Background: The American Society of Echocardiography recommends calculating left atrial (LA) biplane volume because of its greater accuracy and prognostic value over LA diameter. However, biplane methods are not always feasible. The aim of this study was to assess the correlation between the echocardiographic LA biplane and single-plane volumes and their agreement in the classification of LA size when American Society of Echocardiography cutoffs are applied.

Methods: Two-dimensional echocardiography was performed on the participants of the population-based Cardiovascular Abnormalities and Brain Lesions study. LA volume was calculated by the biplane area-length and single-plane modified Simpson’s methods and validated against three-dimensional echocardiography.

Results: The study sample consisted of 527 participants (mean age 69.6 ± 9.7 years; 61.9% women). Both single-plane and biplane LA volumes correlated well with three-dimensional echocardiography ($r = 0.93$, $P < .001$). The correlation between the single-plane and biplane methods was excellent ($r = 0.95$, $P < .001$; intraclass correlation coefficient, 0.92; 95% confidence interval, 0.80–0.96). Categorical agreement between the single-plane and biplane methods was modest ($k = 0.51$; 95% confidence interval, 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% confidence interval, 0.64–0.76), but misclassifications remained in 14.0% of cases.

Conclusions: Single-plane and biplane LA volume measurements have strong correlations, but their agreement for categorical classification is suboptimal. Specific cutoff points should be developed for the single-plane method. (J Am Soc Echocardiogr 2010;23:954-60.)

Keywords: Echocardiography, Left atrium, Volume, Single plane, Biplane, Three-dimensional

Enlargement of the left atrium 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, and dilated and hypertrophic cardiomyopathy, is well documented.6–14 The anteroposterior (AP) diameter of the left atrium, assessed by two-dimensional echocardiography, is the most widely used measure of left atrial (LA) size in epidemiologic studies and in clinical practice. However, AP diameter is inaccurate, because it relies on several geometric assumptions and often results in an underestimation of LA size compared with LA volumes.15–17 Echocardiographic measures of LA volume rely on fewer geometric assumptions than AP diameter16 and have been validated against cine computed tomography, contrast ventriculography, and magnetic resonance imaging.15,18-20 The American Society of Echocardiography (ASE) guidelines recommend measuring 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 with linear LA dimension.21,22 However, biplane planimetry of the left atrium is not always feasible, because the apical two-chamber view sometimes provides suboptimal LA border 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 LA size into different categories when the ASE suggested cutoffs are used. Furthermore, for
For LA volume assessment, two methods were used (1) the biplane area-length method, using the formula $V = \pi/4(h)(A_1 + A_2)/3\pi(L)$, where $A_1$ and $A_2$ represent the LA planimetry respectively in the four-chamber and two-chamber views, and $L$ is the shortest length from the middle of the plane of the mitral annulus to the superior aspect of the left atrium (Figure 1A); (2) modified single-plane Simpson’s rule, assuming the stacked disks are circular, using the formula $V = \pi/4(h)(\Sigma D^2)/2$, 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 to satisfactorily visualize LV and LA walls and to avoid chamber foreshortening. In particular, when needed, in the four-chamber view, the tail of the probe was slightly tilted downward to account for the physiologic angle between the atrial and ventricular long axes, and in the two-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 vein 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. LA volumes were indexed to body surface area. To assess the correlation of LA volume with a widely used measure of LA size, AP diameter from the parasternal long-axis view was also measured and indexed to body surface area. The measurements of the single-plane and the biplane volumes 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, because several cine loops of four-chamber and two-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 version 7.0; Philips Medical Systems) by an experienced physician (C.R.). The software requires the reader to identify five anatomic landmarks (septal, lateral, anterior, and inferior mitral annulus and posterior wall of the left atrium) at end-diastole and end-systole; subsequently, semiautomated 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 two-chamber views were suboptimal for LA border tracing. Excluded subjects were significantly older than the others (74.2 ± 9.4 vs 69.4 ± 9.8 years, $P < .01$) and had a higher prevalence of obesity (42.3% vs 29.0%, $P < .05$). The final study sample consisted therefore of 527 participants.

