Electro-Anatomic (CARTO) Mapping for Measurement of Left Atrial Volume: Validation Against Real-Time 3D Echocardiography

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Abstract: *Background*: Left atrial size is a determinant of atrial fibrillation ablation efficacy and embolic risk. The recent advent of real-time full-volume 3DE allows now rapid measurement of chamber volume more accurately than with standard two-dimensional echocardiography as volume is reconstructed from endocardial contours of the entire chamber without making geometric assumptions. Electro-anatomic (CARTO) mapping allows measurement of chamber volume during the ablation procedure of atrial arrhythmias, but has never been validated for measuring left atrial size against three-dimensional echocardiography (3DE). Our aim was to compare left atrial volume measured using CARTO with that measured by real-time 3D echocardiography.

Methods: 37 patients undergoing CARTO-guided radiofrequency ablation for atrial fibrillation or atypical left atrial flutter were studied and left atrial volume measured by mapping 73±17 points. Full-volume transthoracic real-time 3-D echocardiography was performed within 24 hours in each patient, and end-systolic left atrial volume measured offline.

Results: Left atrial volume measured using CARTO correlated well with that using 3D echocardiography ($r = 0.78$, $p<0.001$), but electro-anatomic mapping consistently yielded greater values (mean difference of 33±19cc).

Conclusion: Left atrial volume measured by CARTO correlates well with that obtained by real-time 3D echocardiography, although the former technique consistently yields larger values.

Keywords: Left atrial volume, three-dimensional echocardiography, electro-anatomic (CARTO) mapping.

INTRODUCTION

Radiofrequency catheter ablation (RFCA) of atypical atrial flutter (AFl) and atrial fibrillation (AF) including principally pulmonary vein isolation (PVI) is now standard therapy in selected patients [1]. Left atrial size is a predictor of RFCA efficacy in AF [2, 3]. During the ablation procedure left atrial volume can be determined with electro-anatomic (CARTO) mapping by three dimensional reconstruction of the left atrium [4, 5]. The most widely used and best available non invasive imaging technique for determination of left atrial size is echocardiography [6]. However no data are available comparing left atrial volume measured by CARTO mapping with echocardiography. The advent of real-time full-volume 3DE allows now rapid measurement of chamber volume [7] without making geometric assumptions, as volume is reconstructed from endocardial contours of the entire chamber [8, 9]. This technique has been validated for left atrial volume determination against MRI [10, 11] and is now more and more frequently used for this application [3, 12-15]. 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 in the follow-up with LA volume determined by transthoracic real-time 3DE. To determine whether the two methods are interchangeable we sought to validate left atrial volume determined by CARTO mapping during the ablation procedure with left atrial volume measured by real-time 3D echocardiography (3DE).

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MATERIALS AND METHODOLOGY

Patients

37 consecutive patients with paroxysmal or chronic AF and atypical AFl undergoing radiofrequency catheter ablation were included in the study. Few patients had significant structural cardiac disease. Patient demographics are shown in Table **1**. The study complies with the Declaration of Helsinki and all patients gave informed consent.

Table 1. Patient Population Demographics

	Patients (n = 37)
M / F	30 (81%) / 7 (19%)
Age (yrs)	60±10
Type of AF	
Paroxysmal	8 (22 %)
Persistent	23 (62 %)
Atypical AFl	6 (16 %)
Ischemic heart disease	1
Hypertension	2
Significant left ventricular dysfunction (EF<45%)	4
Significant mitral regurgitation (at least moderate)	1
Valvular prosthesis	4
Pacemaker	1

AF = Atrial fibrillation, AFl = Atrial flutter.

