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Measurement of left atrial volume in patients undergoing ablation for atrial fibrillation: comparison of angiography and electro-anatomic (CARTO) mapping with real-time three-dimensional echocardiography

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Aims Left atrial (LA) volume can be determined during radiofrequency catheter ablation (RFCA) of atrial fibrillation (AF) with angiography or electro-anatomic (CARTO) mapping. We compared these volumes with LA volume measured using transthoracic real-time three-dimensional echocardiography (3DE).

Methods and results One hundred and twenty-seven consecutive patients undergoing RFCA for AF were studied using biplane pulmonary vein angiography with opacification of the LA. LA volume was calculated from the diameter measurements with a formula using an ellipsoid model. A subset of 22 patients also underwent LA volume determination by CARTO mapping. These volumes were then correlated with LA volume determined non-invasively by real-time 3DE. Linear regression showed a significant correlation between LA volume determined by angiography and 3DE volume ($r = 0.56$, $P < 0.0001$). Bland–Altman analysis showed a bias of 38 ± 22 ml by the angiographic method. LA volume measured using CARTO correlated better ($r = 0.67$, $P < 0.001$), but 3DE yielded smaller values (mean difference of -30 ± 19 ml).

Conclusion LA volume determination by angiography and CARTO mapping correlate significantly with 3DE volume. However, both invasive techniques yield larger values for LA volume. The results indicate that LA volume obtained by angiography or CARTO should not be used as baseline value for non-invasive follow-up of LA remodelling by 3DE.

Keywords Left atrial volume • Three-dimensional echocardiography • Pulmonary vein angiography • Electro-anatomic (CARTO) mapping

Introduction

Radiofrequency catheter ablation (RFCA) of atrial fibrillation (AF) including principally pulmonary vein isolation (PVI) is now standard therapy in selected patients.[1] Measurement of left atrial (LA) volume has gained interest as LA size is a predictor of RFCA efficacy in AF.[2,3] Since a number of approaches are used to measure LA volume it is important to know whether values obtained by different modalities are interchangeable, particularly for follow-up examinations. During the ablation procedure LA volume can be determined with angiography[4] or electro-anatomic (CARTO) mapping.[5] The angiographic LA volume is calculated using biplane diameter measurements made during opacification of the LA with a formula that makes geometrical assumptions using an ellipsoid model.[4] In contrast, CARTO mapping allows three-dimensional reconstruction of the LA without these assumptions.[5] The most widely used and best available non-invasive imaging technique for the determination of LA size is echocardiography.[6] However, few data are available comparing LA volume measured by the invasive imaging techniques with echocardiography.[7]

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The advent of real-time full-volume three-dimensional echocardiography (3DE) allows rapid measurement of chamber volume[8] without making geometric assumptions, as volume is reconstructed from endocardial contours of the entire chamber.[9,10] This technique has been validated for LA volume determination against magnetic resonance imaging (MRI)[11,12] and is now more frequently used for this application.[3,13–17] After the ablation procedure, assessment of LA size is part of the follow-up in these patients. However, it is not clear if LA volume determined invasively during the ablation procedure can be compared at follow-up with LA volume determined by transthoracic real-time 3DE. Furthermore, the invasive methods angiography and CARTO mapping have never been compared with each other for this purpose. To determine whether these different methods are interchangeable, we sought to compare LA volume determined invasively by angiography and by CARTO mapping during the ablation procedure with each other, and with LA volume measured using transthoracic real-time 3DE.

Table 1 Patient population demographics

	Patients (n = 127)
M/F	108 (85%)/19 (15%)
Age (years)	58 ± 9
Type of AF	
Paroxysmal	100 (78.7%)
Persistent	27 (21.3%)
Ischaemic heart disease	12 (9.5%)
Hypertension	40 (31.5%)
Significant LV (EF < 45%)	8 (6%)
Significant mitral regurgitation (at least moderate)	3 (2%)
Valvular prosthesis	1
Pacemaker	4 (3%)

AF, atrial fibrillation; LV, left ventricular, EF, ejection fraction.

