Comparison of Accuracy of Left Atrial Area and Volume by Two-dimensional Trans-thoracic Echocardiography Versus Computed Tomography

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Left atrial (LA) size is prognostic of cardiovascular events and can be quantified as diameter, area, or volume. While LA area measurement by 2-dimensional (2D) echocardiography is performed by tracing LA borders in the apical 4-chamber view, LA volume is derived from a formula that is based on geometrical assumptions. We compared LA area and volume measurements obtained by trans-thoracic echocardiography (TTE) to those obtained using multi-detector computed tomography (MDCT). Sixty-four patients with MDCT and TTE performed within a 1-week period were included in the study. End-systolic LA area was planimetered from the 4-chamber view by TTE and MDCT. LA end-systolic volume was calculated using the biplane area-length (AL) method in both TTE and MDCT. Mean LA volume measurement using MDCT was significantly larger than TTE measurement (92 ± 31 mL vs 68 ± 27 mL, p <0.001). There was moderate correlation between MDCT and TTE in both LA area (0.74, p <0.0001), and volumetric measurements (0.77, p <0.0001). Bland-Altman agreement plots demonstrated a significantly lower bias and narrower 95% confidence intervals (CI) for the 2D area (bias: −5.5; 95% CI: −14.3 to 3.3) as compared with volumetric measurements (bias: −23.7; 95% CI: −64.9 to 17.5, p <0.0001). Contrary to current guidelines for chamber quantification, 2D TTE LA area has better agreement with MDCT than volumetric measurements by TTE. LA volumetric measurements are desirable; however, they are currently less reliable than the direct LA area tracing by 2D TTE and therefore represent a suboptimal and less reproducible method to determine LA size. **(Am J Cardiol 2019;123:1180−1184)**

Left atrial (LA) size as assessed by echocardiography is a strong predictor of cardiovascular outcomes. As LA size is highly prognostic of cardiovascular events, accurate measurement of LA size as part of the complete trans-thoracic echocardiographic (TTE) study is essential. LA area can be planimetered from the apical views. However, the majority of prognostic data published has focused on LA volumes.[1] The LA volume can be measured using either biplane area-length (AL) method or by the disk summation (Simpson's) method.[2] LA area tracing and measurement can be directly corroborated by the echo reader, whereas the volume cannot be directly verified with 2-dimensional (2D) imaging. There is no data demonstrating superiority of LA volume measurement over that of LA area, however, American Society of Echocardiography (ASE) guidelines recommend that LA volume quantification should be preferred for routine use.[2] LA volume measurements obtained by computed tomography (CT) or magnetic resonance imaging (MRI) are reproducible, and accurate.[3,4] LA volumes from 2D TTE has limitations which relate to the difficulty to visualize the LA far wall as well as the potential inaccuracies when calculating, rather than directly measuring, LA volume. We compared the accuracy and reproducibility of echo-derived LA area and LA volume with that obtained by multi-detector computed tomography (MDCT).

Methods

Subjects who were referred for an MDCT at Cedars-Sinai Medical Center, Los Angeles, California, from October 1, 2010 to October 31, 2012 were consecutively

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reviewed. Consecutive patients in whom end-systolic phase was available and who had TTE within a week of their MDCT without a significant intervening event were studied. Based on these criteria, 64 consecutive patients were identified to form the study cohort. The data analyzed in this study have been obtained retrospectively from the existing database at Cedars-Sinai Medical Center (Los Angeles, California). The Institutional Review Board at Cedars-Sinai Medical Center approved the retrospective use of clinical data in this study and informed consent was obtained from all patients.

Consecutive patients underwent MDCT using a standard protocol as previously described.[5] MDCT was performed on a SOMATOM Definition dual-source scanner (Siemens Medical Systems, Forchheim, Germany). Patients were scanned after injection of 80 mL iodinated contrast at a rate of 5 to 6 mL/sec, triggered by 100 HU in the ascending aorta, in a single breath hold. Scan parameters were 64×0.6 mm collimation, tube voltage 120 mV, 350 to 750 mA. Twenty phases of axial data at 2.5-mm thickness were reconstructed from beginning to end of the cardiac cycle in 5% intervals. End of ventricular systole was identified based on percentage time of the R-R interval and was on average 40% ± 5%.

MDCT interpretation was performed by 2 expert readers who were blinded to TTE results. End-systolic LA area was measured in 4- and 2-chamber planes and left atrial end-systolic volume calculated using the AL method[6] (Figure 1).

