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Quantitative Assessment of Left Atrial Volume by ECG-gated Contrast-enhanced Multidetector Computed Tomography

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Abstract

Background—LA volume is a predictor of cardiovascular events. Information on LA volume is available on contrast-enhanced ECG-gated MDCT scans.

Objective—To assess inter- and intraobserver reproducibility of 3-dimensional threshold-based volume (3DTV) and 2D measurements for the assessment of left atrial (LA) volumes using contrast-enhanced cardiac 64-slice Multidetector Computed Tomography (MDCT).

Methods—Contrast-enhanced 64-slice MDCT (0.6mm slice-thickness, 120kVp, 850mAseff) was performed in 96 consecutive subjects (mean age 52, 48% women) as a subset of the ROMICAT study. Two observers independently measured maximal (LAV_{max}) and minimal (LAV_{min}) LA volumes using 1) a modified Simpson's method (3DTV) based on delineation of LA areas in axial slices and 2) estimated LA volumes typically used in 2D echocardiography (Area Length and Prolate Ellipse). Inter- and intraobserver reproducibility for each method as well as correlations between the methods were calculated.

Results—Inter-(n=96) and intra-(n=20) observer variability was significantly lower for 3DTV (8%) than for area length (13%, $p<0.001$) or prolate ellipse (16%, $p<0.001$). 2D based measurements rendered significantly lower LA volumes compared to 3DTV (Area Length: −17% and −22%, Prolate Ellipse: −43% and −46% for LAV_{max} and LAV_{min} , respectively; $p<0.001$ for all). By 3DTV, mean LA volume was 90.4 ± 24.5 mL for LAV_{max} and 52.5 ± 17.6 mL for LAV_{min} .

Conclusion—ECG-gated contrast-enhanced cardiac MDCT offers volumetric assessment of LA with excellent reproducibility without additional contrast administration or radiation exposure. 3D measures of LA volume are more reproducible and render larger volumes than 2D derived estimates, typically used in echocardiography.

Keywords

Left Atrium; volumetric; MDCT; Reproducibility; Area Length; Prolate ellipse

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Introduction

Left atrial (LA) size is an independent predictor of cardiovascular events such as congestive heart failure, myocardial infarction, atrial fibrillation, stroke, and cardiovascular death.[1–9]

While two-dimensional echocardiography is the most commonly used modality for the assessment of LA size,[10] it uses geometric assumptions and when compared to the current gold standard cardiac magnetic resonance imaging, systematically underestimates LA volume.[11] With the rapid rise in usage of ECG-gated contrast-enhanced multidetector computed tomography (MDCT) for coronary artery disease evaluation, supplemental information on the left atrium throughout the cardiac cycle[12] is readily available for analysis.

Recently, Stolzmann et al. reported that CT allows assessment of LA anterior posterior diameter with excellent agreement to echocardiography.[13] Further studies have demonstrated a close correlation of 3-dimensional volume measurements of the LA using contrast-enhanced ECG-gated MDCT with 3D echocardiography in phantom studies and in vivo studies.[14,15] However, Christiaens et al. reported that echocardiography renders 35–37% smaller volumes using the Simpson's method as compared to 3D volume.[15]

In this study, we determined feasibility as well as inter- and intraobserver reproducibility of left atrial volume assessment using a 3 dimensional threshold based semi-automated method (3DTV) in a 96 consecutive subjects undergoing MDCT for evaluation of the coronary anatomy. Furthermore, we determined LA volume using two commonly used 2D methods (area length and prolate ellipse), and compared the volumes, derived from each measurement.

