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ARTICLE

Distribution and Categorization of Echocardiographic Measurements in Relation to Reference Limits

The Framingham Heart Study: Formulation of a Height- and Sex-Specific Classification and Its Prospective Validation

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Abstract: *Background* Despite widespread categorization of echocardiographic measurements, there are no standardized guidelines for partitioning values exceeding reference limits.*Methods and Results* We used regression analyses to develop sex- and height-specific reference limits for cardiac M-mode measurements (left ventricular [LV] mass, LV wall thickness, and LV and left atrial dimensions) in a healthy reference sample (n=1099) from the Framingham Heart Study. We then examined the distribution of measurements in a broad sample (n=4957) and classified

the measurements according to increasing deviation from the height- and sex-specific reference limits and the 95th, 98th, and 99th percentile values for the broad sample (categories 0 through 4, respectively). To validate the categorization scheme, we used multivariable proportional-hazards regression to assess the relations of LV mass and LV wall thickness categories to risk of cardiovascular events and the relations of left atrial size to risk of atrial fibrillation. During a mean follow-up period of 7.7 years, 587 subjects developed new cardiovascular disease events, and 166 subjects developed new-onset atrial fibrillation. After adjustment for known risk factors, there was a 1.2- and 1.3-fold risk of cardiovascular disease events per category of LV wall thickness and LV mass, respectively, and a 1.6-fold risk of atrial fibrillation per category of left atrial size.*Conclusions* Using a large community-based study sample, we propose a classification scheme that provides a standardized and validated framework for partitioning echocardiographic measurements. If adopted, the categorization scheme should promote uniformity in describing measurements among echocardiographic laboratories and enhance the comprehensibility of measurements to clinicians.

Key Words: echocardiography ■ cardiovascular diseases ■ ventricles ■ atrium ■ follow-up studies

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Reference values, often referred to as the “upper limits of normal,” have been proposed for echocardiographic dimensions of cardiac chambers.[1 2 3 4 5 6 7 8 9 10] The current practice in echocardiographic laboratories across the world is to categorize echocardiographic measurements as normal or into mild, moderate, or severe degrees of abnormality. For instance, the expressions “moderate concentric left ventricular hypertrophy” and “severe left atrial enlargement” are used widely to describe quantitative abnormalities of these cardiac structures. Despite the widespread use of such descriptive terms, there are no standardized guidelines in the echocardiographic literature regarding cut points for partitioning values exceeding reference limits. Furthermore, the current clinical practice of categorizing values exceeding reference limits is highly variable between and within institutions, neither height- nor sex-specific, and inadequately substantiated by scientific data.

The choice of cut points for classifying echocardiographic values (or any other quantitative clinical measurement) on an ordinal scale should be based on the distribution of these observations in relation to reference limits in a randomly selected noninstitutionalized sample of the general population.[11] Such a classification system may be useful for descriptive purposes, for prognostication, and for the prevention and treatment of diseases.[12] Previous publications from the Framingham Heart Study have

evaluated the relations of echocardiographic variables as continuous measures to cardiovascular disease events. The objectives of the present investigation were twofold: (1) to develop a classification system of echocardiographic values exceeding reference limits in a community-based study sample and (2) to prospectively examine the utility of our categorization approach for predicting clinically important events during follow-up.

Methods

Study Sample

The selection criteria and study design of the FHS (both original and offspring study cohorts) have been detailed extensively.[13] [14] Original subjects of the FHS who participated in the 16th biennial examination (1979 through 1981) and subjects of the Framingham Offspring Study who participated in the second offspring examination (1979 through 1983) constituted the study sample. The FHS examination has been approved by the Boston Medical Center Institutional Review Board, and all subjects gave informed consent before the examinations.

Of 6216 subjects who attended the index examinations, 1259 subjects (20.3%) with inadequate M-mode echocardiograms were excluded from the present investigation. The study sample included two groups. The larger group, called the broad sample, included all 4957 who

had adequate M-mode echocardiograms. A healthy subgroup of 1099 subjects, henceforth called the reference sample, was selected from the broad sample to formulate reference limits. The reference sample included subjects between the ages of 20 and 45 years who were not obese (body mass index between 19 and 26 kg/m^2), who were of average height (1.5 to 1.9 m in men and 1.4 to 1.8 m in women), and who were free of cardiovascular disease, hypertension,[15] AF, diabetes mellitus, and cardiac medication use.

Echocardiographic Methods

All subjects underwent routine M-mode echocardiography. In >90% of subjects, two-dimensional guided M-mode echocardiograms were obtained from the left parasternal window.[16] All measurements were made according to the American Society of Echocardiography guidelines.[17] Three measurements were averaged for each value. The following echocardiographic variables were studied in the present investigation: LA dimensions, LV mass, LV wall thickness, and LV end-diastolic and end-systolic internal dimensions. LV mass was calculated thus: LV mass=0.8[1.04(LVIDD+IVST+PWT)^3−(LVIDD)^3]+0.6, where LVIDD represents LV end-diastolic internal dimension and IVST and PWT indicate the end-diastolic thicknesses of the interventricular septum and LV posterior wall, respectively.[18] End-diastolic LV wall thickness was calculated as IVST+PWT.

Analysis and Statistical Methods

Development of Classification for Values Exceeding Reference Limits All analyses were sex-specific. Height was used for indexation of echocardiographic variables because the use of body surface area may inappropriately mask obesity-related alterations in cardiac structure.[19 20 21 22] For each echocardiographic variable Y, logarithmic regression analyses were performed using the reference sample with height as the predictor variable, thus: log $Y=\beta_0+\beta_1$ log(height)+E, where β_0 is the Y-axis intercept, β_1 is the slope, and E is an error term. The predicted value of Y was calculated as $Y_p=\exp[\beta_0+\beta_1$ log(height)]. The 95th percentile value of Y was calculated for the reference sample as $Y_{95}=Y\times\exp(1.645\times$root mean square error). The values of Y_{95} represent the sex- and height-specific reference limits for the variable. Reference limits (regression coefficients and the values of $[\text{height}]^k$, *k* being sex-specific and echocardiographic variable–specific) for LV wall thickness, LV internal dimensions, and LV mass have been published previously.[19 20] The distribution of the ratio of the raw observation divided by the value predicted for height and sex, ie, Y/Y_p, in the broad sample was studied. The sex- and height-specific 95th, 98th, and 99th percentile values of the echocardiographic variable in the broad sample were determined subsequently from the corresponding percentiles of the ratio. We classified values of each echocardiographic variable into the following five categories based on sex- and

height-specific percentiles (indicating increasing deviation from the reference limits): category 0 (reference limits), value ≤95th percentile of the reference sample; category 1, 95th percentile of reference sample<value≤95th percentile of broad sample; category 2, 95th percentile of broad sample<value≤98th percentile of broad sample; category 3, 98th percentile of broad sample<value≤99th percentile of broad sample; and category 4, value >99th percentile of broad sample.

Relations of Categories of Echocardiographic Variables to Clinical Outcomes To assess the validity and prognostic significance of the proposed classification scheme, we evaluated the risk of adverse clinical outcomes among subjects in the five proposed categories of each echocardiographic variable (as defined at the baseline examination) during a follow-up period of up to 11 years. Category 0 served as the reference group with which the other categories were compared. The a priori hypothesis was that an increase in risk of adverse clinical events would be observed across the five categories of each echocardiographic variable. Analyses relating to categories of LV mass, LV wall thickness and LA dimensions are presented here. The relations of LV mass and LV wall thickness to the incidence of cardiovascular disease events and of LA dimensions to the incidence of new-onset AF were examined with sex-stratified Cox regression,[23] adjusted for known risk factors for these outcomes. The end points were

selected a priori on the basis of previous studies reporting an association of increasing LV mass[24 25 26 27 28 29] and LV wall thickness[25 27] with risk of cardiovascular events and of increasing LA size with risk of AF.[30 31] All study subjects were under periodic surveillance for development of cardiovascular disease events with the aid of medical history, hospitalization records, and communication with personal physicians. All suspected new cardiovascular events were reviewed by a panel of three investigators who evaluated all pertinent available medical records. Cardiovascular disease events included coronary heart disease (angina pectoris, coronary insufficiency, myocardial infarction, and sudden or nonsudden death attributable to coronary heart disease), congestive heart failure, cerebrovascular disease (stroke or transient ischemic attack), and intermittent claudication. Criteria for these events have been detailed previously.[32] A diagnosis of AF on follow-up was made on the basis of documentation of AF or flutter on ECGs obtained from the FHS examination, hospital records, or private physician records. For examining the impact of LA size categories on risk of AF, we excluded subjects with AF at or before baseline (n=82).

Adjustment for Covariates For multivariable analyses examining cardiovascular events as the outcome, hazard ratios were adjusted for the following covariates: sex, age (years), diastolic blood pressure (mm Hg), pulse pressure (mm Hg), the ratio of total to HDL cholesterol, body mass

index (weight in kg/[height in m]^2), and the following dichotomous variables: hypertension, smoking, diabetes mellitus, and prior cardiovascular disease.[24] The covariates included in the multivariable models evaluating AF as the outcome event included age (years), hypertension status, diabetes mellitus, ECG LV hypertrophy, valve disease, and prior cardiovascular disease.[33] Hypertension was defined according to the JNC-V criteria as a systolic blood pressure value ≥140 mm Hg, a diastolic blood pressure value ≥90 mm Hg,[15] or current drug treatment for hypertension. Valve disease was defined as the presence of a diastolic murmur or a systolic murmur (grade 3/6 or more) on precordial auscultation at baseline. Criteria for other risk factors have been detailed previously.[34] Only subjects with complete information regarding the covariates were included for the proportional-hazards analyses.