Echocardiography was performed with a commercially available system (iE33, Philips, Andover, MA). A single experienced sonographer obtained the standard apical 2 and 4-chamber views at left ventricular (LV) end-systole, just prior to the opening of the mitral valve (Figure 1). Apical views were optimized to avoid foreshortening of the LA, so the base of the left atrium is its largest size. The left atrial area was planimetered from the 4-chamber view, excluding the left atrial appendage and the pulmonary veins. The maximum LA volumes were calculated using the biplane AL method.[6] All images were interpreted by 2 cardiologists who were blinded to the results of the cardiac MDCT. Image quality was graded as good or excellent in all studies.

Continuous variables are expressed as mean ± standard deviation (SD), and were compared using the student *t* test. Categorical variables are expressed as percentages. LA area and volumes measured by MDCT and 2D TTE were compared using Pearson correlation and agreement between modalities was calculated using Bland-Altman plots. For all analyses, p values <0.05 were considered statistically significant. Analyze-it statistical software (Leeds, United Kingdom) was used to perform statistical analysis.

Results

Sixty-four patients consecutively referred to MDCT for whom complete echocardiographic data were available were included in the current analysis. Patients' clinical characteristics are listed in Table 1. The most common indication for MDCT was the evaluation of chest pain (80%).

The mean LA area measurement using MDCT was significantly larger than TTE measurement (25.5 ± 6.4 cm^2 vs 20.0 ± 5.2 cm^2 respectively; $p < 0.0001$). LA area measurement using MDCT were on average 27% larger than the area measurements using TTE. There was a moderate correlation between LA area measurements using MDCT and TTE (0.74, $p < 0.0001$). The Bland-Altman agreement plot comparing area measurements using MDCT and TTE showed a bias of −5.5 (95% CI −14.3 to 3.3, $p < 0.0001$) (Figure 2).

The mean LA volume measurement using MDCT was significantly larger than TTE measurement (92 ± 32 mL vs 68 ± 27 mL, respectively; $p < 0.001$). The LA volume measurements using MDCT were on average 35% larger than volumetric measurements using TTE. There was a moderate correlation between volumetric measurements using MDCT and TTE (0.77, $p < 0.0001$). The Bland-Altman comparing volume measurements using MDCT and TTE showed a bias of −23.7 (95% CI −64.9 to 17.5, $p < 0.0001$) (Figure 3).

There was no significant difference between TTE and MDCT area correlation (0.74) and volumetric measurements (0.77) using Pearson method ($p = 0.697$). The bias

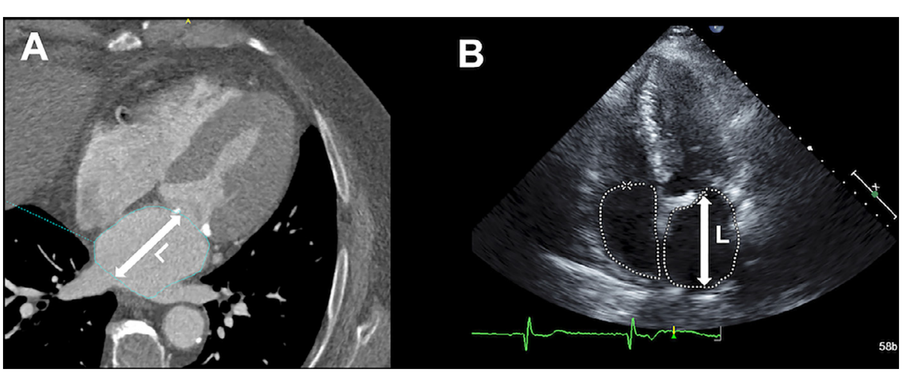

Figure 1. Measurement of LA volume using AL method by MDCT (A) and TTE (B). The LA area is traced from the apical 4-chamber and 2-chamber views at ventricular end-systole (maximal LA size). The length (L) is measured from the back wall to the line across the hinge points of the mitral valve. The shortest length between apical 4-chamber or 2-chamber is used in the equation. The LA volume is measured using the following equation: LA volume = $8/3\pi$ x [(A1) x (A2)/L]. A1, the LA area traced from the apical 4-chamber view; A2, the LA area traced from the apical 2-chamber view.
AL = area-length; LA = left atrial; MDCT = multi-detector computed tomography; TTE = trans-thoracic echocardiography