Methods

Study population

We included 96 consecutive subjects without clinically apparent cardiac disease who presented with chest pain to the emergency department but in whom acute coronary syndrome was ruled out during index hospitalization. These subjects underwent ECG-gated contrast-enhanced 64-slice MDCT as part of the ROMICAT study (Rule Out of Myocardial Infarction by Computer Assisted Tomography), a prospective observational cohort study of consecutive adult patients presenting to the emergency department with acute chest pain in whom initial evaluation of was inconclusive and who were awaiting admission.[16]

We excluded subjects who potentially had acute coronary syndrome (troponin elevation, ECG indicating myocardial ischemia, positive stress test or angiogram) or clinically apparent coronary artery disease (prior myocardial infarction, coronary stent implantation, or coronary artery bypass grafts), congestive heart failure, history of severe mitral or aortic valvular disease, or atrial fibrillation (reported intermittent atrial fibrillation or atrial fibrillation during index hospitalization) as further known predictors of LA enlargement. MDCT specific exclusion criteria were serum creatinine > 1.3 mmol/L, known allergy to iodinated contrast, history of asthma, previous intolerance to a beta-blocker, glucophage use, or referral for invasive coronary angiography. The presence of hypertension (defined as systolic blood pressure >140 mmHg, diastolic blood pressure >90 mmHg, or treatment with antihypertensive medications), hyperlipidemia (defined as total cholesterol >200 mg/dl or lipid lowering treatment), history or presence of smoking, prevalence of diabetes (defined as fasting plasma glucose of > 126 mg/dl or antidiabetic treatment), and a positive family history of early cardiovascular events (defined as myocardial infarction or cardiac death in first degree relatives under the age of 55 for males and 65 for females) were assessed in all subjects.

Approval was obtained from the institutional review board and all subjects provided written informed consent.

MDCT Imaging Protocol

Imaging was performed using a standard coronary artery 64-slice MDCT (Sensation 64, Siemens Medical Solutions, Forchheim, Germany) imaging protocol that included the administration of intravenous beta-blocker (up to 20 mg of intravenous lopressor), if the baseline heart rate was above 65 beats per minute and nitroglycerin (0.6 mg sublingual nitroglycerin), if contraindications were absent.

Images were acquired in spiral mode with 330 ms rotation time, 32×0.6 mm collimation, a pitch of 0.2, tube voltage of 120 kVp, with maximum effective tube current-time product of 850 mAs during a time interval from 470 ms to 140 ms before the next expected R-wave. Tube current was reduced by 80% during the remaining portion of the cardiac cycle. Contrast transit time was determined with a test bolus injection. On average, 80mL of iodinated contrast agent (Iodhexadol 320 g/cm³, Visipaque, General Electric Healthcare, Princeton, NJ), followed by 40mL saline solution was injected at a rate of 5mL/s. The beginning of image acquisition was delayed according to the contrast agent transit time, calculated from the test bolus scan.

Quantitative Assessment of Left Atrial Volumes

The measurements were performed offline using a dedicated workstation (Leonardo, Siemens Medical Solutions, Forchheim, Germany). To determine the interobserver reproducibility, two independent readers performed all measurements on LA volumes. To determine the intra-observer reproducibility, one reader repeated the measurements of 20 randomly selected cases.

Left atrial volume measurements were performed for both the cardiac phase with maximal (LAV_{max}) and minimal LA volume (LAV_{min}). The maximum LA volume (LAV_{max}) was measured from the end-systolic phase just before the mitral valve opening with the largest LA cavity and smallest LV cavity, as determined qualitatively from multiplanar LV short-axis, two-chamber, and four-chamber views. Conversely, the minimum LA volume (LAV_{min}) was measured from the end-diastolic phase at the mitral valve closure with the smallest LA cavity and largest LV cavity. Maximal and minimal LA volumes were assessed using the following methods:

A. 3D Threshold-based volume (3DTV) measurements:

LAV_{max} and LAV_{min} were measured using a modified Simpson's method. The images were reconstructed using a semiautomated software program (Volume Viewer, Leonardo, Siemens Medical Solutions, Forchheim, Germany). Regions of interest (ROI) containing the area of the LA were manually traced in each axial slice (slice thickness of 1.5 mm, Figure 1). Pulmonary veins were excluded by visual determination of the orifice of the pulmonary veins into the LA in axial, coronal, and sagittal view. In addition to the manual delineation, a window of 100 to 1000 Hounsfield units was applied to exclude trabecula and other parts of the muscular wall within the ROI. Afterwards the volume of the LA was calculated using Simpson's rule.

B. Volume estimated from 2D area and diameter measurements:

For the 2D based MDCT measurements, we adapted two commonly used 2D echocardiography methods (Area Length Method [17] and the Prolate Ellipse Technique [17]), which use geometric shape assumptions for estimating LA volumes.

