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**Authors**
Rautaharju, Pentii M
Lacroix, Andrea Z
Savage, Daniel D
et al.

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# Heart Size Estimates Indexed Optimally to Body and Chest Size

## I. The Effect of Age and Hypertensive Status[1]

*Pentti M. Rautaharju*[c], *Andrea Z. Lacroix*[b], *Daniel D. Savage*[a], *Christine S. Cox*[a], *Jennifer H. Madans*[a], *James Warren*[c], *Hermann K. Wolf*[c], *Wilbur Hadden*[a]

[a] US Department of Health and Human Services-National Center for Health Statistics and
[b] National Institute on Aging, Bethesda, Md., USA;
[c] Heart Disease Research Centre, Department of Physiology and Biophysics, Dalhousie University, Halifax, N.S., Canada

**Abstract.** We used multiple-regression methods to investigate the association of radiological cardiac volume, cardiac transverse diameter and a new echocardiographically validated ECG estimate of the left ventricular (LV) mass index with age, hypertensive status and a set of anthropometric and physiological/pathophysiological variables among 2,437 men (2,159 white and 278 black) and 2,941 women (2,582 white and 359 black) aged 25-74 years. Optimal combinations of body and chest size variables were used to derive new race- and sex-specific formulas for heart volume index (HVI) as the ratio of the measured vs. predicted heart volume and cardiac enlargement index (CEI) as the ratio of measured vs. predicted cardiac transverse diameter. LV mass index by ECG was primarily associated with the level of systolic blood pressure, and it was not independently associated with age except among white women. In contrast, age was the primary determinant of increased HVI and CEI in all race/sex groups except for black males. It is concluded that substantial differences exist in the patterns of age-related changes in LV mass index, HVI and CEI among normotensive and hypertensive persons.

## Introduction

There is a renewed interest in the application of various radiographic, electrocardiographic and echocardiographic measures of cardiac size in health surveys and clinical preventive trials due to recent reports [1-6] which have reaffirmed the results from earlier clinical studies [7-9] demonstrating the value of cardiac enlargement in prediction of the risk of cardiovascular disease (CVD) mortality and morbidity, including ventricular arrhythmias.

The ratio of the largest transverse cardiac dimension to the thorax width in the frontal (postero-anterior) plane chest X-ray, or the cardiothoracic ratio introduced by Danzer [10] in 1919, is still one of the most commonly used measures of cardiac enlargement. Cardiothoracic ratio in excess of 0.5 is usually considered to indicate cardiac enlargement [11]. Universal applicabil-

Address for correspondence:
Dr. P.M. Rautaharju, Heart Disease Research Centre
Department of Physiology and Biophysics
Room 4G3, 4th Floor, Sir Charles Tupper Medical Building
Dalhousie University, Halifax, N.S. B3H 4H7 (Canada)

ity of this criterion has been questioned [12], however, because of the well-established anthropometric differences in the cardiac and chest size relationship between blacks and whites [13–15]. These same objections are conceivably valid for other radiological and electrocardiographic cardiac size estimates.

A previous report from the first National Health and Examination Survey (NHANES I) and the NHANES I Epidemiologic Follow-Up Study (NHEFS) revealed that cardiothoracic ratio correlated significantly with transverse thoracic diameter, body weight and body mass index (body weight/body height-squared) [1]. These results suggested that indexing of cardiac transverse diameter to thorax diameter does not optimally standardize it with respect to variations of chest size and that it is also dependent on other variations of body size such as weight and height. Similar questions were recently raised by Levy et al. [16] regarding indexing of echocardiographic left ventricular (LV) mass estimate to body surface area, and these authors suggested indexing of the LV mass to standing height as a more effective way of detecting LV hypertrophy.

The purpose of the present investigation was to perform a systematic analysis of the relationship between three different estimates of cardiac size and a set of anthropometric variables related to body size and chest size. The results indicate that body weight and transverse chest diameter are important determinants of cardiac volume and its transverse diameter, and, in addition, body height contributes significantly to the normal variability of the transverse cardiac diameter. The new heart volume index (measured/predicted heart volume) and cardiac enlargement index (measured/predicted cardiac diameter) introduced here express the percentage deviation of the measured heart volume and transverse diameter from those predicted for a person's body and chest size, thus facilitating the separation of physiological from pathological cardiac enlargement.

## Methods

### Study Population

The study population of the present investigation represents a subset of the NHANES I conducted in the United States between April 1971 and October 1975. This subset (called the detailed examination component) is representative of the United States population aged 25–74 years at the midpoint of the survey. A detailed description of the design and operation of NHANES I is published elsewhere [17–19]. The composition of the study population is summarized in table 1. The subsample of the present study was extracted from the examinees aged 25–77 years in the detailed component, who received extensive physical examinations and laboratory tests, including a chest X-ray and an ECG of adequate quality for computer analysis.

### Radiographic Methods

Posteroanterior roentgenograms were used to measure the transverse cardiac and thoracic diameters using the procedure introduced by Danzer [10] in 1919. The heart volume was determined from the posteroanterior and lateral roentgenograms using the method introduced by Jonsell [20].

### Electrocardiographic Methods

The electrocardiogram data used in the present report were acquired using Beckman Digicorders which recorded the 12-lead electrocardiogram data in a computer-compatible format. Analog-to-digital conversion was performed at the sampling rate of 500 samples per second, sequentially one channel at a time. The NHANES I electrocardiogram data were reprocessed in 1986 using one of the newer generation computer programs, the Novacoder electrocardiogram program [21] specifically designed for analysis and classification of electrocardiograms for epidemiological studies and health surveys. The Novacoder Program incorporates a special algorithm for estimation of LV mass indexed to body surface area $(g/m^2)$ based on a model established using echocardiographic measurements as a standard [1].

