index and height were the strongest anthropometric predictors, and pulse pressure was the strongest hemodynamic predictor of left ventricular mass. Although significant, the contribution of pulse pressure to the prediction of left ventricular mass was small, once body mass index and height were entered into the model. The results of the present study suggest that increased left ventricular mass in boys and African Americans has its origin in late childhood. Apart from these ethnicity and gender effects, individual differences in cardiac growth can mainly be explained by body growth and increases in general adiposity. (Hypertension. 2002;39:943-951.)

Key Words: ventricular function, left ■ longitudinal ■ socioeconomic factors ■ hemodynamics ■ ethnicity

Increased left ventricular mass (LVM) has been established as a strong independent risk factor for cardiovascular morbidity (eg, arrhythmia, congestive heart failure, and myocardial infarction) and mortality. Because the pathogenesis of cardiovascular diseases (CVD) has its origin in childhood, moderators of LVM growth need to be evaluated during this time period. Moreover, it is important to increase our understanding of LVM growth in African Americans (AAs), because increased LVM may contribute to the much higher prevalence of cardiovascular morbidity and mortality in AAs compared with European Americans (EAs).  

LVM is known to increase with body growth, ie, height and weight, from childhood to adulthood, with body growth accounting for less variability of LVM with increasing age. Cross-sectional pediatric and adult studies have shown greater LVM in males and AAs compared with females and EAs, respectively, and these studies have shown positive associations of LVM with several anthropometric and hemodynamic variables in youth and adults. It is not clear to what extent these variables account for LVM variability over time. The number of longitudinal studies on LVM growth and moderators of LVM changes in youth and young adults is limited.

The majority of these studies only measured LVM at baseline and 1 follow-up, which does not provide a sufficient basis for studying development. Two recent longitudinal studies included multiple evaluations of LVM in youth. Schieken et al measured LVM on 5 occasions, which were each 18 months apart, in adolescent AA and EA boys and girls between the ages of 11 and 17 years, with the number of subjects ranging from 231, who were studied on at least 3 occasions, to 87 subjects, who were studied on all 5 occasions. Janz et al measured LVM once every 3 months for a period of 5 years in 125 EA boys and girls with a mean initial age of 10.5 years. Both studies showed tracking of LVM in youth through late childhood and adolescence, with boys having greater LVM compared with that of girls. In addition, Schieken et al observed that AAs had greater LVM than that of EAs, but only at the first visit when subjects were 11 years of age. Janz et al reported that fat-free mass, measured with bioelectrical impedance, is an important determinant of LVM level and growth in boys and girls, and that aerobic fitness also affected heart growth in boys.

In summary, only a few longitudinal studies have evaluated growth of LVM and its determinants, but none have compre-
hensively evaluated LVM in a multiethnic population over a longer period of time from childhood through young adulthood.

To the best of our knowledge, this is the first study to explore the development of LVM from childhood through early adulthood in a multiethnic cohort of individuals. Further, this study assesses the effects of demographic, anthropometric, and hemodynamic variables on LVM level and changes over time. Our subjects had a verified family history of cardiovascular disease, with the majority having a strong family history of essential hypertension. Because this places them at increased risk for development of essential hypertension, it makes the cohort an even more important group to study.

Methods

Subjects

Six hundred eighty-seven children participated in this study. Subjects are participants in an ongoing longitudinal study of the development of cardiovascular risk factors in which evaluations have been conducted annually. Mean±SD of subjects’ characteristics at first visit are shown in Table 1.

Participants had a medical record-verified positive family history of CVD, including essential hypertension and/or premature myocardial infarction (<55 years of age) in 1 or both biological parents or ≥1 grandparents. At baseline evaluation, subjects were normotensive for age and gender and were apparently healthy based on parental report of the child’s medical history. Subjects were classified as AA or EA according to criteria described previously. The Human Subjects Review Committee at the Medical College of Georgia gave approval for the study. Informed consent was obtained from 1 of the parents and from the child.

Information on subject recruitment and evaluation that started in 1989 has been previously described. The annualized attrition rate has been <4% per year and has mostly been due to subjects moving out of the region. There have been no significant differences in age, ethnicity, and gender distribution between dropouts and the subjects who remained in the study.