Choice of Statistical Models We investigated whether the risk of adverse events differed among categories of echocardiographic variables using the several multivariable statistical models: models incorporating clinical variables only; multicategory models, in which risk of adverse outcome in each category was compared with that associated with category 0; trend models, in which we investigated whether there was a stepwise increase in risk of adverse outcome from one category to the next higher one; and threshold models, in which we tested whether there was a particular category above which there was increased risk of adverse

outcomes (eg, risk of adverse events in subjects in categories 0 and 1 versus risk in subjects in categories 2, 3, and 4).

To explore the impact of sex on the risks associated with the echocardiographic categories, we performed secondary analyses incorporating interaction terms. All analyses were performed with the SAS System (SAS Institute Inc) procedures REG[35] and PHREG[36] on a SUNsparc 2 workstation; a two-sided value of $P<.05$ assessed statistical significance.

Results

Study Sample

The characteristics of the study subjects are summarized in Table 1. Compared with the reference sample, subjects in the broad sample were older, heavier, and had higher blood pressure, body mass index, and mean values for the echocardiographic measurements studied. In the broad sample, the prevalence of cardiovascular disease was as follows: hypertension, 33.1%; coronary disease, 6.7%; congestive heart failure, 0.9%; and AF, 1.7%. These conditions were grounds for exclusion from the reference sample.

Classification of Values Exceeding Reference Limits

In general, we noted a significant relation between height and echocardiographic variables in both sexes. The distributions of the ratio of observed to sex- and height-predicted values were examined for each echocardiographic variable; the Figure displays the distribution of this ratio for LA dimension, LV mass, LV wall thickness, and LV end-diastolic dimension. Approximately one quarter of men and one third of women exceeded reference limits for LV wall thickness, LV mass, and LA dimension. Eleven percent of men and 9% of women exceeded reference limits for LV end-diastolic dimension. Tables 2 and 3 provide the sex- and height-specific cut points for the five proposed categories of each echocardiographic variable derived from the percentiles of the ratio of observed to sex- and height-predicted values in the reference (category 0) and broad (categories 1 through 4) samples.

Relation of Category of Echocardiographic Variable to Clinical Outcome

Unadjusted Event Rates According to Category of Variable Three subjects were lost to follow-up. During follow-up of the remaining 4954 subjects (mean age, 7.7 years; range, 0.4 to 11 years), 587 subjects experienced a new cardiovascular event; 55 of these new events were fatal. There were 166 subjects with new-onset AF among the 4872 subjects free of AF at baseline. Crude rates for new events increased across categories of LV mass, LV wall thickness,

and LA size (Tables 4 through 6). Among men and women with a measurement of LV mass or LV wall thickness suggestive of extreme deviation from reference limits (category 4), >60% developed new cardiovascular disease events on follow-up; in comparison, <10% of the subjects in category 0 experienced a new event. Categories of LV mass or LV wall thickness between these two extremes (categories 1 through 3) had intermediate rates of new cardiovascular disease events. For categories of LA dimension, AF rates rose in stepwise fashion; >60% of subjects in category 4 developed AF, compared with 2% of subjects in category 0.

Multivariable Analyses Irrespective of the choice of the statistical model, a significant risk gradient for adverse events was evident across the categories of LV mass, LV wall thickness, and LA dimensions for both sexes after adjustment for other known risk factors. In general, trend models were roughly comparable to the five category models in terms of risk prediction but incorporated fewer variables (ie, were more parsimonious). The threshold models were inferior to the trend and five category models but were better than multivariable models that included only clinical predictors (data not shown). The results of the trend and five-category models are shown in Tables 4 through 6. There was a 1.2- to 1.3-fold increase in hazard for new cardiovascular disease events per increase in category of LV wall thickness and LV mass, respectively (trend model). There was a 1.6-fold increase in hazard of AF per increase in category of LA

dimension (trend model); a 4.4-fold hazard was seen for subjects in the highest category of LA dimension compared with those in the lowest category. There were no significant sex differences in the risks associated with LV mass and LV wall thickness categories (probability values for the respective interaction terms were .29 and .68). There was a 29% greater risk for AF across LA size categories in women than in men (*P*=.08).

Discussion

Need for Classifying Echocardiographic Values in Relation to Reference Limits

Because of the plethora of tests in medicine, raw values of clinical measurements often are poorly comprehended by nonspecialists. Understandably, nonspecialists frequently cannot recall cut points for abnormality, much less retain a sense of how far an abnormal value has strayed from normal.[37] Clinical chemists have tried to resolve this dilemma by presenting any observed value in relation to its reference limits.[38] Classification of abnormal clinical measurements on an ordinal scale, ie, within reference limits and with increasing degrees of deviation from reference limits, is an attractive option because clinicians tend to think in terms of categories when they interpret quantitative clinical data.[39] Besides making clinical data more comprehensible to

nonspecialists, classification also renders the available information more manageable.[40]

When standards for categorization of laboratory tests are absent, clinicians set their own informal criteria for converting noncategorical data into categorical information. This was well illustrated by a study addressing the interpretation of objective measures by physicians; the larger the physician's own set of reference values was, the greater was the leniency in the interpretation of such data.[41] We searched the literature for cut points for classifying echocardiographic values exceeding the reference limits but failed to find standardized guidelines. Despite the routine use of descriptive categories in echocardiography laboratories, there is little scientific literature to support such practice.

Development and Validation of Our Classification

There is no universally accepted method for categorizing continuous variables.[42] [43] [44] In the present investigation, we developed a classification system for echocardiographic reference limits that attempted to meet two broad objectives: standardization of echocardiographic interpretation and clinical sensibility.[39] To achieve the latter goal, we sought to develop a classification system that was straightforward, user-friendly, evidence based, and based on appropriate physiological variables. Because echocardiographic measurements are dependent on sex as well as on body size,[19] [20] [45] echocardiographic variables should be classified

with reference to sex and to anthropometric measurements. We chose height as a physiological obesity-independent determinant of echocardiographic measurements. Although age is an important determinant of cardiac dimensions,[21 46 47] we avoided formulating age-dependent cut points because of uncertainty in distinguishing the physiological from the pathological effects of aging on the heart.[48]

By examining the distribution of values in a broad study sample that included healthy and diseased individuals, we developed a classification in which each echocardiographic variable could be partitioned into four categories based on increasing degrees of deviation from reference limits (category 0). The present investigation suggested that echocardiographic measurements exceeding height- and sex-specific reference limits were associated with an adverse prognosis; furthermore, the greater the extent of deviation, the worse the prognosis. Results of trend models indicated a stepwise increase in hazard per category increase in LV mass (1.3-fold risk of cardiovascular disease events), LV wall thickness (1.2-fold risk of cardiovascular events), and LA size (1.6-fold risk of AF). The adverse impact associated with values in categories 1 through 4 (compared with category 0) was evident in both sexes, persisted in multivariable analyses adjusting for the impact of other known risk factors, and was generally consistent within the various statistical models explored.

Strengths and Limitations

Any classification may be justified on the basis of its peremptory assignment, its consensual validation, or external documentation.[40] Peremptory assignment is desirable when data have no inherent meaning (eg, zip codes). A consensual approach involves establishing a standard by common agreement of experts in the field. External documentation (validation by application) requires providing independent evidence that justifies the creation of the proposed categories. We chose the latter method because we believe that it was unbiased and scientifically more rigorous. Furthermore, the ability of any classification system to predict risk of adverse events considerably enhances its utility to the clinician. The longitudinal design of the FHS facilitated such prospective validation.

To the best of our knowledge, except for LV mass,[49] the present investigation is the first systematic attempt at classifying echocardiographic values exceeding reference limits. The a priori definition of cut points based on the distribution of the echocardiographic measurements instead of post hoc generation based on clinical outcome events is an additional strength of our study.[44] The large, community-based study sample used for deriving our reference limits and for developing and validating our classification approach makes the present investigation unique. In comparison, previous reports of echocardiographic reference limits[1 2 3 4 5 6 7 8 9 10] have been based on percentile estimates drawn from cross-sectional samples of smaller numbers of healthy

subjects. Previous investigations from the FHS[19 50] and elsewhere[1 2 3 4 5 6 7 8 9 10] have not subdivided the values exceeding reference limits for practical use by clinicians.

The exclusion of subjects without satisfactory echocardiograms (who are generally sicker) may have resulted in the lowering of thresholds for abnormal values. The use of M-mode measurements presents other potential limitations. Cardiac disease may result in distorted LV geometry with the possibility of underestimating or overestimating LV mass.[51] Furthermore, M-mode technology (transducer sensitivity, etc) has changed over the past two decades because the echocardiograms were performed. In addition, categories based on M-mode measurements may not be generalizable to two-dimensional echocardiographic measurements. Nonetheless, previous investigations have found reasonable agreement between measurements made by the two techniques.[6 52] Finally, it is possible for a patient to shift between categories simply on the basis of limitations in the reproducibility of echocardiographic measurements.[53]

Because the generation and validation of our classification are based on ambulatory subjects, its prognostic relevance in hospitalized subjects is unknown. A related potential limitation is that in addition to age, the cut points are largely dependent on the prevalent pattern and severity of cardiac disease in the study participants. For instance, cut points for varying degrees of LV hypertrophy and LV dilatation obtained from our study sample may differ

substantially from those obtained from subjects in hypertension and heart failure clinics, respectively. Nonetheless, it is heartening to note that the prevalence of cardiovascular disease in our study sample was consistent with that observed in the general US population.[54] Furthermore, although we have demonstrated significant prognostic value of this categorization scheme, the therapeutic implications of our classification, if any, are unknown. Last, given the largely white racial composition of the Framingham sample, readers should exercise caution in extrapolating the study results to other racial groups.

Clinical Implications

Scrutiny of our cut points reveals that there are some challenges to currently used thresholds for quantitative echocardiographic abnormalities. For example, a sum of septal and posterior LV wall thicknesses of 20 mm is regarded as normal by most clinicians. Nonetheless, we would classify this value as above reference limits in a woman or in a short man; such a value for wall thickness (category 1) is associated with a 1.2-fold risk of cardiovascular disease events compared with values within reference limits. These observations underscore the weaknesses inherent in the use of traditional reference limits that establish an arbitrary dichotomous threshold (mean±2 SD or 95th percentile) without providing insights into risks associated with various levels of the echocardiographic variable.