### Statistical Methods

Both the standard linear and logarithmic multiple regression models were used for the prediction of cardiac size variables from chest and body size measurements. Indexing of the cardiac transverse diameter (C) to body and chest size will be used here to illustrate the logarithmic regression. Let C be a function of transthoracic diameter (T), body weight (W) and standing height (H), i.e. $C = C(T, W, H)$. Specifically, let $C = k \times T^t \times W^w \times H^h$. Thus, $\ln C = \ln k +$

Table 1. Study population extracted from the examinees aged 25–74 years in the detailed component of the First National Health and Nutrition Examination Survey (NHANES I), who received extensive physical examinations and laboratory tests in 1971–1975

| Category | White men | Black men | White women | Black women |
|---|---|---|---|---|
| Number examined by chest X-ray | 2,552 | 376 | 2,982 | 460 |
| Number with ECG and LVMI[1] estimate available | 2,313 | 286 | 2,785 | 381 |
| Number with chest X-ray and ECG available | 2,159 | 278 | 2,582 | 359 |

[1] ECG estimate of LV mass index.

$t \ln T + w \times \ln W + h \ln H$. Coefficient estimates can now be determined for regression of $\ln C$ on $\ln T$, $\ln W$ and $\ln H$ as independent variables, and thus the coefficients $k$, $t$, $w$ and $h$ obtained separately for each race/sex group. Let $C_0$ denote the value of the cardiac diameter predicted from the above formulas and let $C$ be the actual measured diameter. The cardiac enlargement index (CEI) can now be defined as the ratio of $C$ to $C_0$, i.e. $CEI = (C/C_0)$. Multiplied by 100, the value of CEI will express the percentage increase or decrease of the cardiac transverse diameter from the value predicted for the chest and body size of the individual.

The approach described above was used to normalize the radiological heart volume to the variations of the body size and the chest size, to derive heart volume index (HVI). $HVI = V/V_0$, where $V$ is the measured heart volume and $V_0$ is the heart volume predicted from the best regression formula.

The analytic strategies employed in this report were designed to consider the CEI and HVI as continuous variables, thus avoiding the problem of choosing cutpoints for categorization for different race/sex subgroups. Initial analyses were performed to examine the association of the CEI and HVI with age, hypertension, and other baseline risk factors. For these analyses, the hypertensive group included persons whose systolic blood pressure was greater than or equal to 140 mm Hg or whose diastolic blood pressure was greater than or equal to 90 mm Hg or who were currently taking antihypertensive medication at the baseline examination. Mean levels of CEI and HVI among age, race and sex-specific groups of normotensive and hypertensive subjects were compared using a t test. Analysis of covariance was used to compare mean values of cardiac size adjusted for age among hypertensive and normotensive subjects in each race-sex group. Levels of significance reported are those obtained directly from the tests and have not been adjusted for multiple comparisons. Correlations between each cardiac size measure and age, systolic blood pressure and body mass index were also examined for each race-sex group.

## Results

### LV Mass by ECG
The fraction of the variance of the ECG estimate of the LV mass explained by the anthropometric variables was unexpectedly low, with R-square values ranging from 0.01 for white men to 0.08 for white women. These results indicated that the LV mass estimated from the ECG was relatively little influenced by body and chest size variations in all race/sex groups, and further attempts to optimize indexing of the LV mass were abandoned. LV mass estimates are traditionally indexed to body surface area, and this LV mass index was retained for later comparative analyses of relative risk of cardiovascular disease mortality for various cardiac size indexes.

### Heart Volume
Body weight and the transverse thoracic diameter were the only two anthropometric variables which contributed significantly to heart volume variability in all race/sex groups. In addition, chest circumference and subscapular skinfold were significant independent contributors among white women although their partial R-square values were low (0.01 for chest circumference and 0.02 for subscapular skinfold). Neither standing nor sitting height contributed significantly to heart volume variance. Thus, about one-quarter to nearly one-third of the heart volume variance can be explained mainly by body weight and thorax diameter, and it was decided to retain these two body and chest size measurements for further attempts to optimize indexing of the heart volume.

### Cardiac Transverse Diameter
Body weight, standing height and thorax diameter were all significant independent predictors of the cardiac transverse diameter among men. Among women, the first two variables entering into the regression model were the chest circumference in expiration and thorax diameter, with sitting height and body weight also contributing significantly. The fraction of the total cardiac diameter variance explained by these combinations of anthropometric variables was high, ranging from 37% among black women to 43% among white women. The choice of a suitable set of anthropometric variables for indexing of the cardiac diameter in women is problematic in that neither chest circumference nor sitting height are routinely available in practical applications. It was decided to sacrifice chest circumference and to substitute sitting height with standing height in further optimization attempts to index cardiac transverse diameter.

### Prediction Formulas for Cardiac Volume and Transverse Diameter
Both linear and logarithmic regression models were used to derive optimal prediction formulas for cardiac volume and diameter. The logarithmic models gave systematically marginally higher R-square values than linear regression. The coefficients for the log-linear regression models are listed in table 2. The R-square values indicate that about 30% of the cardiac volume variance is explained by thorax diameter and body weight, and about 40% of the variance of the cardiac transverse diameter by thorax diameter, body weight and standing height.

A comparison of the regression coefficients listed in table 2 indicates considerable differences particularly between white and black men in some of the relationships between heart size and anthropometric variables.

Table 2. Coefficients for the log-linear regression models for prediction of the cardiac volume ($V_0$) and the cardiac transverse diameter ($C_0$) from arthropometric variables

| Race/sex group | Model | k | t | w | h | $R^2$ |
|---|---|---|---|---|---|---|
| White men | cardiac volume | 13.43 | 0.606 | 0.498 | – | 0.288 |
| | cardiac diameter | 45.23 | 0.423 | 0.401 | −0.843 | 0.407 |
| Black men | cardiac volume | 4.13 | 1.237 | 0.271 | – | 0.319 |
| | cardiac diameter | 15.44 | 0.428 | 0.310 | −0.560 | 0.384 |
| White women | cardiac volume | 20.30 | 0.453 | 0.485 | – | 0.279 |
| | cardiac diameter | 50.54 | 0.296 | 0.364 | −0.765 | 0.433 |
| Black women | cardiac volume | 29.42 | 0.435 | 0.417 | – | 0.282 |
| | cardiac diameter | 19.57 | 0.254 | 0.262 | −0.460 | 0.403 |

Cardiac volume $V_0 = kT^tW^w$; cardiac diameter $C_0 = kT^tW^wH^h$, where H = Body height (cm); T = chest transverse diameter (cm), and W = body weight (kg).