The fact that 149 of the total of 687 subjects in this study were siblings may have affected the significance of observed effects, because they share genes and environment and, consequently, will be more alike than subjects from different families. When siblings were excluded from the analyses, results were virtually unchanged, so results for the entire sample are reported here.

Because not all subjects participated each consecutive year, the data set is a complicated one, with not all subjects having the same number of visits. The percentage of subjects that had ≥4 visits for each ethnic/gender group is presented in Table 1. In the entire sample, 70% had ≥4 visits, making this data set very informative for the study of LVM changes over time. In total, this study involved 687 subjects who yielded 3303 LVM measurements.

Procedure and Measurements

On each annual laboratory visit during the 10-year period, anthropometric, resting hemodynamic, and cardiac structure evaluations were conducted. Evaluation of height, weight, skinfolds (triceps, subscapular, and suprailiac crest), and waist and hip circumference has been described elsewhere. From these primary measures, the sum of the 3 skinfolds (SSKF) was calculated as a measure of body fat; body mass index (BMI; weight/height²), as a measure of general adiposity; and the waist-to-hip ratio (WHR), as a measure of central

<table>
<thead>
<tr>
<th>TABLE 1. Subjects’ Characteristics at First Visit</th>
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<tbody>
<tr>
<td>Demographics</td>
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<tr>
<td>No. of subjects</td>
</tr>
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<tr>
<td>Age, y</td>
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<td>Subjects with ≥4 visits, %</td>
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<td>Echocardiographic measures</td>
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<tr>
<td>LVM, g</td>
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<tr>
<td>LVM/height¹², g/m²</td>
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<td>LVM/BSA, g/m²</td>
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<td>Hemodynamic measures</td>
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<td>SBP, mm Hg</td>
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<td>DBP, mm Hg</td>
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<td>PP, mm Hg</td>
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<td>HR, bpm</td>
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<td>Socioeconomic measures</td>
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<tr>
<td>Father’s education level, y</td>
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<td>Mother’s education level, y</td>
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<tr>
<td>Single-parent household, %</td>
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</table>

Values are mean±SD. All values are for first visit unless defined otherwise.
adiposity. Waist circumference was used as an alternative measure of central adiposity.

Blood pressure (BP) and heart rate (HR) were measured with an automated oscillatory BP system (Dinamap Vital Signs Monitor, Model 1846 SX; CriticInc Inc), by an appropriately sized BP cuff placed on the subject’s right arm. BP measurements were taken at 11, 13, and 15 minutes during a 15-minute supine relaxation period. The average of the last 2 readings was used to represent resting systolic BP (SBP) and diastolic BP (DBP) values. Pulse pressure, a proxy for arterial stiffness, was computed as the difference between SBP and DBP.

Echocardiographic examinations were conducted at each of the 10 longitudinal visits. The protocol used to perform the echocardiograms has been described elsewhere. LVM was calculated using the necropsy-validated formula of Devereux et al. Intra- and interrater coefficients of variation for all cardiac structures assessed were <10%. Because we were interested in LVM growth as a function of age, we did not adjust LVM for body size (height or body surface area [BSA]). We do report these mean values for each ethnic/gender group at first visit in Table 1, however, to enable comparison with values in the literature.

Socioeconomic status (SES) was represented by parental education level, ie, mother’s or father’s education level or highest level of both, because these measures remained highly stable across the years of the study. Thus, parental education as measured at the midpoint of the study was taken as a representative for the whole study period. Parental education level was measured on a 7-point scale, ranging from less than high school to postgraduate education. Several subjects had missing values for father’s education level (n=44), mother’s education level (n=26), or maximum education level (n=26). These subjects were omitted from analyses in which these respective variables were included.

Statistical Analyses

The development of LVM was explored by use of individual growth curve modeling within a multilevel framework, which is a data analysis technique especially designed to explore longitudinal data. Longitudinal data, such as in the present study, can be considered to be clustered or hierarchical data because repeated observations (first level) are nested within each child (second level). We chose individual growth curve modeling over ordinary regression analysis, because the former method accounts for the dependency of the data owing to this clustering. Ordinary regression analysis would estimate a single equation for all data, whereas individual growth curve modeling fits a curve for each individual subject. These curves (eg, LVM development with age) are characterized by their intercept (or level) and slope (rate of change). Addition of independent variables to the model, such as ethnicity and gender, is aimed at explaining between-subject variation (in level and slope) of the LVM growth curves.