By classifying echocardiographic values on an ordinal scale reflecting an increasing hazard for morbid events across categories, we have reported a framework that will promote greater consistency in echocardiographic interpretation and will provide prognostic information. Such a standardized classification is particularly important in an era when the nonspecialist not only orders echocardiograms but also is expected to interpret and act on the results of the studies.

Selected Abbreviations and Acronyms

AF	=	atrial fibrillation
FHS	=	Framingham Heart Study
LA	=	left atrial
LV	=	left ventricular

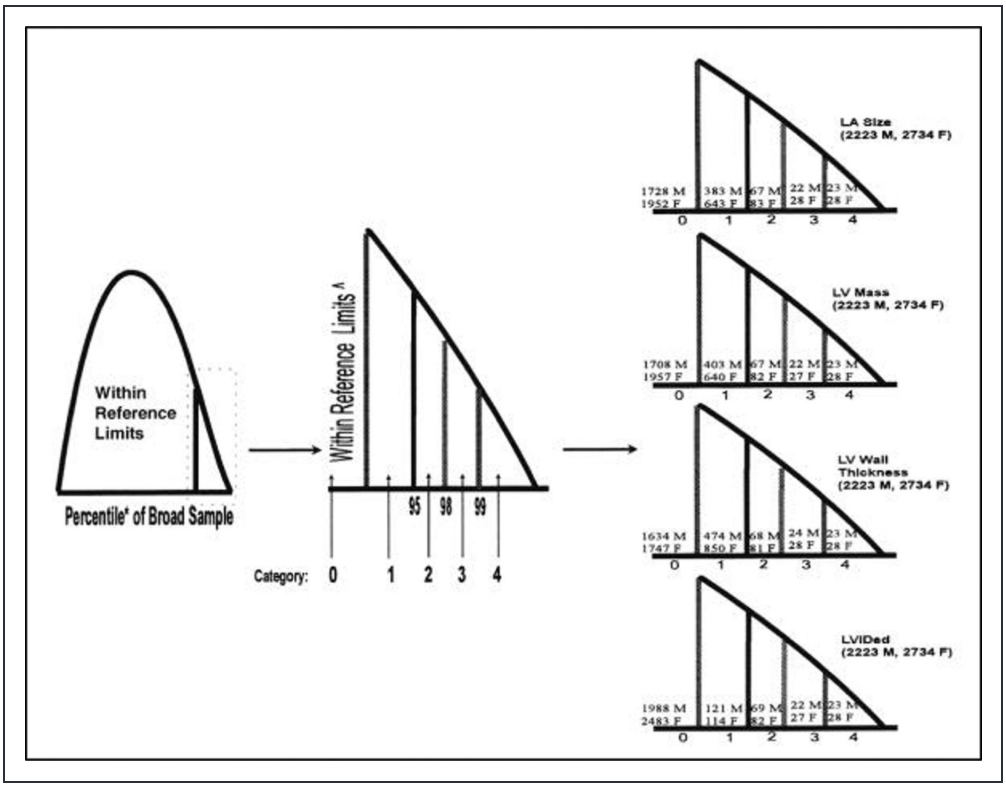

Figure 1. Distribution and categorization of echocardiographic variables in the broad sample of 4957 subjects based on deviation from height- and sex-specific reference limits. Categories were based on relations of 95th, 98th, and 99th percentile values of observed/predicted value for given height and sex in broad sample to reference limits. Reference limits were based on 95th percentile values in a healthy reference sample. Values for 22% of men and 29% of women exceeded reference limits for LA dimensions; values for 17% of men and 24% of women exceeded reference limits but were <95th percentile for broad sample. About 23% of men and 28% of women in broad sample exceeded reference limits for LV mass; LV mass values for 18% of men and 23% of women exceeded reference limits (height- and sex-specific) but were within 95th percentile of values for broad sample. Values for 26% of men and 36% of women exceeded reference limits for LV wall thickness; values for 21% of men and 31% of women were intermediate between reference limits and 95th percentile of values for broad sample. Values for 11% of men and 9% of women exceeded reference limits for LV end-diastolic

internal dimensions (LVIDed); values for 5% of men and 4% of women were between reference limits and 95th percentile for broad sample. For LV end-systolic internal dimensions, distribution of male subjects was 2058, 53, 66, 23, and 23 for categories 0, 1, 2, 3, and 4, respectively; distribution of female subjects was 2545, 51, 83, 27, and 28 for categories 0, 1, 2, 3, and 4, respectively (not shown).

Table 1. Clinical and Echocardiographic Characteristics of Study Samples (Table view)

	Reference Sample		Broad Sample	
	Men (n=387)	Women (n=712)	Men (n=2223)	Women (n=2734
Clinical features				
Age, y (range)	35.7±6.1 (20-45)	36.1±5.5 (21-45)	49.8±13.9 (18-90)	51.6±15 (17-90)
Height, m	1.77±0.06	1.63±0.06	1.75±0.07	1.60 ±0.
Weight, kg	74.0±6.9	58.9±6.1	81.1±12.0	64.1±12
Body surface area, m^2	1.91±0.11	1.63±0.10	1.96±0.16	1.66±0.1
Systolic blood pressure, mm Hg	116.9±9.3	109.6±10.3	128.8 ±17.2	125.0±2
Diastolic blood pressure, mm Hg	74.7±7.0	71.0±7.5	80.3±9.3	75.6±9.6
Coronary disease, %	…	…	8.3	5.3
Hypertension, %	…	…	35.0	31.6
Valve disease, %	…	…	2.8	3.1
Heart failure, %	…	…	0.8	1.0
AF, %	…	…	2.2	1.2

	Reference Sample		Broad Sample	
Diabetes mellitus, %	Men (n=387)	Women (n=712)	Men (n=2223)	Women (n=2734
Echocardiographic features				
LV mass, g	173.9±39.7	114.5±23.5	202.1±61.8	135.9±4
Ventricular wall thickness, mm	18.1±2.0	15.5±1.5	19.8±3.0	17.4±3.(
LA dimension, mm	37.5±3.6	32.9±3.2	40.4±5.1	36.0±5.3
LV end-diastolic dimension, mm	50.9±3.5	46.1±3.1	51.1±4.4	45.7±4.(

Plus-minus values indicate mean±SD.

Table 2. Cut Points for Categorization of Echocardiographic LA Size, LV Mass, Wall Thickness, and LV Diameter in Women (Table view)

Height		Category				
in	cm	0	1	2	3	4
Left atrium, mm						
54	137	≤36.6	36.7-43.0	43.1-47.2	47.3-49.6	>49.6
55	140	≤36.8	36.9-43.3	43.4-47.5	47.6-49.9	>49.9
56	142	≤37.0	37.1-43.5	43.6-47.7	47.8-50.2	>50.2
57	145	≤37.2	37.3-43.7	43.8-48.0	48.1-50.4	>50.4
58	147	≤37.4	37.5-44.0	44.1-48.2	48.2-50.7	>50.7
59	150	≤37.6	37.7-44.2	44.3-48.5	48.6-51.0	>51.0
60	152	≤37.8	37.9-44.4	44.5-48.8	48.9-51.2	>51.2
61	155	≤38.0	38.1-44.7	44.8-49.0	49.1-51.5	>51.5
62	157	≤38.1	38.2-44.9	45.0-49.2	49.3-51.8	>51.8

Height		Category				
in	cm	0	1	2	3	4
63	160	≤38.3	38.4-45.1	45.2-49.5	49.6-52.0	>52.0
64	163	≤38.5	38.6-45.3	45.4-49.7	49.8-52.3	>52.3
65	165	≤38.7	38.8-45.5	45.6-50.0	50.1-52.5	>52.5
66	168	≤38.9	39.0-45.8	45.9-50.2	50.3-52.8	>52.8
67	170	≤39.1	39.2-46.0	46.1-50.4	50.5-53.0	>53.0
68	173	≤39.2	39.3-46.2	46.3-50.7	50.8-53.2	>53.2
69	175	≤39.4	39.5-46.4	46.5-50.9	51.0-53.5	>53.5
70	178	≤39.6	39.7-46.6	46.7-51.1	51.2-53.7	>53.7
71	180	≤39.8	39.9-46.8	46.9-51.3	51.4-53.9	>53.9
72	183	≤39.9	40.0-47.0	47.1-51.6	51.7-54.2	>54.2
LV mass, g						
54	137	≤116	117-159	160-189	190-233	>233
55	140	≤119	120-163	164-194	195-240	>240
56	142	≤123	124-168	169-200	201-247	>247
57	145	≤126	127-173	174-205	206-254	>254
58	147	≤130	131-178	179-211	212-261	>261
59	150	≤133	134-183	184-217	218-268	>268
60	152	≤137	138-188	189-223	224-275	>275
61	155	≤141	142-193	194-229	230-282	>282
62	157	≤144	145-198	199-235	236-290	>290
63	160	≤148	149-203	204-241	242-297	>297
64	163	≤152	153-208	209-247	248-305	>305
65	165	≤155	156-213	214-253	254-312	>312
66	168	≤159	160-218	219-259	260-320	>320
67	170	≤163	164-223	224-266	267-328	>328

