Left Heart Chamber Quantification in Obese Patients: How Does Larger Body Size Affect Echocardiographic Measurements?

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Background: Accurate normalization of cardiac chamber size in the obese population is a challenge. The aim of this study was to develop and assess the performance of allometric models for scaling left heart chamber sizes, including left atrial anteroposterior dimension (LAD_{AP}), left atrial volume (LAV), left ventricular end-diastolic volume (LVEDV), and left ventricular end-diastolic dimension (LVEDD), in an obese population.

Methods: To normalize left heart chamber measurements (Y: LAD_{AP}, LAV, LVEDV, and LVEDD) to body size variables (X: height, weight, body mass index, and body surface area), both isometric models ($Y = aX$) and optimal allometric models ($Y = aX^b$) were tested. A logarithmic transformation ($\mathrm{Ln}Y = \mathrm{Ln}a + b \times \mathrm{Ln}X$) and ordinary least squares linear regression was performed to estimate the allometric scaling exponents. Pearson's correlation coefficients were obtained for measured and indexed left chamber sizes using both isometric and allometric models against body size variables. Gender-specific allometric models were also derived as sensitivity analyses.

Results: A total of 717 healthy obese subjects were included in the analysis. The mean body surface area and body mass index were 2.3 m^2 and 42.2 kg/m^2, respectively. Measured LAD_{AP}, LAV, LVEDD, and LVEDV were positively correlated with body size variables. Allometric scaling of LAD_{AP}, LAV, LVEDD, and LVEDV showed stronger correlation with measured chamber sizes compared with isometric scaling. The overcorrection caused by isometric scaling significantly improved after allometric models were used. The sensitivity analysis showed no significant differences in scaling exponents between men and women.

Conclusions: Normalizing cardiac chamber measurements with allometric scaling methods is superior to the use of isometric methods in removing the effects of body size and minimizing overcorrection in the obese population. Using an allometric model with height provides the most accurate results. (J Am Soc Echocardiogr 2014;■:■-■.)

Keywords: Echocardiography, Left heart, Obesity, Isometric scaling, Allometric scaling

Obesity is epidemic in the United States, affecting >60 million adults, among whom 5 million to 10 million individuals are morbidly obese (body mass index [BMI] $\geq$ 40 kg/m^2).[1] It is known to be associated with the development of various cardiac conditions, including hypertension, heart failure, and arrhythmias. Echocardiography plays a major role in quantifying left heart chamber dimensions, which are thought to increase proportionally with increasing body size.[2] To accurately differentiate pathologic cardiac conditions from normal obesity-related increases in cardiac dimensions, it is important to normalize chamber size with an appropriate body size variable. However, the accurate scaling of left heart chamber size in the obese population remains challenging.

The American Society of Echocardiography suggests an isometric scaling method to normalize the measured cardiac chamber sizes.[3] This method is based on the assumption of a linear relationship between the cardiac chamber size variable (Y, the dependent variable) and the body size variable (X, the independent variable) such as body surface area (BSA) or height, resulting in $Y = aX$, where a is a scaling factor.[4] However, previous studies have suggested that the relationship between cardiac dimensions and body size may be exponential rather than linear.[5,6] An allometric model, on the other hand, would allow for a nonlinear relationship between the cardiac chamber size variable (Y) and the body size variable (X). This would assume the form $Y = aX^b$, where b is a scaling exponent. An allometric approach using an optimal scaling exponent for normalization could effectively remove the effect of body size on cardiac chamber sizes.[7,8]

A few studies have shown the value of allometric scaling for cardiac dimensions. Neilan *et al.*[9] showed that an allometric model using body

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Abbreviations

BMI = Body mass index

BSA = Body surface area

LAD_{AP} = Left atrial anteroposterior dimension

LAV = Left atrial volume

LVEDD = Left ventricular end-diastolic dimension

LVEDV = Left ventricular end-diastolic volume

weight as the scaling variable would remove the effect of body size and yielded more accurate results in normal middle-aged adults. Further supporting the use of an allometric model, Yao *et al.*[10] demonstrated, in an obese population (n = 266), that applying the same allometric model using the variable of height provided more consistent results in scaling left atrial anteroposterior dimension (LAD_{AP}). However, the use of allometric models has yet to be fully adopted, mainly because of their mathematical complexity and a lack of supportive evidence from larger studies.

In this study, we aimed to develop allometric models for scaling left heart chamber dimensions and to assess the performance of these models in a large obese population. We hypothesized that allometric models would be more accurate than conventional isometric models in normalizing left heart chamber sizes with body size variables in obese individuals.