The method has a number of advantages over traditional statistical methods for analysis of quantitative longitudinal data. First, substantive questions can be addressed within the multilevel framework, eg, whether LVM of some individuals increases at faster rate over time than those of other individuals. Second, the method accounts for the dependency of observations caused by clustering. Third, any number of waves of data can be accommodated; the occasions of measurement need not be equally spaced; and data-collection schedules can be different for different individuals. Finally, the approach is particularly suitable for dealing with incomplete data.

Analytical Strategy

The repeated LVM measurements may be regarded as a 2-level hierarchy, with subjects at level 2 (between-subject level) and repeated LVM measurements (or waves) at level 1 (within-subject level). To quantify the presence of within-subject (level 1) and between-subject (level 2) variation, we first fitted an intercept-only model and computed the intraclass correlation. See Appendix for an elaborate explanation of the modeling.

Next, we specified the unconditional growth model, in which fixed and random linear and quadratic trends were fitted, by adding respectively age and age² to the intercept-only model. Age was expressed as a deviation from its mean of age 16.

In the third step, ethnicity and gender were separately added to the unconditional growth model to test the effects on LVM intercept and on the rate of change in LVM, and the latter modeled as interactions with age and age². The ethnicity × gender and ethnicity × gender × age interactions were tested as well.

In the fourth step, we separately added anthropometric variables (ie, weight, height, BMI, WHR, waist circumference, and SSKF), hemodynamic variables (ie, SBP, DBP, pulse pressure [PP], HR), and socioeconomic variables (ie, father’s and mother’s education level, and maximum education level) to the ethnicity and gender model to examine the ethnicity and gender effects adjusted for individual differences in these anthropometric, hemodynamic, and SES variables. The main effects of these variables and the effects of their interactions with age, ethnicity, and gender on LVM were tested as well. All anthropometric and hemodynamic variables were centered at their means.

Next, by entering the significant anthropometric variables and their significant interactions simultaneously into a model, we tried to obtain an anthropometric model that explained the maximum amount of between-subject variance in LVM. In this model, we wanted to have only 1 measure representing fat-free mass (ie, height), 1 representing general adiposity (BMI or SSKF), and 1 representing central adiposity (WHR or waist circumference). We kept those anthropometric measures (and significant interactions) in the model, which explained most of the between-subject variance in LVM.

Weight was not used to obtain this model, because it is not a pure measure of fat-free mass or general or central adiposity, but covers all 3. In similar ways, but with the significant hemodynamic and SES variables (and their respective significant interactions), we obtained respectively a hemodynamic and an SES model that each explained the maximum amount of the between-subject variance in LVM.

In the final step, the best anthropometric, SES, and hemodynamic models were simultaneously entered in a full model. A likelihood ratio test was used to determine the significance of the fixed and random effects that were added to the model in each of the analysis steps. This test yields the deviance of the model which is defined as \(-2\times\log likelihood\). The deviance difference (between 2 models) is asymptotically \(\chi^2\) distributed, with the number of degrees of freedom equal to the difference in number of estimated parameters between the 2 models. To judge the significance of parameters in the full model, each parameter was removed from the model, and a likelihood ratio test with 1 degree of freedom was used to examine whether its effect was significant in this full model. Multilevel modeling was performed using the program MLwiN.

Results

The intraclass correlation of 0.60 indicated that 60% of the LVM variation was at between-subject level and 40% at within-subject level. The amount of between-subject variance was significant \((P<0.001)\). This indicated that observations clustered within individuals, confirming the need for a multilevel modeling approach.

The unconditional growth model with a fixed and random linear (age) effect and a fixed quadratic (age²) effect provided the best fit (Table 2, model 6). Age explained twice as much variance in LVM level within subjects (22.2%) than between subjects (11.2%).