For instance, the heart volume prediction formula for black men appears heavily weighted on the coefficient for chest diameter (t) compared to all other subgroups whereas the contrary seems true for the coefficient for body weight (w).

### Heart Size Correlations with Age, Blood Pressure and Body Mass Index

Neither HVI nor CEI correlated significantly with body mass index, reflecting the fact that this new method of indexing heart size removes the correlation between heart size and obesity. As expected, all three heart size indexes were significantly correlated with age and systolic blood pressure. HVI and CEI were highly correlated, as expected, with correlation coefficients ranging from 0.60 among white women to 0.69 among black men. The correlation between LV mass index and the other two cardiac size indexes were substantially lower, ranging from 0.17 among white women to 0.36 among black men and women.

### Age Trends in Normotensive Subgroups

The mean values and standard deviations of the three cardiac size variables by age, sex, race and hypertensive status are listed in tables 3–5. There was a notable lack of the expected increase with age in the ECG estimate of LV mass index among normotensive white and black men (table 3), whereas HVI estimate by X-ray among normotensive men showed a clear age trend towards an increased cardiac volume (table 4). All three cardiac size measurements increased significantly with age among white and black women.

### Age Trends and Hypertensive Status

Larger sample sizes of white men and women permitted more extensive analyses of age trends in these two subgroups. Special attention was paid to the assessment of differences in the patterns of cardiac size distributions among the youngest (25–34 years) and oldest (≥ 65 years) age groups by hypertensive status. The significance of the overall difference in the cumulative percentile distributions was determined by performing $\chi^2$ test for the observed and expected relative fractions of young vs. older or hypertensive vs. normotensive individuals within quintiles of the distribution of each cardiac size variable. Substantial differences were observed in the age-related changes when comparing the distributions of LV mass index vs. the distributions of HVI and CEI for normotensive and hypertensive subgroups of men and women.

The similarity of the LV mass index distribution of young and older normotensive white men is again illustrated in figure 1a, reflecting the lack of overall increase of LV mass index with age in normotensive men as noted before (p = 0.24 for $\chi^2$ test for quintiles of the distributions). On the other hand, the LV mass index distribution of older hypertensive men was shifted distinctly towards higher values throughout its whole range in comparison with older and younger normotensive men shown in figure 1a, and with hypertensive young men (not shown) whose LV mass index distributions were not significantly different from those of young or older normotensive men.

Compared to the aging patterns of LV mass index distributions among older normotensive and hypertensive

**Table 3.** Mean values and SD for ECG estimate of left ventricular mass index by hypertensive status at baseline examination, race, age and sex

| Race/sex group | Age years | Normotensive | | | Hypertensive[1] | | |
|---|---|---|---|---|---|---|---|
| | | n | mean | SD | n | mean | SD |
| White men | 24–34 | 361 | 108.3 | 19.28 | 122 | 108.1 | 19.78 |
| | 35–44 | 242 | 104.2 | 19.87 | 145 | 109.9 | 22.86* |
| | 45–54 | 238 | 104.3 | 21.01 | 266 | 109. | 20.48* |
| | 55–64 | 165 | 106.0 | 24.61 | 250 | 111.5 | 27.59* |
| | ≥65 | 134 | 108.9 | 29.64 | 236 | 123.9 | 38.47*** |
| | all | 1,140 | 106.3 | 22.06 | 1,019 | 113.1 | 28.18*** |
| Black men | 24–34 | 37 | 118.2 | 25.25 | 18 | 109.0 | 19.45 |
| | 35–44 | 19 | 106.3 | 21.36 | 19 | 127.1 | 25.00** |
| | 45–54 | 26 | 118.7 | 32.89 | 49 | 127.7 | 34.89 |
| | 55–64 | 14 | 111.9 | 28.75 | 35 | 128.8 | 35.82 |
| | ≥65 | 16 | 114.7 | 25.72 | 45 | 137.6 | 42.04* |
| | all | 112 | 115.0 | 27.05 | 166 | 128.5 | 35.51*** |
| White women | 24–34 | 549 | 85.4 | 16.72 | 75 | 89.8 | 16.19* |
| | 35–44 | 378 | 85.5 | 16.42 | 92 | 93.3 | 18.81*** |
| | 45–54 | 361 | 90.7 | 17.59 | 247 | 97.4 | 21.44*** |
| | 55–64 | 202 | 93.1 | 20.53 | 275 | 100.8 | 21.50*** |
| | ≥65 | 113 | 99.4 | 25.36 | 290 | 107.5 | 27.12** |
| | all | 1,603 | 88.6 | 18.55 | 979 | 100.4 | 23.37*** |
| Black women | 24–34 | 59 | 82.3 | 17.99 | 17 | 92.0 | 21.71 |
| | 35–44 | 38 | 77.2 | 19.61 | 38 | 92.4 | 24.69** |
| | 45–54 | 29 | 83.2 | 19.06 | 55 | 91.7 | 26.94 |
| | 55–64 | 15 | 103.8 | 62.53 | 42 | 94.9 | 27.83 |
| | ≥65 | 11 | 89.9 | 24.72 | 55 | 100.3 | 38.17 |
| | all | 152 | 83.9 | 27.26 | 207 | 94.8 | 29.74*** |

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$ for the difference between the mean values of hypertensive and normotensive groups.
[1] Systolic blood pressure ≥ 140 mm Hg and/or diastolic blood pressure ≥ 90 mm Hg or on antihypertensive medication.