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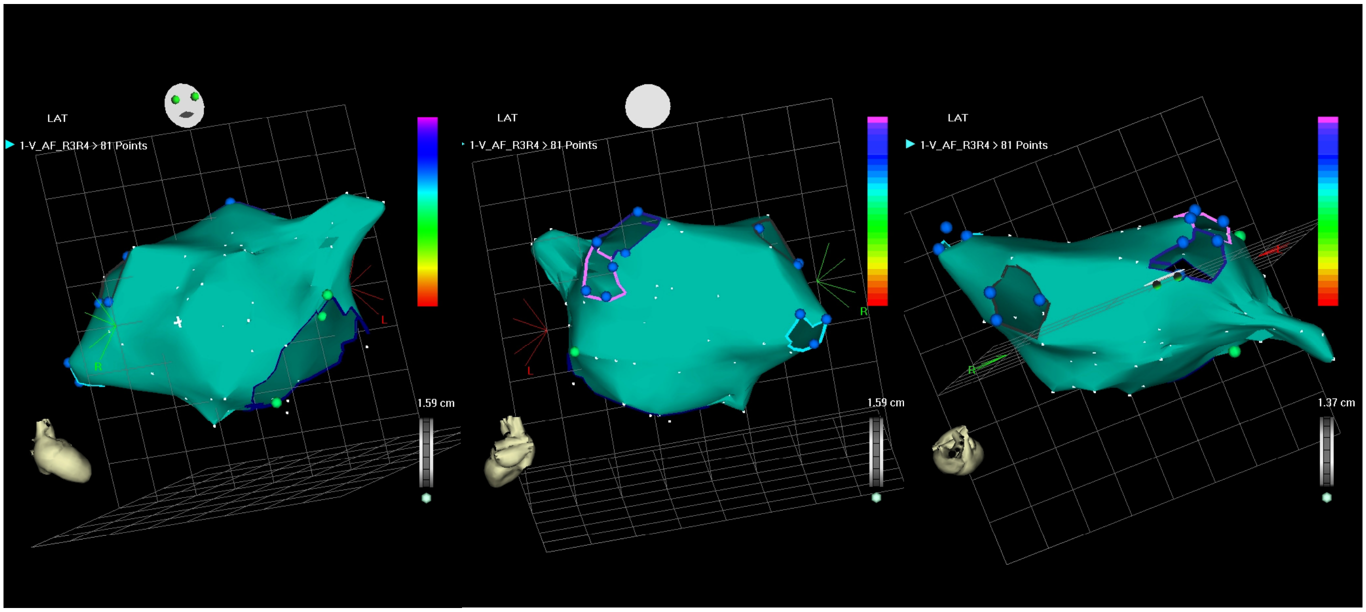


Fig. (1). Example of three-dimensional reconstruction of the LA using CARTO mapping.

Radiofrequency Catheter Ablation and Electro-Anatomic (CARTO) Mapping

The ablation procedure was reported in detail previously [3]. In brief selective biplane pulmonary vein (PV) angiography was used to define the anatomic PV ostium. Segmental ostial PVI was 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 three-dimensional reconstruction of the LA (Fig. **1**). The technology and the technique have been described earlier [5]. In brief, three electromagnetic emitters are fixed on a frame attached to the underside of the cath lab table. The patient is placed so that his heart is within the intersection of the 3 fields. An ablation catheter mounted with a miniature sensor at its tip can sense the 3 different fields (distinct frequencies) and by triangulation can allow calculation of its precise location coordinates with respect to a reference within the emitted field. An external patch (stuck on the patient's back) with a position sensor serves as an anatomic reference. A 3 dimensional virtual shell of the mapped chamber is created by software interpolation over the coordinates of multiple endocardial points and its volume is automatically calculated. The operator manually places the sensor-equipped catheter tip in endocardial contact at multiple uniformly distributed locations.

A multipolar catheter introduced within the coronary sinus was used during flutter to obtain atrial electrograms for timing purposes. Because of irregular and rapid atrial activation during atrial fibrillation, coronary sinus electrograms were not used for reference timing and anatomic information alone was obtained. During flutter, the reference coronary sinus electrogram determined the instant at which the anatomic information was recorded, whereas during atrial fibrillation, the surface ECG QRS or the coronary sinus ventricular electrogram was used to gate anatomical information. The ostia of all the pulmonary veins were delineated as orifices on the system using selective venograms as a guide to the individual venous anatomy. The mitral orifice was also delineated as an orifice guided by the pulmonary vein angiograms (which opacified the left atrium as well as the mitral valve – left ventricular junction) and electrograms (ventricular electrogram amplitude >> atrial electrograms). After establishing this basic framework of the left atrium, at least 50 uniformly distributed location points were acquired with the ablation catheter tip in stable contact with the endocardium. Repeat maps were obtained in 6 patients to assess reproducibility. Volume measurements were automatically obtained during the procedure [5]. The ablation procedure and the CARTO mapping were done by one operator (DS) blinded to the data obtained by 3DE.

