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Gender-Specific Reference M-Mode Values in Adults: Population-Derived Values With Consideration of the Impact of Height

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Objectives. **The purpose of this investigation was to derive population-based reference values for M-mode echocardiographic dimensions that can be applied in epidemiologic studies, clinical trials and clinical practice and to determine optimal methods for adjusting these dimensions for body size.**

Background. **M-mode echocardiography remains an important modality for studying cardiovascular disease; this is especially true with regard to detecting target organ damage in systemic hypertension. Most previously published reference values were derived from hospital-based series or relatively small samples and were not gender specific.**

Methods. **Using a sample of 288 men and 524 women who were between 20 and 45 years of age and who were free of cardiovascular disease, reference values were derived for end-diastolic and end-systolic left ventricular internal dimensions, left ventricular wall thickness and left atrial dimension. The relations between these dimensions and height, a measure of body size relatively independent of obesity, were investigated using various regression models.**

Results. **Nomograms for mean and 95th percentile values in men and women were constructed on the basis of linear regression models relating echocardiographic dimensions to height. Adjustment for body surface area greatly attenuated associations between obesity and cardiac dimensions in a separate healthy but less restricted sample of 411 men and 503 women.**

Conclusions. **Gender-specific M-mode reference values and nomograms, with mean and 95th percentile values for echocardiographic dimensions as a function of height, are reported. The use of body surface area as means of body size adjustment is called into question.**

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M-mode echocardiography remains an important modality for studying cardiovascular disease in population studies, clinical trials and investigations of hypertensive disease (1–6). For echocardiography to be a more effective epidemiologic tool, it would be helpful to have well defined gender-specific reference values derived from healthy subjects within population-based samples. Previously published reference values (7–9) were derived from hospital-based series or relatively small samples and were not gender-specific.

This report presents reference echocardiographic values for several important cardiac dimensions in a healthy subset of the Framingham Heart Study. Any consideration of normal cardiac dimensions must take into account the known interactions between cardiac size and body size, which in previous reports has been assessed using height, body surface area, weight and estimated lean body mass (10,11). Therefore, the relations of height and M-mode left ventricular dimensions are explored. Height was chosen as a measure of body size because it is obesity independent and may represent a readily available surrogate for lean body mass, which has been shown to be associated with cardiac size (12).

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Methods

Study samples. Study design and selection criteria for the Framingham Heart Study and Framingham Offspring Study have been described previously (13–15). The original cohort comprised a sample of adult residents of Framingham, Massachusetts between the ages of 28 and 62 years; since 1948, these subjects have undergone biennial examinations. Offspring of the original cohort and spouses of offspring were enrolled in 1972. Data for this investigation were obtained as part of examination 16 (1979 to 1982) of the original cohort and examination 2 (1979 to 1983) of the offspring cohort. Written informed consent was obtained from all subjects before the study.

Two subsets of examinees were studied: a "healthy, restricted" sample and a "healthy, less restricted" sample; criteria for similar samples have been described elsewhere (16). Briefly, members of the healthy, restricted sample had to be between ages 20 and 45 years, between 1.5 and 1.9 m in height

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in men or between 1.4 and 1.8 m in height in women, free of cardiovascular disease and hypertension (i.e., systolic blood pressure <140 mm Hg, diastolic blood pressure <90 mm Hg and taking any antihypertensive medications), not currently using any cardiovascular medications, not diabetic, not obese (body mass index between 19 and 26 kg/m^2) and had to have a technically adequate echocardiogram. Members of the healthy, less restricted sample had only to be free of overt cardiovascular disease (i.e., no signs or symptoms of cardiovascular disorders), not taking any cardiovascular medications and had to have a technically adequate echocardiogram. Thus, the major difference between the two samples was whether or not body size restrictions were applied: the healthy, less restricted sample had no body size requirements. Criteria for cardiovascular diagnoses and diabetes have been detailed elsewhere (17,18).

To avoid overlap between the healthy, restricted and healthy, less restricted samples, all subjects were split randomly into two groups (one group comprising 75% of the study sample, and the other group 25%). From the 75% subset, we derived the healthy, restricted sample that was used for model fitting, whereas from the 25% subset we derived the healthy, less restricted sample.

Baseline measurements. Examinations routinely included measurements of height, weight and blood pressure. Rest systolic and diastolic blood pressures were measured in the left arm of seated subjects using a mercury column sphygmomanometer. Two physician-measured systolic and diastolic pressures were averaged to derive rest systolic and diastolic blood pressures. Body surface area was calculated using the Dubois formula (19): body surface area (m^2) = (0.0001) × (71.84) × (weight, kg)$^{0.425}$ × (height, cm)$^{0.725}$. Body mass index (kg/m^2) was used as an index of obesity.

