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Left atrial size and function by three-dimensional echocardiography to predict arrhythmia recurrence after first and repeated ablation of atrial fibrillation

Sílvia Montserrat[1,2], Luigi Gabrielli[1,2,3], Roger Borras[1,2], Sílvia Poyatos[1,2], Antonio Berruezo[1,2], Bart Bijnens[1,2,4], Josep Brugada[1,2], Lluis Mont[1,2], and Marta Sitges[1,2]*

[1]Department of Cardiology, Thorax Institute, Hospital Clinic, IDIBAPS, University of Barcelona, Villarroel 170, Barcelona 08036, Spain; [2]Institut d'Investigacions Biomèdiques August Pi i Sunyer, Barcelona, Spain; [3]Division of Cardiovascular Disease, Pontificia Universidad Católica de Chile, Santiago, Chile; and [4]ICREA, Universitat Pompeu Fabra, Barcelona, Spain

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Aims Left atrial (LA) size has been related to the success of radiofrequency catheter ablation (RFCA) for atrial fibrillation (AF). However, potential predictors after a repeated procedure are unknown. We evaluate predictive factors related to successful AF ablation after a first and a repeated RFCA.

Methods and results A total of 154 patients with AF were treated with RFCA. LA size and function were assessed with three-dimensional echocardiography (3D Echo) before RFCA. The effectiveness of RFCA was evaluated after 6 months. Recurrence of the arrhythmia was defined as any documented (clinically or by 24-h Holter recording) atrial tachyarrhythmia lasting >30 s after 12 weeks following RFCA. Of 154 patients, 103 (67%) underwent a first ablation (Group 1) and 51 (33%) a repeated RFCA (Group 2). At follow-up, arrhythmias were eliminated in 56 of 103 (54%) patients after a first RFCA and in 20 of 51 (40%) after a repeated ablation. In Group I, hypertension and LA expansion index derived from 3D Echo were independent predictors of arrhythmia elimination. In Group 2, only age predicted persistence of sinus rhythm; and only in younger patients (≤54 year old), though 3D LA maximal volumes were significantly smaller in those without when compared with those with AF recurrences.

Conclusion A combination of the analysis of LA function with 3D Echo and clinical data predicts elimination of AF after a first ablation procedure for AF, beyond LA size. Among patients undergoing a repeated procedure, age and 3D echocardiographic LA maximum volume in younger patients predict the success of RFCA.

Keywords atrial fibrillation • atrial function • three-dimensional echocardiography • catheter ablation • predictors

Introduction

Radiofrequency catheter ablation (RFCA) is a potentially curative invasive treatment of drug-refractory atrial fibrillation (AF).[1] Patient selection is especially important in a repeated procedure, where the potential of complication is higher. Currently, predictors of non-recurrence, derived from non-invasive cardiac imaging, are not well established, especially in case of repeated procedures, which are required in up to 30% of patients to achieve a complete success.[2]

Prior studies have demonstrated that an enlarged left atrial (LA), measured by echocardiography,[3–5] by magnetic resonance and computed tomography[6,7] predicts the recurrence of AF after RFCA. More recently, the potential of LA function analysis with strain imaging to predict AF burden and efficacy of RFCA in patients with AF has also been reported.[8,9] Accordingly, early expert consensus considered that patient selection for AF ablation should include severity of symptoms, age, duration of AF, and LA diameter (IIaC).[10] However, as the role of LA dimensions in predicting success of AF

* Corresponding author. Tel: +34 932275509; Fax: +34 932275509, Email: msitges@clinic.ub.es

ablation remains controversial, more recent recommendations no longer include LA size criteria for the selection of patients with AF as candidates for RFCA.[11]

The aim of the present study was to analyse whether pre-procedural patient characteristics[12] and imaging parameters related to LA dimensions and function are similarly associated with the effectiveness of RFCA in patients with AF after a first or a repeated procedure. We used three-dimensional (3D Echo) and two-dimensional (2D Echo) echocardiography to investigate LA dimensions and function.

Methods

Study population and study protocol

This prospective cohort study included 154 patients (78% men, aged 53 ± 10 years) with symptomatic drug-refractory AF undergoing RFCA at our centre: in 103 (67%) it was a first RFCA (Group 1) and 51 (33%) had a repeated procedure (Group 2). Indications for AF ablation were symptomatic AF refractory or intolerant to at least one Class I or III anti-arrhythmic medication in paroxysmal or persistent AF. We excluded patients with moderate and severe valvulopathy or severe left ventricular hypertrophy (>14 mm).

All our patients had non-valvular AF. Most of them had factors related to the development of AF such as sleep apnoea syndrome (10% of patients), hypertension (45% of patients), and endurance sport practice (10% of patients). The presence of hypertension was noted when there was anti-hypertensive drug intake and/or a history of high blood pressure referred during the interview with the patient or in the medical records. The rest of the patients were classified as having idiopathic AF.