Area Length Method

The area of the left atrium was determined by manual drawings of the boundaries in both four- and two-chamber view. The anterior-posterior diameter of the left atrium was measured in four-chamber view (Figure 2). LA volumes were calculated for both LAV_{max} and LAV_{min} as follows:

$$Volume = \frac{\text{Area (4 – chamber)} \times \text{Area (2 – chamber)} \times 0.85}{\text{Anterior – posterior diameter}}$$

Prolate Ellipse Technique

The anterior-posterior (D1) and the medial-lateral diameter (D2) of the left atrium in four-chamber view and the anterior-posterior diameter in three-chamber view (D3) were measured (Figure 2). LA volumes were calculated for both LAV_{max} and LAV_{min} as follows:

$$Volume = 0.523 \times D1 \times D2 \times D3$$

Statistical Analysis

The distribution of continuous variables is presented as mean $\pm$ standard deviation and binary variables are given in percentages. We determined the inter- and intra-observer reproducibility using a single measure interclass correlation model for all volume measurements. Absolute and relative differences of the reads for inter- and intra-observer variability were compared for the all methods using paired student's t-test. Similarly, differences between 3D and 2D derived LA volumes and differences between genders were compared using paired student's t-test.

LA volume index was calculated as the volume divided by the body surface area based on the DuBois formula.[18] A p-value of ≤ 0.05 was considered to indicate statistical significance. All statistical analyses were performed using SPSS 14.01 software (LEAD Technologies, New York).

Results

We included 96 consecutive subjects (mean age 52 ± 12 years, 46 female (48 %)). Subject demographics are shown in table 1. LAV_{max} and LAV_{min} could be assessed for all subjects.

Measurement Reproducibility

Using 3DTV, inter- and intra-observer reproducibility was excellent for the assessment of end-diastolic and end-systolic LA volume as quantified by contrast-enhanced ECG-gated MDCT (Table 2, $p < 0.001$). Compared to 2D measurements, which are based on geometric assumptions, 3DTV as modified by Simpson's method has a significantly smaller inter- and intraobserver variability (Table 2, $p < 0.001$).

LA volumes based on 3DTV and comparison to 2D based volumes

Mean LAV_{max} was 90.38 ± 24.48 mL (range: 46.96–166.71 mL) and LAV_{min} was 52.39 ± 17.62 mL (range: 25.71–108.07 mL) (Table 3). Mean LAV_{max} volume index was 41.96 ± 10.76 mL/m² and LAV_{min} volume index was 24.35 ± 8.33 mL/m².

Although, correlations between the volume derived from the 2D methods (Area Length and Prolate Ellipse) and 3DTV were very good (Area Length vs. 3DTV: $r = 0.90$ LAV_{max} , $r = 0.93$ LAV_{min} ; Prolate Ellipse vs. 3DTV: $r = 0.81$ LAV_{max} , $r = 0.85$ LAV_{min} ; $p < 0.001$ for all), LA

volumes estimated by 2D based methods were significantly lower as compared to 3DTV (Area Length vs. 3DTV: 74.97 ± 22.24 vs. 90.38 ± 24.48 mL, 17.1%; 40.83 ± 18.24 vs. 52.39 ± 17.62 mL, 22.1%, for $LAV_{\max}$ and $LAV_{\min}$, respectively and Prolate Ellipse vs. 3DTV: 51.18 ± 18.84 vs. 90.38 ± 24.48 mL, 43.4%; 28.20 ± 13.60 vs. 52.39 ± 17.62 mL, 46.2% for $LAV_{\max}$ and $LAV_{\min}$, respectively; $p < 0.001$ for all, Figure 3, 3).

Discussion

We demonstrate the excellent reproducibility of 3D methods for the assessment of LA volume in the phase of maximal and minimal LA volume as quantified by contrast-enhanced ECG-gated MDCT. Compared to 2D measurements, which are based on geometric assumptions, 3DTV as modified by Simpson's method has a significantly smaller inter- and intraobserver variability. Although 2D based methods, commonly used in echocardiography, were strongly correlated to 3DTV, these measurements rendered significantly smaller LA volumes when compared to 3DTV. Quantification of LA volume was feasible in all subjects, even though they had undergone MDCT for other reasons than determination of LA size and scanning technique has not been specifically modified in order to allow LA assessment.