METHODS

Study Population

A total of 717 obese (BMI ≥ 30 kg/m^2) adults >18 and <40 years of age with normal echocardiographic results obtained between 2010 and 2012 at Montefiore Medical Center (Bronx, NY) were included in the study. The catchment area of Montefiore Medical Center, with nearly 1,500 inpatient beds and approximately 50 primary care outpatient sites, represents one of the most diverse populations in the New York metropolitan area and in the nation. To ensure a healthy study population, adults with preexisting diagnoses of hypertension, valvular heart disease, myocardial infarction, cardiomyopathy, atrial arrhythmia, pericardial disease, or congenital heart disease, ascertained by International Classification of Diseases, Ninth Revision, codes from emergency room, outpatient, and inpatient visits were excluded. We also reviewed and assessed the electronic medical record of each patient to ensure that the subjects were free of the aforementioned cardiac conditions. The institutional review board approved this study.

Body Size Measurements and Echocardiographic Assessments

To calculate BMI, body weight (in kilograms) was divided by the square of height (in meters), while BSA was calculated using both the Du Bois and Du Bois formula (BSA [m^2] = 0.007184 × height [cm]$^{0.725}$ × weight [kg]$^{0.425}$) and the more recently used Haycock formula (0.024265 × height [cm]$^{0.3964}$ × weight [kg]$^{0.5378}$). The Haycock formula was shown to provide the best fit for most echocardiographic measurements among seven BSA formulas in infants and toddlers.[11]

Left heart chamber dimensions were calculated in accordance with the American Society of Echocardiography's chamber quantifications guidelines.[3] LAD_{AP} was measured from the parasternal long-axis view at the level of the aortic valve. A measurement was taken from the trailing edge of the posterior aortic root to the leading edge of the posterior left atrial wall. Left atrial volume (LAV) was measured using the biplane method of disks (modified Simpson's rule) using apical four-chamber and apical two-chamber views at ventricular end-systole (maximum left atrial size). Left ventricular end-diastolic dimension (LVEDD) measurements were made from the two-dimensional parasternal long-axis acoustic window at the level of the left ventricular minor axis, approximately at the level of the mitral valve leaflet tips. A linear measurement was taken at end-diastole (maximum left ventricular size) from the leading edge of the septal wall to the leading edge of the posterior wall. Left ventricular end-diastolic volume (LVEDV) was calculated using the biplane method of disks (modified Simpson's rule) in the apical four-chamber and apical two-chamber views at ventricular end-diastole. Papillary muscles were excluded from the cavity in the tracing.

Data Analysis and Statistics

To normalize left heart chamber measurements (including LAD_{AP}, LAV, LVEDD, and LVEDV) to body size, we tested both isometric and allometric models. In the isometric models, a proportional relationship between left chamber measurements (Y: LAD_{AP}, LAV, LVEDD, and LVEDV) and the body size variables (X: height, weight, Du Bois and Du Bois BSA, Haycock BSA, and BMI) was assumed, resulting in $Y = aX$. Hence, the indexed chamber sizes were equal to chamber measurements/body size (Y/X). In the allometric models, indexed left chamber measurements (Y: LAD_{AP}, LAV, LVEDD, and LVEDV) were obtained using each of the body size variables (X: height, weight, Du Bois and Du Bois BSA, Haycock BSA, and BMI) by applying the equation $Y = aX^b$. The indexed chamber sizes were equal to Y/X^b, where b is the scaling exponent.

In the allometric models, the scaling factor a and the scaling exponent b were determined using the body size and echocardiographic measurements in our patient population. A commonality of scaling exponents between men and women was assumed. A logarithmic transformation of the above equation was used: $\mathrm{Ln}Y = \mathrm{Ln}a + b \times \mathrm{Ln}X$. Ordinary least squares linear regression was then performed to estimate the allometric scaling (a) factors and scaling exponents (b). The homoscedasticity and normality of residual variance were tested using the Breusch-Pagan/Cook-Weisberg tests and the Shapiro-Wilk tests, respectively. The indexed left chamber measurements using the allometric models and scaling exponents are presented in Table 2. For LAD_{AP}, the scaling factors and scaling exponents derived by Neilan *et al.*[9] were also applied.

To evaluate the performance of indexing models, Pearson's correlation coefficients were obtained for measured and indexed left chamber sizes using both isometric and allometric models against each body size variable (Tables 3–6). The ratio of unindexed Y to indexed Y for any individual represents the degree of deviation of left chamber sizes from that expected on the basis of change in body size alone. Two essential criteria had to be met for the scaling model and body size variables for normalizing left heart chamber measurements to be accurate. First, the indexed echocardiographic value had to closely correlate with the measured value (ideally $r = 1.00$); second, the correlation of the indexed echocardiographic value with body size variables had to be removed (ideally $r = 0$; negative values indicate overcorrection).

We also examined gender-specific allometric models as our sensitivity analyses. The gender-specific scaling exponents were derived and graphically illustrated. The left heart chamber measurements