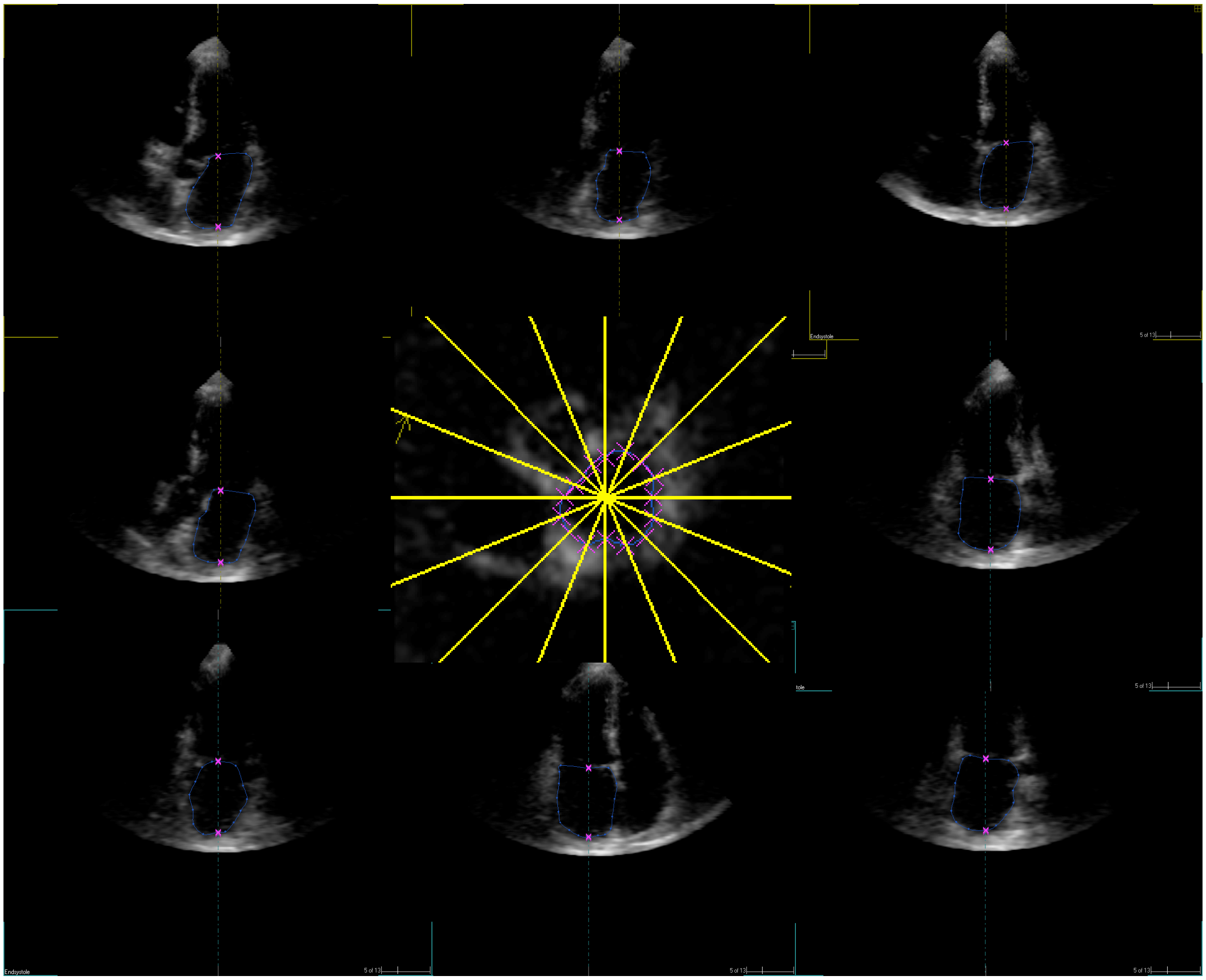
Standard Echocardiography

Standard echocardiograms according to current guidelines [6] were acquired in all patients within 24 hrs of the ablation procedure (70% 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, Mass). 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 4-chamber view was used for planimetry of the LA crossectional area (4CH planimetry). Acquisition of the echo images was done by two observers (HM and HB). Measurements were done off-line by one observer (HM).