Comparison of 3DTV to 2D methods

Two-dimensional methods are most commonly used for the evaluation of LA size in clinical practice because of their simplicity. However, we found larger variability and significant underestimation as compared to 3DTV (17–46%). These findings are in good agreement with previously published cardiac magnetic resonance imaging (17–34%), [11] and 3D echocardiography (19%) [19] literature. Notably, the Prolate Ellipse method appears to underestimate LA volumes even more than the Area Length method as demonstrated in our study and by echocardiographic comparisons [20] (16% by echocardiography, 32% in our data). The underestimation of LA volumes by area length method and prolate ellipse technique may be due to the inherent limitations of 2D methods, which are based on geometric shape assumptions. In contrast, with 3DTV the volume is measured, using data from all 3 dimensions by tracing the area in every single slice and calculating the volume based on the Simpson's rule.

LA volume by MDCT using 3DTV

Notably, we report a wide range of LA volumes in this cohort of subjects without any objective evidence for coronary artery disease or other cardiac disease as predictors of LA enlargement. Our LA volume measurements show good agreement with previously published cardiac magnetic resonance imaging based volumes obtained in a healthy study population [21] ($LAV_{\max}$ volume: 96.7mL vs. 90.46mL and $LAV_{\min}$ volume: 42.9mL vs. 52.5mL; respectively).

Using 3DTV we found larger LA volumes than reference values for echocardiography that have previously been published. Together with the finding of Christiaens et al., reporting that echocardiography using Simpson's method renders 35–37% smaller LA volumes than MDCT, this may indicate the need of modality specific reference values for LA volumes.

Potential Clinical Applications

Available data suggest that quantitative assessment of maximal LA volume may add value for cardiovascular risk stratification. [6–8,22,23] Contrast-enhanced ECG-gated MDCT scans are preformed clinically for a variety of reasons. While MDCT is an accepted technique for assessment of the LA prior to ablation therapy, [24] information on the LA is also available in scans preformed for other primary indications like assessment of the coronary anatomy. With the developments of MDCT scanners and thereby achieved improvement of temporal

resolution, 64-slice MDCT allows reliable information on cardiac function as determined for left ventricular volumes throughout the cardiac cycle [25,26] with good correlation to cardiac magnetic resonance imaging.[26]

Recently studies have outlined the accuracy of 3D LA volume measurements from contrast-enhanced 64-slice MDCT.[14,15] Our results indicate that with the advent of cardiac CT, information on LA 3-dimensional volume is simultaneously available and can be quantified within minutes with high reproducibility without any additional contrast administration or radiation. The time needed to assess 3D LA volume using our approach may be too long to perform these measurements on daily clinical bases. However, by selection of an expanded slice thickness and new software programs, the evaluation may be cut down to a minute or less.

Limitations

We did not compare our MDCT-derived measurements to cardiac magnetic resonance imaging or echocardiography as a gold standard for the assessment of LA dimensions. However, previous studies have compared 3DTV by MDCT to 3D LA volume by echocardiography and shown a close correlation of both techniques. Furthermore, our results are in good agreement with previously published studies on cardiac magnetic resonance imaging, echocardiography, and post mortem examinational studies.[11,19,21,27] As a further limitation – although subjects with a cardiac origin of their chest discomfort were excluded – this is not an asymptomatic study population. Therefore, combined with our limited sample size, normal values can not be defined based on our study sample. Larger studies will be necessary to define normative values and to assess whether MDCT-based measures of LA are associated with cardiovascular risk factors and provide incremental information for the prediction of cardiovascular events.

Conclusion

Contrast-enhanced ECG-gated MDCT allows quantitative evaluation of LA volume with excellent reproducibility. 3D threshold-based measurements have significantly smaller inter- and intraobserver variability and render significantly larger LA volumes as compared to 2D based estimates of LA volume. CT based measures of LA volumes can be derived from any ECG-gated contrast-enhanced cardiac CT scan without additional radiation exposure or contrast administration.

