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Comparison of Echocardiographic Single- vs. Biplane Method in the Assessment of Left Atrial Volume and Validation by Real Time Three-Dimensional Echocardiography

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Abstract

Background—The American Society of Echocardiography (ASE) recommends to calculate LA biplane volume because of its greater accuracy and prognostic value over LA diameter. However, biplane methods are not always feasible. We sought to assess the correlation between the echocardiographic LA biplane and single-plane volume and their agreement in the classification of LA size when ASE cut-offs are applied.

Methods—We performed 2D-echocardiography in the participants of the population-based CABL (Cardiovascular Abnormalities and Brain Lesions) study. LA volume was calculated by biplane area-length and single-plane modified Simpson's methods, and validated against three-dimensional (3D) echocardiography.

Results—The study sample consisted of 527 participants (69.6±9.7 years, 61.9% women). Both single- and biplane LA volume correlated well with 3D-echocardiography ($r=0.93$; $p<0.001$). Correlation between the single-plane and biplane methods was excellent ($r=0.95$, $p<0.001$; intraclass correlation coefficient: 0.92, 95% confidence intervals [CI] 0.80-0.96). Categorical agreement between single- and biplane was modest ($k=0.51$, 95% CI 0.45-0.57, disagreement rate 26.0%), mainly because of overestimation by the single-plane method. The correction of the single-plane volume by a regression equation improved the agreement ($k=0.70$, 95% CI 0.64-0.76), but a misclassification remained in 14.0% of cases.

Conclusions—Single- and biplane LA volume measurements have strong correlations, but their agreement for categorical classification is suboptimal. Specific cut-off points should be developed for the single-plane method.

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Keywords

Echocardiography; Left atrium; Volume; single plane; biplane; three-dimensional

INTRODUCTION

Enlargement of the left atrium (LA) is an independent predictor of adverse cardiovascular outcomes,¹⁻⁵ and its prognostic value in a variety of cardiovascular diseases such as atrial fibrillation, myocardial infarction, dilated and hypertrophic cardiomyopathy is well documented.⁶⁻¹⁴ Antero-posterior (A-P) diameter of the LA, assessed by two-dimensional echocardiography, is the most widely used measure of LA size in epidemiological studies and in the clinical practice. However, the A-P diameter is inaccurate, as it relies on several geometrical assumptions and often results in an underestimation of the LA size when compared to LA volumes.¹⁵⁻¹⁷ Echocardiographic measures of LA volume rely on fewer geometrical assumptions than the A-P diameter,¹⁶ and have been validated against cinecomputed tomography, contrast ventriculography and magnetic resonance imaging.^{15,18-20} The American Society of Echocardiography (ASE) guidelines recommend to measure LA volume using either the biplane area-length formula or the biplane modified Simpson's rule, because of their high accuracy and their stronger prognostic value compared to linear LA dimension.^{21,22} However, the biplane planimetry of the LA is not always feasible as the apical two-chamber view sometimes provides suboptimal LA borders visualization.

The aim of our study was to compare a biplane method for LA volume measurement with a measurement obtained from a single-plane four-chamber view in a population-based cohort with a wide range of LA sizes. Besides assessing the correlation and agreement between the two methods, we tested the ability of the single-plane LA volume determination to correctly classify the LA size into different categories when the ASE suggested cut-offs are used. Furthermore, for comparison and validation of the two-dimensional methods, we calculated the LA volume by real time three-dimensional (3D) echocardiography in a subgroup of subjects.

METHODS

The study was conducted at the Adult Cardiovascular Ultrasound Laboratories of Columbia University Medical Center. The study sample was derived from the NIH-sponsored Cardiac Abnormalities and Brain Lesions (CABL) study, whose aim is to assess the relationship between cardiovascular subclinical disease and silent brain infarctions in a community-based cohort. Participants in CABL were drawn from the Northern Manhattan Study (NOMAS), an epidemiologic study carried out in Northern Manhattan, NY. Extensive details about NOMAS population and enrollment have been published previously.^{23,24} Briefly, subjects were eligible if they: (1) had never been diagnosed with a stroke, (2) were age 50 or older, and (3) resided in Northern Manhattan for at least 3 months in a household with telephone. The study was approved by the Institutional Review Board of Columbia University Medical Center and informed consent was obtained from all study participants.