Echocardiographic methods. Standard M-mode methods were used as previously reported (20–22). End-diastolic and end-systolic measurements of left ventricular internal dimension, interventricular septal thickness, posterior free wall thickness and left atrial dimension were obtained using the American Society of Echocardiography convention (21). The left ventricular wall thickness was defined as the sum of the thicknesses of the interventricular septum and the posterior free wall. In >90% of the echocardiograms, two-dimensional images were used to guide M-mode measurements.

Statistical methods. The healthy, restricted sample was used to estimate reference values, whereas the healthy, less restricted sample was studied to assess the clinical impact of height and body surface area adjustment methods. Gender-specific mean values and standard deviations were calculated for baseline characteristics of both samples.

Gender-specific regression analyses were performed to investigate the relations between left ventricular M-mode dimensions and height. Height was chosen as a measure of body size because unlike body surface area, it is relatively independent of obesity. In the healthy, less restricted sample, body surface area was correlated strongly with body mass index ($r = 0.61$ for men; $r = 0.72$ for women), but height was only minimally correlated with body mass index (in men $r = -0.09$ for men; $r = -0.13$ for women).

Three methods of regression were used (23). 1) *Standard linear regression*: $Y = \beta_0 + \beta_1 \times \text{height} + E$, where β_0 = Y intercept; β_1 = slope; and E = an error term. 2) *Log-linear model*: $\log Y = \beta_0 + \beta_1 \times \log(\text{height}) + E$. 3) *Nonlinear regression*: $Y = \beta_0 \times \text{Height}^{\beta'} + E$. To compare these models, the R^2 and root-mean-square errors were calculated; for the log-linear model, estimates were converted back to original units to calculate the root-mean-square error. In addition, residuals and fitted values from each model were examined graphically.

Examination of the fitted plots, the root-mean-square errors and the R^2 values revealed that none of the three models showed any clear superiority. Furthermore, residuals from the linear model appeared to have constant variance and also normal distribution (except for wall thickness in women). For greatest simplicity, therefore, to construct nomograms the standard linear models were used. For each gender and left ventricular M-mode dimension (except wall thickness in women and left atrial dimension in both genders, which yielded nonsignificant regressions [men] with very low R^2 values), nomograms of mean and upper 95th percentile values were made, plotting the fitted M-mode values against height (using ranges 1.55 to 1.90 m in men, 1.45 to 1.80 m in women). The upper 95th percentile was approximated by predicted value plus 1.65 times root-mean-square error.

To determine the clinical impact of different body size considerations, Pearson correlation coefficients relating left ventricular M-mode variables to systolic blood pressure and body mass index were calculated in the healthy, less restricted sample. Simple correlations, partial correlations adjusted for height and partial correlations adjusted for body surface area were computed. Because age and cardiovascular disease limitations were used to define the healthy, less restricted sample, analyses regarding age and cardiovascular diseases were not performed.

All analyses were performed on a SUN Sparcstation2 using the SAS 6.07 statistical package (24). Regression analyses were performed using the PROC REG and PROC NLIN procedures. All analyses were gender-specific.

Results

Characteristics of subjects (healthy, restricted and healthy, less restricted samples). The clinical characteristics of the study subjects are summarized in Table 1. The healthy, restricted sample included 288 men and 524 women; the healthy, less restricted sample included 411 men and 503 women. Compared with the healthy, restricted sample, the healthy, less restricted sample was older, heavier, had a larger body mass index and body surface area, higher blood pressure and larger left ventricular wall thickness, left ventricular mass and left atrial dimension but had similar diastolic and systolic left ventricular cavity dimensions. Whereas none of the subjects in the healthy, less restricted sample had any signs or symptoms

Table 1. Clinical Characteristics of the Healthy, Restricted and Healthy, Less Restricted Study Samples

	Healthy, Restricted Sample				Healthy, Less Restricted Sample			
	Men (n = 288)		Women (n = 524)		Men (n = 411)		Women (n = 503)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Age (yr)	35.7	6.1	35.9	5.5	46.3	12.8	47.5	13.2
Height (m)	1.77	0.06	1.63	0.06	1.75	0.07	1.61	0.06
Weight (kg)	74.1	6.9	59.3	6.1	80.7	12.0	62.2	11.4
Body mass index (kg/m^2)	23.5	1.6	22.1	1.7	26.1	3.4	23.9	4.2
Body surface area (m^2)	1.91	0.11	1.64	0.10	1.96	0.16	1.65	0.14
Systolic blood pressure (mm Hg)	117	9.1	110	10.5	124	15.6	119	17.3
Diastolic blood pressure (mm Hg)	74.8	6.8	70.9	7.5	78.8	8.8	74.3	8.5
LV diastolic dimension (mm)	50.8	3.6	46.1	3.0	51.1	3.7	45.7	3.6
LV systolic dimension (mm)	32.9	3.4	28.9	2.8	32.9	3.5	28.3	3.2
LV wall thickness (mm)	18.1	2.0	15.5	1.5	19.2	2.6	16.7	2.5
LA dimension (mm)	37.5	3.6	33.1	3.2	39.6	4.2	34.3	4.2

LA = left atrial; LV = left ventricular.

of cardiovascular disease, 133 (15%) did meet the criteria for hypertension (systolic blood pressure ≥140 mm Hg or diastolic blood pressure ≥90 mm Hg; by definition no subjects were taking antihypertensive medications).