**Statistical Analysis**

All descriptive data are expressed as mean ± SD for continuous variables and as percentages 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 intraclass correlation coefficient (ICC) for absolute agreement. Pearson’s coefficients and ICCs were obtained in the overall study group and in several demographic and clinical subsets of patients. Mean differences between single-plane and biplane LA volumes were assessed using paired Student’s $t$ tests. Bland-Altman plots were created to calculate the limits of agreement. A linear regression model was used to calculate 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 National Institutes of Health–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 New York City. Extensive details about the population and enrollment of NOMAS have been published previously.23,24 Briefly, subjects were eligible if they (1) had never been diagnosed with stroke, (2) were aged $\geq 50$ years, and (3) resided in northern Manhattan for $\geq 3$ months in a household with a 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 $\geq 140$ mm Hg or diastolic blood pressure $\geq 90$ mm Hg (mean of two readings) or a patient’s self-reported history of hypertension or antihypertensive medication use. 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 two-dimensional echocardiography was performed in all participants in the lateral recumbent position, using a commercially available system (iE33; Philips Medical Systems, Andover, MA) equipped with a 2.5-MHz to 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 ASE guidelines,21 and LV ejection fraction (LVEF) was computed using the modified Simpson’s formula. LVEF was considered abnormal if $<50$%.

For LA volume assessment, two methods were used (1) the biplane area-length method, using the formula $V = 8(A_1 + A_2)/3\pi(L)$, where $A_1$ and $A_2$ represent the LA planimetry respectively in the four-chamber and two-chamber views, and $L$ is the shortest length from the middle of the plane of the mitral annulus to the superior aspect of the left atrium (Figure 1A); (2) modified single-plane Simpson’s

**Abbreviations**

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AP</td>
<td>Anteroposterior</td>
</tr>
<tr>
<td>ASE</td>
<td>American Society of Echocardiography</td>
</tr>
<tr>
<td>CABL</td>
<td>Cardiovascular Abnormalities and Brain Lesions</td>
</tr>
<tr>
<td>CAD</td>
<td>Coronary artery disease</td>
</tr>
<tr>
<td>CI</td>
<td>Confidence interval</td>
</tr>
<tr>
<td>ICC</td>
<td>Intraclass correlation coefficient</td>
</tr>
<tr>
<td>LA</td>
<td>Left atrial</td>
</tr>
<tr>
<td>LVEF</td>
<td>Left ventricular ejection fraction</td>
</tr>
<tr>
<td>NOMAS</td>
<td>Northern Manhattan Study</td>
</tr>
<tr>
<td>$r$</td>
<td>Pearson’s correlation coefficient</td>
</tr>
<tr>
<td>3D</td>
<td>Three-dimensional</td>
</tr>
</tbody>
</table>
the predicted biplane volume value from the single-plane volume measurement. Single-plane LA volume was set as the independent variable, and 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 derived using the slope of the relation and the intercept. The regression equation was then applied to the single-plane volume to obtain a corrected single-plane measurement.

Categorization of LA size into four groups (normal, mild, moderate, and severe dilation) was performed using the cutoffs suggested by the ASE: \( \leq 28 \), 29 to 33, 34 to 39, and \( \geq 40 \) ml/m\(^2\). Categorical agreement between the single-plane and biplane methods was evaluated using \( \kappa \) statistics. Agreement between the biplane and the corrected single-plane volumes was also assessed. For all statistical analyses, two-tailed \( P \) values < .05 were considered significant.

**RESULTS**

**Clinical Characteristics of the Study Sample**

The study sample included 527 participants. The clinical characteristics are shown in Table 1. The mean age was 69.6 ± 9.7 years, and 61.9% were women. Hypertension was present in 68.5%, CAD in 5.9%, and 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 and ethnic composition of the community living in northern Manhattan.

**Validation of the Biplane and Single-Plane Methods by 3D LA Volume Estimation**

Three-dimensional LA volume was measured and compared with the single-plane and biplane methods in a subgroup of 80 participants. The clinical characteristics of this subgroup were not significantly different from the remainder of the study sample (all \( P \) values > 0.10, data not shown). Mean LA volumes were 23.8 ± 6.7 ml/m\(^2\) for the 3D method, 24.1 ± 7.2 ml/m\(^2\) for the biplane method, and 25.9 ± 8.2 ml/m\(^2\) for the single-plane method. Correlations with

![Figure 1](image)

**Figure 1** LA volume (Vol) measurement. (A) Biplane (BP) area-length method. LA planimetry is performed in the four-chamber view (A I) and the two-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.

**Comparison Between Biplane and Single-Plane LA Volumes in the Entire Sample**

**Reproducibility of the Measurements.** Intraobserver 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 method (standard error, 1.08 mL; ICC, 0.95) and 1.60 mL (standard error, 1.18 mL; ICC, 0.95) for the single-plane method. No significant differences were found between the first and second sets of measurements for both the biplane and the single-plane methods (ICC, 0.93; 95% confidence interval [CI], 0.89–0.95) than for the single-plane method (ICC, 0.88; 95% CI, 0.68–0.95).