Table 1
Baseline characteristics (n = 64)

Characteristics Mean ± SD or n (%)	
Age (years)	62 ± 13
Men	48 (75%)
Diabetes Mellitus	20 (31%)
Hypertension*	43 (67%)
Hyperlipidemia†	36 (56%)
Smoker	16 (25%)
Family History of Coronary Artery Disease	26 (41%)
Ejection Fraction (%)	60 ± 12
Mitral Regurgitation ≥ Moderate	7 (11%)
Tricuspid Regurgitation ≥ Moderate	6 (9%)

* Hypertension was defined by the diagnosis of hypertension in the medical record or if anti-hypertensive medications were prescribed.

† Hyperlipidemia was defined by the diagnosis of hyperlipidemia in the medical record or if lipid-lowering medications were prescribed.

and 95% CI were smaller for the 2D TTE area measurements versus volumetric measurements when compared to MDCT ($p < 0.0001$). The interobserver variability for LA area measurements by TTE and MDCT was 5.8% ± 5.3 and 6.6% ± 4.1, respectively. For LA volumes the interobserver variability was 7.1% ± 4.5 for TTE and 8.6% ± 3.8 for MDCT.

Discussion

LA size measurements can be obtained using linear, 2D area, or volumetric measurements. LA enlargement by any one of these parameters is predictive of combined adverse cardiovascular outcomes.[7–9] Current ASE guidelines recommend using the highly desirable but nonvalidated volumetric measurements for assessment of LA size utilizing either the AL method or the Simpson's method.[2,10] Both area and volumetric measurements are dependent on correct angulation and positioning of the ultrasound beam relative to the LA as well as accurate measurement of the area and volume within the thin and poorly reflective LA walls, which are in the far field of the TTE image plane. Thus, both area and volumetric measurements rely heavily on the ability to accurately trace the LA area. However, measurement of LA volume also depends on additional uncorroborated assumptions regarding LA geometry. Namely, the recommended biplane method and formula have never been validated as being accurate and reproducible for LA volume. Volumetric measurements require a skilled sonographer so that image quality is optimal on both 4- and 2-chamber views, timing is precise (end-systole) and the LA is not foreshortened so its length and borders be accurately traced with the pulmonary veins and appendage excluded.[11] This makes LA volumes more prone to error and lower reproducibility particularly given the poor spatial resolution of the far