Left ventricular M-mode dimensions and height (healthy, restricted sample). Summaries of regression analyses relating left ventricular M-mode dimensions to height are shown in Tables 2 and 3. Except for left ventricular wall thickness in

Table 2. Three Regression Models Relating Left Ventricular M-Mode Echocardiographic Dimensions to Height Derived From Men in the Healthy, Restricted Study Sample

LV Dimension	Estimated β_0	Estimated β_1 (95% CI)	R^2	RMSE	p Value
Model: LV Dimension = β_0 + β_1 Height + E					
LV diastolic dimension	21.36	16.63 (10.1–23.2)	0.08	3.460	0.0001
LV systolic dimension	12.60	11.47 (5.2–17.7)	0.04	3.307	0.0004
LV wall thickness	2.70	8.68 (5.0–12.3)	0.07	1.930	0.0001
LA dimension	29.20	4.69 (−2.2–11.5)	0.01	3.619	0.1812
Model: log(LV dimension) = β_0 + β_1 log(Height) + E					
LV diastolic dimension	3.60	0.57 (0.34–0.80)	0.08	3.463	0.0001
LV systolic dimension	3.15	0.60 (0.26–0.94)	0.04	3.312	0.0005
LV wall thickness	2.41	0.84 (0.49–1.18)	0.07	1.932	0.0001
LA dimension	3.49	0.22 (−0.10–0.55)	0.01	3.624	0.1758
Model: LV Dimension = β_0 Height$^{\beta_1}$ + E					
LV diastolic dimension	36.51	0.58 (0.35–0.81)	0.08	3.461	0.0001
LV systolic dimension	23.13	0.62 (0.28–0.96)	0.04	3.308	0.0003
LV wall thickness	11.14	0.85 (0.49–1.21)	0.07	1.930	0.0001
LA dimension	33.09	0.22 (−0.10–0.54)	0.01	3.619	0.1819

RMSE = root-mean-square error; other abbreviations as in Table 1.

Table 3. Three Regression Models Relating Left Ventricular M-Mode Dimensions to Height Derived From Women in the Healthy, Restricted Study Sample

LV Dimension	Estimated β_0	Estimated β_1 (95% CI)	R^2	RMSE	p Value
Model: LV Dimension = β_0 + β_1 Height + E					
LV diastolic dimension	23.48	13.85 (9.7–18.0)	0.07	2.903	0.0001
LV systolic dimension	9.51	11.91 (8.0–15.8)	0.06	2.707	0.0001
LV wall thickness	9.26	3.84 (1.7–6.0)	0.02	1.511	0.0006
LA dimension	22.83	6.27 (1.7–10.8)	0.01	3.175	0.0076
Model: log(LV dimension) = β_0 + β_1 log(Height) + E					
LV diastolic dimension	3.59	0.50 (0.35–0.65)	0.08	2.905	0.0001
LV systolic dimension	3.03	0.68 (0.45–0.90)	0.06	2.709	0.0001
LV wall thickness	2.54	0.41 (0.19–0.64)	0.02	1.510	0.0004
LA dimension	3.34	0.31 (0.08–0.53)	0.01	3.172	0.0083
Model: LV Dimension = β_0 Height$^{\beta_1}$ + E					
LV diastolic dimension	36.26	0.49 (0.34–0.64)	0.07	2.903	0.0001
LV systolic dimension	20.85	0.67 (0.45–0.89)	0.06	2.707	0.0001
LV wall thickness	12.74	0.40 (0.17–0.63)	0.02	1.511	0.0006
LA dimension	28.42	0.31 (0.08–0.53)	0.01	3.175	0.0075

Abbreviations as in Tables 1 and 2.

women, all models yielded normally distributed residuals. The nonnormality of residuals for left ventricular wall thickness was due to the small number of distinct values. Examination of residuals, root-mean-square errors and fitted values revealed that all three models were essentially equivalent. Therefore, simple linear regression models were used to derive nomograms for M-mode dimensions.

The confidence intervals for β_1 for left atrial dimension in men for two of three models included zero, and the slope estimates were quite small. This finding suggests that the relation between left atrial dimension and height is minimal.

