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Assessment of left atrial shape and volume in structural remodeling secondary to atrial fibrillation

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Abstract
Purpose Assessment of volume in relation with left atrial (LA) shape alteration before and after PV isolation.
Methods We compared trapezoidal modification of LA using echocardiography with the ellipsoid formula (EEL) and CT, with both ellipsoid (CTEL) and truncated cone formulas (CTTR), in 40 patients, before and ±3 months after AF ablation.
Results A trapezoidal shape was present in 76.3% of patients. The different volume measurements were statistically correlated (r=0.603–0.837, p<0.001) irrespective of the formula used. After reverse remodeling, with 77.5% of patients in stable sinus rhythm, correlation coefficient for volume remained significant (p<0.001).
Conclusions In AF, dilation of the LA is associated with a geometrical trapezoidal change in many cases. The CT truncated cone formula applies best for precise evaluation of trapezoidal shape alteration in dilated AF atria. There is a good correlation between CTTR and echocardiography which remains a valuable estimation for volume calculation in clinical practice.

Keywords Atrial fibrillation · Structural remodeling · Trapezoidal shape · Ablation

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1 Introduction

In persistent and paroxysmal atrial fibrillation (AF) left atrium (LA) geometry and shape could change and a single linear dimension such as antero-posterior diameter may not be representative of LA size. [1–3]. Thus the measured LA size may be misleading and LA volume determination should be used in both clinical practice and research [4].

Routine echocardiography can not adequately assess the largest LA dimensions [5] and therefore the ellipsoid formula is known to underestimate LA volume [6]. Magnetic resonance imaging and CT could be more adequate methods for atrial size evaluation.

Progressive LA dilation is associated with asymmetrical structural remodeling and shape changes. LA dilatation may thus modify the ellipsoidal shape into a more trapezoidal one because of atrialization of pulmonary veins in AF patients [7]. Therefore, the assessment of LA volume taking into account LA shape in structurally remodeled atria in AF patients could avoid underestimation with the ellipsoid formula by echocardiography or overestimation by standard CT measurements.

A comparison of LA volume obtained by echocardiography and CT, in relation with shape alteration in structural remodeling has not yet been performed.

2 Methods

Forty patients with paroxysmal AF underwent radiofrequency ablation for isolation of pulmonary veins. The ablation procedure consisted of endocardial ostial isolation of each pulmonary vein antrum by radiofrequency energy using a Lasso™ catheter (Biosense Webster, CA, USA) and an irrigated tip Celsius™ Thermo Cool (Biosense Webster, CA, USA).

We analyzed the influence of LA shape in volume assessment by means of two different imaging methods, echocardiography and CT scan. We evaluated the evolution of LA volume using the ellipsoid formula applied both to conventional echocardiography (E_{EL}) and computed tomography (CT_{EL}). We also performed measurements on CT using the truncated cone formula (CT_{TR}) and either ellipsoid or the truncated cone formula according to LA shape ($CT_{TR/EL}$). LA shape was defined as trapezoidal if basal dimension, at the level of the atrium-pulmonary vein junction, was greater than the mitral annular dimension. In the opposite situation it was considered as a classical ellipsoidal shape.

LA volume was calculated in the 40 enrolled patients with AF, before and 3 months after ostial endocardial pulmonary vein isolation. We thus performed a total of 80 measurements with each method: E_{EL}, CT_{EL}, CT_{TR} and $CT_{TR/EL}$.

2.1 Echocardiographic evaluation of left atrial volume

LA volume measurements were done using two-dimensional (2D) echocardiography with an IE33 machine (iE 33 Echocardiography System, Philips Healthcare, The Netherlands). Considering the LA as a prolate ellipse we applied the biplane dimension-length formula: LA volume = $4\pi/3.(d/2).(l/2).(t/2)$. The two orthogonal diameters (t=medial-lateral and l=superior-inferior) were measured in the apical four chamber view and the antero-posterior diameter (d) in the parasternal long axis. All echocardiographic measurements were performed at end-ventricular systole, at maximal LA size. We optimized each view in order to avoid: an underestimation of LA volume by foreshortening of the major length of the LA, inaccurate assumption of the mitral annulus boundary, loss of lateral resolution of the LA wall in the apical view or dropout of the interatrial septum or anterior wall. All measurements by echocardiography (E_{EL}) were performed by the same operator, before and at 3 months after ostial endocardial AF ablation.