Cardiovascular risk factors were ascertained through direct examination and interview by trained research assistants. Among the variables used in the analyses, hypertension was defined as systolic blood pressure ≥ 140 mm Hg or diastolic blood pressure ≥ 90 mm Hg (mean of two readings) or a patient's self-reported history of hypertension or of antihypertensive medication. Coronary artery disease (CAD) was defined as a history of myocardial infarction, coronary artery bypass grafting, percutaneous coronary intervention, typical angina or use of anti-ischemic medications.

Echocardiographic Evaluation

Extensive 2D echocardiograms were performed in all participants in lateral recumbent position, using a commercially available system (iE 33, Philips, Andover, MA) equipped with a 2.5-3.5-MHz transducer, by a trained sonographer, following a standardized protocol. All the exams were stored on digital media for subsequent analysis. Left ventricular (LV) diameters and wall thickness were measured according the ASE guidelines,²¹ and LV ejection fraction (LVEF) was computed using the modified Simpson's formula. LVEF was considered abnormal if < 50%.

For the LA volume assessment, two methods were used: (1) Biplane area-length method, using the formula $V = 8 (A1) (A2) / 3 \pi (L)$, where A1 and A2 represent the LA planimetry respectively in 4-chamber view and 2-chamber view, and L is the shortest length from the middle of the plane of the mitral annulus to the superior aspect of the LA (Figure 1A); (2) Modified single-plane Simpson's rule, assuming the stacked disks are circular, by the formula $V = \pi / 4 (h) \sum (D)^2$, where V is volume, h is the height of the disks and D is the orthogonal axis of the disks (Figure 1B). Apical views were optimized in order to satisfactorily visualize LV and LA walls and to avoid chambers foreshortening. In particular, when needed, in the 4-chamber view the tail of the probe was slightly tilted downward to account for the physiologic angle between the atrial and ventricular short axes, and in the 2-chamber view the probe was adjusted to correctly visualize both anterior and inferior LV and LA walls. The LA endocardial border was traced, and the volumes were calculated by the online software package. The LA appendage and the pulmonary veins confluence were excluded from the LA tracings, and a straight line was traced between the attachment points of the mitral annulus with the valve leaflets. The LA volumes were indexed by body surface area (BSA). To assess correlation of LA volume with a widely used measure of LA size, A-P diameter from the parasternal long-axis view was also measured and indexed by BSA. The measurements of the single- and the biplane volume were taken at different times by a single trained sonographer, blinded to the results of the first measurement. The choice of which image to consider for the measurement was left to the reader, since several cine-loops of 4- and 2-chamber views were stored for each patient, and every clip had four cardiac cycles in it. Measurements were taken at end-systole, defined as the frame immediately preceding the mitral valve opening. The average of two consecutive measurements was considered.

In a subset of 80 patients, LA volume measurement at end-systole was also obtained by real time 3D echocardiography, which was used as a reference to evaluate the accuracy of the two-dimensional methods. A full volume loop was acquired from an apical window using an X3-1 matrix array transducer over four cardiac cycles. Measurements of 3D LA volume were performed offline (QLAB Advanced Quantification software, version 7.0, Philips) by an experienced physician (C.R.). The software requires the reader to identify five anatomical landmarks (septal, lateral, anterior and inferior mitral annulus, and posterior wall of the LA) at end-diastole and end-systole, subsequently a semi-automated border detection is performed, and LA borders are tracked throughout the entire cardiac cycle. Manual correction on all possible 3D planes is performed by the reader in case of inaccurate endocardial automated detection.

Of the 583 study participants who underwent echocardiographic evaluation, 56 (9.0%) were excluded from analysis because the 2-chamber view was suboptimal for LA borders tracing. Excluded subjects were significantly older than the others (74.2 ± 9.4 vs. 69.4 ± 9.8 years, $p < 0.01$) and had higher prevalence of obesity (42.3% vs. 29.0%, $p < 0.05$). The final study sample consisted therefore of 527 participants.

