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Echocardiography

Measurement of Left and Right Atrial Volume in Patients Undergoing Ablation for Atrial Arrhythmias: Comparison of a Manual versus Semiautomatic Algorithm of Real Time 3D Echocardiography

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Aims: Real time full-volume 3D echocardiography (3DE) allows rapid and noninvasive measurement of left (LA) and right atrial (RA) volume without geometric assumptions. Different algorithms from different commercial providers are available. Older software requires manual tracing of endocardial contours. Recently, software with semiautomatic endocardial contour-finding algorithms has become available, which considerably speeds up the procedure. Our aim was to compare, in the same dataset, both LA and RA volumes determined by an algorithm involving manual tracing to the corresponding volumes obtained by an algorithm with semiautomatic contour detection. Methods: Maximal atrial volumes were measured in 88 patients using a multiplane interpolation method algorithm based on manual planimetry of 8 slices. These volumes were compared with volumes determined by the QLAB 8.1 software using semiautomatic border detection. Results: Linear regression showed excellent correlation between volumes determined by manual and by semiautomatic software for both LA and RA (r^2 = 0.90 and 0.89, respectively, P < 0.001). Bland–Altman analysis of manual versus semiautomatic volume determination showed narrow 95% limits of agreement (−15.9 to +12.0 mL for LA volume and −13.9 to +12.2 mL for RA volume) with a minimal bias of −1.9 ± 7.0 mL and −0.8 ± 6.5 mL, respectively, by the semiautomatic method. Conclusion: The semiautomatic border detection method shows excellent correlation for maximal LA and RA volume determination compared to the more time-consuming, multiplane interpolation method, with only slight underestimation. The results indicate that values of LA and RA volumes obtained by either algorithm can be compared, for example, during follow-up examinations. (Echocardiography 2014;31:499–507)

Key words: left atrial volume, right atrial volume, three-dimensional echocardiography

There is now good evidence that left atrial (LA) and right atrial (RA) enlargement, as determined by echocardiography, predict cardiovascular outcomes.[1–6] In fact, LA size is increasingly recognized as marker of atrial fibrillation (AF) recurrence following cardioversion and as predictor of radiofrequency catheter ablation (RFCA) efficacy in AF,[7,8] now standard therapy in selected patients.[9] On the other hand, RA size has prognostic implications in a number of arrhythmias, pulmonary hypertension, valvular lesions, and congenital heart disease.[3,10–13] The most widely used and best available noninvasive imaging technique for determination of LA and RA size is echocardiography.[14] The advent of real time full-volume three-dimensional

echocardiography (3DE) now allows rapid measurement of chamber volume without making geometric assumptions,[15,16] as volume is reconstructed from endocardial contours of the entire chamber.[17,18] This method, extensively used for measurement of left ventricular (LV) volume and ejection fraction,[15,19] has recently also been validated for LA volume determination against magnetic resonance imaging (MRI)[20–24] and multislice CT[25,26] and is more reproducible than 2DE.[27,28] Indeed, 3DE is increasingly used for measurement of LA size[8,29–33] and can also be applied to the RA.[8,33–36] Different algorithms from different commercial providers are available. Older software requires manual tracing of endocardial contours.[20,21,36] Recently, software with semiautomatic endocardial contour-finding algorithms has become available, which considerably speeds up the procedure.[22,30–33] We previously showed limited interchangeability of different imaging modalities for measurement of

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LA volume.[37,38] The same may be true for different software algorithms of the same modality. Therefore, it is important to know whether values obtained by different algorithms of 3DE are interchangeable, particularly for follow-up examinations. Our aim was to compare, in the same 3D dataset, LA and RA volumes determined by an algorithm involving manual tracing to corresponding values obtained by a software algorithm with semiautomatic contour detection.