Nomograms (healthy, restricted sample). Figures 1 to 3 provide gender-specific nomograms relating left ventricular M-mode dimensions to height. The upper lines refer to the 95th percentile values, and the lower lines refer to mean values. All lines were derived from the linear regression models in Table 2. Thus, these lines can be used to determine an upper "normal" value for any given height. The predicted upper normal values were compared with the original data set for each cardiac dimension. For all dimensions except left ventricular wall thickness in women, both the predicted and actual data were comparable, with roughly 5% of the sample categorized as abnormal. Among women, a substantial number had left ventricular wall thickness (sum of interventricular septum and posterior wall) measured at 18 mm, such that choosing >18 mm as a cutoff yielded only 2% abnormally high, whereas choosing a cutoff ≥18 yielded 11% abnormally high.

Clinical implications of differing body size measurements (healthy, less restricted sample). Table 4 shows correlation coefficients between left ventricular M-mode dimensions and systolic blood pressure in the healthy, less restricted sample. Moderate correlations were noted for left ventricular wall thickness and left atrial dimension with systolic blood pressure. Using partial correlations adjusted for height or body surface area resulted in little change. For example, adjusting for height increased the correlation between left ventricular wall thickness and systolic blood pressure from 0.27 to 0.30 in men and did not change the correlation in women (0.46).

Table 5 shows simple and partial correlation coefficients for M-mode dimensions and body mass index in the healthy, less restricted sample. Moderate correlations were noted for left ventricular wall thickness and left atrial dimension with body mass index. Using partial correlations adjusted for height resulted in slight increases in the correlation coefficients; in

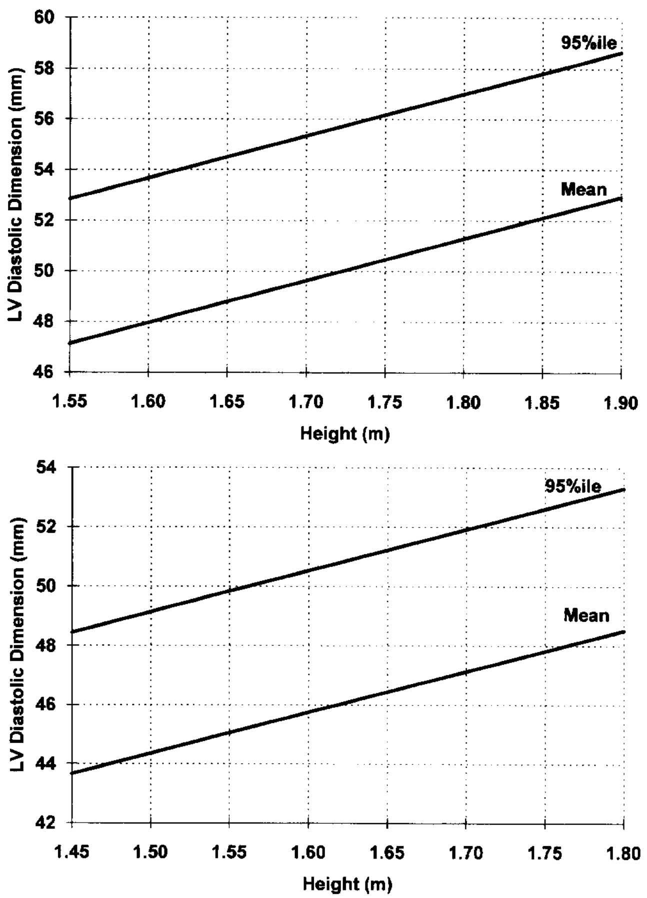

Figure 1. Nomogram plots of predicted mean and 95th percentile (95%ile) values for left ventricular (LV) end-diastolic dimension as a function of height for men (**top**) and women (**bottom**), derived from linear regression models in Tables 2 and 3. Values above the 95th percentile for any given height may be considered abnormally high.