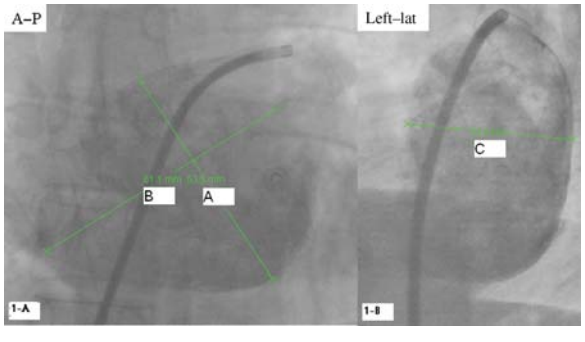

Figure 1 Example of biplane PV angiography with opacification of the LA with anterior–posterior (A–P, *A*) and left lateral (left–lat, *B*) projections. Measurement of maximal axial (*A*) and transverse (*B* and *C*) diameters at ventricular end-systole in the different projections.

Methods

Patients

A total of 127 consecutive patients with paroxysmal or chronic AF undergoing RFCA were included in the study. All patients underwent biplane pulmonary vein (PV) angiography and real-time 3DE. In a subset of 22 patients, LA volume was also measured by CARTO mapping. Few patients had significant structural cardiac diseases. Patient demographics are shown in *Table 1*. All patients were anticoagulated with vitamin K antagonists for a consecutive period of at least 4 weeks with a target INR of 2–3 until 48 h before the procedure. A transoesophageal echocardiogram was performed prior to the procedure to exclude the presence of LA thrombi. The study complies with the Declaration of Helsinki and was approved by the local ethics committee. All patients gave informed consent.

Radiofrequency catheter ablation and electro-anatomic (CARTO) mapping

The ablation procedure has been reported in detail earlier.[3] In brief, selective biplane PV angiography was used to define the anatomic PV ostium. Segmental ostial PVI was then performed. Supplementary linear LA ablation was performed in patients with persistent AF or in those with AF recurrence despite complete isolation of all the PVs. The electro-anatomic mapping system (CARTO XP) was used for reconstruction of the LA in a subset of patients. The technology and the technique have also been described in detail earlier.[7,18] The operator manually places the sensor-equipped catheter tip in stable endocardial contact at multiple (at least 50) uniformly distributed locations. A three-dimensional virtual shell of the mapped chamber is created by software interpolation over the co-ordinates of multiple endocardial points and its volume is automatically calculated. We have previously reported reproducibility of CARTO mapping for LA volume measurements in patients with atrial arrhythmias with 95% limits of agreement of −16.5 to 22 ml.[7] The ablation procedure and the CARTO mapping were performed by a single operator blinded to the data obtained by 3DE and angiography.

PV angiography

Biplane PV angiography with opacification of the LA with anterior–posterior (A–P) and left lateral projections was performed during the procedure in all patients. PV angiography was performed by hand injection of 8–20 ml of contrast solution (through the 8F Preface sheath for the usually larger diameter upper PVs and through a 7F MPA2 catheter for both inferior PVs). Simultaneous A–P and lateral projections that showed largest LA in both projections were analysed. The angiographic LA volume was calculated off-line by a single observer from biplane diameter measurements with a formula using an ellipsoid model as previously reported and validated in post-mortem hearts.[4] Maximal axial (A) and transverse diameter (B) in the A–P projection and maximal transverse diameter (C) in the left lateral projection were measured at ventricular end-systole (*Figure 1*). The volume was calculated by inserting the different diameters in the following formula for the volume of an ellipsoid: $V = 4/3 \times \pi \times A/2 \times B/2 \times C/2$. In 19 patients measurements were repeated to assess intra-observer reproducibility.

Standard echocardiography

Standard echocardiograms according to current guidelines[6] were acquired in all patients within 24 h of the ablation procedure (90.6% of the patients had the images acquired before the 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 view was used for measuring the diameter of the LA (PLAX). The apical four-chamber view was used for planimetry of the LA cross-sectional area (4CH planimetry). The echo images were acquired by two observers and measurements were done off-line by one of the observers.