Methods:

Patients:

Three-dimensional echocardiography datasets of 88 patients, mainly with a history of paroxysmal or persistent AF, undergoing RFCA were included in the study. We chose patients who all had adequate 3DE datasets for LA and RA volume analysis by an algorithm involving manual tracing of endocardial contours. The datasets had been already analyzed by a manual tracing method for a previously published study of our group.[29,34] For the purpose of this study, the selected datasets were analyzed, in addition, with a semiautomatic algorithm, which was feasible in most patients (in 99% for LA and in 95% for RA volume analysis). The present analysis included only patients who were in sinus rhythm when studied by standard 2D echocardiography and real time 3DE. Few patients had significant structural cardiac diseases. Patient demographics are shown in Table I. Approximately one-third of the patients had dilated atria according to recent guidelines[14,39] that are based on four-chamber planimetry (Table II). The study complies with the Declaration of Helsinki and was approved by the local ethics committee. All patients gave informed consent.

Standard Echocardiography:

Standard echocardiograms according to current guidelines[14] were acquired in all patients within 24 h of the ablation procedure, using a transthoracic 3 MHz phased-array transducer and a Sonos 7500 echocardiograph (Philips Medical Systems, Andover, MA, USA). We acquired several recordings from each view, and performed measurements on the best images. The parasternal long-axis (PLAX) view was used for measuring the diameter of the LA. The apical four-chamber view was used for planimetry of the cross-sectional area (4CH planimetry) and long-axis diameter of the LA and RA. The apical two-chamber view was recorded for planimetry and long-axis diameter of the LA. The echo images were acquired by 2 experienced observers and measurements were done off line at ventricular end-systole by 1 of the observers (H.M.).

Real Time 3DE Acquisition:

The 3DE images were obtained during the same session as the standard echocardiograms from an apical window using the "full volume acquisition mode" over 4 cardiac cycles during a breath hold near the end-expiratory phase using a matrix-array ultrasonographic transducer (X4, Sonos 7500; Philips Medical Systems). At least 3 pyramid-shaped acquisitions including both atria were performed with a temporal resolution between 15 and 19 volume frames/sec depending on the sector size. The dataset with the best image quality for the respective atrium was chosen for analysis.

3DE Atrial Volume Measurement with the Multiplane Interpolation Method Algorithm (Cardio-View v.1.3; Tomtec):

Measurement of 3DE LA and RA volumes was performed off line by a single observer (H.M.) using dedicated commercially available software (4D Analysis Cardio-View v1.3; Tomtec Gmbh, Unterschleissheim, Germany) allowing volume measurements without geometric assumptions.[40] The left and right atria were evaluated separately. The technique has been described in our previous publications[8,29,34] and by others.[21,36] In brief, the full-volume dataset was centered on the atrium being studied and 8 uniformly spaced long-axis planes, 22.5° apart, were created, ensuring that all portions of the atrium were included in the analyzed 3D dataset. LA and RA volume measurements were done by planimetry of endocardial contours in the 8 longitudinal slices. Contour tracing was performed manually at ventricular end-systole in the frame just before

TABLE I

Patient Population Demographics

	Patients (n = 88)
M/F	75 (85.3%)/13 (14.7%)
Age (Years ± SD)	56.9 ± 9.4 Range [36–74]
Type of AF	
Paroxysmal	72 (81.8%)
Persistent	12 (13.6%)
Type of AFL	
Typical	1
Atypical	3
Ischemic heart disease	3 (3.4%)
Significant left ventricular dysfunction (EF < 45%)	6 (6.8%)
Significant mitral regurgitation (at least moderate)	1
Valvular prosthesis	1
Pacemaker	2

AF = atrial fibrillation; AFL = atrial flutter.

TABLE II

Results of the Different Imaging Modalities for LA and RA Size

	Patients	Mean $\pm$ SD (Range)
Left atrium (LA)		
LA PLAX (cm)	88	4.1 $\pm$ 0.6 (2.6–6)
(cm/m^2)		2.1 $\pm$ 0.3 (1.4–3.1)
LA 4CH planimetry (cm^2)	88	18.2 $\pm$ 5.3 (9.1–37)
LA 4CH planimetry $\geq$20 cm^2	32 (36%)	
3DE manual LA volume (mL)	88	56.2 $\pm$ 22.0 (16.0–116.2)
LA volume (mL/m^2)		27.9 $\pm$ 10.1 (8.7–57.4)
3DE semiautomatic LA volumes (mL)	87	54.1 $\pm$ 21.7 (14.4–127.7)
LA volume (mL/m^2)		26.9 $\pm$ 10.2 (7.9–57)
Right atrium (RA)		
RA 4CH planimetry (cm^2)	88	16.1 $\pm$ 4.1 (8.5–29)
RA 4CH planimetry $\geq$18 cm^2	28 (32%)	
3DE manual RA volume (mL)	88	48.0 $\pm$ 19.1 (17.8–112.0)
RA volume (mL/m^2)		24.1 $\pm$ 9 (8.2–50.3)
3DE semiautomatic RA volume (mL)	84	47.4 $\pm$ 18.9 (20.9–104.6)
RA volume (mL/m^2)		23.8 $\pm$ 9 (10.5–50.6)