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 4 cardiac cycles during a breath hold near the end-expiratory phase using a matrix-array ultrasonographic transducer (X4, Sonos 7500, Philips Medical Systems). Care was taken that acquisition was done during stable ventricular response. At least 3 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

(**A**)



(**B**)

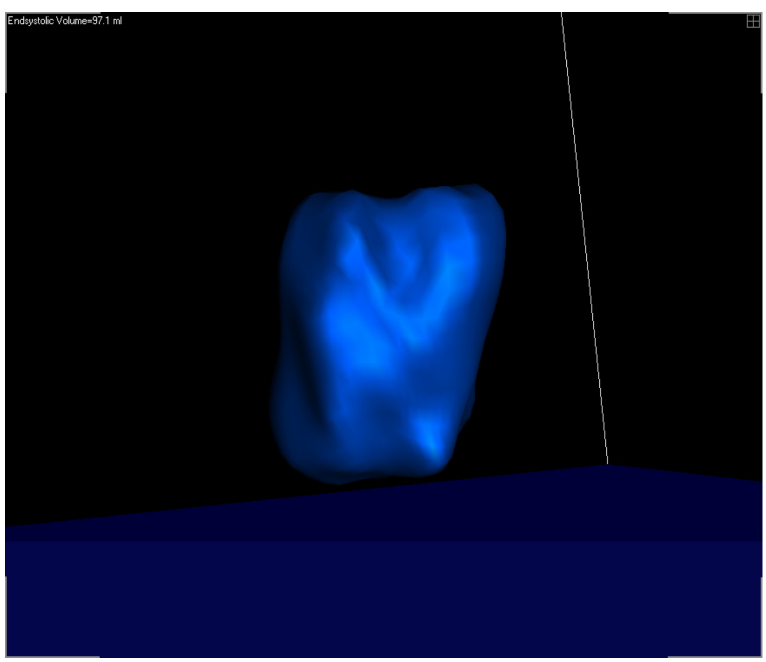


Fig. (2). Example of reconstruction of the LA using real-time 3DE. Selection of 8 slices (**A**, 22.5 degrees/slice). Manual endocardial border tracing of each slice at ventricular end systole with interpolation of all contours and rendering of volume (**B**).

(H.M) using dedicated commercially-available software (4D Analysis Cardio-View v1.3, Tomtec Gmbh, Unterschleissheim, Germany) allowing volume measurements without geometric assumptions [8]. The image was centred on the left atrium and 8 equidistant slices were created in the long axis, ensuring that all portions of the left atrium (including the LA appendix if identified) were shown on the 3D data set with the aid of the navigation plane, placed in orthogonal position to the longitudinal slice planes. Care was taken to obtain a good visualisation of the mitral annulus and the endocardial borders. Left atrial volume measurements were done by planimetry of endocardial contours in 8 equidistant slices (22.5 degrees/slice, Fig. **2A**). Contour tracing was performed manually at ventricular end-systole. The resulting three-dimensional cast yielded left atrial volume (Fig. **2B**). We have previously reported high feasibility and good reproducibility of left atrial 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. The reproducibility was comparable for patients in sinus rhythm compared to those in atrial fibrillation [13]. The echocardiographic observer was blinded to the data obtained by CARTO mapping.

Statistical Analysis

Analysis was performed using SPSS for Windows (Chicago, IL, USA). Correlation between 3DE and CARTO left atrial volume measurements were done by linear regression analysis using Pearson's correlation. Reproducibility for CARTO left atrial volume measurements as well as agreement between 3DE and CARTO volume measurements were evaluated using the method of Bland and Altman [16]. A *P* value of <0.05 was considered statistically significant. Values are expressed as mean ±SD.

RESULTS

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

Table 2. Results of the Different Imaging Modalities for Left Atrial (LA) Size

2D Echocardiography Parameters	n = 37
LA PLAX (cm)	4.6±0.7
LA 4CH planimetry (cm^2)	22.3±5.3
3DE LA volume (ml)	73±20
CARTO LA volume (ml)	106±30

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

3DE volumes: All patients had echo images that were of sufficient quality for LA volume determination. Mean left atrial volume measured by 3DE was 73 ± 20 ml. 12 patients were in AF or atypical AFL during image acquisition, the remaining in sinus rhythm.