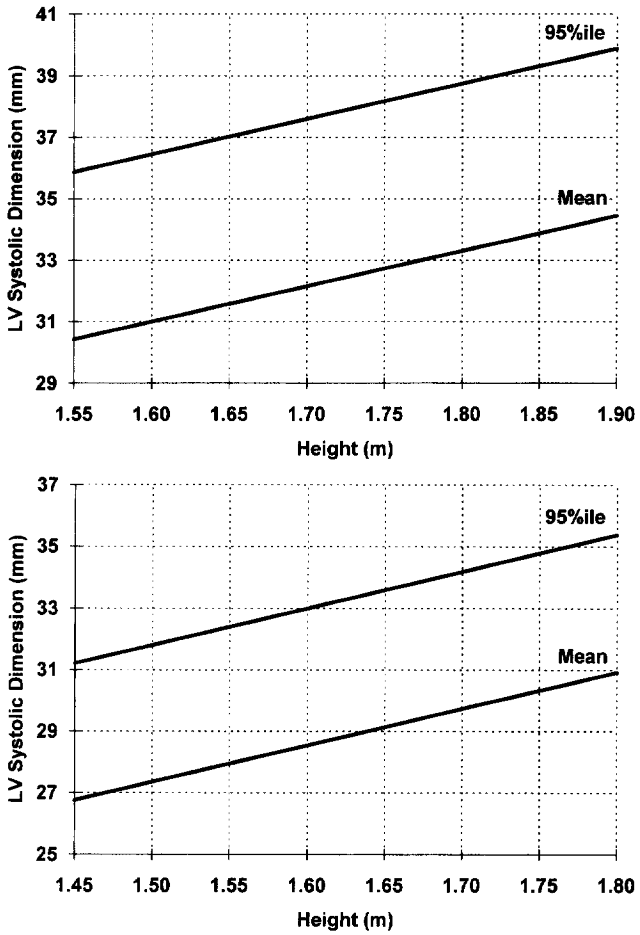

Figure 2. Nomogram plots of predicted mean and 95th percentile (95%ile) values for left ventricular (LV) end-systolic dimension as a function of height for men (**top**) and women (**bottom**), derived from linear regression models in Tables 2 and 3. Values above the 95th percentile for any given height may be considered abnormally high.

contrast, adjusting for body surface area resulted in marked attenuation of correlations, especially between M-mode dimensions and body mass index. For example, adjusting for body surface area decreased the correlation of left atrial dimension and body mass index in women from 0.49 to 0.34. These observations are not surprising, given the correlation of body surface area with body mass index (see Statistical methods).

The data from Tables 4 and 5 suggest that in the setting of obesity, the use of body surface area as a method of adjusting cardiac dimensions may be inappropriate. For correlations of cardiac dimensions and systolic blood pressure, body size adjustment seems to make little difference.

Discussion

In a young, healthy, population-based sample, we derived reference values and nomograms for echocardiographic left ventricular internal dimensions and wall thickness that can be used for future epidemiologic studies, clinical trials and clinical practice. These values can potentially be used in M-mode echocardiographic studies of the effects of obesity, cardiovascular disease processes, hypertension and various medications on cardiac structure and function. They may have important implications for population-based studies. Also, these models can be used to define continuous measures of left ventricular dimensions in study or clinical populations by utilizing the observed values versus those predicted from the regression models in the healthy, restricted population.

As echocardiographic techniques have advanced from M-mode to two-dimensional and, more recently, three-dimensional techniques (25,26), it might be argued that this type of M-mode research is rapidly becoming irrelevant. We believe that this is not so. Quantitative M-mode echocardiography remains widely used in most echocardiography laboratories. Furthermore, M-mode echocardiography still plays an important role in cardiovascular research. For example, M-mode techniques figured prominently in the methods and tables of two recent articles on clinical hypertension and cardiac structure (5,6). M-mode techniques also were used in recent reports from the Cardiovascular Health Study (2,27) and a widely cited study of physiologic hypertrophy in athletes

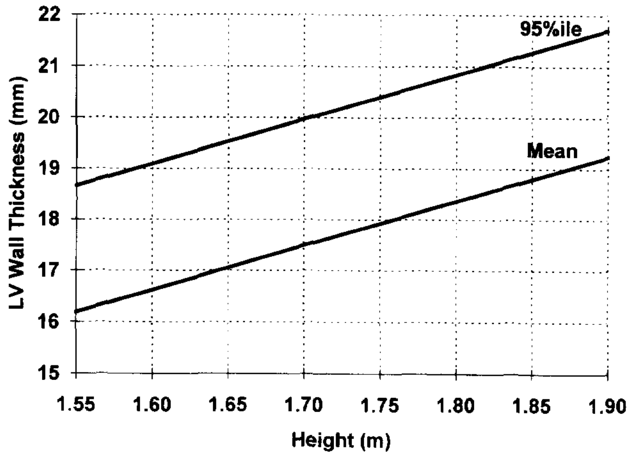

Figure 3. Nomogram plots of predicted mean and 95th percentile (95%ile) values for left ventricular (LV) wall thickness in men as a function of height, derived from linear regression models in Tables 2 and 3. Values above the 95th percentile for any given height may be considered abnormally high.

(28). Furthermore, M-mode measurements have been found to be powerful predictors of cardiovascular prognosis (29–32).