PLAX = parasternal long axis; 4CH planimetry = apical four-chamber planimetry area; 3DE = three-dimensional echocardiography.
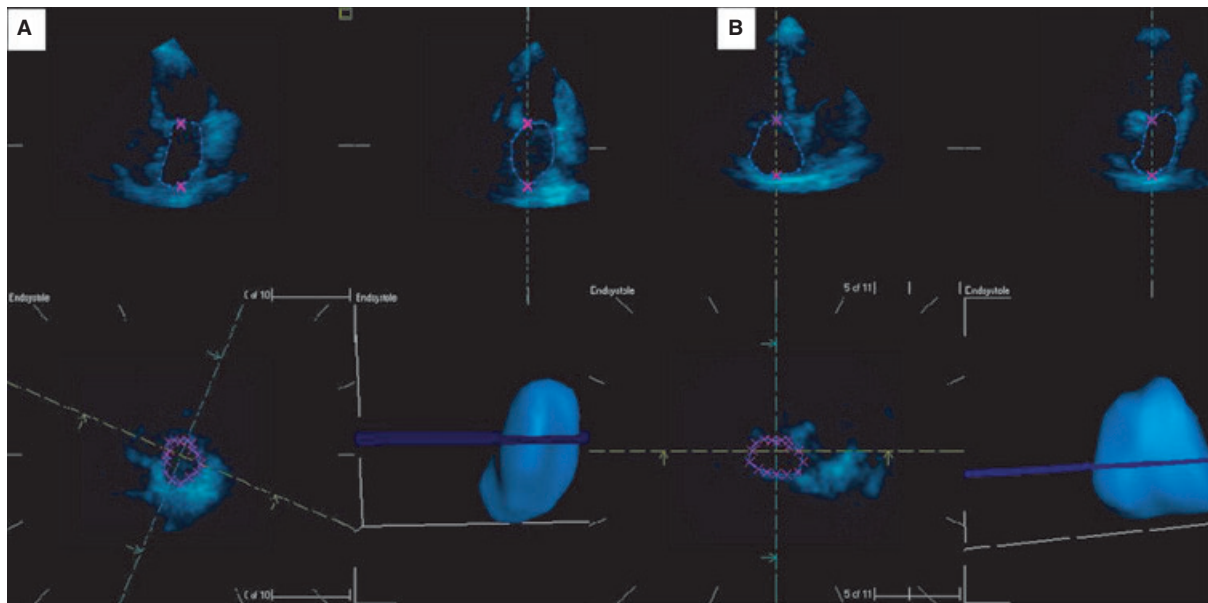
Figure 1. Example of left atrial (LA) **A.** and right atrial (RA) **B.** volume measurement by the manual (Tomtec) software. Planimetry of endocardial contours in 8 uniformly spaced long-axis planes, 22.5° apart. Contour tracing was performed manually at ventricular end-systole in the frame just before mitral, respectively, tricuspid valve opening. The resulting three-dimensional cast yielded maximal LA or RA volume.