Ethnicity and Gender Model

In Table 2, the results of growth curve modeling of LVM with sociodemographic variables are shown. Both ethnicity \((b=8.1, P<0.001)\) and gender \((b=-28.2, P<0.001)\) had a significant effect on LVM level, indicating that AAs and males had higher LVM levels than EAs and females, respectively (Table 2, models 7 and 10). In addition, gender showed...
a significant interaction with age (b = −3.5, \( P < 0.001 \)), reflecting that males showed a stronger linear increase in LVM over time than did females (model 11). The ethnicity and gender model explained an additional 29.6% (40.8 − 11.2) of the between-subject variance in LVM, but 1% of the within-subject variance compared with the unconditional growth model. The model explained 43.8% of the variance in rate of change (ie, slope) of LVM, which was caused by the interaction of gender with age and age\(^2\). Gender explained 26.6%, whereas ethnicity only explained 2% of the between-subject variance in LVM.

Figure 1 shows mean values of raw LVM data from childhood to early adulthood by ethnicity and gender. It can be observed that LVM level for the 4 groups did not differ at younger ages, that the differences in LVM level between the ethnicity and gender groups only become apparent in early adolescence, and that these differences remain fairly stable with age.

**SES Model**

Of parental education level, only father’s education level (model 16) showed a significant negative effect on LVM (b = −1.1, \( P < 0.05 \)), indicating that subjects whose fathers have lower education levels have higher LVM levels. Father’s education level showed no significant interactions with age, ethnicity, or gender. When father’s education level was taken into account, the ethnicity and gender effects remained significant. Compared with the ethnicity and gender model, this SES model explained only an additional 0.6%.

**Anthropometric Model**

In Table 3, the results of growth curve modeling for LVM with anthropometric variables are shown. Weight (b = 0.95), BMI (b = 2.49), SSKF (b = 0.32), and height (b = 1.29) (models 15, 21, 31, 36) each had a significant (\( P < 0.001 \)) effect on LVM level, reflecting that LVM increases with increasing weight.
weight, height, and obesity. In addition, weight showed a significant negative interaction with age (model 16: b = -0.03, P < 0.01), indicating that heavier subjects showed a smaller linear increase in LVM.

Both waist circumference (b = 2.45, P < 0.001) and WHR (b = 85.19, P < 0.001) were significant predictors of average LVM level, indicating a positive association between LVM and central adiposity. The significant (b = 8.55, P < 0.01) interaction between WHR and age (model 42) showed that subjects with more abdominal fat had a stronger linear increase in LVM than did subjects with less abdominal fat.

Table 3 shows that weight accounted for most of the interindividual variance in LVM by explaining an additional 33.5% of the between-subject variance in LVM compared with the ethnicity and gender model, followed successively by BMI (27.6%), waist circumference (26.9%), SSKF (19.4%), height (11.9%), and WHR (7.8%). These variables explained little (<2%) of the within-subject variance of LVM. The effects of gender and ethnicity on LVM remained significant after adjustment for these anthropometric variables.

Height, BMI, waist circumference, and their interactions were simultaneously entered into a model to obtain an anthropometric model that explained the most between-subject variance in LVM. The model in which BMI, height, and their significant interactions with ethnicity were entered turned out to be the anthropometric model that explained most of the between-subject variance in LVM. The contribution of waist circumference was no longer significant. Com-

<table>
<thead>
<tr>
<th>Model Variables</th>
<th>-2×loglikelihood</th>
<th>χ²</th>
<th>Δ df</th>
<th>Versus Model</th>
<th>P</th>
<th>% Explained Variance*</th>
</tr>
</thead>
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<td>16</td>
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<td>1</td>
<td>17</td>
<td>NS</td>
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</tr>
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χ² indicates Δ -2×loglikelihood; Δ df, difference in degrees of freedom.

*The % explained variance at the centered value for age is given (age 16).
pared with the ethnicity and gender model, this model explained an additional 35.7% of the between-subject variance in LVM and an additional 29% of the variance in slope. The model hardly contributed to the proportion explained within-subject variance in LVM (<2%).

**Hemodynamic Model**

Table 4 shows the results of growth curve modeling of LVM with hemodynamic predictor variables. Both SBP (b=0.34, *P*<0.001) and PP (b=0.53, *P*<0.001) had significant effects on LVM, indicating that LVM increases with increasing SBP and PP (model 15 and 20). SBP and PP showed no significant interactions with age, ethnicity, or gender. HR was not a significant predictor of LVM (data not shown).