**Table 4.** Mean values and SD for radiological estimate of heart volume index by hypertensive status at baseline examination, race, age and sex

| Race/sex group | Age years | Normotensive | | | Hypertensive[1] | | |
|---|---|---|---|---|---|---|---|
| | | n | mean | SD | n | mean | SD |
| White men | 24–34 | 361 | 0.94 | 0.141 | 122 | 0.91 | 0.142 |
| | 35–44 | 242 | 0.97 | 0.159 | 145 | 1.00 | 0.162 |
| | 45–54 | 238 | 1.00 | 0.178 | 266 | 1.02 | 0.183 |
| | 55–64 | 165 | 1.05 | 0.168 | 250 | 1.07 | 0.186 |
| | ≥65 | 134 | 1.12 | 0.250 | 236 | 1.13 | 0.240 |
| | all | 1,140 | 1.00 | 0.182 | 1,019 | 1.04 | 0.202*** |
| Black men | 24–34 | 37 | 0.96 | 0.165 | 18 | 0.96 | 0.168 |
| | 35–44 | 19 | 0.90 | 0.125 | 19 | 1.00 | 0.162* |
| | 45–54 | 26 | 0.99 | 0.197 | 49 | 1,03 | 0.190 |
| | 55–64 | 14 | 1.04 | 0.217 | 35 | 1.06 | 0.224 |
| | ≥65 | 16 | 1.06 | 0.148 | 45 | 1.09 | 0.253 |
| | all | 112 | 0.98 | 0.177 | 166 | 1.05 | 0.213** |
| White women | 24–34 | 549 | 0.93 | 0.155 | 75 | 0.91 | 0.139 |
| | 35–44 | 378 | 0.98 | 0.156 | 92 | 0.99 | 0.161 |
| | 45–54 | 361 | 1.01 | 0.168 | 247 | 1.03 | 0.191 |
| | 55–64 | 202 | 1.06 | 0.194 | 275 | 1.08 | 0.202 |
| | ≥65 | 113 | 1.11 | 0.229 | 290 | 1.14 | 0.218 |
| | all | 1,603 | 0.99 | 0.178 | 979 | 1.07 | 0.207*** |
| Black women | 24–34 | 59 | 0.92 | 0.134 | 17 | 0.98 | 0.155 |
| | 35–44 | 38 | 0.95 | 0.160 | 38 | 1.06 | 0.216* |
| | 45–54 | 29 | 0.95 | 0.224 | 55 | 1.04 | 0.157* |
| | 55–64 | 15 | 1.08 | 0.220 | 42 | 1.04 | 0.191 |
| | ≥65 | 11 | 1.13 | 0.200 | 55 | 1.11 | 0.244 |
| | all | 152 | 0.96 | 0.184 | 207 | 1.06 | 0.203*** |

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$ for the difference between the mean values of hypertensive and normotensive subgroups.
[1] Systolic blood pressure ≥ 140 mm Hg and/or diastolic blood pressure ≥ 90 mm Hg or on antihypertensive medication.

men (fig. 1a), a contrasting pattern was observed for HVI (fig. 2a) as well as for CEI (fig. 3a). The HVI distribution in older normotensive men was not significantly different from that of the older hypertensive men. Compared to young normotensive men (fig. 2a) or young hypertensive men (not shown), HVI distributions of older hypertensive as well as normotensive men were shifted to about the same degree towards higher cardiac volume values throughout their whole range.

Similar, although less drastic age trend differences in the patterns of distribution of LV mass index and HVI as described above for white men, were observed in white women (fig. 2b). Compared to young normotensive women, the LV mass index distribution of older hypertensive women was shifted strongly towards higher LV mass index values throughout its whole range. A similar trend was observed in the LV mass index distribution shift among normotensive older women ($p < 0.001$, compared to young normotensive women), although the magnitude of this shift with age appeared to be about one-half of that seen among older hypertensive women. HVI distribution shifts with age among white women (fig. 2b) demonstrated aging patterns which were nearly identical with those observed among white men. The shift towards higher HVI values with age was equally strong among normotensive and hypertensive women,

Table 5. Mean values and SD for radiological estimate of CEI by hypertensive status at baseline examination, race, age and sex

| Race/ sex group | Age years | Normotensive | | | Hypertensive[1] | | |
|---|---|---|---|---|---|---|---|
| | | n | mean | SD | n | mean | SD |
| White men | 24–34 | 361 | 0.96 | 0.076 | 122 | 0.96 | 0.082 |
| | 35–44 | 242 | 0.99 | 0.078 | 145 | 1.00 | 0.094 |
| | 45–54 | 238 | 1.00 | 0.093 | 266 | 1.02 | 0.095* |
| | 55–64 | 165 | 1.02 | 0.086 | 250 | 1.03 | 0.093 |
| | ≥65 | 134 | 1.04 | 0.099 | 236 | 1.06 | 0.103 |
| | all | 1,140 | 0.99 | 0.089 | 1,019 | 1.02 | 0.099*** |
| Black men | 24–34 | 37 | 0.96 | 0.067 | 18 | 0.99 | 0.087 |
| | 35–44 | 19 | 0.94c | 0.079 | 19 | 0.99 | 0.102 |
| | 45–54 | 26 | 0.99 | 0.099 | 49 | 1.02 | 0.100 |
| | 55–64 | 14 | 1.01 | 0.117 | 35 | 1.04 | 0.105 |
| | ≥65 | 16 | 1.00 | 0.077 | 45 | 1.04 | 0.103 |
| | all | 112 | 0.98 | 0.088 | 166 | 1.03 | 0.102*** |
| White women | 24–34 | 549 | 0.95 | 0.078 | 75 | 0.94 | 0.080 |
| | 35–44 | 378 | 0.98 | 0.078 | 92 | 0.99 | 0.085 |
| | 45–54 | 361 | 1.00 | 0.093 | 247 | 1.01 | 0.094* |
| | 55–64 | 202 | 1.04 | 0.090 | 275 | 1.03 | 0.082 |
| | ≥65 | 113 | 1.05 | 0.117 | 290 | 1.07 | 0.099 |
| | all | 1,603 | 0.98 | 0 094 | 979 | 1.03 | 0.097*** |
| Black women | 24–34 | 59 | 0.94 | 0.065 | 17 | 0.98 | 0.080 |
| | 35–44 | 38 | 0.97 | 0.079 | 38 | 1.04 | 0.107** |
| | 45–54 | 29 | 0.99 | 0.107 | 55 | 1.03 | 0.076 |
| | 55–64 | 15 | 1.04 | 0.096 | 42 | 1.02 | 0.107 |
| | ≥65 | 11 | 1.06 | 0.119 | 55 | 1.05 | 0.086 |
| | all | 152 | 0.98 | 0.092 | 207 | 1.03 | 0.093*** |

* p < 0.05, ** p < 0.01, *** p < 0.001 for the difference between the mean values of hypertensive and normotensive subgroups.
[1] Systolic blood pressure ≥ 140 mm Hg and/or diastolic blood pressure ≥ 90 mm Hg or on antihypertensive medication.