mitral, respectively, tricuspid valve opening. The system calculated the cavity volume using an algorithm which fills the gaps between the traced image planes (interpolation method).[40] The resulting 3D cast yielded maximal LA or RA volume (Fig. 1). Processing of the images took ~10 minutes for each case. For this method, we have previously reported high feasibility and good reproducibility of LA and RA 3DE volume measurements in patients with atrial arrhythmias with 95% limits of agreement of −5.9 to 8.9 mL and −7.5 to 11.2 mL, respectively, for intra-observer reproducibility, and −12.5 to 11.3 mL and −10.9 to 12.9 mL, respectively, for inter-observer reproducibility.[29,34] The reproducibility was similar for patients in sinus rhythm compared

to those with AF.[29,34] The time interval for intra-observer reproducibility was at least 2 months. The second observer for determination of inter-observer reproducibility was blinded to the results of the first observer.
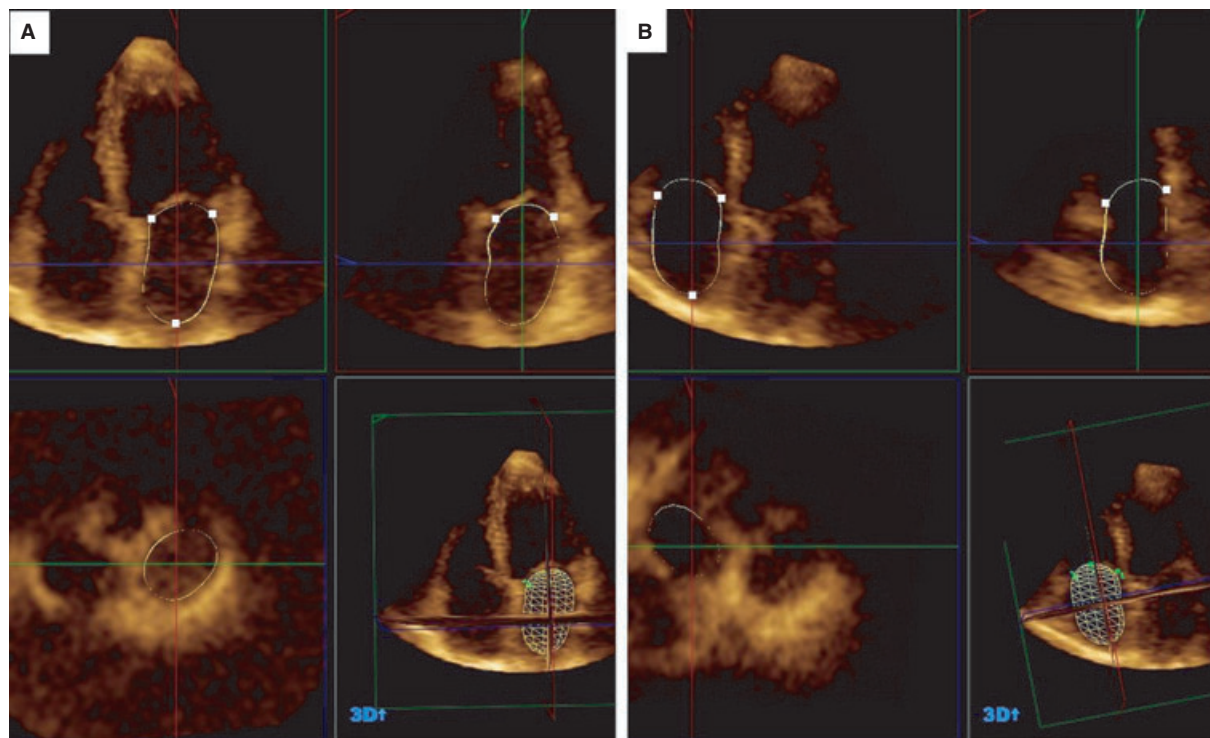
3DE Atrial Volume Measurement with the Semiautomatic Endocardial Border Detection Method (QLAB 8.1; Philips):