Real-time 3DE and atrial volume measurement

The 3DE images were obtained during the same session as the standard echocardiograms from an apical window over four 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 three acquisitions were performed and the dataset with the best image quality was chosen for analysis. Measurement of 3DE LA volume was performed offline by a single observer using dedicated commercially available software (4D Analysis Cardio-View v.1.3, Tomtec Gmbh, Unterschleissheim, Germany) allowing volume measurements without geometric assumptions.[9] The technique has been described earlier.[3,7] In brief, the image was centred on the left atrium and eight equidistant slices were created in the long axis, ensuring that all portions of the LA (including the LA appendix if identified) were shown on the analysed 3D data set. LA volume measurements were done by planimetry of endocardial contours in the eight equidistant slices (22.5 degrees/slice). Contour tracing was performed manually at ventricular end-systole. The resulting three-dimensional cast yielded LA volume. The echocardiographic observer was blinded to the data obtained by angiography and CARTO mapping. We have previously reported high feasibility and good reproducibility of LA 3DE volume measurements in patients with atrial arrhythmias with, respectively, 95% limits of agreement of −5.9 to 8.9 ml for intra-observer reproducibility and −12.5 to 11.3 ml for inter-observer reproducibility.[15] The reproducibility was comparable for patients in sinus rhythm compared with those in atrial fibrillation.[15]

Statistical analysis

Analysis was performed using SPSS for Windows (Chicago, IL, USA). Correlation between the different volume measurement methods were done by linear regression analysis using Pearson's correlation. Reproducibility as well as agreement between the different volume measurement methods were evaluated using the method of Bland and Altman.[19] In addition, agreement analysis was repeated for angiography and 3DE in patients in concordant rhythm in order to evaluate the effect of the underlying rhythm. A *P*-value of <0.05 was considered statistically significant. Values are expressed as mean ± SD.

Results

The results of LA size for the different imaging modalities are shown in *Table 2*.

3DE volumes ($n = 127$): All patients had echo images that were of sufficient quality for LA volume determination. Mean LA volume measured by 3DE was 58.8 ± 21 ml. Fifteen patients were in AF ($n = 14$) or atypical atrial flutter (AFL, $n = 1$) during image acquisition, the remaining in sinus rhythm.

Biplane PV angiography volumes ($n = 127$): Mean LA volume measured by angiography was 96 ± 24.7 ml. Thirty-seven patients were in AF ($n = 36$) or atypical AFL ($n = 1$) during image acquisition, the remaining in sinus rhythm. There were 25 cases with discordant rhythm between 3DE and angiography but 102 patients (80.3%) were in the same rhythm (88 patients in sinus rhythm, 13 patients in AF, and 1 patient in atypical AFL).

Table 2 Results of the different imaging modalities for LA size

2D echocardiography parameters and LA volume by angiography and 3DE for the entire cohort ($n = 127$)	
LA PLAX (cm)	4.4 ± 1
LA 4CH planimetry (cm^2)	19.3 ± 4.9
3DE LA volume (ml)	58.8 ± 21
Biplane angiography LA volume (ml)	96 ± 24.7
Subgroup with LA volumes available by all three imaging modalities ($n = 22$)	
CARTO LA volume (ml)	107.9 ± 24.8
Biplane angiography LA volume (ml)	109.7 ± 25.9
3DE LA volume (ml)	76 ± 20.2

PLAX, parasternal long axis; 4CH planimetry, apical four-chamber planimetry area.

CARTO mapping volumes ($n = 22$): Mean LA volume measured by mapping 73 ± 17 points was 107.9 ± 24.8 ml. There were three cases with discordant rhythm between 3DE and CARTO mapping but 19 patients (86%) were in the same rhythm (13 patients in sinus rhythm or atrial stimulation, 5 patients in AF, and 1 patient in atypical AFL). There were 8 patients with discordant rhythm between angiography and CARTO mapping and 14 patients (64%) were in the same rhythm (11 patients in AF, 3 patients in sinus rhythm).

Correlation between LA volume determined by angiography and 3DE (*Figure 2A* and *Table 3*): Linear regression showed a significant correlation between LA volume determined by angiography and 3DE volume ($r = 0.56$, $P < 0.0001$). Analysis for the subgroup of 102 patients with concordant rhythm showed similar correlation ($r = 0.53$, $P < 0.0001$).

Agreement between LA volume determined by angiography and 3DE (*Figure 2B* and *Table 3*): Biplane PV angiography yielded greater values than 3DE (mean difference of 38 ± 22 ml) with wide 95% limits of agreement (−6 to 81 ml). Analysis for the subgroup of 102 patients with concordant rhythm showed similar values for agreement (mean difference of 39.4 ± 22 ml, 95% limits of agreement of −5 to 83.4 ml).