Fig. 1 a, b. Distributions of LV mass index in young and old normotensive (NT) and old hypertensive (HT) white men and white women.
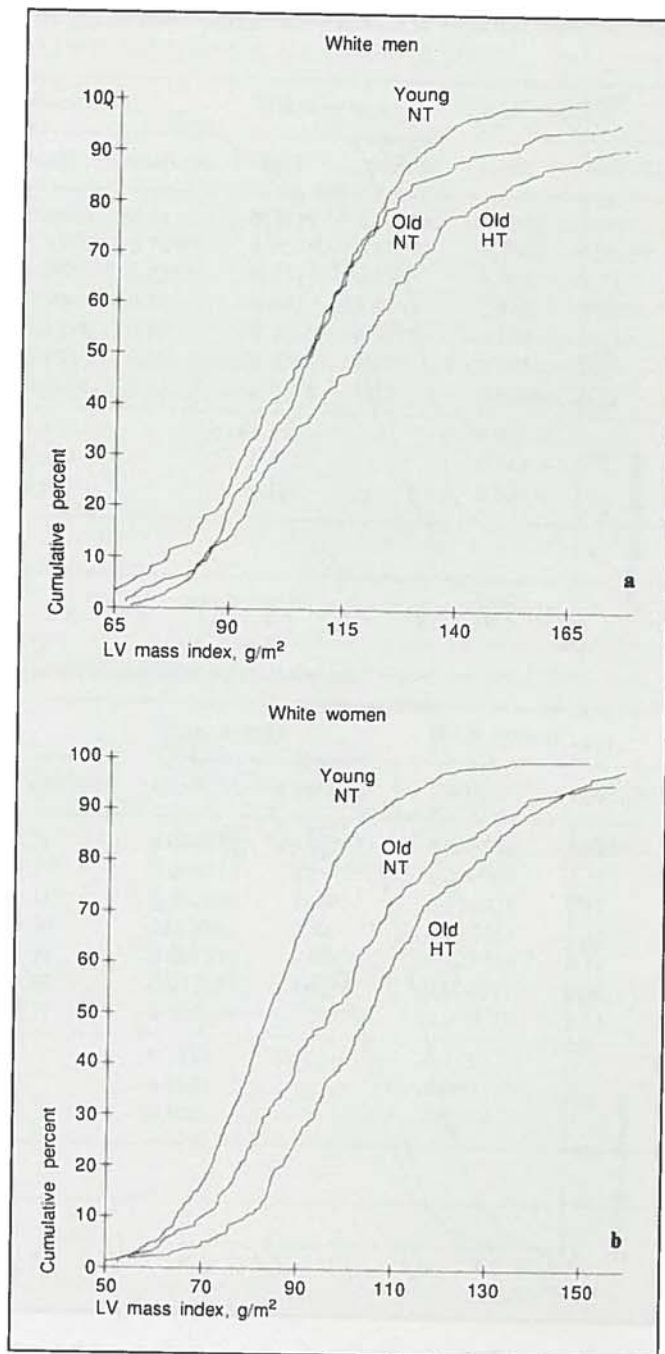
and there was no significant difference between the HVI distributions of older hypertensive and normotensive women.

Aging trends in the CEI distributions of white women revealed patterns which were similar to those for HVI (fig. 3b). The shift to higher CEI values with age was about equally prominent among normotensive and hypertensive women.

*Pathophysiological Determinants of LV Mass Index*
Linear multiple regression models were used to investigate the association of a set of pathophysiological variables with the three cardiac size indexes.