After importation of the 3DE dataset from CD in the workstation with QLAB 8.1 software (Philips Ultrasound, Bothell, WA, USA), offline 3D reconstruction of LA and RA volumes was performed by the same investigator (H.M.). The technique has been described earlier.[22,30–32] In brief, the full-volume dataset was centered on the atrium being studied with alignment of the atrial long axis in 2 orthogonal planes, avoiding foreshortening. The measurements were performed in the frame with the largest atrial size at end-systole in the frame just before opening of the mitral or tricuspid valve. The mitral or tricuspid annulus and the center of the respective atrial posterior wall were marked with 5 reference points. The software algorithm then performed semiautomatic endocardial border tracing of the whole atrial endocardial surface, using a deformable 3D surface model initially developed for the LV,[41] providing maximal LA and RA volumes (Fig. 2). The contour tracing was reviewed and manually corrected if needed. Processing of the images took approximately 2–3 minutes for each case. Measurements were repeated in a different dataset in 25 randomly selected patients by the same observer (H.M.) and in 24 randomly selected patients by a second observer (S.R.) to test for determination of intra- and inter-observer reproducibility. The time interval for intra-observer reproducibility was at least 2 months and, for determination of inter-observer variability, the second observer was blinded to the results of the first.

Statistical Analysis:

Analysis was performed using SPSS for Windows (Chicago, IL, USA) and MedCalc for Windows (Ostend, Belgium). Correlation between the different volume measurement algorithms was performed by linear regression analysis using Pearson's correlation. Reproducibility as well as agreement between the different algorithms was evaluated using the method of Bland and Altman.[42] A P value of <0.05 was considered statistically significant. Values are expressed as

Figure 2. Example of left atrial (LA) **A.** and right atrial (RA) **B**. volume measurement by the semiautomatic (QLAB) software. After alignment of the atrial long axis in 2 orthogonal planes the mitral, respectively, tricuspid annulus and the center of the respective atrial posterior wall were marked with 5 reference points. The software algorithm then performed semiautomatic endocardial border tracing of the whole atrial endocardial surface providing maximal LA and RA volumes.

mean ± SD. For inter- and intra-observer variability, the corresponding intra-class correlation coefficient and coefficient of variation were calculated.

Results:

The results of LA and RA size obtained by 2DE, 3DE volume measurement with the manual multiplane interpolation (Tomtec), and 3DE volume measurement with the semiautomatic endocardial border detection (QLAB) are summarized in Table II.

3DE Atrial Volumes by the Manual (Tomtec) Method (n = 88):

Results for LA and RA volumes are shown in Table II. Mean maximal LA volume measured by the manual tracing method was 56.2 ± 22.0 mL (range 16.0–116.2 mL). Mean maximal RA volume was 48.0 ± 19.1 mL (range 17.8–112.0 mL). All patients were in sinus rhythm during image acquisition.

3DE Atrial Volumes by the Semiautomatic (QLAB) Method:

Mean maximal LA volume measured by the semiautomatic method was 54.1 ± 21.7 mL (range 14.4–127.7 mL). LA volume could be measured by the semiautomatic software in 87 of 88 (99%) datasets. Mean maximal RA volume was 47.4 ± 18.9 mL (range 20.9–104.6 mL). RA volume could be measured by the semiautomatic software in 84 of 88 (95%) datasets. All patients were in sinus rhythm during image acquisition. (Table II)

Correlation and Agreement between Atrial Volumes Determined by Manual (Tomtec) and Semiautomatic (QLAB) Software:

Linear regression showed an excellent correlation between maximal LA and RA volumes determined by Tomtec and semiautomatic software ($r^2 = 0.90$ and 0.89, respectively, P < 0.001). Bland–Altman analysis of Tomtec versus semiauto-

matic volume determination showed narrow 95% limits of agreement (−15.9 to +12.0 mL for LA volume and −13.9 to +12.2 mL for RA volume). There was a minimal bias by the semiautomatic method which amounted to −1.9 ± 7.0 mL for the LA and to −0.8 ± 6.5 mL for the RA. In other terms underestimation by the semiautomatic method averaged 3.4 ± 12.5% for LA volume and 1.7 ± 13.5% for RA volume compared to the manual reference method (Figs. 3 and 4).

Reproducibility of Atrial Volume Determination by Semiautomatic (QLAB) Software:

For LA volume, Bland–Altman analysis showed good intra- and inter-observer reproducibility with a small mean difference (1.6 ± 4.9 mL and −0.9 ± 6.8 mL, respectively) and narrow 95% limits of agreement (−8.2 to +11.5 mL and −14.5 to 12.6 mL, respectively). The corresponding intra-class correlation coefficients were 0.98 (range 0.96–0.99) for intra-observer variability and 0.97 (range 0.94–0.99) for inter-observer variability. The corresponding coefficients of variation were 5.9 ± 3.6% for intra-observer and 7.6 ± 4.8% for inter-observer variability (Figs. 5 and 6).