CARTO mapping volumes: Mean left atrial volume measured by mapping 73±17 points was 106 ±30 ml. 8 patients were in AF or atypical AFL during mapping and the remaining had a regular atrial rhythm (sinus rhythm or atrial stimulation). There were 5 cases with discordant rhythm between 3DE and CARTO mapping but 32 patients (86%) were in the same rhythm (24 patients in sinus rhythm or atrial stimulation and 8 patients in AF or atypical AFL).

Correlation between left atrial volume determined by CARTO mapping and 3DE (Fig. **3**)*:* Left atrial volume measured using CARTO correlated well with that using 3D echocardiography (r = 0.78, p<0.001).

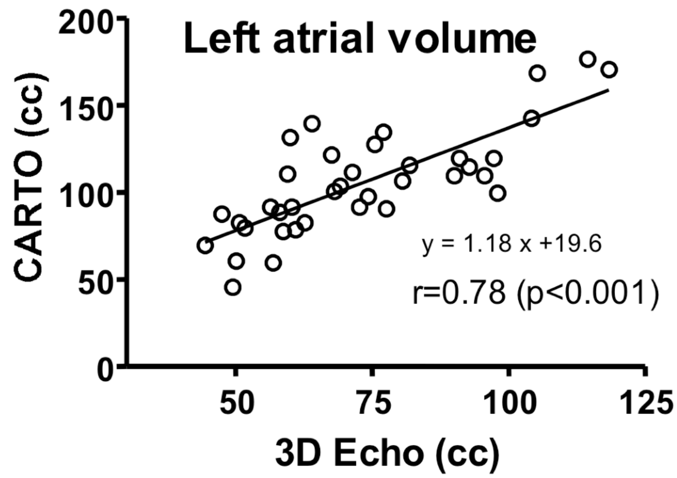


Fig. (3). Correlation between left atrial volumes determined by CARTO mapping and 3DE by linear regression analysis.

Agreement between left atrial volume determined by CARTO mapping and 3DE (Fig. **4**)*:* Electro-anatomic mapping consistently yielded greater values than 3DE (mean difference of 33 ± 19ml and 95% limits of agreement of -5 to 71 ml).

Reproducibility of CARTO mapping: Reproducibility of CARTO mapping volume measurements showed a mean difference of 3 ± 9.5 ml and 95% limits of agreement of -16.5 to 22 ml (Fig. **5**).

DISCUSSION

Three-dimensional reconstruction of the left atrium by CARTO mapping is often used as a guide for RFCA of AF. CARTO has been shown to exhibit excellent accuracy for anatomic reconstruction compared to multi-slice computed tomography [4]. Real-time 3DE is now widely available and has been validated for left atrial volume determination against MRI [10, 11] as evidenced by excellent correlation and agreement without significant under- or overestimation of LA volume compared to MRI. This method is now more frequently used for this application and we have previously shown its usefulness in the follow-up of atrial volume measurements in patients after RFCA of AF [3]. However CARTO mapping has never been validated against 3DE for measuring left atrial size.

Our study shows a good correlation for left atrial volume determined by electro-anatomic mapping during the ablation procedure with the non-invasive assessment by real-time 3DE. The good correlation most likely reflects the fact that both methods do volume measurements without geometric assumptions. However, CARTO mapping yielded consistently greater values than 3DE (mean difference of 33ml). This means that for follow-up of left atrial volume after RFCA, CARTO volume measured during the procedure

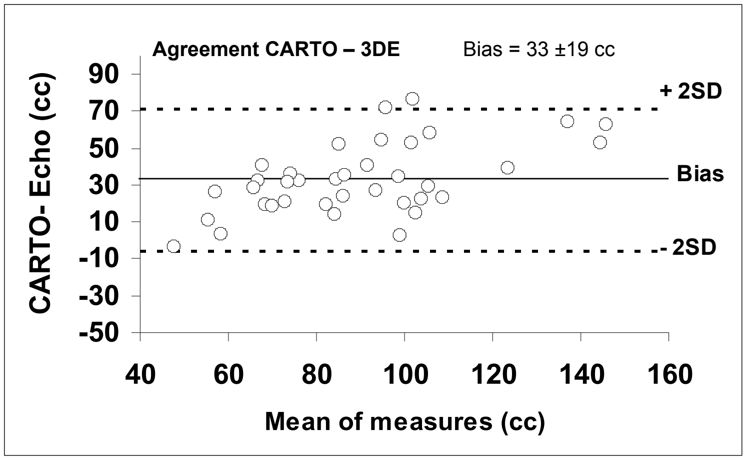


Fig. (4). Agreement between left atrial volumes determined by CARTO mapping and 3DE using the method of Bland and Altman. Mean difference of 33 ± 19cc and 95% limits of agreement of -5 to 71cc.