SBP and PP accounted, respectively, for an additional 4.0% and 7.6% of the proportion explained between-subject variance in LVM compared with the ethnicity and gender model. The proportion of within-subject variance accounted for by SBP and PP is negligible (<1%). Similar to SES and anthropometric findings, gender and ethnicity effects adjusted for individual differences in hemodynamic variables were still significant.

When SBP and PP were simultaneously entered into the model, the significant SBP effect on average LVM level disappeared. Thus, the model in which only PP was entered turned out to be the hemodynamic model that explained the maximum amount of between-subject variance in LVM, ie, 7.6% compared with the ethnicity and gender model. In addition, it explained an additional 5.2% in rate of change of LVM.

**Full Model**

In the full model, in which the ethnicity and gender, SES, and anthropometric and hemodynamic models were combined, father’s education level was no longer significant and therefore omitted from the model.

The best-fitting full model, in which only the ethnicity and gender and anthropometric and hemodynamic models were entered simultaneously, explained in total 77.4% of the between-subject variance in LVM (at age 16). The percentage of explained between-subject variance in LVM by the full model is plotted as a function of age. To get an impression of the independent contribution of ethnicity and gender and the anthropometric and hemodynamic variables to the explained LVM between-subject variance, we also plotted the percentage of explained between-subject variance in LVM by these separate models (Figure 2). It can be observed that gender and ethnicity start to explain between-subject variance in LVM around age 10 and that their percentage explained between-subject variance increases with age and levels off in early adulthood. Both the anthropometric and hemodynamic variables already explain between-subject variance at younger ages and keep explaining a relatively stable percentage of this variance through early adulthood, although the anthropometric variables (ie, height and BMI) explain a much higher proportion of the between-subject variance in LVM than do the hemodynamic variables (ie, PP). Thus, the anthropometric variables are stronger predictors of LVM than are the hemodynamic variables.

The full model explained most of the between-subject variance in LVM from childhood through adulthood in a way similar to the hemodynamic and anthropometric variables. Ethnicity, gender, and the anthropometric variables accounted for most of the explained between-subject variance of LVM in the full model, whereas the contribution of PP was minimal. The full model explained an additional 30% of the rate of change in LVM compared with the ethnicity and gender model, and only explained 1.6% of the within-subject variance in LVM level, indicating that the proportion explained within-subject variance in LVM level by any of the variables, except age, is negligible.

**Discussion**

The aim of this study was to assess the potential moderating influences of a variety of sociodemographic, anthropometric, and hemodynamic variables on LVM level and growth from childhood to early adulthood. This is the first longitudinal study that involves annual LVM measurements over a 10-
year period from childhood into early adulthood, in both AA and EA males and females.

As expected, our results showed that the majority of the within-subject variance in LVM growth was explained by age. In addition, higher LVM levels were observed in males than in females from late childhood through early adulthood. Greater LVM in males compared with females from late childhood throughout adolescence has been observed previously.6,13 Moreover, we found that males had a stronger linear increase of LVM than did females, from childhood to early adulthood. Similar findings have been observed during puberty,4,27 but no gender difference in rate of change of LVM was observed in children, age ≤12 years, and adults (≥17 years).27 Our finding of a stronger LVM increase in males than in females from late childhood through early adulthood is consistent with large sectional findings.7,29 Because SSKF and BMI are highly positively correlated, the finding of a positive interaction of SSKF with gender, but a negative interaction of BMI with gender was unexpected. These significant interactions, however, turned out to be rather weak because they both disappeared in the full model. Consistent with the finding by Daniels et al,8 we found that central adiposity is associated with a less favorable LVM. The effect of central adiposity on LVM disappeared when it was simultaneously entered in a model with BMI and height, however, probably because of the strong correlations between central adiposity and BMI. Height and general adiposity were the strongest anthropometric predictors of LVM, together explaining a considerable proportion of between-subject variance in LVM level (35.7%). These results indicate that apart from the influence of ethnicity and gender, the increase in LVM in our subjects from childhood through early adulthood was mainly caused by normal growth and increases in general adiposity.

Overall, the anthropometric findings suggest that overweight subjects have an increased risk of developing LV hypertrophy. In contrast to gender, ethnicity, and height, adiposity can be modified to reduce the risk of developing increased LVM. Thus, effective primary prevention of elevated LVM should focus on reducing or controlling adiposity, eg, by increasing physical activity and/or altering dietary intake.