For RA volume, Bland–Altman analysis showed good intra- and acceptable inter-observer reproducibility with a small mean difference (1.1 ± 6.0 mL and −0.4 ± 9.1 mL, respectively) and 95% limits of agreement of −10.8 to +13.0 mL and −18.6 to 17.9 mL, respectively. The intra-class correlation coefficients for intra- and inter-observer variability in RA volume determinations were 0.96 (range 0.92–0.98) and 0.92 (range 0.82–0.96), respectively. The corresponding coefficients of variations were 8.5 ± 4.2% for intra-observer and 12.5 ± 6.3% for inter-observer variability.

Discussion:

Transthoracic real time 3DE allowing rapid measurement of chamber volume without making
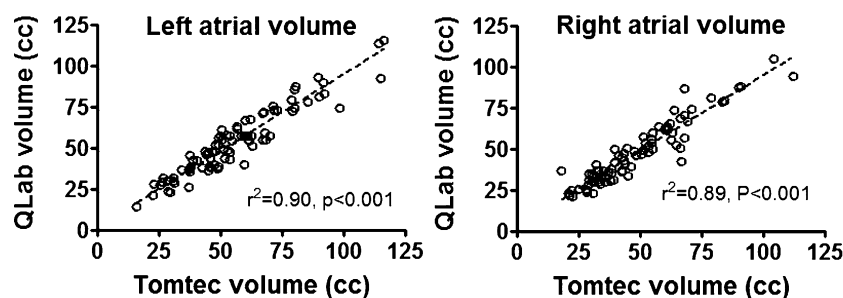
Figure 3. Correlation between left atrial (LA) and right atrial (RA) volumes determined by the manual (Tomtec) and semiautomatic (QLAB) software by linear regression analysis.
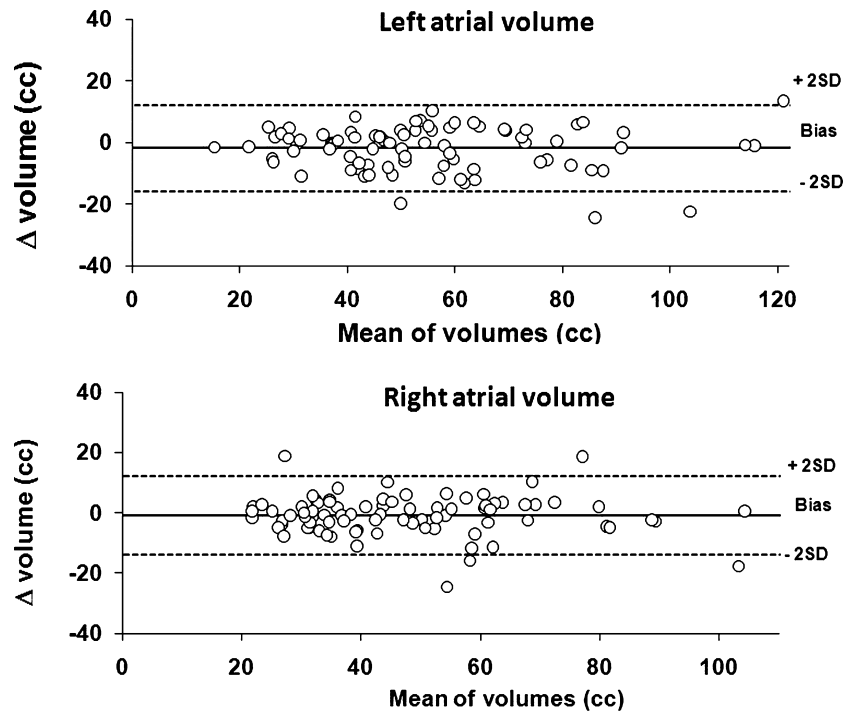
Figure 4. Agreement between left atrial (LA) and right atrial (RA) volumes determined by the manual (Tomtec) and semiautomatic (QLAB) software using the method of Bland and Altman.
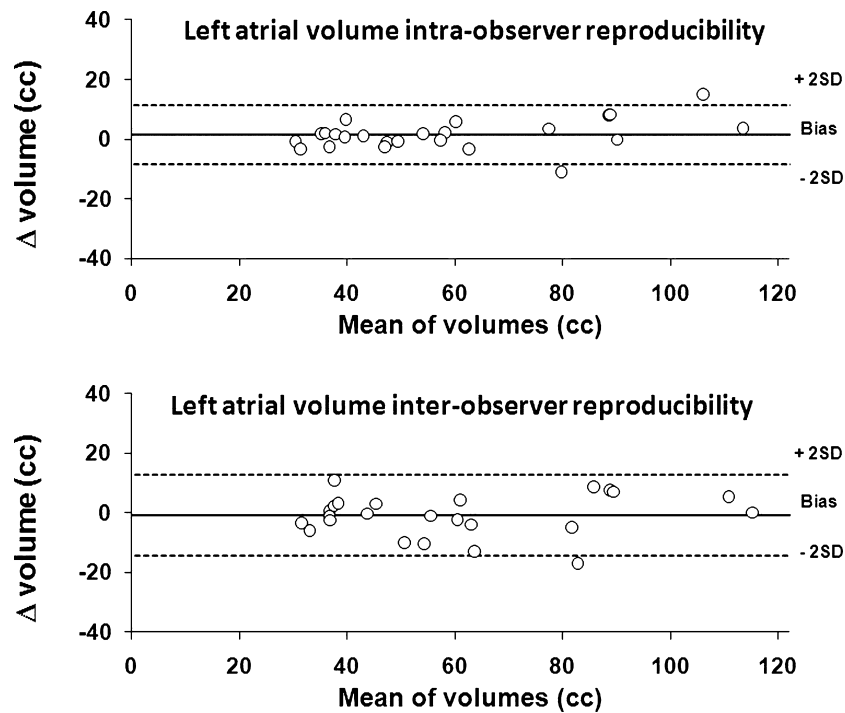
Figure 5. Intra- and inter-observer reproducibility of left atrial (LA) volume measurement by the semiautomatic software (n = 25 and n = 24).