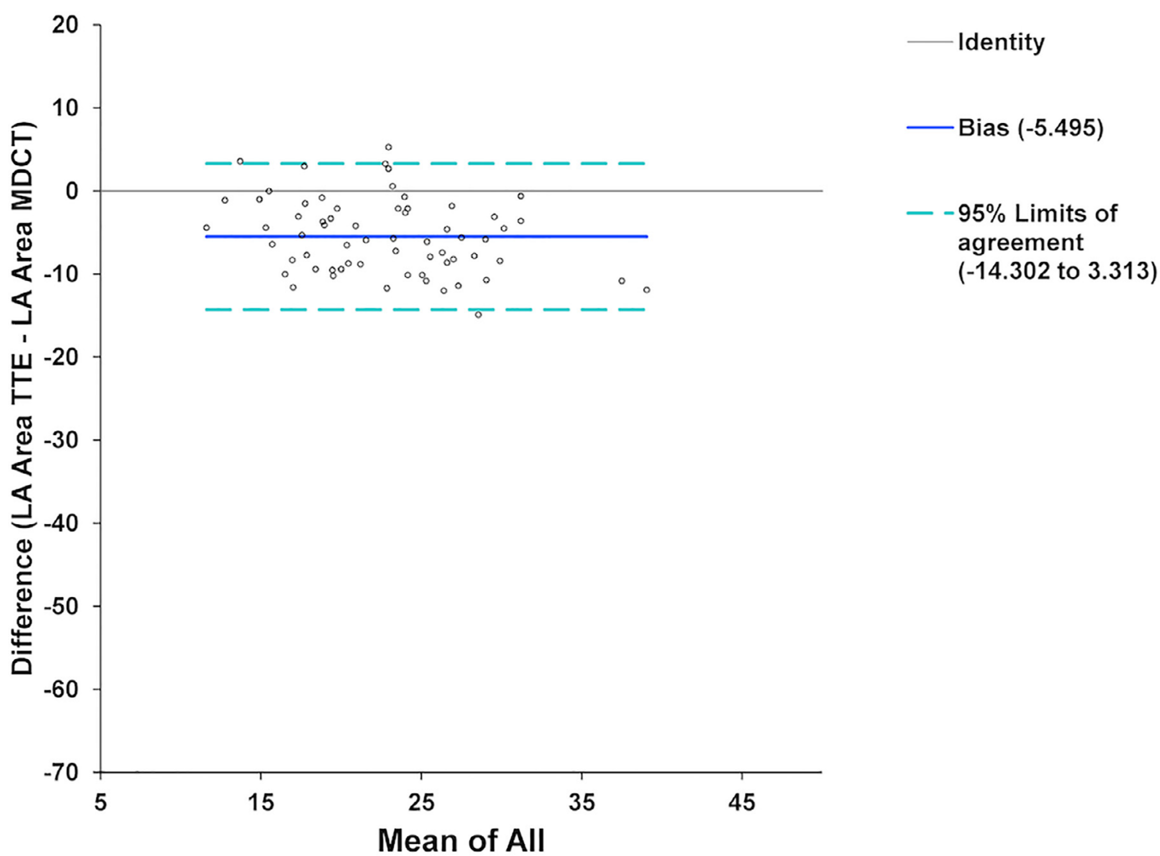

Figure 2. Bland-Altman plot demonstrating absolute differences of 2-dimensional LA area measurements between TTE and MDCT. The solid horizontal line represents the overall mean of the differences, and the dashed lines are 95% limits of agreement.
LA = left atrial; MDCT = multi-detector computed tomography; TTE = trans-thoracic echocardiography