Correlation between LA volume determined by CARTO mapping and 3DE (*Figure 3A* and *Table 3*): LA volume measured using CARTO correlated better than angiography with that using 3DE ($r = 0.67$, $P < 0.001$).

Agreement between LA volume determined by CARTO mapping and 3DE (*Figure 3B*, *Table 3*): 3DE yielded smaller values than CARTO mapping for LA volume (mean difference of −30 ± 19 ml) with wide 95% limits of agreement (−68 to 8 ml).

Reproducibility of angiography: Reproducibility of angiography volume measurements showed a mean difference of −4 ± 11 ml with wide 95% limits of agreement of −26 to 17 ml.

Correlation between LA volume determined by CARTO mapping and angiography (*Table 3*): Linear regression showed a significant correlation between LA volume determined by angiography and CARTO mapping ($r = 0.65$, $P = 0.001$).

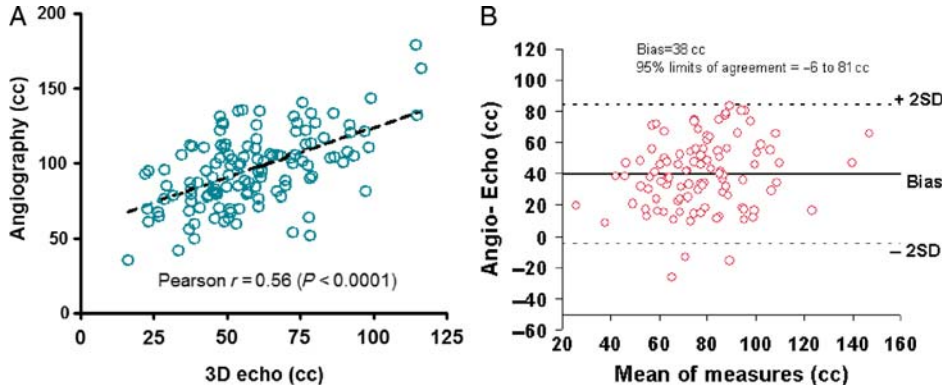

Figure 2 Correlation between LA volumes determined by angiography and 3DE by linear regression analysis (*A*). Agreement between LA volumes determined by angiography and 3DE using the method of Bland and Altman. Mean difference of 38 ± 22 cc and 95% limits of agreement of −6 to 81 cc (*B*).

Table 3 Correlation and agreement for LA volume measurements between the different imaging modalities

Angiography vs. 3DE for the entire cohort ($n = 127$)	
Correlation	$r = 0.56$, $P < 0.0001$
Agreement: angiography yielded greater values	38 ± 22 ml (−6 to 81 ml)
Subgroup CARTO mapping vs. 3DE ($n = 22$)	
Correlation	$r = 0.67$, $P < 0.0001$
Agreement: 3DE yielded smaller values	−30 ± 19 ml (−68 to 8 ml)
Subgroup CARTO mapping vs. Angiography ($n = 22$)	
Correlation	$r = 0.65$, $P = 0.001$
Agreement: good agreement of mean values	1.9 ± 21 ml (−40 to 44 ml)

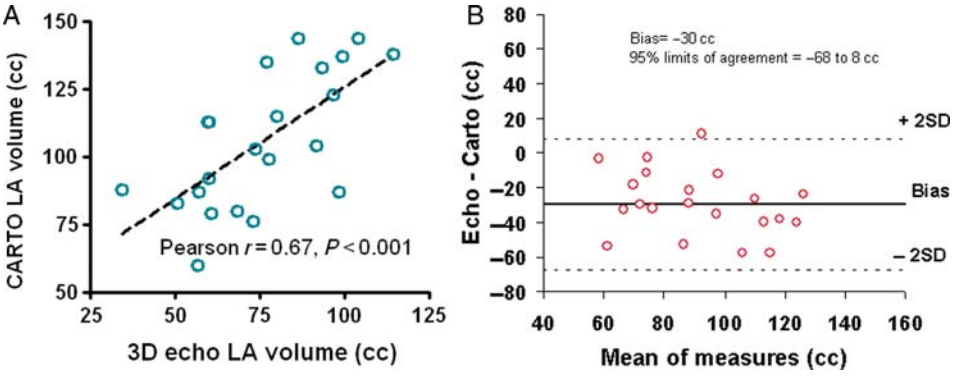

Figure 3 Correlation between LA volumes determined by CARTO mapping and 3DE by linear regression analysis (*A*). Agreement between LA volumes determined by CARTO mapping and 3DE using the method of Bland and Altman. Mean difference of −30 ± 19 cc and 95% limits of agreement of −68 to 8 cc (*B*).