How to adjust echocardiographic dimensions optimally for body size remains controversial (16,33,34). We previously reported (16) height indexation of echocardiographic left ventricular mass derived from a log–log regression model. Here we showed that adjusting for body surface area may inappropriately attentuate the relation between M-mode left ventricular mass and obesity; this finding may be especially important given the impact of even mild to moderate degrees of obesity on left ventricular mass and geometry (35). In contrast, a recent study (34) of 611 normotensive adults and 253 hypertensive patients demonstrated that height-based indexes of M-mode left ventricular mass maintained, and possibly enhanced, the association of increased left ventricular mass with an adverse cardiovascular prognosis.

There is some impact of height on left ventricular M-mode cavity dimensions and on left ventricular wall thickness (in particular in men). Left atrial dimension, however, has only a minimal relation with height, as demonstrated by the very low R^2 values for the regression models; for this reason we do not present nomograms of left atrial size. The powers <1 noted in Tables 2 and 3 suggest that simple indexation of M-mode dimensions (e.g., left ventricular diastolic dimension/height as a distinct variable) is inappropriate.

Previous investigations. Triulzi et al. (9) reported reference values of M-mode and two-dimensional echocardiographic dimensions in 72 volunteers 15 to 76 years old. Feigenbaum (36) reported reference M-mode values based on ~130 adults, whereas Schnittger et al. (7) studied 35 adults, and Henry et al. (8) studied 136 adults. Compared with those investigations, the current study had a much larger sample of apparently healthy subjects. Also, we performed separate analyses for men and women.

Devereux et al. (10) investigated the association of left ventricular dimensions to body size and lean body mass in 92 hospital-based and 133 population-based subjects. Indexes of body size considered included height, weight, body surface area, weight/height ratio, poneral index and body mass index. All echocardiographic measurements were found to correlate most closely with body surface area. In addition, when lean body mass, as estimated by 24-h urine creatinine excretion, was considered, gender differences in M-mode estimated left ventricular mass were eliminated.

In a very intriguing study involving 196 children and 72 adults, Nidorf et al. (37) reported that height was the best predictor of aortic annular size, left atrial dimension, left ventricular end-diastolic dimension and left ventricular length (as assessed by the apical two-chamber view). In a multivariable model, including age, gender, height, weight and body surface area, only height was independently predictive of cardiac dimensions. The association of cardiac dimensions with height was weaker in the current study than in that by Nidorf et al., probably because the current study included only adults, and thus the variance of height was substantially smaller.

Study limitations. The study sample was overwhelmingly white and European in ancestry, so the reported reference values may not apply to nonwhite, non-European populations. Although this is an acknowledged limitation, data from the Framingham Heart Study and other homogeneous white populations continue to provide valuable contributions, as evidenced, for example, by two recent publications on isolated borderline systolic hypertension (in the Framingham Study) (38) and on asthma mortality (in Olmstead County) (39).

The age restrictions do not allow us to define separate "reference" values in elderly patients. A potential problem in defining separate reference values in the elderly stems from

Table 4. Correlations of Left Ventricular Dimensions With Systolic Blood Pressure in the Healthy, Less Restricted Study Sample

	Correlation With Systolic Blood Pressure in Men			Correlation With Systolic Blood Pressure in Women		
LV Dimension	Simple	Partial Adjusted for Height	Partial Adjusted for BSA	Simple	Partial Adjusted for Height	Partial Adjusted for BSA
LV diastolic dimension	0.10	0.15*	0.09	−0.11†	−0.05	−0.14*
LV systolic dimension	0.04	0.09	0.04	−0.13*	−0.08	−0.16‡
LV wall thickness	0.27‡	0.30‡	0.27‡	0.46‡	0.46‡	0.47‡
LA dimension	0.24‡	0.24‡	0.24‡	0.26‡	0.25‡	0.26‡

*$p < 0.01$. †$p < 0.05$. ‡$p < 0.001$. BSA = body surface area; other abbreviations as in Table 1.

Table 5. Correlations of Left Ventricular Dimensions With Body Mass Index in the Healthy, Less Restricted Study Sample

	Correlation With Body Mass Index in Men			Correlation With Body Mass Index in Women		
LV Dimension	Simple	Partial Adjusted for Height	Partial Adjusted for BSA	Simple	Partial Adjusted for Height	Partial Adjusted for BSA
LV diastolic dimension	0.25*	0.28*	0.04	0.24*	0.30*	−0.07
LV systolic dimension	0.17*	0.19*	−0.01	0.19*	0.23*	−0.09†
LV wall thickness	0.33*	0.35*	0.19*	0.40*	0.40*	0.30*
LA dimension	0.46*	0.46*	0.35*	0.49*	0.49*	0.34*

*$p < 0.001$. †$p < 0.05$. Abbreviations as in Tables 1 and 4.

pathologic effects of aging and comorbid disease (i.e., factors other than body size) on left ventricular geometry (40).