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List of abbreviations

LA	Left atrium
LAV_{max}	volume of the left atrium at the cardiac phase of maximal LA size
LAV_{min}	volume of the left atrium at the cardiac phase of minimal LA size
MDCT	

Multidetector Computed Tomography

3DTV

3-dimensional threshold-based volume

References

1. Corbalan R, Arriagada D, Braun S, Tapia J, Huete I, Kramer A, Chavez A. Risk factors for systemic embolism in patients with paroxysmal atrial fibrillation. *American heart journal* 1992;124(1):149–153. [PubMed: 1615799]
2. Vaziri SM, Larson MG, Benjamin EJ, Levy D. Echocardiographic predictors of nonrheumatic atrial fibrillation. The Framingham Heart Study *Circulation* 1994;89(2):724–730.
3. Budeus M, Felix O, Hennersdorf M, Wieneke H, Erbel R, Sack S. Prediction of conversion from paroxysmal to permanent atrial fibrillation. *Pacing Clin Electrophysiol* 2007;30(2):243–252. [PubMed: 17338722]
4. Kizer JR, Bella JN, Palmieri V, Liu JE, Best LG, Lee ET, Roman MJ, Devereux RB. Left atrial diameter as an independent predictor of first clinical cardiovascular events in middle-aged and elderly adults: the Strong Heart Study (SHS). *American heart journal* 2006;151(2):412–418. [PubMed: 16442908]
5. Tsang TS, Abhayaratna WP, Barnes ME, Miyasaka Y, Gersh BJ, Bailey KR, Cha SS, Seward JB. Prediction of cardiovascular outcomes with left atrial size: is volume superior to area or diameter? *Journal of the American College of Cardiology* 2006;47(5):1018–1023. [PubMed: 16516087]
6. Tsang TS, Barnes ME, Gersh BJ, Bailey KR, Seward JB. Left atrial volume as a morphophysiologic expression of left ventricular diastolic dysfunction and relation to cardiovascular risk burden. *The American journal of cardiology* 2002;90(12):1284–1289. [PubMed: 12480035]
7. Tsang TS, Barnes ME, Gersh BJ, Takemoto Y, Rosales AG, Bailey KR, Seward JB. Prediction of risk for first age-related cardiovascular events in an elderly population: the incremental value of echocardiography. *Journal of the American College of Cardiology* 2003;42(7):1199–1205. [PubMed: 14522480]
8. Gottdiener JS, Kitzman DW, Aurigemma GP, Arnold AM, Manolio TA. Left atrial volume, geometry, and function in systolic and diastolic heart failure of persons ≥ 65 years of age (the cardiovascular health study). *The American journal of cardiology* 2006;97(1):83–89. [PubMed: 16377289]
9. Pritchett AM, Jacobsen SJ, Mahoney DW, Rodeheffer RJ, Bailey KR, Redfield MM. Left atrial volume as an index of left atrial size: a population-based study. *Journal of the American College of Cardiology* 2003;41(6):1036–1043. [PubMed: 12651054]
10. Tops LF, van der Wall EE, Schalij MJ, Bax JJ. Multi-modality imaging to assess left atrial size, anatomy and function. *Heart (British Cardiac Society)* 2007;93(11):1461–1470. [PubMed: 17934005]
11. Rodevan O, Bjornerheim R, Ljosland M, Maehle J, Smith HJ, Ihlen H. Left atrial volumes assessed by three- and two-dimensional echocardiography compared to MRI estimates. *Int J Card Imaging* 1999;15(5):397–410. [PubMed: 10595406]
12. Flohr T, Ohnesorge B. Heart rate adaptive optimization of spatial and temporal resolution for electrocardiogram-gated multislice spiral CT of the heart. *Journal of computer assisted tomography* 2001;25(6):907–923. [PubMed: 11711804]
13. Stolzmann P, Scheffel H, Trindade PT, Plass AR, Husmann L, Leschka S, Genoni M, Marincek B, Kaufmann PA, Alkadhi H. Left ventricular and left atrial dimensions and volumes: comparison between dual-source CT and echocardiography. *Investigative radiology* 2008;43(5):284–289. [PubMed: 18424948]
14. Avelar E, Durst R, Thangaroopan M, Rosito GA, Tournoux F, Chan RC, Hung J, Hoffmann U, Abbata S, Cury RC. Accuracy of Multi-detector Computed Tomography Evaluation of Left Atrial Volume for Prognostic Evaluation: a Phantom and Echo Correlation Study. *Journal of the American College of Cardiology* 2008, Supplement A 2008;51:A153.
15. Christiaens L, Lequeux B, Ardilouze P, Ragot S, Mergy J, Herpin D, Bonnet B, Allal J. A new method for measurement of left atrial volumes using 64-slice spiral computed tomography: Comparison with two-dimensional echocardiographic techniques. *Int J Cardiol.* 2008