geometric assumptions[15–18] is now widely available and may be preferred for sequential echocardiographic atrial volume measurements even

if not yet currently recommended.[14,15] The technique has been extensively validated for assessment of LV volume and ejection fraction,[15,19,43]
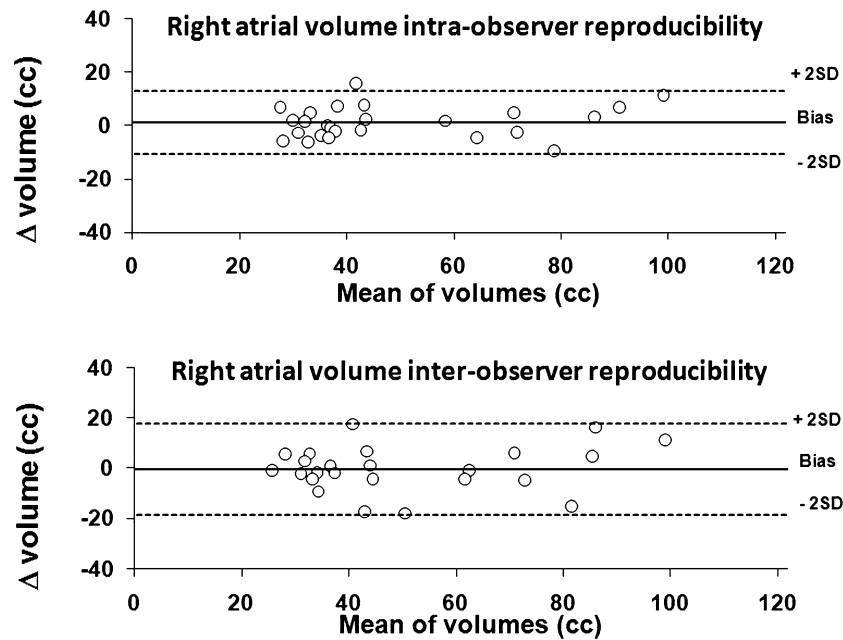
Figure 6. Intra- and inter-observer reproducibility of right atrial (RA) volume measurement by the semiautomatic software (n = 25 and n = 24).