**Table 1** General characteristic of the study participants

<table>
<thead>
<tr>
<th>Variable</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>69.6 ± 9.7</td>
</tr>
<tr>
<td>Men</td>
<td>201 (38.1%)</td>
</tr>
<tr>
<td>Body mass index (kg/m(^2))</td>
<td>28.1 ± 4.6</td>
</tr>
<tr>
<td>Hypertension</td>
<td>361 (68.5%)</td>
</tr>
<tr>
<td>Diabetes</td>
<td>149 (28.3%)</td>
</tr>
<tr>
<td>CAD</td>
<td>31 (5.9%)</td>
</tr>
<tr>
<td>Atrial fibrillation</td>
<td>11 (2.1%)</td>
</tr>
<tr>
<td>LVEF</td>
<td>63 ± 7.2</td>
</tr>
<tr>
<td>Left ventricular mass (g/m(^2))</td>
<td>106.6 ± 26.3</td>
</tr>
</tbody>
</table>

Data are expressed as mean ± SD or as number (percentage).

3D LA volume were excellent both for the biplane (\( r = 0.93, P < .01; \) Figure 2A) and the single-plane (\( r = 0.93, P < .01; \) Figure 2B) methods. However, the ICC for 3D LA volume was higher for the biplane method (ICC, 0.93; 95% confidence interval [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. The mean LA volume measured by the biplane area-length method was 25.9 ± 8.3 ml/m², the mean LA volume by the single-plane Simpson’s method was 27.9 ± 9.1 ml/m² (mean difference, 1.9 ml/m², *P* < .01), and the mean AP diameter was 22.3 ± 3.1 mm/m².

The correlation between biplane and single-plane LA volumes was excellent (*r* = 0.95, *P* < .01), and their relation was linear throughout the entire spectrum of volumes (Figure 3A). The ICC between the two methods was 0.92 (95% CI, 0.80–0.96). The correlation between LA AP diameter and LA volume was considerably weaker, though still statistically significant (*r* = 0.66 with the biplane method, *P* < .01, Figure 3B; *r* = 0.67 with the single-plane method, *P* < .01). When the study sample was divided into different demographic and clinical subgroups, the correlation and the agreement between biplane and single-plane volume measurements remained strong (*r* = 0.95 in men, *r* = 0.94 in women, *r* = 0.95 in normotensive subjects, *r* = 0.95 in hypertensive subjects, *r* = 0.96 in those with CAD, *r* = 0.95 in those without CAD, *r* = 0.94 in those with normal LVEFs, and *r* = 0.99 in those with reduced LVEFs; all *P* values < .01; ICC range, 0.91–0.97).

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

Because of the strong correlation between single-plane 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 versus the single-plane volumes showed a mean difference of 1.9 ml/m² and limits of agreement of −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 Cutoffs. Single-plane LA volumes were significantly larger than biplane volumes in each LA size category as defined by the ASE cutoffs (mean differences were 1.9 ± 2.9, 1.8 ± 3.0, 2.1 ± 3.4, and 2.9 ± 4.9 ml/m² in the normal, mild, moderate, and severe dilation categories, respectively; all P values < .01).

Using the single-plane method, with the biplane method as the reference, 390 individuals (74.0%) were correctly classified (k = 0.51; 95% CI, 0.45–0.57; Table 3), while 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 atria. The single-plane method resulted in overestimations of LA size category in 85.4% (117 of the 137 misclassified individuals) and in underestimations in 14.6% (n = 20).