16. Hoffmann U, Nagurney JT, Moselewski F, Pena A, Ferencik M, Chae CU, Cury RC, Butler J, Abbata S, Brown DF, et al. Coronary multidetector computed tomography in the assessment of patients with acute chest pain. *Circulation* 2006;114(21):2251–2260. [PubMed: 17075011]
17. Feigenbaum, H.; Armstrong, WF.; Ryan, T. Feigenbaum's Echocardiography. Vol. 6. Philadelphia: Lippincott Williams & Wilkins; 2004.
18. DuBois EF. A formula to estimate the approximate surface area if height and weight be known. *Archives of internal medicine* 1916;17:865–871.
19. Maddukuri PV, Vieira ML, DeCastro S, Maron MS, Kuvin JT, Patel AR, Pandian NG. What is the best approach for the assessment of left atrial size? Comparison of various unidimensional and two-dimensional parameters with three-dimensional echocardiographically determined left atrial volume. *J Am Soc Echocardiogr* 2006;19(8):1026–1032.
20. Ujino K, Barnes ME, Cha SS, Langins AP, Bailey KR, Seward JB, Tsang TS. Two-dimensional echocardiographic methods for assessment of left atrial volume. *The American journal of cardiology* 2006;98(9):1185–1188. [PubMed: 17056324]
21. Hudsmith LE, Petersen SE, Francis JM, Robson MD, Neubauer S. Normal human left and right ventricular and left atrial dimensions using steady state free precession magnetic resonance imaging. *J Cardiovasc Magn Reson* 2005;7(5):775–782. [PubMed: 16353438]
22. Alsaleek AA, Osranek M, Fatema K, McCully RB, Tsang TS, Seward JB. Predictive value of normal left atrial volume in stress echocardiography. *Journal of the American College of Cardiology* 2006;47(5):1024–1028. [PubMed: 16516088]
23. Moller JE, Hillis GS, Oh JK, Seward JB, Reeder GS, Wright RS, Park SW, Bailey KR, Pellikka PA. Left atrial volume: a powerful predictor of survival after acute myocardial infarction. *Circulation* 2003;107(17):2207–2212. [PubMed: 12695291]
24. Saremi F, Krishnan S. Cardiac conduction system: anatomic landmarks relevant to interventional electrophysiologic techniques demonstrated with 64-detector CT. *Radiographics* 2007;27(6):1539–1565. [PubMed: 18025502]discussion 1566-1537
25. Mahnken AH, Hohl C, Suess C, Bruder H, Muhlenbruch G, Das M, Gunther RW, Wildberger JE. Influence of heart rate and temporal resolution on left-ventricular volumes in cardiac multislice spiral computed tomography: a phantom study. *Investigative radiology* 2006;41(5):429–435. [PubMed: 16625105]
26. Brodoefel H, Klumpp B, Reimann A, Fenchel M, Heuschmid M, Miller S, Schroeder S, Claussen C, Scheule AM, Kopp AF. Sixty-four-MSCT in the characterization of porcine acute and subacute myocardial infarction: determination of transmural extent in comparison to magnetic resonance imaging and histopathology. *European journal of radiology* 2007;62(2):235–246. [PubMed: 17187952]
27. Ernst G, Stollberger C, Abzieher F, Veit-Dirscherl W, Bonner E, Bibus B, Schneider B, Slany J. Morphology of the left atrial appendage. *Anat Rec* 1995;242(4):553–561. [PubMed: 7486025]

Figure 1. Boundaries of the left atrium traced in an axial slide (A) and the 3D reconstruction of the region of interest in coronal view (B) and sagittal (C) view. After manual delineation, the volume is automatically calculated by summation of pixels inside the region of interest within a window of 100–1000 Hounsfield Units (white pixels, D–F).