Systolic blood pressure appeared a strong determinant of LV mass index in all race/sex groups (table 6). In black women, systolic blood pressure and history of heart attack were the only independent variables with a
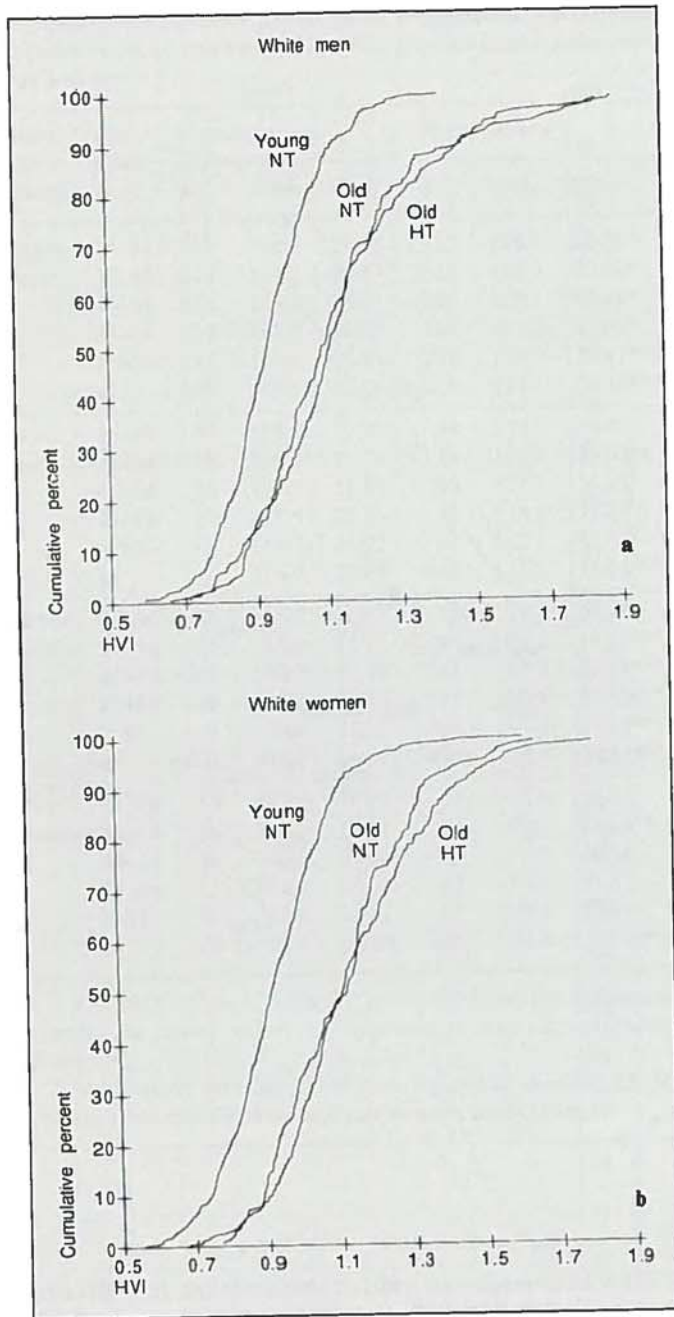
Fig. 2 a, b. Distribution of HVI in young and old normotensive (N) and old hypertensive (HT) white men and white women.
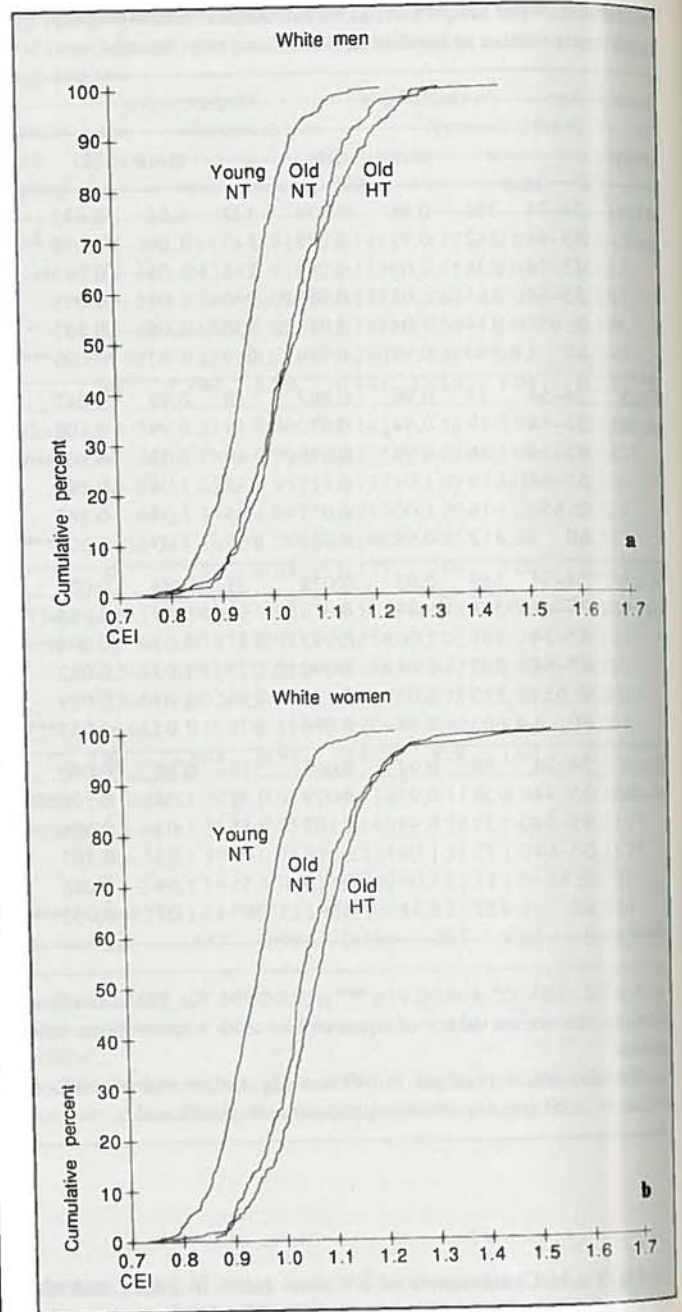


Fig. 3 a, b. Distribution of CEI in young and old normotensive (N) and old hypertensive (HT) white men and white women.

significant association with LV mass index. When systolic blood pressure was entered into the step-up regression model with age, the association of age with LV mass index was no longer significant among white and black men and black women, and the coefficient for age was substantially reduced (from 0.506 to 0.277) among white

women. This observation supports the finding portrayed in figure 1a, b, suggesting that the increase of LV mass index with age was largely dominated by the level of systolic blood pressure. In addition to the systolic blood pressure, among white men there was a significant positive association between LV mass index and history of

Table 6. Regression of the ECG estimate of LV mass index (g/m²) on age and six other independent variables in white and black men and women

| Independent variables | White men | | Black men | | White women | | Black women | |
|---|---|---|---|---|---|---|---|---|
| | coeff. | coeff./SE | coeff. | coeff./SE | coeff. | coeff./SE | coeff. | coeff./SE |
| Age | −0.0468 | −1.08 | −0.0632 | −0.43 | 0.2819 | 7.67*** | −0.0059 | −0.04 |
| Systolic blood pressure, mm Hg | 0.2296 | 7.91*** | 0.4376 | 6.22*** | 0.2075 | 8.87*** | 0.3506 | 6.10*** |
| History of heart attack (yes = 1, no = 0) | 14.620 | 6.23*** | 41.067 | 4.22*** | 0.9242 | 0.39 | 13.766 | 1.78 |
| History of angina pectoris (yes = 1, no = 0) | 8.463 | 2.24* | −2.709 | −0.24 | 4.493 | 1.69 | −2.848 | −0.38 |
| History of diabetes (yes = 1, no = 0) | 8.964 | 2.46* | 4.8318 | 0.59 | 6.291 | 2.95** | −1.159 | −0.21 |
| Cigarette smoking status (yes = 1, no = 0) | −5.348 | −4.89*** | −3.953 | −1.03 | 1.976 | 2.27* | 0.105 | 0.03 |
| Serum cholesterol, mg/dl | 0.0021 | 0.18 | 0.0414 | 1.13 | 0.0118 | 1.29 | 0.0069 | 0.21 |
| Constant | 81.9 | | 55.3 | | 48.9 | | 36.7 | |
| R² multivariate | 0.084 | | 0.234 | | 0.152 | | 0.141 | |
| R² age alone | 0.013 | | 0.030 | | 0.101 | | 0.036 | |