and the algorithms designed for this application have also been used and validated for LA volume[8,20–24,27–34,37,38] showing, however, consistently underestimation, albeit of varying degree, when compared to MRI.[20–22,24] Furthermore, the algorithms proved to be feasible when applied to the right atrium.[8,33–36] However, for the RA, validation against MRI has only been done so far for volumes obtained by reconstruction of 3D datasets based on multiple 2D image planes showing also underestimation of RA volume, even slightly more pronounced than for LA volume.[44]

As mentioned before, in the clinical setting, 3DE offers advantages in the follow-up of atrial size as 3DE allows repeat measurement of atrial volumes without the necessity to replicate the same imaging planes. With 2DE it is difficult to reproduce the same planes in sequential studies[45] and this limitation can be overcome by 3DE. Indeed, this method is now increasingly used for follow-up of LA remodeling after RFCA[8,30,31] or CRT.[32]

Different algorithms from different commercial providers are available.[21,22,25] For follow-up examinations, it is important to know whether values obtained by different algorithms of 3DE are interchangeable to ensure correct information on anatomic atrial remodeling. Therefore, we compared, in the same 3D dataset, LA and RA volumes determined by an algorithm involving manual tracing[21,36] to values obtained by a software algorithm with semiautomatic contour

detection.[22,33] One of the advantages of semiautomatic systems is that volume determination is less time consuming than with systems requiring manual planimetry and therefore may facilitate the use of 3DE volume analysis software in clinical routine. Another advantage of certain semiautomatic systems (e.g., the QLAB system used in this study) is the possibility to use them directly on the ultrasound machine. Other systems need transfer of the dataset to an external workstation and this may refrain from use in a routine setting.

Our study shows for both atria an excellent correlation between maximal volume determination by the semiautomatic border detection method (QLAB 8.1; Philips) and the older, more time-consuming, manual multiplane interpolation method (4D Analysis Cardio-View v1.3; Tomtec), with only slightly lower values by the semiautomatic method. The results indicate that values of maximal LA and RA volumes obtained by either algorithm can be compared, for example, during follow-up examinations. The slight underestimation by the semiautomatic border detection method may be due to manual tracing nearer to the tissue blood interface using the manual method. In this study, which included only patients with 3D datasets of sufficient quality for manual tracing of endocardial contours, semiautomatic border detection method showed excellent feasibility (≥95%) for maximal LA and RA volume determination in patients with a history of AF. The feasibility of the semiautomatic

border detection method may rely more on good image quality explaining why few datasets could not be analyzed with this method. Feasibility in an unselected population addressed for RFCA is likely to be good, as we observed previously high feasibility of the manual reference method in consecutive AF patients for LA (98%) and RA (87%) volume determination.[29,34] The inter-observer reproducibility was slightly better with the manual method compared with the semiautomatic method.[29,34] However, the difference was small and may be related to variable experience of the operators involved.

Study Limitations:

First, acquisition of datasets was done with an older system (X4-probe, Sonos 7500) than those currently available, which have considerably better image resolution. This study may therefore underestimate agreement between the techniques, which is likely to critically depend on intrinsic image quality. Second, our data were obtained in patients with a history of atrial arrhythmias, mainly AF, and may not apply to other study populations. Third, we selected datasets already successfully processed by the manual software; therefore, feasibility for consecutive patients could not be tested for the semiautomatic software alone. However, feasibility most likely is good as discussed above. Fourth, all datasets were acquired in sinus rhythm, and the results may not apply to acquisitions done during irregular rhythms like AF or flutter.

Conclusions:

The semiautomatic border detection method shows excellent correlation for maximal LA and RA volume determination compared to the older, more time-consuming, multiplane interpolation method using manual planimetry, with only slight underestimation. The results indicate that values of LA and RA volumes obtained by either algorithm can be compared, for example, during follow-up examinations for monitoring anatomic atrial remodeling.

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