Height		Category				
in	cm	0	1	2	3	4
68	173	≤167	168-229	230-272	273-336	>336
69	175	≤171	172-234	235-278	279-344	>344
70	178	≤175	176-240	241-285	286-352	>353
71	180	≤179	180-245	246-291	292-360	>360
72	183	≤183	184-251	252-298	299-368	>368
LV wall thickness, mm						
54	137	≤16.9	17.0-21.4	21.5-24.7	24.8-27.4	>27.4
55	140	≤17.0	17.1-21.6	21.7-24.9	25.0-27.6	>27.6
56	142	≤17.1	17.2-21.8	21.9-25.1	25.2-27.8	>27.8
57	145	≤17.2	17.3-21.9	22.0-25.3	25.4-28.0	>28.0
58	147	≤17.4	17.5-22.1	22.2-25.5	25.6-28.2	>28.2
59	150	≤17.5	17.6-22.2	22.3-25.6	25.7-28.4	>28.4
60	152	≤17.6	17.7-22.4	22.5-25.8	25.9-28.6	>28.6
61	155	≤17.7	17.8-22.5	22.6-26.0	26.1-28.8	>28.8
62	157	≤17.8	17.9-22.7	22.8-26.2	26.3-29.0	>29.0
63	160	≤18.0	18.1-22.8	22.9-26.3	26.4-29.2	>29.2
64	163	≤18.1	18.2-23.0	23.1-26.5	26.6-29.4	>29.4
65	165	≤18.2	18.3-23.1	23.2-26.7	26.8-29.6	>29.6
66	168	≤18.3	18.4-23.3	23.4-26.9	27.0-29.8	>29.8
67	170	≤18.4	18.5-23.4	23.5-27.0	27.1-29.9	>29.9
68	173	≤18.5	18.6-23.6	23.7-27.2	27.3-30.1	>30.1
69	175	≤18.6	18.7-23.7	23.8-27.4	27.5-30.3	>30.3
70	178	≤18.8	18.9-23.9	24.0-27.5	27.6-30.5	>30.5
71	180	≤18.9	19.0-24.0	24.1-27.7	27.8-30.7	>30.7
72	183	≤19.0	19.1-24.1	24.2-27.8	27.9-30.8	>30.8

RS indicates reference sample; BS, broad sample. Categories are 0, value≤95th percentile RS; 1, 95th percentile RS<value≤95th percentile BS; 2, 95th percentile BS<value≤98th percentile BS; 3, 98th percentile BS<value≤99th percentile BS; and 4, value>99th percentile BS. For women in category 0, the RS 95th percentile values correspond to the following percentiles of the broad sample: For LA size, 71%; for LV mass 72%, for LV wall thickness 64%, for LV internal diameter end diastole 91%, for LV diameter end systole 93%.

Table 3. Cut Points for Categorization of Echocardiographic LA Size, LV Mass, Wall Thickness, and LV Diameter in Men (Table view)

Height		Category				
in	cm	0	1	2	3	4
Left atrium, mm						
60	152	≤42.4	42.5-47.7	47.8-51.7	51.8-53.9	>53.9
61	155	≤42.5	42.6-47.9	48.0-51.9	52.0-54.1	>54.1
62	157	≤42.7	42.8-48.1	48.2-52.1	52.2-54.3	>54.3
63	160	≤42.8	42.9-48.3	48.4-52.3	52.4-54.5	>54.5
64	163	≤43.0	43.1-48.4	48.5-52.5	52.6-54.7	>54.7
65	165	≤43.1	43.2-48.6	48.7-52.6	52.7-54.9	>54.9
66	168	≤43.3	43.4-48.8	48.9-52.8	52.9-55.1	>55.1
67	170	≤43.4	43.5-48.9	49.0-53.0	53.1-55.3	>55.3
68	173	≤43.6	43.7-49.1	49.2-53.2	53.3-55.5	>55.5
69	175	≤43.7	43.8-49.3	49.4-53.4	53.5-55.6	>55.6
70	178	≤43.9	44.0-49.4	49.5-53.5	53.6-55.8	>55.8
71	180	≤44.0	44.1-49.6	49.7-53.7	53.8-56.0	>56.0
72	183	≤44.2	44.3-49.7	49.8-53.9	54.0-56.2	>56.2
73	185	≤44.3	44.4-49.9	50.0-54.0	54.1-56.4	>56.4
74	188	≤44.4	44.5-50.0	50.1-54.2	54.3-56.5	>56.5
75	190	≤44.6	44.7-50.2	50.3-54.4	54.5-56.7	>56.7
76	193	≤44.7	44.8-50.3	50.4-54.5	54.6-56.9	>56.9
77	196	≤44.8	44.9-50.5	50.6-54.7	54.8-57.0	>57.0

Height		Category				
in	cm	0	1	2	3	4
78	198	≤45.0	45.1-50.6	50.7-54.8	54.9-57.2	>57.2
LV mass, g						
60	152	≤170	171-221	222-264	265-295	>295
61	155	≤175	176-228	229-272	273-305	>305
62	157	≤181	182-235	236-281	282-314	>314
63	160	≤186	187-242	243-289	290-324	>324
64	163	≤192	193-249	250-298	299-334	>334
65	165	≤198	199-257	258-307	308-344	>344
66	168	≤204	205-264	265-316	317-354	>354
67	170	≤210	211-272	273-325	326-364	>364
68	173	≤216	217-280	281-335	336-375	>375
69	175	≤222	223-288	289-344	345-385	>385
70	178	≤228	229-296	297-354	355-396	>396
71	180	≤234	235-304	305-363	364-407	>407
72	183	≤240	241-312	313-373	374-418	>418
73	185	≤247	248-320	321-383	384-429	>429
74	188	≤253	254-329	330-393	394-440	>440
75	190	≤260	261-337	338-403	404-451	>451
76	193	≤266	267-346	347-413	414-463	>463
77	196	≤273	274-355	356-424	425-475	>475
78	198	≤280	281-363	364-434	435-486	>486
LV wall thickness, mm						
60	152	≤18.8	18.9-22.9	23.0-25.2	25.3-27.0	>27.0
61	155	≤19.1	19.2-23.2	23.3-25.6	25.7-27.4	>27.4
62	157	≤19.3	19.4-23.5	23.6-25.9	26.0-27.8	>27.8

Height		Category				
in	cm	0	1	2	3	4
63	160	≤19.6	19.7-23.8	23.9-26.3	26.4-28.1	>28.1
64	163	≤19.8	19.9-24.1	24.2-26.6	26.7-28.5	>28.5
65	165	≤20.1	20.2-24.4	24.5-27.0	27.1-28.9	>28.9
66	168	≤20.4	20.5-24.8	24.9-27.3	27.4-29.3	>29.3
67	170	≤20.6	20.7-25.1	25.2-27.7	27.8-29.6	>29.6
68	173	≤20.9	21.0-25.4	25.5-28.0	28.1-30.0	>30.0
69	175	≤21.1	21.2-25.7	25.8-28.3	28.4-30.4	>30.4
70	178	≤21.4	21.5-26.0	26.1-28.7	28.8-30.7	>30.7
71	180	≤21.6	21.7-26.3	26.4-29.0	29.1-31.1	>31.1
72	183	≤21.9	22.0-26.6	26.7-29.4	29.5-31.5	>31.5
73	185	≤22.2	22.3-26.9	27.0-29.7	29.8-31.8	>31.8
74	188	≤22.4	22.5-27.2	27.3-30.1	30.2-32.2	>32.2
75	190	≤22.7	22.8-27.5	27.6-30.4	30.5-32.6	>32.6
76	193	≤22.9	23.0-27.8	27.9-30.7	30.8-32.9	>32.9
77	196	≤23.2	23.3-28.2	28.3-31.1	31.2-33.3	>33.3
78	198	≤23.4	23.5-28.5	28.6-31.4	31.5-33.6	>33.6

Abbreviations and categories as in Table 2. For men in category 0, the RS 95th percentile values correspond to the following percentiles of the broad sample: For LA size, 78%; for LV mass, 77%; for LV wall thickness, 74%; for LV internal end-diastolic diameter, 89%; and for LV end-systolc internal diameter, 93%.

Table 4. Relations of Categories of LV Mass to Incidence of New Cardiovascular Disease Events: Results of Cox Proportional-Hazards Models (Table view)

Proposed Category	Men			Women	
	No. in	No. of	Rate	No. in	No. of

Proposed Category	Category Men	Events on Follow-up	per 1000	Category Women	Events on Follow-up
	No. in Category	No. of Events on Follow-up	Rate per 1000 Person-Years[1]	No. in Category	No. of Events on Follow-up
Value ≤95 percentile reference sample (category 0)	1707	189	18.1	1955	107
95 percentile reference sample<value≤95 percentile broad sample (category 1)	403	89	32.3	640	96
95 percentile broad sample<value≤98 percentile broad sample (category 2)	67	29	71.1	82	23
98 percentile broad sample<value≤99 percentile broad sample (category 3)	22	10	92.7	27	8
Value >99 percentile broad sample (category 4)	23	19	181.7	28	17

1 Based on 587 new cardiovascular events among 4954 subjects in the broad sample. Cardiovascular events include coronary disease (angina, myocardial infarction, coronary

insufficiency, and sudden cardiac death), heart failure, stroke, transient ischemic attacks, and intermittent claudication.

[2] Hazards ratio adjusted for age, sex, hypertension, diastolic blood pressure, pulse pressure, smoking, total cholesterol/HDL cholesterol, diabetes mellitus, and previous cardiovascular disease. These proportional-hazards analyses are based on 555 subjects with new cardiovascular events among 4775 subjects with complete information regarding covariates.

Table 5. Relations of Categories of LV Wall Thickness to Incidence of New Cardiovascular Disease Events: Results of Cox Proportional-Hazards Models (Table view)

Proposed Category	Men			Women	
	No. in Category	No. of Events on Follow-up	Rate per 1000 Person-Years[1]	No. in Category	No. of Events on Follow-up
Value ≤95 percentile reference sample (category 0)	1633	184	15.4	1745	69
95 percentile reference sample<value≤95 percentile broad sample (category 1)	474	101	31.2	850	137

Proposed Category	Men			Women	
	No. in Category	No. of Events	Rate per 1000 Person-Years[1]	No. in Category	No. of Events
95 percentile broad sample<value≤98 percentile broad sample (category 2)	68	22	49.0	81	20
98 percentile broad sample<value≤99 percentile broad sample (category 3)	24	14	109.4	28	10
Value >99 percentile broad sample (category 4)	23	15	138.7	28	15

[1] Based on 587 new cardiovascular events in 4954 subjects of the broad sample. Cardiovascular events include coronary disease (angina, myocardial infarction, coronary insufficiency, and sudden cardiac death), heart failure, stroke, transient ischemic attacks, and intermittent claudication.