Agreement between LA volume determined by CARTO mapping and angiography (*Table 3*): CARTO mapping showed a slight bias compared with angiography (mean difference of 1.9 ± 21 ml) but wide 95% limits of agreement (−40 to 44 ml).

Discussion

Biplane angiography has never been validated against 3DE for measuring LA size and only limited data are available for

CARTO mapping.[7] Transthoracic real-time 3DE is now widely available and may be preferred for sequential echocardiographic volume measurements even if not yet currently recommended.[6] For these reasons we decided to compare invasive imaging modalities with real-time 3DE as the echocardiographic reference method for the purpose of this study.

Our study shows a significant correlation for LA volume determined by biplane PV angiography and electro-anatomic mapping with the non-invasive assessment by real-time 3DE. The better correlation for CARTO mapping volume most likely reflects the fact that CARTO mapping and real-time 3DE allows volume measurement without making geometric assumptions, whereas the volume determined by biplane PV angiography was calculated using an ellipsoid model making geometric assumptions that may not apply to anatomically remodelled atria. However, both invasive techniques yielded larger values for LA volume. This means that for follow-up of LA volume after RFCA, angiographic or CARTO volume measured during the procedure cannot be compared with the volume determined by transthoracic real-time 3DE. If 3DE is used for follow-up, a baseline study with this technique should be performed to ensure correct information about anatomic atrial remodelling.

There are several possible explanations for the overestimation of LA volume by angiography and CARTO mapping. First, endocardial contour tracing for echo was done within the chamber at the tissue blood interface as recommended by the current guidelines.[6] This approach may have contributed to a smaller LA volume measured by this method. However, recent work showed no significant underestimation of LA volume by real-time 3DE using the same method as in our study compared with MRI.[12] Second, it is possible that stretching of the LA wall by the ablation catheter during the procedure enlarged the resulting LA volume. Third, the 3DE images were obtained during a breath hold, whereas angiography and CARTO mapping were done during normal breathing. This may have contributed to differences in LA volume, but changes in intra-thoracic pressure most likely were minimal in the absence of a Valsalva manoeuvre. Fourth, the LA appendage and the ostia of the PVs may not have been consistently included by the different imaging techniques.

Direct comparison of the two invasive methods showed moderate correlation and only small bias but wide 95% limits of agreement. Thus these methods are also not completely interchangeable. This could be explained by the fact that angiography determines volume by making geometric assumptions in contrast to CARTO mapping as discussed above.

Study limitations

First, endocardial border tracings for measurement of LA volume by 3DE were performed manually, and therefore are more operator-dependent than semi-automatic border detection algorithms that are now available. Second, some patients had a discordant rhythm during the different methods of image acquisition. However, this applies only to a minority of patients and analysis showed similar values for agreement and correlation between 3DE and angiography after exclusion of the patients with discordant rhythm. Third, transseptal access for CARTO results in limited mapping capabilities of the septal region[5] and this may lead to under- or overestimation of the real LA volume. Fourth, because the invasive methods angiography and CARTO mapping were not done simultaneously with 3DE different haemodynamic conditions may have contributed to measurement differences. Fifth, during CARTO mapping, the time reference when anatomic information is recorded depends on the underlying rhythm, whereas for 3DE and angiography LA volume was measured at ventricular end-systole. Sixth, CARTO mapping volumes were assessed only in a small number of patients but the results for comparison with 3DE are in line with our previously reported work.[7]

Conclusions

LA volume reconstructed by CARTO mapping correlates slightly better than angiography with transthoracic real-time 3DE. However, both invasive techniques yield larger values for LA volume. The results indicate that LA volume obtained invasively should not be used as baseline value for follow-up by 3DE to ensure correct information about anatomic atrial remodelling. This underlines the limited interchangeability of different imaging modalities.

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Conflicts of interest: none declared.

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