*** p < 0.001; ** p < 0.01; * p < 0.05.

Table 7. Regression of heart volume index on age and six other independent variables by race and sex

| Independent variables | White men | | Black men | | White women | | Black women | |
|---|---|---|---|---|---|---|---|---|
| | Coeff. | Coeff./SE | Coeff. | Coeff./SE | Coeff. | Coeff./SE | Coeff. | Coeff./SE |
| Age | 0.004430 | 13.33*** | 0.001645 | 1.71 | 0.004918 | 14.04*** | 0.003144 | 3.02** |
| Systolic BP | 0.000567 | 2.50* | 0.001560 | 3.19* | 0.000775 | 3.89*** | 0.000989 | 2.31* |
| History of MI | 0.065226 | 3.58*** | 0.201965 | 3.16* | 0.047886 | 2.19* | 0.010025 | 0.17 |
| History of angina | −0.031858 | −1.08 | 0.022286 | 0.30 | 0.013605 | 0.52 | −0.027403 | −0.55 |
| History of diabetes | 0.017301 | 0.79 | −0.056034 | −0.99 | −0.021530 | −1.08 | 0.027755 | 0.71 |
| Smoking status | 0.017894 | 2.13* | 0.000028 | 0.00 | 0.033301 | 4.02*** | 0.020091 | 0.87 |
| Serum cholesterol | −0.000216 | −2.28 | −0.000186 | −0.77 | −0.000294 | −3.27** | −0.000028 | −0.11 |
| Constant | 0.7631 | | 0.7532 | | 0.7384 | | 0.7153 | |
| R² multivariate | 0.135 | | 0.127 | | 0.153 | | 0.099 | |
| R² age alone | 0.124 | | 0.030 | | 0.101 | | 0.036 | |

*** p < 0.001; ** p < 0.01; * p < 0.05.

heart attack (p < 0.001), history of angina pectoris (p < 0.05) and history of diabetes (p < 0.05), and a negative association with cigarette smoking (p < 0.001).

The history of heart attack was the only covariate in addition to systolic blood pressure with a significant association with LV mass index among black men (p < 0.001). Among white women, age (p < 0.001), history of diabetes (p < 0.01) and cigarette smoking (p < 0.05) had a significant positive association with LV mass index in addition to the highly significant association (p < 0.001) with systolic blood pressure. The combina-

tion of seven independent variables in table 6 explained from 8% (white men) to 22% (black men) of the variance of the ECG estimate of LV mass index.

*Determinants of Heart Volume Index* (table 7)

Age, systolic blood pressure and history of heart attack were significantly associated with HVI for white males and females. Systolic blood pressure was also significantly associated with HVI for both black males and females. In addition to age, systolic blood pressure and history of heart attack, a number of other covariates

**Table 8.** Regression of the cardiac enlargement index on age and six other independent variables by race and sex

| Independent variables | White men | | Black men | | White women | | Black women | |
|---|---|---|---|---|---|---|---|---|
| | Coeff. | Coeff./SE | Coeff. | Coeff./SE | Coeff. | Coeff./SE | Coeff. | Coeff./SE |
| Age | 0.002024 | 12.30*** | 0.001002 | 2.10* | 0.002895 | 16.86*** | 0.001896 | 3.84*** |
| Systolic BP | 0.000310 | 2.76** | 0.000870 | 3.60*** | 0.000252 | 2.58* | 0.000484 | 2.38* |
| History of MI | 0.029422 | 3.27*** | 0.058916 | 1.86 | 0.027853 | 2.59*** | 0.008264 | 0.30 |
| History of angina | −0.004528 | −0.31 | −0.001251 | −0.03 | 0.015828 | 1.23 | −0.000647 | −0.03 |
| History of diabetes | −0.010663 | −0.98 | −0.049444 | −1.77 | −0.010673 | −1.09 | 0.019436 | 1.05 |
| Smoking status | 0.001459 | 0.35 | −0.006913 | −0.55 | 0.015524 | 3.83*** | 0.013932 | 1.28 |
| Serum cholesterol | 0.000002 | 0.05 | 0.000047 | 0.39 | −0.000088 | −1.99* | −0.000047 | −0.40 |
| Constant | 0.8648 | | 0.8277 | | 0.8436 | | 0.8463 | |
| $R^2$ multivariate | 0.124 | | 0.138 | | 0.197 | | 0.134 | |
| $R^2$ age alone | 0.116 | | 0.067 | | 0.184 | | 0.114 | |

*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$.