[2] Hazards ratio adjusted for age, sex, hypertension, diastolic blood pressure, pulse pressure, smoking, total cholesterol/HDL-cholesterol, diabetes mellitus, and previous cardiovascular disease. These proportional-hazards analyses are based on 555 subjects with new cardiovascular events among 4775 subjects with complete information regarding covariates.

Table 6. Relations of Categories of LA Dimension to Incidence of AF: Results of Cox Proportional-Hazards Models (Table view)

Proposed Category	Men			Women	

Proposed Category	Men			Women	
	No. in Category	No. of Events on Follow-up	Rate per 1000 Person-Years[1]	No. in Category	No. of Events on Follow-up
Value ≤95 percentile reference sample (category 0)	1720	49	8.7	1947	26
95 percentile reference sample<value≤95 percentile broad sample (category 1)	371	23	8.4	638	21
95 percentile broad sample<value≤98 percentile broad sample (category 2)	59	11	25.9	78	15
98 percentile broad sample<value≤99 percentile broad sample (category 3)	17	3	30.1	22	7
Value >99 percentile broad sample (category 4)	7	4	91.9	13	7

[1] Based on 166 new onset AF events in 4872 subjects in the broad sample who were free of AF at baseline.

[2] Hazard ratio adjusting for age, sex, hypertension, valve disease, ECG LV hypertrophy, diabetes mellitus, and previous cardiovascular disease. These proportional-hazards analyses are based on 164 subjects with new-onset AF among 4851 subjects free of AF at baseline and who had complete information regarding covariates. For LA size hazard ratios, categories were combined because of small numbers.

Table 2A. Continued (Table view)

Height		Category				
in	cm	0	1	2	3	4
LV end-diastolic diameter, mm						
54	137	≤46.8	46.9-47.9	48.0-50.0	50.1-52.1	>52.1
55	140	≤47.3	47.4-48.3	48.4-50.4	50.5-52.6	>52.6
56	142	≤47.7	47.8-48.7	48.8-50.9	51.0-53.0	>53.0
57	145	≤48.1	48.2-49.2	49.3-51.4	51.5-53.5	>53.5
58	147	≤48.5	48.6-49.6	49.7-51.8	51.9-54.0	>54.0
59	150	≤49.0	49.1-50.0	50.1-52.2	52.3-54.4	>54.4
60	152	≤49.4	49.5-50.4	50.5-52.7	52.8-54.9	>54.9
61	155	≤49.8	49.9-50.8	50.9-53.1	53.2-55.3	>55.3
62	157	≤50.2	50.3-51.2	51.3-53.5	53.6-55.8	>55.8
63	160	≤50.6	50.7-51.7	51.8-54.0	54.1-56.2	>56.3
64	163	≤51.0	51.1-52.1	52.2-54.4	54.5-56.7	>56.7
65	165	≤51.4	51.5-52.5	52.6-54.8	54.9-57.1	>57.1
66	168	≤51.8	51.9-52.9	53.0-55.2	55.3-57.5	>57.5
67	170	≤52.1	52.2-53.3	53.4-55.6	55.7-58.0	>58.0
68	173	≤52.5	52.6-53.6	53.7-56.1	56.2-58.4	>58.4
69	175	≤52.9	53.0-54.0	54.1-56.5	56.6-58.8	>58.8
70	178	≤53.3	53.4-54.4	54.5-56.9	57.0-59.2	>59.2
71	180	≤53.7	53.8-54.8	54.9-57.3	57.4-59.7	>59.7
72	183	≤54.0	54.1-55.2	55.3-57.7	57.8-60.1	>60.1

Height		Category				
in	cm	0	1	2	3	4
LV end-systolic diameter, mm						
54	137	29.9	30.0-30.6	30.7-32.3	32.4-33.9	>33.9
55	140	30.3	30.4-30.9	31.0-32.7	32.8-34.3	>34.3
56	142	30.7	30.8-31.3	31.4-33.1	33.2-34.7	>34.7
57	145	31.1	31.2-31.7	31.8-33.5	33.6-35.1	>35.1
58	147	31.4	31.5-32.1	32.2-33.9	34.0-35.6	>35.6
59	150	31.8	31.9-32.4	32.5-34.3	34.4-36.0	>36.0
60	152	32.2	32.3-32.8	32.9-34.7	34.8-36.4	>36.4
61	155	32.5	32.6-33.2	33.3-35.1	35.2-36.8	>36.8
62	157	32.9	33.0-33.5	33.6-35.5	35.6-37.2	>37.2
63	160	33.2	33.3-33.9	34.0-35.9	36.0-37.6	>37.6
64	163	33.6	33.7-34.3	34.4-36.2	36.3-38.0	>38.0
65	165	33.9	34.0-34.6	34.7-36.6	36.7-38.4	>38.4
66	168	34.3	34.4-35.0	35.1-37.0	37.1-38.8	>38.8
67	170	34.6	34.7-35.3	35.4-37.4	37.5-39.2	>39.2
68	173	35.0	35.1-35.7	35.8-37.8	37.9-39.6	>39.6
69	175	35.3	35.4-36.1	36.2-38.1	38.2-40.0	>40.0
70	178	35.7	35.8-36.4	36.5-38.5	38.6-40.4	>40.4
71	180	36.0	36.1-36.8	36.9-38.9	39.0-40.8	>40.8
72	183	36.4	36.5-37.1	37.2-39.2	39.3-41.2	>41.2

Table 3A. Continued (Table view)

Height		Category				
in	cm	0	1	2	3	4
LV end-diastolic diameter, mm						

Height		Category				
in	cm	0	1	2	3	4
60	152	≤52.1	52.2-54.2	54.3-56.6	56.7-60.1	>60.1
61	155	≤52.6	52.7-54.7	54.8-57.1	57.2-60.7	>60.7
62	157	≤53.0	53.1-55.2	55.3-57.7	57.8-61.2	>61.2
63	160	≤53.5	53.6-55.8	55.9-58.2	58.3-61.8	>61.8
64	163	≤54.0	54.1-56.3	56.4-58.7	58.8-62.3	>62.3
65	165	≤54.5	54.6-56.8	56.9-59.3	59.4-62.9	>62.9
66	168	≤55.0	55.1-57.3	57.4-59.8	59.9-63.5	>63.5
67	170	≤55.5	55.6-57.8	57.9-60.3	60.4-64.0	>64.0
68	173	≤55.9	56.0-58.2	58.3-60.8	60.9-64.5	>64.5
69	175	≤56.4	56.5-58.7	58.8-61.3	61.4-65.1	>65.1
70	178	≤56.9	57.0-59.2	59.3-61.8	61.9-65.6	>65.6
71	180	≤57.3	57.4-59.7	59.8-62.3	62.4-66.2	>66.2
72	183	≤57.8	57.9-60.2	60.3-62.8	62.9-66.7	>66.7
73	185	≤58.2	58.3-60.7	60.8-63.3	63.4-67.2	>67.2
74	188	≤58.7	58.8-61.1	61.2-63.8	63.9-67.7	>67.7
75	190	≤59.2	59.3-61.6	61.7-64.3	64.4-68.3	>68.3
76	193	≤59.6	59.7-62.1	62.2-64.8	64.9-68.8	>68.8
77	196	≤60.0	60.1-62.5	62.6-65.3	65.4-69.3	>69.3
78	198	≤60.5	60.6-63.0	63.1-65.8	65.9-69.8	>69.8
LV end-systolic diameter, mm						
60	152	35.3	35.4-36.3.	36.4-39.4	39.5-42.0	>42.0
61	155	35.7	35.8-36.7	36.8-39.8	39.9-42.4	>42.4
62	157	36.0	36.1-37.0	37.1-40.2	40.3-42.8	>42.8
63	160	36.4	36.5-37.4	37.5-40.6	40.7-43.2	>43.2
64	163	36.7	36.8-37.7	37.8-41.0	41.1-43.6	>43.6

Height		Category				
in	cm	0	1	2	3	4
65	165	37.1	37.2-38.1	38.2-41.4	41.5-44.0	>44.1
66	168	37.4	37.5-38.4	38.5-41.8	41.9-44.4	>44.4
67	170	37.8	37.9-38.8	38.9-42.1	42.2-44.8	>44.9
68	173	38.1	38.2-39.1	39.2-42.5	42.6-45.2	>45.2
69	175	38.4	38.5-39.5	39.6-42.9	43.0-45.6	>45.6
70	178	38.8	38.9-39.8	39.9-43.3	43.4-46.0	>46.0
71	180	39.1	39.2-40.2	40.3-43.6	43.7-46.4	>46.4
72	183	39.4	39.5-40.5	40.6-44.0	44.1-46.8	>46.8
73	185	39.8	39.9-40.8	40.9-44.4	44.5-47.2	>47.2
74	188	40.1	40.2-41.2	41.3-44.7	44.8-47.6	>47.6
75	190	40.4	40.5-41.5	41.6-45.1	45.2-48.0	>48.0
76	193	40.7	40.8-41.8	41.9-45.5	45.6-48.4	>48.5
77	196	41.1	41.2-42.2	42.3-45.8	45.9-48.7	>48.7
78	198	41.4	41.5-42.5	42.6-46.2	46.3-49.1	>49.1