Statistical Analysis

All descriptive data are expressed as mean $\pm$ standard deviation for continuous variables and as percentage for categorical variables. Correlations between LA size measurements were assessed by Pearson's correlation coefficient (r). Agreement between different measurements of LA volume as continuous variables was assessed by the intra-class correlation coefficient for absolute agreement. Pearson's and intra-class correlation coefficients were obtained in the overall study group and in several demographic/clinical subsets of patients. Mean differences between single- and biplane LA volumes were assessed by paired Student's t -test. Bland-Altman plots were created to calculate the limits of agreement. A linear regression model was used to calculate the predicted biplane volume value from the single-plane volume measurement. Single-plane LA volume was set as the independent variable and the biplane volume was set as the dependent variable, and a regression equation was derived using the slope of the relation and the intercept. The regression equation was: $y = 0.855x + 3.71$, where y represented the predicted biplane volume and x the single plane measured volume (standard errors: 0.65 for the constant, 0.013 for the slope). The regression equation was then applied to the single-plane volume to obtain a corrected single-plane measurement.

Categorization of the LA size into 4 groups (normal, mild, moderate and severe dilation) was performed using the cut-offs suggested by the ASE: ≤ 28 ml/m², 29-33 ml/m², 34-39 ml/m², ≥ 40 ml/m².²¹ The categorical agreement between the single- and the biplane methods was evaluated by kappa statistic. The agreement between the biplane and the corrected single-plane volume was also assessed.

For all statistical analyses, a two-tailed $p < 0.05$ was considered significant.

RESULTS

Clinical characteristics of the study sample

The study sample included 527 participants. The clinical characteristics are shown in Table 1. Mean age was 69.6 ± 9.7 years, 61.9% were females. Hypertension was present in 68.5%, coronary artery disease in 5.9%, atrial fibrillation in 2.1%. As expected, the large majority of the study participants were of Hispanic ethnic background (71.3%), with a minority of Caucasian (11.0%) and African-American (14.2%) participants, reflecting the racial/ethnic composition of the community living in Northern Manhattan.

Validation of the biplane and single-plane methods by three-dimensional LA volume estimation

Three-dimensional LA volume was measured and compared to the single- and biplane methods in a subgroup of 80 participants. Clinical characteristics of this subgroup were not significantly different from the remainder of the study sample (all $p > 0.10$, data not shown). Mean LA volumes were 23.8 ± 6.7 ml/m² for the 3D, 24.1 ± 7.2 ml/m² for the biplane and 25.9 ± 8.2 ml/m² for the single-plane methods. Correlations with 3D LA volume were excellent both for the biplane ($r = 0.93$, $p < 0.01$; Figure 2A) and for the single-plane methods ($r = 0.93$, $p < 0.01$; Figure 2B). However, intra-class correlation coefficient (ICC) with 3D LA volume was higher for the biplane [ICC = 0.93, 95% confidence intervals (CI) 0.89-0.95] than for the single-plane method (ICC = 0.88, 95% CI 0.68-0.95).

Comparison between biplane and single-plane LA volumes in the entire sample

Reproducibility of the measurements—Intra-observer variability, calculated as the mean difference between LA volumes in two separate readings on a sample of 20 randomly chosen exams, was 1.25 ml for the biplane (standard error 1.08 ml, ICC = 0.95) and 1.60 ml (standard error 1.18 ml, ICC = 0.95) for the single-plane measurement. No significant

differences were found between the first and the second set of measurements for both the biplane and the single-plane methods ($p=0.26$ and $p=0.19$ respectively). To test the inter-observer variability, LA volumes were re-obtained by an experienced reader in 30 randomly chosen patients. The mean difference between the two sets of measurements was 1.48 ml (S.E. 1.30, ICC = 0.90) for the biplane method ($p=0.26$ for the difference between the two readings) and 2.13 ml (S.E. 1.67, ICC = 0.91) for the single-plane ($p=0.21$).

Comparison between biplane and single-plane LA volumes—Mean LA volume measured by the biplane area-length method was 25.9 ± 8.3 ml/m²; mean LA volume by single-plane Simpson's method was 27.9 ± 9.1 ml/m² (mean difference 1.9 ml/m², $p<0.01$); mean A-P diameter was 22.3 ± 3.1 mm/m².