Corrected single-plane volume showed improved agreement with the biplane measurement (Table 3), with 453 participants correctly classified (κ = 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 echocardiographic single-plane LA volume determination with the biplane method. This is the first study to compare single-plane and 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 biplane and the single-plane was excellent throughout the entire spectrum of LA volumes and was not affected by demographics (gender and age) or clinical variables that can affect LA size (hypertension, CAD, and impaired ejection fraction). The AP diameter showed only a moderate correlation with both measures of volume, confirming its low accuracy as an index of LA size, as reported previously in several studies. The ASE recommends the use of two-dimensional biplane measurement of LA volume, either by the area-length or the modified Simpson’s method. However, in daily...
clinical practice, the visualization of the two-chamber view, needed for the biplane determination, is not always adequate. In our study, 9.0% of participants had suboptimal two-chamber views, which prevented 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 volumes have very good correlations with 3D-determined volumes. Three-dimensional echocardiography seems to provide a more accurate estimation of LA volume than single-plane or biplane methods, but it requires time-consuming offline analysis and is not available in all labs. Moreover, categorical cutoff values for clinical-use of 3D echocardiography are not established yet. Biplane volume showed better absolute agreement with 3D volume than single-plane volume, confirming it to be a closer expression of the “real” LA volume. Single-plane volume, despite the excellent correlation with 3D and biplane volumes, tended to slightly but significantly overestimate 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 normally be considered small, but it was enough to strongly affect the categorical agreement between the two methods when the ASE cutoffs were applied. The intervals for the definition of LA size categories are rather narrow, with only 5 ml/m² between normal size and mild, moderate, and severe dilation. 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 determination and its simplicity of execution, the current ASE-recommended cutoffs should not be used. Specific cutoffs should instead be developed on the basis of single-plane measurements alone.

The reason why single-plane LA volumes yielded bigger volumes than biplane volumes is not immediately apparent, and several potential explanations may exist for the differences observed between the two methods. Anatomic factors possibly affecting the four-chamber LA area are the right convexity of the atrial septum, unclear separation between the LA cavity and the LA appendage, and pronounced wall partitions at the entrance sites of the pulmonary veins. However, no subjects with atrial septal aneurysms were present in our study, and particular attention was paid to exclude the LA appendage and pulmonary veins from the LA tracings. We found that the four-chamber area was often bigger than the two-chamber area; it is possible that LA enlargement may develop preferentially in the lateral dimension, as anatomic factors (the spine and sternum) may limit expansion in the AP direction. Intrinsic differences in geometric assumptions between the single-plane and biplane methods may be another source of variability in LA volume. Jiamsripong et al. reported smaller LA volumes by Simpson’s method compared with the area-length method. However, these differences were small and cannot explain our findings; in fact, we observed bigger LA volumes using the single-plane Simpson’s rule. Furthermore, if systematic differences due to mathematical assumptions were the cause of the differences we observed, they would invariably result in bigger single-plane volumes, whereas in our study, 22% of the subjects had biplane volumes bigger than their single-plane counterparts. Therefore, in some patients, LA enlargement in the two-chamber view might play a greater role in determining LA volume.

One of the clinical implications of our study is that the use of single-plane volume determination can be acceptable for LA volume measurement, especially when the two-chamber view is not optimal for LA border tracing. In our experience, the most common reason for the exclusion of the two-chamber view was an inadequate visualization of the LA anterior wall. This happened more frequently in older subjects with larger body sizes, a group with often suboptimal acoustic windows and frequent mitral annular calcifications. However, although the single-plane LA volume correlated well with the biplane volume, we do not think that it should routinely replace it. In this study, we confirmed that the biplane LA measurement comes closer to the 3D-determined LA volume than the single-plane measurement and is therefore a better expression of the “real” LA volume and might therefore have better prognostic value.

Another important implication of our findings is that single-plane and biplane volumes are not interchangeable and therefore should not be used as such in the same patient. Therefore, the method used for LA volume calculation should be specified in the echocardiographic report, so that the same method can be used for serial echocardiographic evaluations in the same patient.

Our study had some limitations. The measurements of LA volumes were performed by a single observer; however, the intraobserver variability of our measurements, as well as the mean differences between the single-plane and the biplane methods, were similar to those reported in previous studies from other groups, and so was the interobserver variability observed in a subset of patients reexamined for this purpose. We cannot exclude that the use of two different geometric assumptions for the calculation of LA volume may account for part of the differences observed between the single-plane and biplane volumes. The study sample included middle-aged to elderly participants with high cardiovascular risk, and participants were mostly of Hispanic ethnic background. Given the cardiac structural and functional changes associated with age, and the different cardiovascular risk burden observed in different racial and ethnic groups, the results of our study should not be extrapolated to different populations.

### CONCLUSIONS

This study shows that two-dimensional methods correlate well with 3D LA volume determination and that the single-plane method has a strong general correlation with the biplane method, suggesting its possible role as a simpler tool for measuring 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 cutoffs are applied. The simpler single-plane method could be used for clinical categorization once specific cutoffs are established.

ACKNOWLEDGMENTS

We wish to thank Michele Alegre, RDCS, Rui Liu, MD, Janet DeRosa, MPH, and Rafi Cabral, MD, for their help in the collection of the data.

REFERENCES