The R^2 values, which were mostly statistically significant, are quite low; nonetheless, they are comparable to those relating left ventricular mass to systolic blood pressure, a well recognized and accepted clinically important association. Some of the regressions, particularly for left atrial dimension, did not give statistically significant slopes; height-based nomograms were therefore not generated for those situations.

The results of the log-linear and nonlinear regressions are remarkable for powers <1, similar to previous observations by de Simone et al. (41). These findings suggest that upper limits of normal cardiac dimensions as a function of height may lose accuracy compared with nomograms that take into account curvilinear relations, assuming that the latter are correct. In our data, examination of fitted values and residuals, root-mean-square errors and R^2 values revealed that none of the three models showed any clear superiority. Therefore, the standard linear models were used to construct nomograms.

Conclusions. We report gender-specific population-based reference M-mode values and nomograms based on a healthy sample of Framingham Heart Study subjects. Although two- and three-dimensional echocardiographic techniques are rapidly improving, the results of the present study are important because M-mode echocardiography is still widely used in clinical practice and, more important, it continues to figure prominently in epidemiologic studies, clinical trials and clinical investigations of hypertensive disease. The issue of body size indexation, which we previously studied for echocardiographic left ventricular mass (16), is explored with regard to linear echocardiographic dimensions. The use of body surface area adjustment is called into question once again because it masks obesity-related alterations in cardiac geometry.

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References

1. Lauer MS, Evans JC, Levy D. Prognostic implications of subclinical left ventricular dilatation and systolic dysfunction in men free of overt cardiovascular disease. Am J Cardiol 1992;70:1180–4.
2. Fried LP, Borhani NO, Enright P, et al. The Cardiovascular Health Study: design and rationale. Ann Epidemiol 1991;1:263–76.
3. Pearson AC, Gudipati C, Nagelhout D, Sear J, Cohen JD, Labovitz AJ. Echocardiographic evaluation of cardiac structure and function in elderly subjects with isolated systolic hypertension. J Am Coll Cardiol 1991;17:422–30.
4. Koren MJ, Devereux RB, Casale PN, Savage DD, Laragh JH. Relation of left ventricular mass and geometry to morbidity and mortality in uncomplicated essential hypertension. Ann Intern Med 1992;114:345–52.
5. Gottdiener JS, Reda DJ, Materson BJ, et al. Importance of obesity, race and age to the cardiac structural and functional effects of hypertension. J Am Coll Cardiol 1994;24:1492–8.
6. Chaturvedi N, Athanassopoulos G, McKeigue P, Marmot M, Nihoyannopoulos P. Echocardiographic measures of left ventricular structure and their relation with rest and ambulatory blood pressure in blacks and whites in the United Kingdom. J Am Coll Cardiol 1994;24:1499–505.
7. Schnittger I, Gordon EP, Fitzgerald PJ, Popp RL. Standardized intracardiac measurements of two-dimensional echocardiography. J Am Coll Cardiol 1983;2:934–8.
8. Henry WL, Gardin JM, Ware JH. Echocardiographic measurements in normal subjects from infancy to old age. Circulation 1980;62:1054–61.
9. Triulzi M, Gillam LD, Gentile R, Newell JB, Weyman AE. Normal adult cross-sectional echocardiographic values: linear dimensions and chamber areas. Echocardiography 1984;1:403–26.
10. Devereux RB, Lutas EM, Casale PN, et al. Standardization of M-mode echocardiographic left ventricular anatomic measurements. J Am Coll Cardiol 1984;4:1222–30.
11. de Simone G, Devereux RB, Roman MJ, Alderman MH, Laragh JH. Relation of obesity and gender to left ventricular hypertrophy in normotensive and hypertensive adults. Hypertension 1994;23:600–6.
12. Hammond IW, Devereux RB, Alderman MH, Laragh JH. Relation of blood pressure and body build to left ventricular mass in normotensive and hypertensive employed adults. J Am Coll Cardiol 1988;12:996–1004.
13. Dawber TR, Kannel WB, Lyell LP. An approach to longitudinal studies in a community: the Framingham Study. Ann NY Acad Sci 1983;107:539–56.
14. Dawber TR, Meadors GR, Moore FE. Epidemiologic approaches to heart disease: the Framingham Heart Study. Am J Public Health 1951;41:279–86.
15. Kannel WB, Feinlieb M, McNamara PM, Garrison RJ, Castelli WP. An investigation of coronary heart disease in families: the Framingham Offspring Study. Am J Epidemiol 1979;110:281–90.
16. Lauer MS, Anderson KM, Larson MG, Levy D. A new method for indexing left ventricular mass for differences in body size. Am J Cardiol 1994;74:487–91.
17. Levy D, Garrison RJ, Savage DD, Kannel WB, Castelli WP. Prognostic implications of echocardiographically determined left ventricular mass in the Framingham Heart Study. N Engl J Med 1990;322:1561–6.
18. Shurtleff D. Some characteristics related to the incidence of cardiovascular disease and death: the Framingham Study 18-year follow-up. In: Kannel WB, Gordon T, editors. The Framingham Study: An Epidemiologic Investigation of Cardiovascular Disease, Section 30 (DHEW publication No. (NIH) 74-599). Washington (D.C.): Government Printing Office, 1974.
19. Dubois D, Dubois EF. A formula to estimate the approximate surface area if height and weight are known. Arch Intern Med 1916;17:863–71.
20. Feigenbaum H. Echocardiography. 3rd ed. Philadelphia: Lea & Febiger, 1981:51–118.
21. Sahn DJ, DeMaria A, Kisslo J, Weyman A. Recommendations regarding quantitation in M-mode echocardiography: results of a survey of echocardiographic measurements. Circulation 1978;58:1072–83.
22. Savage DD, Garrison RJ, Kannel WB, Anderson SJ, Feinlieb M, Castelli WP. Considerations in the use of echocardiography in epidemiology: the Framingham Study. Hypertension 1987;9: Suppl. II:II-40–4.