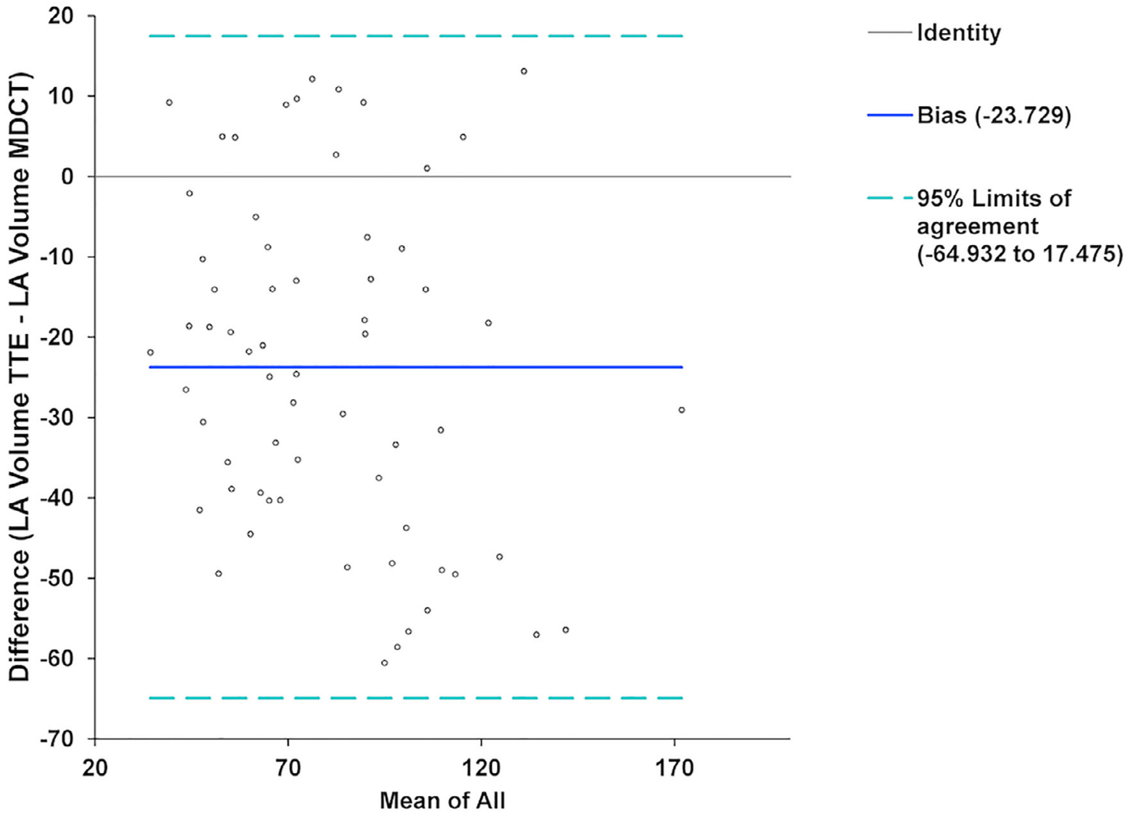

Figure 3. Bland-Altman plot demonstrating absolute differences of LA volumetric measurements between TTE and MDCT. The solid horizontal line represents the overall mean of the differences, and the dashed lines are 95% limits of agreement.
LA = left atrial; MDCT = multi-detector computed tomography; TTE = trans-thoracic echocardiography

field left atrium by 2D TTE. Furthermore, the echo reader is unable to adjust tracings for LA volume measurements while those for area measurements can be easily reviewed and adjusted, therefore decreasing the potential for error. Finally, volumetric measurements are more time-consuming. Indeed, as demonstrated in our current study, the limits of agreement, as well as bias, are significantly wider when using volumetric measurements as compared to area.

Prior studies comparing TTE volumetric measurements to MDCT or MRI have demonstrated that echocardiographic measurements tend to underestimate LA volumes.[10,12] Intravenous ultrasound enhancing agents (contrast) has been shown to improve accuracy.[13] A prior study by Koka et al[14] compared volumetric measurements using MDCT and TTE. Similar to our findings they have demonstrated moderate correlation between TTE and MDCT ($r = 0.60$ to 0.70). As in our study they also found that the mean indexed LA volumes measured on MDCT (53 ± 15 mL/m^2) were significantly higher than TTE measurements (28 ± 12 mL/m^2, $p < 0.001$), and with wide limits of agreement between the 2 modalities as in our study.

Tsang et al. reported that in patients with atrial fibrillation neither LA volume nor LA area were predictors of cardiovascular outcomes.[15] However, in patients with sinus rhythm, the authors concluded that LA volume was "a more robust marker of cardiovascular events" than LA area.[15] This conclusion was not well substantiated based on several methodologic flaws of this study: First, whenever the 2-chamber view appeared foreshortened, the investigators used the apical long axis as the complimentary plane for volume measurements, which is not performed during a standard measurement of the LA volume. Second, the difference in performance between LA area and LA volume in predicting cardiovascular events was modest (area under the curve of 0.64 vs 0.71, respectively), and in specific subgroups, such as those with moderate LA enlargement, LA area outperformed indexed LA volume in predicting cardiovascular events (adjusted hazard ratio of 3.9 vs 3.2, respectively).

Due to inaccuracies, geometric assumptions and foreshortening of the LA cavity with 2D echo, 3-dimensional (3D) echocardiography has potential advantages over 2D echo. Data is accumulating regarding normal reference values for 3D LA volumes, which is larger than those obtained by 2D echo.[16] However, 3D ultrasound systems are still not standardly used for LA volume measurement, they are limited in their temporal and spatial resolution, and 3D LA volumes underestimate those obtained by MRI.[16,17] Moreover, acquiring a 3D TTE multi-beat full volume data sets followed by off-line volume measurements is time-consuming, and the image quality is variable and dependent on patient cooperation and habitus. 3D accuracy and reproducibility depend on image quality, temporal and spatial resolution, operator's skill and experience, and type of software used.[16] In the future, improvements in echocardiographic software and automatization may overcome the current limitations of trans-thoracic 3D echo.

We acknowledge the limitation of this study as this was a retrospective, single-center study with a relatively small number of patients, although most prior studies comparing MDCT and TTE have had a relatively similar sample size. We also cannot exclude minor differences in cardiac cycle timing between echo and CT measurements, although LA dimensions were obtained at end-systole on both modalities.

LA volume measurements are desirable. However, its acquisition by 2D TTE is problematic. LA volumes by TTE are smaller than MDCT measurements. Compared to LA area measurements, LA volume measurements by 2D TTE are more time-consuming and difficult for an observer or over-reader to corroborate. LA volume has poorer limits of agreement than LA area when compared to MDCT, which makes it less reliable and consequently less suitable for serial assessment of LA size. Considering these findings, current ASE guidelines should be revisited, and at the present time, echo-cardiologists should be encouraged to reconsider reporting LA area as a useful and reliable method for assessing LA size.

Dislosures

The authors have no conflicts of interest to disclose.

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