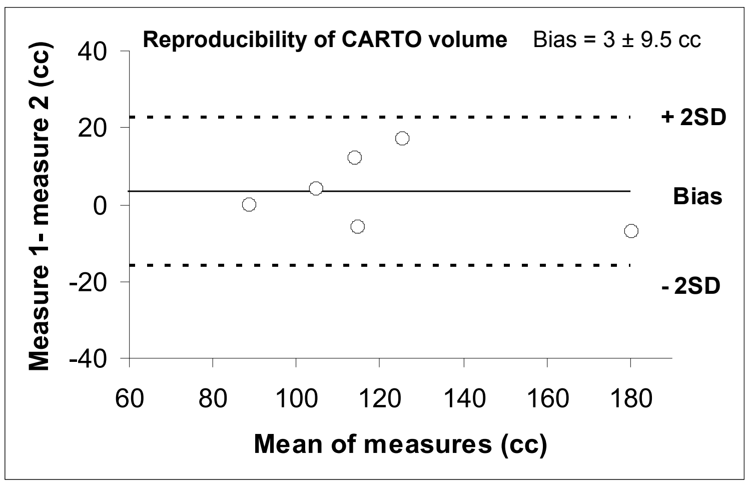


Fig. (5). Intra-observer reproducibility of CARTO mapping volume measurements (n = 6) using the method of Bland and Altman. Mean difference of 3 ± 9.5 cc and 95% limits of agreement of -16 to 22 cc.

cannot be compared with volume determined by 3DE at follow-up. If 3DE is used for follow-up, a baseline study with this technique should be performed to ensure correct information about atrial remodelling.

There are several possible explanations for the overestimation of left atrial volume by CARTO mapping. First, endocardial contour tracing of echo was done within the chamber at the tissue-blood interface as recommended by current guidelines [6]. This approach may have contributed to a smaller left atrial volume measured by this method. However recent work showed that real-time 3DE derived volumes are only slightly underestimated compared to MRI with respect to the left ventricle [17]. For LA volume determination, if one uses at least 8 equidistant slices as we did in our study, a recent work showed even no significant underestimation of LA volume by this technique compared to MRI [10]. Second, it is possible that stretching of the left atrial wall by the ablation catheter during CARTO mapping enlarged the resulting left atrial volume. Third, the 3DE images were obtained during a breath hold whereas CARTO mapping was done during normal breathing. This may have contributed to differences in left atrial volume, but changes in intra-thoracic pressure most likely were minimal in the absence of a Valsalva manoeuvre. Fourth, the left atrial appendage and the ostia of the pulmonary veins may not have been consistently included by the two imaging techniques.

Study Limitations

First the number of patients in this study is comparatively small. Second, endocardial border tracings for 3DE measurement of left atrial volume were done manually, and therefore are more operator-dependent than semi-automatic border detection algorithms that are now available. Third, some patients had a discordant rhythm during the different methods of image acquisition and this could possibly have influenced comparison of left atrial size. However this applies only to a minority of patients (14%) and is unlikely to have affected the overall results. Fourth, CARTO mapping and 3DE were done in different hemodynamic conditions. Fifth, during CARTO mapping, the time reference when anatomic information is recorded depends on the underlying rhythm whereas for 3DE LA volume was always measured at ventricular end-systole and this could also have contributed to differences in measured volumes. Sixth, transseptal access for CARTO results in limited mapping capabilities of the septal region [4]. Seventh, reproducibility for CARTO was assessed only in a limited number of patients (n = 6).

CONCLUSION

Left atrial volume reconstructed by CARTO mapping correlates well with that measured by real-time 3D echocardiography, although the former technique consistently yields larger values. If 3DE is used for follow-up, a baseline study with this technique has to be done to appropriately follow left atrial remodelling because the two methods are not interchangeable.

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