2.2 Computer-tomographic evaluation of left atrial volume

All patients underwent cardiac contrast enhanced CT (Siemens Somatom Senzation 64-Slice Configuration, Siemens AG, Germany) for evaluation of the morphology of the left atrium, less than 24 h prior to ablation and at ± 3 months after this procedure. We applied the ellipsoid formula to CT and echocardiography regardless of left atrial shape. When taking into account LA geometrical changes we used either the ellipsoid or the truncated cone formula ($CT_{TR/EL}$). For the ellipsoidal shape, the two orthogonal diameters were measured on the greatest LA section, after we obtained an optimal contour in transverse axis by tracing the endocardial border cavity (Fig. 1). The third dimension was calculated by the number of LA slices. Each of these CT slices was performed at 1 mm. The truncated cone formula was as follows:

LA volume = $\pi.LAl.(LAa^2+LAb^2+LAa.LAb)/12$, with the LAb dimension measured at the base of the atrium and the LAa at the mitral annular level (Fig. 2), on the greatest LA area (at end-ventricular systole), in transverse section views. Likewise, LAl was measured as the longitudinal dimension.

We performed the measurements avoiding an overestimation of LA volume on CT, by the following: the inclusion of part of LA appendage volume, the incorporation of the pulmonary veins or overlap and the duplicate measurements of the multiple sequence scans. All measurements on computer-tomography (CT_{EL}, CT_{TR} and $CT_{TR/EL}$) were performed by the same operator, before and at 3 months after antral endocardial AF ablation.

3 Statistical analysis

Data are presented as frequency distributions and simple percentages. Continuous variables are expressed as mean ±

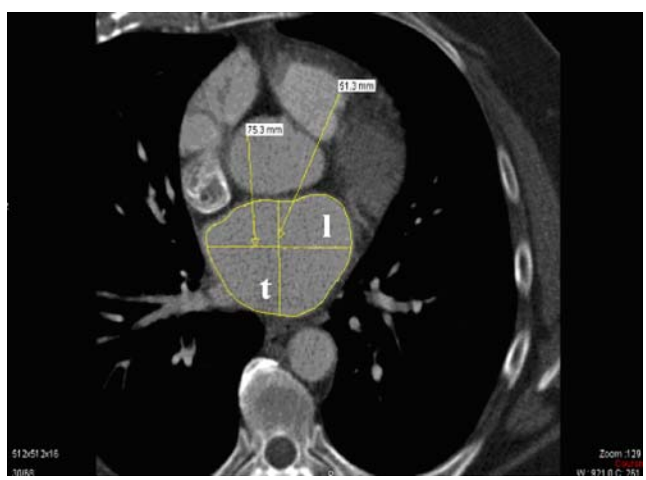

Fig. 1 An ellipsoidal shape on computer-tomography (transverse axis); the two orthogonal diameters are marked (t=transverse, l=longitudinal)

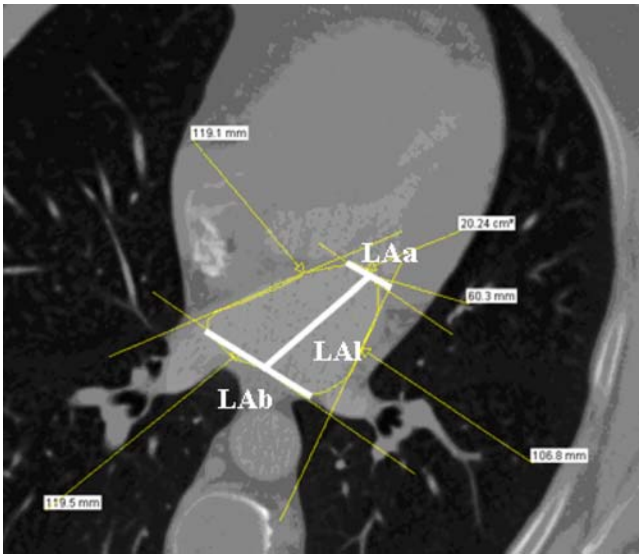

Fig. 2 Computer-tomography image in transverse axis displays the trapezoidal shape of the left atrium (LAa=annular dimension, LAb=basal dimension, LAl=longitudinal dimension)

standard deviation. Statistical analysis was performed using SPSS 10 for Windows (SPSS Inc., Chicago, IL, USA). A *p* value <0.05 was considered significant. We calculated the Pearson's correlation coefficient between the echocardiographic method and the computer-tomography methods and afterwards we compared the correlation coefficients.