**Table 9.** Percentile limits for heart size indexes for CVD-free normotensive subgroups

| Sex/race group | Age years | n | LVMI | | | HVI | | | CEI | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 50th % | 90th % | 95th % | 50th % | 90th % | 95th % | 50th % | 90th % | 95th % |
| White men | 25–34 | 324 | 107 | 130 | 138 | 0.92 | 1.11 | 1.19 | 0.96 | 1.06 | 1.11 |
| | 35–44 | 218 | 104 | 126 | 138 | 0.96 | 1.17 | 1.28 | 0.98 | 1.10 | 1.12 |
| | 45–54 | 212 | 100 | 124 | 138 | 0.99 | 1.22 | 1.29 | 0.99 | 1.12 | 1.15 |
| | 55–64 | 133 | 104 | 134 | 142 | 1.02 | 1.27 | 1.34 | 1.01 | 1.17 | 1.21 |
| | ≥65 | 96 | 106 | 130 | 175* | 1.05 | 1.45 | 1.53* | 1.04 | 1.17 | 1.21* |
| | all | 983 | 104 | 128 | 138 | 0.97 | 1.20 | 1.29 | 0.99 | 1.11 | 1.15 |
| White women | 25–34 | 475 | 85 | 107 | 116 | 0.92 | 1.10 | 1.18 | 0.94 | 1.04 | 1.07 |
| | 35–44 | 355 | 87 | 106 | 111 | 0.97 | 1.17 | 1.24 | 0.97 | 1.07 | 1.11 |
| | 45–54 | 331 | 89 | 114 | 124 | 1.00 | 1.22 | 1.28 | 0.99 | 1.11 | 1.13 |
| | 55–64 | 180 | 92 | 116 | 129 | 1.02 | 1.31 | 1.39 | 1.03 | 1.13 | 1.20 |
| | ≥65 | 93 | 98 | 138 | 151* | 1.09 | 1.31 | 1.39* | 1.03 | 1.17 | 1.23* |
| | all | 1,434 | 87 | 111 | 120 | 0.97 | 1.20 | 1.28 | 0.98 | 1.10 | 1.13 |
| Black men | all | 83 | 112 | 144 | 153* | 0.96 | 1.15 | 1.26* | 0.96 | 1.07 | 1.10* |
| Black women | all | 123 | 84 | 109 | 121 | 0.94 | 1.16 | 1.28 | 0.97 | 1.08 | 1.11 |

* Unstable upper 95th percentile limits.

were significantly associated with HVI among white men and women. Cigarette smoking had a significant positive association with HVI among white men ($p < 0.05$) and white women ($p < 0.001$). Serum cholesterol had a significant negative association with HVI both among white men ($p < 0.05$) and white women ($p < 0.01$). The combination of seven independent variables in table 7 explained from 10% (black women) to 15% (white wom-

en) of the total variance of HVI, i.e. the variance remaining after indexing heart volume to normal variability associated with body and chest size.

*Determinants of Cardiac Enlargement Index* (table 8)

Age and systolic blood pressure were significantly associated with CEI in all race/sex groups. In addition, history of heart attack was significantly associated with

HVI among white men and white women (p < 0.001) for both. Smoking status had a significant (positive) association with CEI among white women only (p < 0.001). The combination of age and six other independent variables used in the regression model in table 8 explained from 12% (white men) to 20% (white women) of the variance of CEI.

### Normal Limits for Heart Size Indexes

Percentile limits (50th, 90th and 95th percentiles) for the three cardiac size indexes for CVD-free normotensive subgroups are listed in table 9.

### Discussion

The present study demonstrated that chest size, in addition to the body size, is an important determinant of the normal variability of the heart volume and its transverse diameter. The transverse chest diameter combined with body weight explained about 30% of the variance of cardiac volume. Body height did not significantly contribute to the heart volume variability. Chest diameter, together with body weight and height, explained about 40% of the variance of the cardiac transverse diameter.

The results from the present study demonstrated considerable differences in the patterns of age-related changes in the distributions of the three different measures of cardiac size. These differences prevailed after removing cardiac size variability due to normal anthropometric/physiological factors by optimal indexing of cardiac size to body and chest size. Of interest was the observation that LV mass index by ECG was primarily associated with systolic blood pressure level rather than with age, whereas age was the primary determinant of HVI and CEI in all race/sex groups whether normotensive or hypertensive.

History of heart attack appeared an important determinant of cardiac size. This observation is consistent with the fact that heart size is known to increase following acute myocardial infarction [22].

Valid criticism has been voiced [13] regarding the inappropriate use of the cardiothoracic ratio for comparison of the prevalence of cardiomegaly between blacks and whites in some of the recent clinical trials such as the Hypertension Detection and Follow-Up Program [23]. Similar objections because of racial differences in anthropometric variables are equally valid regarding indexing of cardiac size in general. Ungerleider and Clark [24]

demonstrated already in 1939 in their study on 1,460 life insurance applicants that the transverse cardiac diameter is dependent on both body weight and height, varying in proportion with the square root of the weight/height ratio. These investigators pointed out that the functional relationship between the body size and internal chest diameter is substantially different from that between cardiac transverse diameter and body size, thus demonstrating the chief fallacy in attempts to index cardiac transverse diameter to linear chest dimensions.

Problems similar to those related to indexing of radiological heart size measurements are also encountered with the use of the traditional amplitude criteria for left ventricular hypertrophy. The lack of success in attempts to index the ECG estimate of the left ventricular mass to body and chest size measurements was unexpected. More detailed analyses in the population of the present study revealed that some of the ECG amplitude measurements used in LVH criteria are strongly dependent on constitutional variables whereas others, particularly those based on multiple measurements, are not [25]. The fact that the ECG model used for LV mass estimation is based on multiple regression formula with six ECG variables may partially explain its independence from anthropometric variables.

### Limitations of the Present Study

The sample size limits the possibility of deriving stable estimates for the upper and lower percentile limits for population standards from the distributions of cardiac size indexes among the black, as well as for any subgroups stratified by age and hypertensive status. It is evident that combination of population data from other health surveys will be necessary for these more refined analyses.

### Conclusions

Chest size, in addition to body size, is an important determinant of normal cardiac size variability. Optimal indexing of the transverse cardiac diameter requires the inclusion of thorax diameter and body weight, and the indexing of cardiac volume standing height in addition to thorax diameter and body weight. Separate prediction formulas are required for each race/sex group for indexing of the cardiac size. Body and chest size variables explained about 30% of the total variance of the heart volume and about 40% of the variance of the cardiac transverse diameter. On the other hand, the fraction of

the variance of the ECG estimate of LV mass explained by body size variables was too low for a meaningful indexing of this cardiac size variable.

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