The correlation between biplane and single plane LA volumes was excellent ($r=0.95$, $p<0.01$), and their relation was linear throughout the entire spectrum of volumes (Figure 3A). ICC between the two methods was 0.92 (95% CI 0.80-0.96). The correlation between the LA A-P diameter and LA volume was considerably weaker, though still statistically significant ($r=0.66$ with biplane method, $p<0.01$, Figure 3B; $r=0.67$ with single-plane method, $p<0.01$). When the study sample was divided into different demographic/clinical subgroups, the correlation and the agreement between biplane and single-plane volume measurements remained strong (r values = 0.95 in men, 0.94 in women, 0.95 in normotensive and 0.95 in hypertensive participants, 0.96 in those with CAD, 0.95 in those without CAD, 0.94 in those with normal LVEF, 0.99 in those with reduced LVEF; all $p<0.01$, ICCs ranging from 0.91 to 0.97).

The correlation between single- and biplane LA volume was also analyzed separately in different age strata, and it was strong in all age groups ($r = 0.90$ in subjects between 50-60 years, $r = 0.94$ in those between 60-70 years and $r = 0.95$ in those >70 years) with the single-plane method yielding bigger volumes than the biplane in all the subgroups (Table 2). Both single - and biplane LA volumes tended to increase in participants > 70 years, but this trend was not present when subjects with hypertension and CAD were excluded from the analysis.

Because of the strong correlation between single- and biplane LA volumes, with the former generally overestimating the latter, a linear regression model was used to obtain a corrected single-plane measurement. The ICC for the agreement between the biplane and the corrected single-plane LA volume was 0.94 (95% CI 0.93-0.95). Bland-Altman plots for the biplane vs. the single-plane volume showed a mean difference of 1.9 ml/m² and limits of agreement from -4.2 to 8.0 ml/m² (Figure 4A); after application of the regression formula, the mean difference was virtually eliminated (0.002 ml), and the limits of agreement slightly narrowed (-5.5 to 5.6 ml/m²; Figure 4B).

Categorization of LA volumes using ASE cut-offs—Single-plane LA volumes were significantly larger than biplane volumes in each LA size category as defined by the ASE cut-offs (mean differences were 1.9 ± 2.9 ml/m², 1.8 ± 3.0 ml/m², 2.1 ± 3.4 ml/m² and 2.9 ± 4.9 ml/m² in the normal, mild, moderate and severe dilation categories, respectively; all $p<0.01$).

Using the single-plane method, with the biplane method as the reference, 390 individuals (74.0%) were correctly classified ($\kappa=0.51$, 95% CI 0.45-0.57; Table 3), while a disagreement was seen in 137 (26.0%). In particular, agreement was greater for normal or severely dilated atria, while it was low ($<50\%$) for mildly and moderately dilated LA. The single-plane method resulted in an overestimation of the LA size category in 85.4% (117 of the 137 misclassified individuals) and in an underestimation in 14.6% (20) of cases.

The corrected single-plane volume showed improved agreement with the biplane measurement (Table 3), with 453 participants correctly classified ($\kappa=0.70$, 95% CI 0.64-0.76; agreement

86.0%) and 74 (14.0%) misclassified. With the correction, overestimation by the single-plane method accounted for 37.8% of the disagreement (28 of 74 participants), while underestimation was observed in 62.2% of the misclassified volumes.

DISCUSSION

In our study, we compared the echocardiographic single-plane LA volume determination with the biplane method. This is the first study to compare a single- and a biplane LA volume determination in a large population based-cohort, and to explore the clinical reproducibility of the categorical agreement between the methods using current ASE cutoffs. The linear correlation between the bi- and the single-plane was excellent throughout the entire spectrum of LA volumes and was not affected by demographics (gender, age) or clinical variables that can affect LA size (hypertension, CAD, impaired ejection fraction). The A-P diameter only showed a moderate correlation with both the measures of volume, confirming its low accuracy as an index of LA size, as reported previously in several studies.^{16,18,25} The ASE recommends the use of two-dimensional biplane measurement of LA volume, either by the area-length or the modified Simpson's method.²¹ However, in daily clinical routine, the visualization of the 2-chamber view, needed for the biplane determination, is not always adequate. In our study, 9.0% of the participants had suboptimal 2-chamber views, which prevented an accurate tracing of the LA border, mostly because of poor visualization of the endocardial border of the anterior atrial wall. Therefore, the use of a single-plane method could make the determination of LA volume simpler, faster and of more widespread application.