4 Results

Forty patients were consecutively included in this study. Mean age was 56±11 years and 77.5% were men. Mean LA volume of the measurements for EEL, CTEL and CTTR was 53 ml, 71 ml, and 65 ml, respectively. In order to assess reverse LA remodeling we compared mean LA volume by the ellipsoid method (EEL and CTEL), before and 3 months after ablation: 57.9±24.7 ml vs. 50.8±20.8 ml and 67.33±29.37 vs. 60.01±21.42 ml, respectively ($p<0.001$). Seventy seven and a half percent of patients were in stable sinus rhythm. There was no significant reverse remodeling in patients ($n=9$) who continued to have AF at 3 months after the procedure, 60.7±21.3 ml vs 58.2±19.7 ml, $p>0.05$ and 73.2±20.2 ml vs. 71.5±17.7 ml, $p>0.05$ respectively for E_{EL} and CT_{EL}.

All mean LA volumes, irrespective of imaging method or formula were >50 ml, probably due to AF structural remodeling. The actual shape of the LA was evaluated on CT scan and showed a trapezoidal shape in 61 out of 80 measurements (76%). A significant reversal of trapezoidal shape, found in 37 out of 40 pts (92.5%) before ablation compared to 24 out of 40 (60%) after ablation was observed at 3 months after the procedure.

Irrespective of the LA formula, each measure of LA volume by computer-tomography (CTEL, CTTR and CTTR/EL) was significantly correlated with EEL ($p<0.001$) (Table 1). However the correlation coefficient between EEL-CTTR/EL, before ablation, was stronger than the correlation coefficient between EEL-CTTR ($p<0.001$). At 3 months after ablation and reverse remodeling, with 77.5% of patients in stable sinus rhythm, we found nearly the same correlation coefficients ($p<0.001$).

5 Discussion

It has been shown that the largest LA surface in AF patients is frequently situated just under the upper pulmonary veins [8]. In AF patients, LA dilation is a marker of LA structural remodeling, and is associated with dilation of the pulmonary vein antrum. This results in a larger LA surface that changes LA shape into a more trapezoidal one.

Because LA volume calculated by the CT truncated cone formula correlates significantly with each of the other ellipsoidal methods, it seems appropriate for assessing remodeled LA volume. The better correlation of EEL with CTTR/EL than with CTEL, before ablation, could be explained by the geometrical changes which occur in structurally remodeled atria. EEL was not best correlated with CTTR probably because not all LA follow the same degree of dilatation and shape change. In our study, in patients without AF recurrences, there was a significant reverse LA remodeling at a mean of 3 months after ostial endocardial pulmonary vein isolation. Perhaps the LA returns to a more ellipsoidal shape after AF ablation, in stable sinus rhythm and after reverse remodeling. This could be an explanation for the better correlation between EEL and CTEL than with CTTR or CTTR/EL at 3 months after AF ablation.

There was no significant reverse remodeling in patients ($n=9$) who continued to have AF at 3 months after the procedure.

Table 1 The correlation coefficients between EEL and CT methods

	CT methods	EEL
Before ablation	CTEL	0.779*
	CTTR	0.614*
	CTTR/EL	0.837*
After ablation	CTEL	0.753*
	CTTR	0.603*
	CTTR/EL	0.608*

EEL= echocardiography by ellipsoid formula CTEL = computer-tomography by ellipsoid formula; CTTR= computer-tomography by truncated cone formula; CTTR/EL= computer-tomography by truncated cone formula or ellipsoid formula depending on LA shape (* means $p<0.001$).

LA shape thus seems important in LA volume assessment for precise evaluation of LA volume in the context of AF ablation.

In practice, despite a frequent trapezoidal shape modification, echocardiography with the ellipsoid biplane dimension-length formula remains an adequate method for assessment of LA volume, although implying a certain degree of volume underestimation. This method can still be used because it is less costly, avoids irradiation exposure and is easier to use in daily practice.

6 Limitations of the study

In this study we did not calculate the indexed LA volume, which avoids the influence of weight and gender, because it was a comparative one. We did not use any software for computer-tomography volume measurements. By performing single operator evaluations we avoided inter- but not intra-operator variability. There was no control group consisting of AF free patients to compare LA geometry because this is a comparative study for structural LA remodeling in patients with AF. In addition, it could be ethically difficult to justify a CT scan of the LA in patients not submitted to an AF intervention.

7 Conclusions

The well-known overestimation by computer-tomography and underestimation by echocardiography using the ellipsoid formula for the assessment of left atrial volume could be, at least partly, explained by changes in the geometry of remodeled atria. In atrial fibrillation, left atrial structural remodeling and left atrial shape are related. Therefore, for precise assessment of left atrial dilatation in atrial fibrillation patients, a trapezoidal left atrial shape would probably be more appropriate. However due to an acceptable correlation between methods, echocardiographic ellipsoid formula could still be used in clinical practice because it still remains the easiest available tool.

Changes in LA shape and morphology after ablation may predict how reverse remodeling might correlate with a better outcome after AF ablation.

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