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Sections

List of Illustrations

1. Figure 1

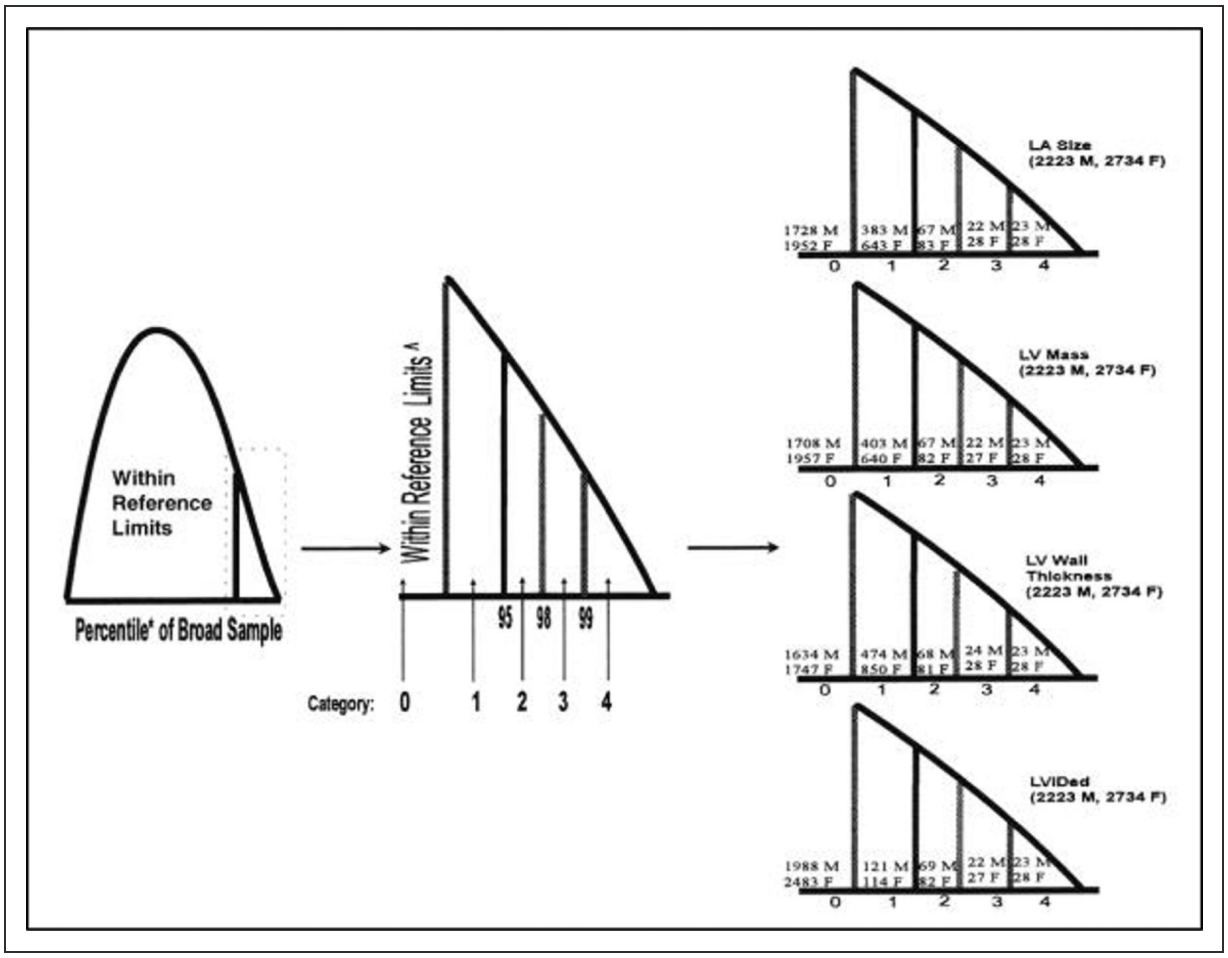

Figure 1. Distribution and categorization of echocardiographic variables in the broad sample of 4957 subjects based on deviation from height- and sex-specific reference limits. Categories were based on relations of 95th, 98th, and 99th percentile values of observed/predicted value for given height and sex in broad sample to reference limits. Reference limits were based on 95th percentile values in a healthy reference sample. Values for 22% of men and 29% of women exceeded reference limits for LA dimensions; values for 17% of men and 24% of women exceeded reference limits but were <95th percentile for broad sample. About 23% of men and 28% of women in broad sample exceeded reference limits for LV mass; LV mass values for 18% of men and 23% of women exceeded reference limits (height- and sex-specific) but were within 95th percentile of values for broad sample. Values for 26% of men and 36% of women exceeded reference limits for LV wall thickness; values for 21% of

men and 31% of women were intermediate between reference limits and 95th percentile of values for broad sample. Values for 11% of men and 9% of women exceeded reference limits for LV end-diastolic internal dimensions (LVIDed); values for 5% of men and 4% of women were between reference limits and 95th percentile for broad sample. For LV end-systolic internal dimensions, distribution of male subjects was 2058, 53, 66, 23, and 23 for categories 0, 1, 2, 3, and 4, respectively; distribution of female subjects was 2545, 51, 83, 27, and 28 for categories 0, 1, 2, 3, and 4, respectively (not shown).

AF	=	atrial fibrillation
FHS	=	Framingham Heart Study
LA	=	left atrial
LV	=	left ventricular

Table 1. Clinical and Echocardiographic Characteristics of Study Samples

	Reference Sample		Broad Sample	
	Men (n=387)	Women (n=712)	Men (n=2223)	Women (n=2734
Clinical features				
Age, y (range)	35.7±6.1 (20-45)	36.1±5.5 (21-45)	49.8±13.9 (18-90)	51.6±15 (17-90)
Height, m	1.77±0.06	1.63±0.06	1.75±0.07	1.60 ±0.
Weight, kg	74.0±6.9	58.9±6.1	81.1±12.0	64.1±12
Body surface area, m^2	1.91±0.11	1.63±0.10	1.96±0.16	1.66±0.
Systolic blood pressure, mm Hg	116.9±9.3	109.6±10.3	128.8 ±17.2	125.0±2
Diastolic blood pressure, mm Hg	74.7±7.0	71.0±7.5	80.3±9.3	75.6±9.6
Coronary disease, %	…	…	8.3	5.3
Hypertension, %	…	…	35.0	31.6
Valve disease, %	…	…	2.8	3.1
Heart failure, %	…	…	0.8	1.0
AF, %	…	…	2.2	1.2
Diabetes mellitus, %	…	…	4.6	3.3
Echocardiographic features				

	Reference Sample		Broad Sample	
LV mass, g	173.9±39.7	114.5±23.5	202.1±61.8	135.9±4
Ventricular wall thickness, mm	Men (n=387)	Women (n=712)	Men (n=2223)	Women (n=2734
	18.1±2.0	15.5±1.5	19.8±3.0	17.4±3.(
LA dimension, mm	37.5±3.6	32.9±3.2	40.4±5.1	36.0±5.3
LV end-diastolic dimension, mm	50.9±3.5	46.1±3.1	51.1±4.4	45.7±4.(

Plus-minus values indicate mean±SD.

Table 2. Cut Points for Categorization of Echocardiographic LA Size, LV Mass, Wall Thickness, and LV Diameter in Women

Height		Category				
in	cm	0	1	2	3	4
Left atrium, mm						
54	137	≤36.6	36.7-43.0	43.1-47.2	47.3-49.6	>49.6
55	140	≤36.8	36.9-43.3	43.4-47.5	47.6-49.9	>49.9
56	142	≤37.0	37.1-43.5	43.6-47.7	47.8-50.2	>50.2
57	145	≤37.2	37.3-43.7	43.8-48.0	48.1-50.4	>50.4
58	147	≤37.4	37.5-44.0	44.1-48.2	48.2-50.7	>50.7
59	150	≤37.6	37.7-44.2	44.3-48.5	48.6-51.0	>51.0
60	152	≤37.8	37.9-44.4	44.5-48.8	48.9-51.2	>51.2
61	155	≤38.0	38.1-44.7	44.8-49.0	49.1-51.5	>51.5
62	157	≤38.1	38.2-44.9	45.0-49.2	49.3-51.8	>51.8
63	160	≤38.3	38.4-45.1	45.2-49.5	49.6-52.0	>52.0
64	163	≤38.5	38.6-45.3	45.4-49.7	49.8-52.3	>52.3
65	165	≤38.7	38.8-45.5	45.6-50.0	50.1-52.5	>52.5
66	168	≤38.9	39.0-45.8	45.9-50.2	50.3-52.8	>52.8
67	170	≤39.1	39.2-46.0	46.1-50.4	50.5-53.0	>53.0
68	173	≤39.2	39.3-46.2	46.3-50.7	50.8-53.2	>53.2
69	175	≤39.4	39.5-46.4	46.5-50.9	51.0-53.5	>53.5
70	178	≤39.6	39.7-46.6	46.7-51.1	51.2-53.7	>53.7
71	180	≤39.8	39.9-46.8	46.9-51.3	51.4-53.9	>53.9
72	183	≤39.9	40.0-47.0	47.1-51.6	51.7-54.2	>54.2
LV mass, g						
54	137	≤116	117-159	160-189	190-233	>233
55	140	≤119	120-163	164-194	195-240	>240

Height		Category				
in	cm	0	1	2	3	4
56	142	≤123	124-168	169-200	201-247	>247
57	145	≤126	127-173	174-205	206-254	>254
58	147	≤130	131-178	179-211	212-261	>261
59	150	≤133	134-183	184-217	218-268	>268
60	152	≤137	138-188	189-223	224-275	>275
61	155	≤141	142-193	194-229	230-282	>282
62	157	≤144	145-198	199-235	236-290	>290
63	160	≤148	149-203	204-241	242-297	>297
64	163	≤152	153-208	209-247	248-305	>305
65	165	≤155	156-213	214-253	254-312	>312
66	168	≤159	160-218	219-259	260-320	>320
67	170	≤163	164-223	224-266	267-328	>328
68	173	≤167	168-229	230-272	273-336	>336
69	175	≤171	172-234	235-278	279-344	>344
70	178	≤175	176-240	241-285	286-352	>353
71	180	≤179	180-245	246-291	292-360	>360
72	183	≤183	184-251	252-298	299-368	>368
LV wall thickness, mm						
54	137	≤16.9	17.0-21.4	21.5-24.7	24.8-27.4	>27.4
55	140	≤17.0	17.1-21.6	21.7-24.9	25.0-27.6	>27.6
56	142	≤17.1	17.2-21.8	21.9-25.1	25.2-27.8	>27.8
57	145	≤17.2	17.3-21.9	22.0-25.3	25.4-28.0	>28.0
58	147	≤17.4	17.5-22.1	22.2-25.5	25.6-28.2	>28.2
59	150	≤17.5	17.6-22.2	22.3-25.6	25.7-28.4	>28.4
60	152	≤17.6	17.7-22.4	22.5-25.8	25.9-28.6	>28.6