23. Draper NR, Smith H. Applied Regression Analysis. 2nd ed. New York: Wiley, 1981:1–47, 141–53, 169–71, 222–5, 458–89.
24. SAS Institute. SAS/STAT User's Guide. Version 6, 4th ed., Vol. 2. Cary, (NC): SAS Institute Inc., 1989:1135–94, 1351–456.
25. Gopal A, Keller AM, Shen Z, Sapin P, et al. Three-dimensional echocardiography: in vitro and in vivo validation of left ventricular mass and comparison with conventional echocardiographic methods. J Am Coll Cardiol 1994;24:504–13.
26. Mensah GA, Byrd BF III. Heart size: one-, two-, and now three-dimensional echocardiography. J Am Coll Cardiol 1994;24:514–6.
27. Psaty BM, Furberg CD, Kuller LH, et al. Isolated systolic hypertension and subclinical cardiovascular disease in the elderly: initial finding from the Cardiovascular Health Study. JAMA 1992;268:1287–91.
28. Pelliccia A, Maron BJ, Spataro A, Proschan MA, Spirito P. The upper limit of physiologic cardiac hypertrophy in highly trained elite athletes. N Engl J Med 1991;324:295–301.
29. Galderisi M, Lauer MS, Levy D. Echocardiographic determinants of clinical outcome in subjects with coronary artery disease: the Framingham Heart Study. Am J Cardiol 1992;70:971–6.
30. Lauer MS, Evans JC, Levy D. Prognostic implications of left ventricular dilatation and systolic dysfunction in men free of overt cardiovascular disease. Am J Cardiol 1992;70:1180–4.
31. Ghali JK, Liao Y, Simmons B, Castaner A, Cao G, Cooper RS. The prognostic role of left ventricular hypertrophy patients with or without coronary artery disease. Ann Intern Med 1992;117:831–6.
32. Bikkina M, Levy D, Evans JC, et al. Left ventricular mass and risk of stroke in an elderly cohort: the Framingham Heart Study. JAMA 1994;272:33–6.
33. Gutsegell HP, Rembold CM. Growth of the human heart relative to body surface area. Am J Cardiol 1990;65:662–8.
34. de Simone G, Devereux RB, Daniels SR, Koren MJ, Meyer RA, Laragh JH. Effect of growth on variability of left ventricular mass: assessment of allometric signals in adults and children and their capacity to predict cardiovascular risk. J Am Coll Cardiol 1995;25:1065–2.
35. Lauer MS, Anderson KM, Kannel WB, Levy D. The impact of obesity on left ventricular mass and geometry: the Framingham Heart Study. JAMA 1991;266:231–6.
36. Feigenbaum H. In ref. 20:549–50.
37. Nidorf SM, Picard MH, Triulzi MO, et al. New perspectives in the assessment of cardiac chamber dimensions during development and adulthood. J Am Coll Cardiol 1992;19:983–8.
38. Sagie A, Larson MG, Levy D. The natural history of borderline isolated systolic hypertension. N Engl J Med 1993;329:1912–7.
39. Silverstein MD, Reed CF, O'Connell EJ, Melton LJ III, O'Fallon MO, Yunginger JW. Long-term survival of a cohort of community residents with asthma. N Engl J Med 1994;331:1537–41.
40. Wei JY. Age and the cardiovascular system. N Engl J Med 1992;327:1735–9.
41. de Simone G, Daniels SR, Devereux RB, et al. Left ventricular mass and body size in normotensive children and adults: assessment of allometric relations and impact of overweight. J Am Coll Cardiol 1992;20:1251–60.