Individuals with elevated SBP showed increased LVM, which is in line with evidence suggesting that elevated cardiac load, by increasing wall stress and strain, results into myocardial hypertrophy.30 The positive significant influence of SBP on LVM has frequently been reported in cross-sectional studies involving youth and adults.7,9,10,16 PP had an even stronger effect on LVM than SBP. In adults, PP has been suggested to be positively associated with LVM7 and has been found to be a significant predictor of all-cause total cardiovascular and coronary mortality.31 Our study is the first one to find PP to be a significant predictor of LVM in children and adolescents. Further longitudinal evaluations in children and adolescents are needed to confirm the early role of arterial stiffness on LVM. Although PP turned out to be the strongest hemodynamic predictor in our study, it contributed little to the proportion of explained between-subject variance, once the anthropometric variables height and general adipo-
iti (BMI) were entered in the full model. This indicates that anthropometric variables were stronger predictors of LVM than were hemodynamic variables. These findings are in line with those by de Simone et al., who found body growth to be the main predictor of LVM in children and adolescence, whereas loading conditions became the strongest determinant of LVM in adulthood. Continued follow-up of the cohort is needed to confirm these observations.

Several limiting points in this study need consideration. First, it has to be noted that all our subjects had a verified positive family history of CVD. Rationale for this inclusion criterion was the high relevance of studying determinants of progression of CVD risk factors for this high-risk group of susceptible children. However, given the high prevalence of CVD, particularly in the southeastern United States, we do not expect this to have a major adverse effect on the generalizability of our study.

Second, ethnicity and gender differences in BP may be due to differences in pubertal maturation stage. Of the few LVM studies that have addressed sexual maturation stage, all report that sexual maturation stage is not an independent predictor of LVM and that its effect on LVM may operate through changes in body size. Because we addressed measures of body size (eg, height, weight, and BMI) in the present study, we have at least partly controlled for sexual maturation.

Third, we have not included total peripheral resistance (TPR) in our study, because TPR measurements were only available for a portion of LVM measurements. In an earlier study of our group in a subsample of the same cohort, elevated TPR was a significant predictor of mid wall fractional shortening, and increased LVM height and LVM/BSA, suggesting that increased TPR plays a role in cardiac function and remodeling. However, TPR only explained 2% of the variance of LVM indexed by height or BSA.

Perspectives

The aim of this study was to evaluate the growth of LVM from childhood to early adulthood and its possible sociodemographic, anthropometric and hemodynamic moderators. Our results showed that ethnicity and gender differences in LVM become apparent in early adolescence and remain relatively stable through early adulthood, with AAs and males having greater LVM levels than EAs and females, respectively. These ethnic and gender differences in LVM persisted even after adjusting for SES, anthropometric, and hemodynamic variables. Apart from these effects of ethnicity and gender, height and BMI appeared to be the strongest predictors of LVM in the present study. Thus, the increase in LVM in our subjects from childhood through early adulthood was mainly due to normal growth and increases in general adiposity. Reducing or controlling adiposity—eg, by increasing physical activity and/or altering dietary intake—could be considered to reduce the risk of developing increased LVM.

Appendix

First, we set up a simple model in which only the intercept is modeled to provide a baseline with which to compare more complex models. This intercept-only model can be written as $y_{ij} = 0 + u_{ij}$, in which $y_{ij}$ is the LVM of individual $j$ on measurement occasion $i$, $X_0$ is 1 for all subjects and the parameter for $x_i$ may be written as $\beta_i = \beta_{0i} + u_{0i}$. Because $x_i$ is always 1, $\beta_{0i}$ is the overall intercept. The other 2 parameters $u_{0i}$ and $u_{1i}$ are the “error” terms that indicate the deviations from the general growth curve. Parameter $u_{0i}$ indicates the individual deviation at the subject level. Because this term is identical for all repeated measures made on the same individual, it accounts for the dependency of observations. Parameter $u_{1i}$ represents the deviations within subjects between measurement occasions.