Height		Category				
in	cm	0	1	2	3	4
61	155	≤17.7	17.8-22.5	22.6-26.0	26.1-28.8	>28.8
62	157	≤17.8	17.9-22.7	22.8-26.2	26.3-29.0	>29.0
63	160	≤18.0	18.1-22.8	22.9-26.3	26.4-29.2	>29.2
64	163	≤18.1	18.2-23.0	23.1-26.5	26.6-29.4	>29.4
65	165	≤18.2	18.3-23.1	23.2-26.7	26.8-29.6	>29.6
66	168	≤18.3	18.4-23.3	23.4-26.9	27.0-29.8	>29.8
67	170	≤18.4	18.5-23.4	23.5-27.0	27.1-29.9	>29.9
68	173	≤18.5	18.6-23.6	23.7-27.2	27.3-30.1	>30.1
69	175	≤18.6	18.7-23.7	23.8-27.4	27.5-30.3	>30.3
70	178	≤18.8	18.9-23.9	24.0-27.5	27.6-30.5	>30.5
71	180	≤18.9	19.0-24.0	24.1-27.7	27.8-30.7	>30.7
72	183	≤19.0	19.1-24.1	24.2-27.8	27.9-30.8	>30.8

RS indicates reference sample; BS, broad sample. Categories are 0, value≤95th percentile RS; 1, 95th percentile RS<value≤95th percentile BS; 2, 95th percentile BS<value≤98th percentile BS; 3, 98th percentile BS<value≤99th percentile BS; and 4, value>99th percentile BS. For women in category 0, the RS 95th percentile values correspond to the following percentiles of the broad sample: For LA size, 71%; for LV mass 72%, for LV wall thickness 64%, for LV internal diameter end diastole 91%, for LV diameter end systole 93%.

Table 3. Cut Points for Categorization of Echocardiographic LA Size, LV Mass, Wall Thickness, and LV Diameter in Men

Height		Category				
in	cm	0	1	2	3	4
Left atrium, mm						
60	152	≤42.4	42.5-47.7	47.8-51.7	51.8-53.9	>53.9
61	155	≤42.5	42.6-47.9	48.0-51.9	52.0-54.1	>54.1
62	157	≤42.7	42.8-48.1	48.2-52.1	52.2-54.3	>54.3
63	160	≤42.8	42.9-48.3	48.4-52.3	52.4-54.5	>54.5
64	163	≤43.0	43.1-48.4	48.5-52.5	52.6-54.7	>54.7
65	165	≤43.1	43.2-48.6	48.7-52.6	52.7-54.9	>54.9
66	168	≤43.3	43.4-48.8	48.9-52.8	52.9-55.1	>55.1
67	170	≤43.4	43.5-48.9	49.0-53.0	53.1-55.3	>55.3
68	173	≤43.6	43.7-49.1	49.2-53.2	53.3-55.5	>55.5
69	175	≤43.7	43.8-49.3	49.4-53.4	53.5-55.6	>55.6
70	178	≤43.9	44.0-49.4	49.5-53.5	53.6-55.8	>55.8
71	180	≤44.0	44.1-49.6	49.7-53.7	53.8-56.0	>56.0
72	183	≤44.2	44.3-49.7	49.8-53.9	54.0-56.2	>56.2
73	185	≤44.3	44.4-49.9	50.0-54.0	54.1-56.4	>56.4
74	188	≤44.4	44.5-50.0	50.1-54.2	54.3-56.5	>56.5
75	190	≤44.6	44.7-50.2	50.3-54.4	54.5-56.7	>56.7
76	193	≤44.7	44.8-50.3	50.4-54.5	54.6-56.9	>56.9
77	196	≤44.8	44.9-50.5	50.6-54.7	54.8-57.0	>57.0
78	198	≤45.0	45.1-50.6	50.7-54.8	54.9-57.2	>57.2
LV mass, g						
60	152	≤170	171-221	222-264	265-295	>295
61	155	≤175	176-228	229-272	273-305	>305

Height		Category				
in	cm	0	1	2	3	4
62	157	≤181	182-235	236-281	282-314	>314
63	160	≤186	187-242	243-289	290-324	>324
64	163	≤192	193-249	250-298	299-334	>334
65	165	≤198	199-257	258-307	308-344	>344
66	168	≤204	205-264	265-316	317-354	>354
67	170	≤210	211-272	273-325	326-364	>364
68	173	≤216	217-280	281-335	336-375	>375
69	175	≤222	223-288	289-344	345-385	>385
70	178	≤228	229-296	297-354	355-396	>396
71	180	≤234	235-304	305-363	364-407	>407
72	183	≤240	241-312	313-373	374-418	>418
73	185	≤247	248-320	321-383	384-429	>429
74	188	≤253	254-329	330-393	394-440	>440
75	190	≤260	261-337	338-403	404-451	>451
76	193	≤266	267-346	347-413	414-463	>463
77	196	≤273	274-355	356-424	425-475	>475
78	198	≤280	281-363	364-434	435-486	>486
LV wall thickness, mm						
60	152	≤18.8	18.9-22.9	23.0-25.2	25.3-27.0	>27.0
61	155	≤19.1	19.2-23.2	23.3-25.6	25.7-27.4	>27.4
62	157	≤19.3	19.4-23.5	23.6-25.9	26.0-27.8	>27.8
63	160	≤19.6	19.7-23.8	23.9-26.3	26.4-28.1	>28.1
64	163	≤19.8	19.9-24.1	24.2-26.6	26.7-28.5	>28.5
65	165	≤20.1	20.2-24.4	24.5-27.0	27.1-28.9	>28.9
66	168	≤20.4	20.5-24.8	24.9-27.3	27.4-29.3	>29.3

Height		Category				
in	cm	0	1	2	3	4
67	170	≤20.6	20.7-25.1	25.2-27.7	27.8-29.6	>29.6
68	173	≤20.9	21.0-25.4	25.5-28.0	28.1-30.0	>30.0
69	175	≤21.1	21.2-25.7	25.8-28.3	28.4-30.4	>30.4
70	178	≤21.4	21.5-26.0	26.1-28.7	28.8-30.7	>30.7
71	180	≤21.6	21.7-26.3	26.4-29.0	29.1-31.1	>31.1
72	183	≤21.9	22.0-26.6	26.7-29.4	29.5-31.5	>31.5
73	185	≤22.2	22.3-26.9	27.0-29.7	29.8-31.8	>31.8
74	188	≤22.4	22.5-27.2	27.3-30.1	30.2-32.2	>32.2
75	190	≤22.7	22.8-27.5	27.6-30.4	30.5-32.6	>32.6
76	193	≤22.9	23.0-27.8	27.9-30.7	30.8-32.9	>32.9
77	196	≤23.2	23.3-28.2	28.3-31.1	31.2-33.3	>33.3
78	198	≤23.4	23.5-28.5	28.6-31.4	31.5-33.6	>33.6

Abbreviations and categories as in Table 2. For men in category 0, the RS 95th percentile values correspond to the following percentiles of the broad sample: For LA size, 78%; for LV mass, 77%; for LV wall thickness, 74%; for LV internal end-diastolic diameter, 89%; and for LV end-systolc internal diameter, 93%.

Table 4. Relations of Categories of LV Mass to Incidence of New Cardiovascular Disease Events: Results of Cox Proportional-Hazards Models

Proposed Category	Men			Women	
	No. in Category	No. of Events on Follow-up	Rate per 1000 Person-Years[1]	No. in Category	No. of Events on Follow-up
Value ≤95 percentile reference sample (category 0)	1707	189	15.1	1955	107
95 percentile reference sample<value≤95 percentile broad sample (category 1)	403	89	32.3	640	96
95 percentile broad sample<value≤98 percentile broad sample (category 2)	67	29	71.1	82	23

Proposed Category	Men			Women	
	No. in Category	No. of Events on Follow-up	Rate per 1000 Person-Years[1]	No. in Category	No. of Events on Follow-up
98 percentile broad sample<value≤99 percentile broad sample (category 3)	22	10	92.7	27	8
Value >99 percentile broad sample (category 4)	23	19	181.7	28	17

[1] Based on 587 new cardiovascular events among 4954 subjects in the broad sample. Cardiovascular events include coronary disease (angina, myocardial infarction, coronary insufficiency, and sudden cardiac death), heart failure, stroke, transient ischemic attacks, and intermittent claudication.

[2] Hazards ratio adjusted for age, sex, hypertension, diastolic blood pressure, pulse pressure, smoking, total cholesterol/HDL cholesterol, diabetes mellitus, and previous cardiovascular disease. These proportional-hazards analyses are based on 555 subjects with new cardiovascular events among 4775 subjects with complete information regarding covariates.