In our study, we also demonstrated that both single-plane and biplane LA volume have very good correlation with 3D-determined volumes. 3D echocardiography seems to provide a more accurate estimation of LA volume compared to single-or biplane methods,²⁶ but it requires time-consuming offline analysis, and is not available in all labs. Moreover, categorical cutoff values for clinical use 3D echo are not established yet. Biplane volume showed a better absolute agreement with 3D than single-plane volume, confirming to be a closer expression of the "real" LA volume. The single -plane volume, despite the excellent correlation with 3D and biplane, tended to slightly but significantly overestimate the LA volume throughout the spectrum of LA sizes and in all age categories, with an overall mean difference of 1.9 ml/m². Such difference would be normally considered small, but it was enough to strongly affect the categorical agreement between the two methods when the ASE cut-offs were applied. The intervals for the definition of LA size categories are rather narrow, with only 5 ml/m² between normal size, mild, moderate and severe dilation.²¹ Hence, even small differences in volume can result in a significant rate of disagreement (26.0% in our study). The application of a regression equation to the single-plane volume reduced the disagreement to 14.0%, a value approaching the limits of reproducibility of the technique. This observation indicates that, if the single-plane method is to be used because of its excellent general correlation with the biplane method in absolute volume age, and the different cardiovascular risk burden observed in different race/ethnic groups, the results of our study should not be extrapolated to different populations.

In conclusion, our study shows that 2D methods correlate well with 3D LA volume determination, and that the single-plane measurement has a strong general correlation with the biplane method, suggesting its possible role as a simpler tool for measuring the LA volume and its adequate accuracy when a biplane determination is not feasible. However, the frequent, albeit small, volume overestimation by the single-plane method results in a significant misclassification of patients when the ASE cut-offs are applied. The simpler single-plane method could be used for clinical categorization once specific cut-offs are established.

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Figure 1. Left atrial volume measurement

(A) Biplane area-length method. The LA planimetry is performed in 4-chamber view (A I) and 2-chamber view (A II). (B) Modified single-plane Simpson's rule. The volume is calculated assuming the stacked disks are circular. ESV: End-systolic volume; BP: Biplane.

Figure 2.
Correlations of 3D with biplane LA volume (A) and with single-plane LA volume (B).

Figure 3.
Relation between biplane LA volume and single-plane volume (A) and antero-posterior diameter (B).

Figure 4.
Bland-Altman plots showing the agreement between: (A) Biplane vs. single-plane LA volume;
(B) Biplane vs. corrected single-plane LA volume.

Table 1

General characteristic of the study participants

	N=527
Age, years	69.6±9.7
Male gender, n (%)	201 (38.1)
Body mass index, kg/m²	28.1±4.6
Hypertension, n (%)	361 (68.5)
Diabetes, n (%)	149 (28.3)
Coronary artery disease, n (%)	31 (5.9)
Atrial fibrillation, n (%)	11 (2.1)
Ejection fraction, %	63±7.2
Left ventricular mass, g/m²	106.6±26.3

Table 2

Biplane and single-plane LA volumes in different age groups

Overall population	50–60 y (n=86)	60–70 y (n=193)	>70 y (n=246)	P ANOVA[†]
Biplane, ml/m ²	25.7±6.3	24.4±7.6	27.2±9.2	0.004
Single plane, ml/m ²	27.1±6.6**	26.5±8.5**	29.3±10.2**	0.002
Participants without hypertension/CAD	50–60 y (n=40)	60–70 y (n=60)	>70 y (n=56)	P ANOVA[†]
Biplane, ml/m ²	26.1±6.4	23.5±7.9	24.5±6.5	0.21
Single-plane, ml/m ²	27.1±5.9*	25.3±8.9**	25.9±7.8**	0.53

[†] Analysis of variance among the age groups*
p<0.05 and**
p<0.01 vs. biplane measurement in the same age group

Table 3

Agreement between biplane and single-plane methods in the overall study sample and in different LA size categories

	Single-Plane Volume	Corrected Single- Plane Volume	Agreement Change After Correction
LA Volume Category (Biplane)	Agreement (%)	Agreement (%)	(%)
All categories	74.0	86.0	+13.7
Normal	83.3	94.8	+11.5
Mild dilation	46.6	65.9	+19.3
Moderate dilation	43.8	62.5	+18.7
Severe dilation	91.7	70.8	-20.9