To quantify the proportion of between-subject variance (level 2) the intraclass correlation coefficient was computed according to the following formula:

$$\rho = \frac{\sigma^2_{\text{u0}}}{\sigma^2_{\text{u0}} + \sigma^2_{\text{e0}}}$$

Our unconditional growth model assumed polynomial growth as a function of age and age and can be written as follows:

$$y_{ij} = [\beta_{0i} + \beta_{1i}x_{ij} + \beta_{2i}x_{ij}^2]$$

where $x_{ij}$ is 1 for all subjects, and $x_{ij}$ is age. Parameters $\beta_{1i}$ and $\beta_{2i}$ are fixed coefficients that indicate the average polynomial growth in the whole sample. Age was expressed as a deviation from its mean of age 16. One implication is that at age 16 the between-subject variance of this model (and subsequent models), which is a function of age (see below), simplifies to the between-subject variance of the intercept.

Individuals may grow at different rates. To account for this, parameters $\beta_{1i}$ and $\beta_{2i}$ can be made random at the subject level:

$$y_{ij} = [\beta_{0i} + \beta_{1i}x_{ij} + \beta_{2i}x_{ij}^2]$$

with $\beta_{1i} = \beta_{10i} + u_{1i}$ and $\beta_{2i} = \beta_{20i} + u_{2i}$. The covariance structure of the random parameters at the person level is assumed to be as follows:

$$\begin{pmatrix}
  u_{0i} \\
  u_{1i} \\
  u_{2i}
\end{pmatrix} \sim N(0, \Omega)$$

with $\Omega = \begin{pmatrix}
  \sigma^2_{\text{u0}} & 0 & 0 \\
  0 & \sigma^2_{\text{u1}} & \sigma_{\text{u12}} \\
  0 & \sigma_{\text{u12}} & \sigma^2_{\text{u2}}
\end{pmatrix}$

Thus, the random parameters are multivariate normally distributed with a mean of 0 and a variance-covariance matrix $\Omega$. The variances of the parameters are on the diagonal and the covariances in the off-diagonal cells of $\Omega$.

An implication of the fact that individuals grow at different rates is that the between-subject variance (level 2), $\text{var}(u_{0i} + u_{1i} + u_{2i})$, becomes a function of age and is no longer constant. The covariance structure of the random parameters at the measurement or within-subject level equals

$$\begin{pmatrix}
  e_{0i} \\
  e_{1i} \\
  e_{2i}
\end{pmatrix} \sim N(0, \Omega_e)$$

with $\Omega_e = \begin{pmatrix}
  \sigma^2_{\text{e0}} \\
  \sigma_{\text{e01}} & \sigma^2_{\text{e1}} \\
  \sigma_{\text{e01}} & \sigma_{\text{e12}} & \sigma^2_{\text{e2}}
\end{pmatrix}$

Thus, there is only 1 random parameter at level 1, which is assumed to be normally distributed with a mean of 0 and variance of $\sigma^2_{\text{e0}}$.

We were not merely interested in LVM change over time, but we also wanted to assess the effects of the covariates ethnicity and gender on the growth curve of LVM, encompassing both LVM level and the rate of LVM change over time. Moreover, we wanted to examine these ethnicity and gender effects after controlling for the effects of SES, anthropometric and hemodynamic variables. If $x_i$ is gender, ethnicity, or 1 of the covariates, this can be achieved by adding the following terms:

$$y_{ij} = [\beta_{0i} + \beta_{1i}x_{ij} + \beta_{2i}x_{ij}^2 + \beta_{3i}x_3 + \beta_{4i}x_4 + \beta_{5i}x_5]$$

where $\beta_i$ is the effect of gender, ethnicity, or 1 of the covariates on the intercept, $\beta_1$ and $\beta_2$ the effects of gender, ethnicity, or 1 of the covariates on the linear and quadratic terms, respectively, of the growth curve.

To improve the statistical behavior and the interpretation of the parameters we rescaled (“centered”) the continuous independent variables (eg, age, height, and BMI) to have a mean of 0. Centering age $x_{ij}$ will reduce the collinearity between the parameters $\beta_{1i}$ and $\beta_{2i}$ for the linear and quadratic terms, respectively. Centering covariate $x_3$ may improve the interpretation because the other parameters $\beta_{0i}$, $\beta_{1i}$, and $\beta_{2i}$ now indicate the growth curve at the mid point of the covariate scale rather than at some extreme or unusual value.

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