Figure 2.

LA volume by Area Length method and Prolate Ellipse technique. For Area Length, the area of the left atrium was determined by manual drawings of the boundaries in both four- and two-chamber view (A, B). The anterior-posterior diameter of the left atrium was measured in four-chamber view (A). For Prolate Ellipse, the anterior-posterior and the medial-lateral diameter of the left atrium in four-chamber view (C) and the anterior-posterior diameter in three-chamber view (D) were measured.

Figure 3.

End-diastolic volumes of left atrium by 3D Threshold-based Volume compared to 2D based Area Length (A) and Prolate Ellipse (B) methods showing significant underestimation of left atrial volume by the 2D methods compared to 3DTV ($p < 0.001$ for both).

Figure 4.

Differences between the LA volumes determined by 3D Threshold-based Volume and Area Length and Prolate Ellipse, showing that 2D methods underestimate LA volume compared to 3DTV for low but even more for higher values. This underestimation is more distinctive for Prolate Ellipse than for Area Length. The continuous line represents the mean difference, the dashed lines are positioned at ± 2 standard deviations.

AL = Area Length, PE = Prolate Ellipse

Table 1

Subject Demographics (n = 96), Data presented as mean $\pm$ standard deviation for continuous traits or n (percents) for dichotomous traits

Characteristic	Gender		Total
	Female	Male	
Number of subjects	46 (48%)	50 (52%)	96
Age	55 $\pm$ 12	50 $\pm$ 11	52 $\pm$ 12 years
Body mass index	28.4 $\pm$ 5.8	28.8 $\pm$ 4.6	28.6 $\pm$ 5.3 kg/m ²
Body surface area	2.0 $\pm$ 0.2	2.3 $\pm$ 0.2	2.2 $\pm$ 0.3 m ²
Hypertension	21 (47%)	21 (41%)	42 (44%)
Hyperlipidemia	15 (33%)	20 (40%)	35 (36%)
Smoker	16 (35%)	27 (54%)	43 (45%)
Diabetes	3 (7%)	3 (6%)	6 (6%)
Family History of CVD	11 (24%)	7 (14%)	18 (19%)

CVD = Cardiovascular disease

Table 2

Interclass correlation and relative difference of inter- and intraobserver reads of 3D Threshold-based Volume, Area Length, and Prolate Ellipse, showing significantly better reproducibility of 3D Threshold-based Volume compared to the 2D methods

		Interobserver Variability		Intraobserver Variability	
		Interclass-Coefficient	Relative Difference $\pm$ SD	Interclass-Coefficient	Relative Difference $\pm$ SD
LAV _{max}	3D Threshold-based Volume	0.981 [*]	5.7 $\pm$ 4.0%	0.996 [*]	2.5 $\pm$ 2.3%
	Area Length	0.908 [*]	9.9 $\pm$ 7.7%	0.962 [*]	8.1 $\pm$ 6.7
	Prolate Ellipse	0.907 [*]	13.3 $\pm$ 10.3%	0.967 [*]	5.9 $\pm$ 7.0%
LAV _{min}	3D Threshold-based Volume	0.926 [*]	9.4 $\pm$ 8.8%	0.997 [*]	2.8 $\pm$ 1.8%
	Area Length	0.867 [*]	15.2 $\pm$ 12.0%	0.961 [*]	10.4 $\pm$ 6.5%
	Prolate Ellipse	0.882 [*]	18.0 $\pm$ 14.6%	0.968 [*]	12.1 $\pm$ 9.9%

^{*} p<0.001, SD = standard deviation

Table 3

LA volumes using 3D Threshold-based Volume

	LAV _{max}	LAV _{min}
Mean ±SD (mL)	90.4±24.5	52.5±17.6
Median (mL)	88.3	48.9
Range (mL)	47.0 – 166.7	25.7 – 108.1

SD = standard deviation