Table 5. Relations of Categories of LV Wall Thickness to Incidence of New Cardiovascular Disease Events: Results of Cox Proportional-Hazards Models

Proposed Category	Men			Women	
	No. in Category	No. of Events on Follow-up	Rate per 1000 Person-Years[1]	No. in Category	No. of Events on Follow-up
Value ≤95 percentile reference sample (category 0)	1633	184	15.4	1745	69
95 percentile reference sample<value≤95 percentile broad sample (category 1)	474	101	31.2	850	137
95 percentile broad sample<value≤98 percentile broad sample (category 2)	68	22	49.1	81	20

Proposed Category	Men			Women	
	No. in Category	No. of Events on Follow-up	Rate per 1000 Person-Years[1]	No. in Category	No. of Events on Follow-up
98 percentile broad sample<value≤99 percentile broad sample (category 3)	24	14	109.4	28	10
Value >99 percentile broad sample (category 4)	23	15	138.7	28	15

[1] Based on 587 new cardiovascular events in 4954 subjects of the broad sample. Cardiovascular events include coronary disease (angina, myocardial infarction, coronary insufficiency, and sudden cardiac death), heart failure, stroke, transient ischemic attacks, and intermittent claudication.

[2] Hazards ratio adjusted for age, sex, hypertension, diastolic blood pressure, pulse pressure, smoking, total cholesterol/HDL-cholesterol, diabetes mellitus, and previous cardiovascular disease. These proportional-hazards analyses are based on 555 subjects with new cardiovascular events among 4775 subjects with complete information regarding covariates.

Table 6. Relations of Categories of LA Dimension to Incidence of AF: Results of Cox Proportional-Hazards Models

Proposed Category	Men			Women	
	No. in Category	No. of Events on Follow-up	Rate per 1000 Person-Years[1]	No. in Category	No. of Events on Follow-up
Value ≤95 percentile reference sample (category 0)	1720	49	3.7	1947	26
95 percentile reference sample<value≤95 percentile broad sample (category 1)	371	23	8.4	638	21
95 percentile broad sample<value≤98 percentile broad sample (category 2)	59	11	25.9	78	15
98 percentile broad sample<value≤99 percentile broad sample (category 3)	17	3	30.1	22	7

Proposed Category	Men			Women	
	No. in Category	No. of Events on Follow-up	Rate per 1000 Person-Years[1]	No. in Category	No. of Events on Follow-up
Value >99 percentile broad sample (category 4)	7	4	91.9	13	7

[1] Based on 166 new onset AF events in 4872 subjects in the broad sample who were free of AF at baseline.

[2] Hazard ratio adjusting for age, sex, hypertension, valve disease, ECG LV hypertrophy, diabetes mellitus, and previous cardiovascular disease. These proportional-hazards analyses are based on 164 subjects with new-onset AF among 4851 subjects free of AF at baseline and who had complete information regarding covariates. For LA size hazard ratios, categories were combined because of small numbers.

Table 2A. Continued

Height		Category				
in	cm	0	1	2	3	4
LV end-diastolic diameter, mm						
54	137	≤46.8	46.9-47.9	48.0-50.0	50.1-52.1	>52.1
55	140	≤47.3	47.4-48.3	48.4-50.4	50.5-52.6	>52.6
56	142	≤47.7	47.8-48.7	48.8-50.9	51.0-53.0	>53.0
57	145	≤48.1	48.2-49.2	49.3-51.4	51.5-53.5	>53.5
58	147	≤48.5	48.6-49.6	49.7-51.8	51.9-54.0	>54.0
59	150	≤49.0	49.1-50.0	50.1-52.2	52.3-54.4	>54.4
60	152	≤49.4	49.5-50.4	50.5-52.7	52.8-54.9	>54.9
61	155	≤49.8	49.9-50.8	50.9-53.1	53.2-55.3	>55.3
62	157	≤50.2	50.3-51.2	51.3-53.5	53.6-55.8	>55.8
63	160	≤50.6	50.7-51.7	51.8-54.0	54.1-56.2	>56.3
64	163	≤51.0	51.1-52.1	52.2-54.4	54.5-56.7	>56.7
65	165	≤51.4	51.5-52.5	52.6-54.8	54.9-57.1	>57.1
66	168	≤51.8	51.9-52.9	53.0-55.2	55.3-57.5	>57.5
67	170	≤52.1	52.2-53.3	53.4-55.6	55.7-58.0	>58.0
68	173	≤52.5	52.6-53.6	53.7-56.1	56.2-58.4	>58.4
69	175	≤52.9	53.0-54.0	54.1-56.5	56.6-58.8	>58.8
70	178	≤53.3	53.4-54.4	54.5-56.9	57.0-59.2	>59.2
71	180	≤53.7	53.8-54.8	54.9-57.3	57.4-59.7	>59.7
72	183	≤54.0	54.1-55.2	55.3-57.7	57.8-60.1	>60.1
LV end-systolic diameter, mm						
54	137	29.9	30.0-30.6	30.7-32.3	32.4-33.9	>33.9
55	140	30.3	30.4-30.9	31.0-32.7	32.8-34.3	>34.3
56	142	30.7	30.8-31.3	31.4-33.1	33.2-34.7	>34.7

Height		Category				
in	cm	0	1	2	3	4
57	145	31.1	31.2-31.7	31.8-33.5	33.6-35.1	>35.1
58	147	31.4	31.5-32.1	32.2-33.9	34.0-35.6	>35.6
59	150	31.8	31.9-32.4	32.5-34.3	34.4-36.0	>36.0
60	152	32.2	32.3-32.8	32.9-34.7	34.8-36.4	>36.4
61	155	32.5	32.6-33.2	33.3-35.1	35.2-36.8	>36.8
62	157	32.9	33.0-33.5	33.6-35.5	35.6-37.2	>37.2
63	160	33.2	33.3-33.9	34.0-35.9	36.0-37.6	>37.6
64	163	33.6	33.7-34.3	34.4-36.2	36.3-38.0	>38.0
65	165	33.9	34.0-34.6	34.7-36.6	36.7-38.4	>38.4
66	168	34.3	34.4-35.0	35.1-37.0	37.1-38.8	>38.8
67	170	34.6	34.7-35.3	35.4-37.4	37.5-39.2	>39.2
68	173	35.0	35.1-35.7	35.8-37.8	37.9-39.6	>39.6
69	175	35.3	35.4-36.1	36.2-38.1	38.2-40.0	>40.0
70	178	35.7	35.8-36.4	36.5-38.5	38.6-40.4	>40.4
71	180	36.0	36.1-36.8	36.9-38.9	39.0-40.8	>40.8
72	183	36.4	36.5-37.1	37.2-39.2	39.3-41.2	>41.2

Table 3A. Continued

Height		Category				
in	cm	0	1	2	3	4
LV end-diastolic diameter, mm						
60	152	≤52.1	52.2-54.2	54.3-56.6	56.7-60.1	>60.1
61	155	≤52.6	52.7-54.7	54.8-57.1	57.2-60.7	>60.7
62	157	≤53.0	53.1-55.2	55.3-57.7	57.8-61.2	>61.2
63	160	≤53.5	53.6-55.8	55.9-58.2	58.3-61.8	>61.8
64	163	≤54.0	54.1-56.3	56.4-58.7	58.8-62.3	>62.3
65	165	≤54.5	54.6-56.8	56.9-59.3	59.4-62.9	>62.9
66	168	≤55.0	55.1-57.3	57.4-59.8	59.9-63.5	>63.5
67	170	≤55.5	55.6-57.8	57.9-60.3	60.4-64.0	>64.0
68	173	≤55.9	56.0-58.2	58.3-60.8	60.9-64.5	>64.5
69	175	≤56.4	56.5-58.7	58.8-61.3	61.4-65.1	>65.1
70	178	≤56.9	57.0-59.2	59.3-61.8	61.9-65.6	>65.6
71	180	≤57.3	57.4-59.7	59.8-62.3	62.4-66.2	>66.2
72	183	≤57.8	57.9-60.2	60.3-62.8	62.9-66.7	>66.7
73	185	≤58.2	58.3-60.7	60.8-63.3	63.4-67.2	>67.2
74	188	≤58.7	58.8-61.1	61.2-63.8	63.9-67.7	>67.7
75	190	≤59.2	59.3-61.6	61.7-64.3	64.4-68.3	>68.3
76	193	≤59.6	59.7-62.1	62.2-64.8	64.9-68.8	>68.8
77	196	≤60.0	60.1-62.5	62.6-65.3	65.4-69.3	>69.3
78	198	≤60.5	60.6-63.0	63.1-65.8	65.9-69.8	>69.8
LV end-systolic diameter, mm						
60	152	35.3	35.4-36.3.	36.4-39.4	39.5-42.0	>42.0
61	155	35.7	35.8-36.7	36.8-39.8	39.9-42.4	>42.4
62	157	36.0	36.1-37.0	37.1-40.2	40.3-42.8	>42.8

Height		Category				
in	cm	0	1	2	3	4
63	160	36.4	36.5-37.4	37.5-40.6	40.7-43.2	>43.2
64	163	36.7	36.8-37.7	37.8-41.0	41.1-43.6	>43.6
65	165	37.1	37.2-38.1	38.2-41.4	41.5-44.0	>44.1
66	168	37.4	37.5-38.4	38.5-41.8	41.9-44.4	>44.4
67	170	37.8	37.9-38.8	38.9-42.1	42.2-44.8	>44.9
68	173	38.1	38.2-39.1	39.2-42.5	42.6-45.2	>45.2
69	175	38.4	38.5-39.5	39.6-42.9	43.0-45.6	>45.6
70	178	38.8	38.9-39.8	39.9-43.3	43.4-46.0	>46.0
71	180	39.1	39.2-40.2	40.3-43.6	43.7-46.4	>46.4
72	183	39.4	39.5-40.5	40.6-44.0	44.1-46.8	>46.8
73	185	39.8	39.9-40.8	40.9-44.4	44.5-47.2	>47.2
74	188	40.1	40.2-41.2	41.3-44.7	44.8-47.6	>47.6
75	190	40.4	40.5-41.5	41.6-45.1	45.2-48.0	>48.0
76	193	40.7	40.8-41.8	41.9-45.5	45.6-48.4	>48.5
77	196	41.1	41.2-42.2	42.3-45.8	45.9-48.7	>48.7
78	198	41.4	41.5-42.5	42.6-46.2	46.3-49.1	>49.1