A repeated procedure was indicated when symptomatic AF persisted after 3 months of a first ablation, despite optimum pharmacological treatment. All patients underwent 2D and 3D Echo before the procedure. The ethics committee of our institution approved the study, and all patients provided signed informed consent. Clinical characteristics of the overall population are summarized in *Table 1*.

Table 1 Baseline characteristics

	First RFCA (*N* = 103)	Repeated RFCA (*N* = 51)
Age (year old)	53 ± 11	53 ± 10
Men, *n* (%)	81 (79%)	39 (76%)
Hypertension, *n* (%)	45 (44%)	24 (47%)
Paroxysmal AF, *n* (%)	54 (52%)	23 (45%)
Persistent AF, *n* (%)	33 (32%)	22 (43%)
Long persistent AF, *n* (%)	16 (16%)	6 (12%)
Sinus rhythm at baseline, *n* (%)	53 (51%)	26 (51%)
Anti-arrhythmic drugs	1.5 ± 1	1.7 ± 1
AF duration (months)	52 ± 34	71 ± 54
LV hypertrophy, *n* (%)	24 (23%)	11 (22%)
Mild mitral regurgitation, *n* (%)	46 (45%)	25 (49%)
Mild aortic regurgitation, *n* (%)	16 (16%)	7 (14%)
LVEF <50%, *n* (%)	11 (11%)	7 (14%)
LVEF (%)	59 ± 9	59 ± 10
LV end-diastolic diameter (mm)	52 ± 5	53 ± 5
LV end-systolic diameter (mm)	34 ± 6	34 ± 7
LA anteroposterior diameter (mm)	43 ± 6	43 ± 6
LA maximum volume 3D (mL)	60 ± 19	57 ± 18
LA minimum volume 3D (mL)	39 ± 18	37 ± 17
LA EF (%)	36 ± 18	35 ± 17
LA expansion index (%)	61.8 (28.2–99.8)	49.9 (25.2–90.7)
LA active contraction (%)	25 ± 14	23 ± 18

AF, atrial fibrillation; LA, left atrial; EF, ejection fraction; LV, left ventricular.
*$P < 0.05$.

Radiofrequency catheter ablation

Catheters were introduced percutaneously; a trans-septal puncture was performed to access the LA. A 3D map was constructed using an electro-anatomical mapping system (CARTO®, Biosense-Webster, Diamond Bar, CA, USA) to support the creation and validation of radiofrequency lesions. Continuous radiofrequency lesions surrounding the pulmonary vein were delivered as previously described.[13,14] Ablation lines were also deployed in the LA roof (22% of first RFCA and 50% of second RFCA), along the mitral isthmus (4% of first RFCA and 32% of second RFCA), and on sites with Complex Atrial Fractionated Electrograms (CAFEs; 14% of first RFCA and 19% of second RFCA). Radiofrequency was delivered through an irrigated-tip, thermocouple-equipped catheter, using a target temperature of 45°C at 40 W. The endpoint was a reduction in local electrogram to <0.15 mV and the establishment of a bidirectional conduction block between the LA and pulmonary veins.

Clinical follow-up

After ablation, all patients continued oral anti-coagulation and anti-arrhythmic therapy, including flecainide and beta-blocker in paroxysmal AF and amiodarone in persistent AF, were maintained up to 3 months after RFCA. Thereafter, anti-arrhythmic therapy was withheld according to the clinical evolution (recurrence or not of the arrhythmia). Patients were followed up at the outpatient clinic with serial electrocardiogram (ECG) at 1, 3, and 6 months and 24-h Holter at 3 and 6 months to evaluate the recurrence and frequency of palpitations and to detect asymptomatic AF episodes. The procedure was considered successful if no recurrences of atrial tachycardia, lasting >30 s, were present during post-discharge follow-up, spontaneously referred by the patient or detected in serial ECG and 24-h Holter.[15]

Echocardiography

All patients underwent 2D and 3D transthoracic and transoesophageal echocardiography prior to the RFCA procedure. All images, obtained with a commercially available system (IE33, Philips, Andover, MA, USA), were digitally stored and transferred to a workstation for off-line analysis. Additionally, patients with persistent AF and non-controlled heart rate (mean heart rate >90 bpm) were excluded to avoid stitching artefacts in the 3D acquisitions and to ensure adequate quality images.

The LA anteroposterior diameters and left ventricular dimensions were measured in the parasternal long axis, and left ventricular ejection fraction (EF) was determined using the biplane Simpson method. Additionally, 2D LA volumes were measured from the apical four-chamber view using the multiple disc summation method.

Three-dimensional echocardiographic studies were obtained from the apical view using a 4× matrix-array transducer (Philips). Full-volume LA scans were acquired by wide-angle acquisition in breath-hold, as previously described extensively elsewhere (*Figure 1*).[16–21] Volume data were post-processed using the commercially available software (QLab 7.1, Philips). After defining the mitral annulus (with four points in the four- and two-chamber views) and the roof of the LA (as a surrogate

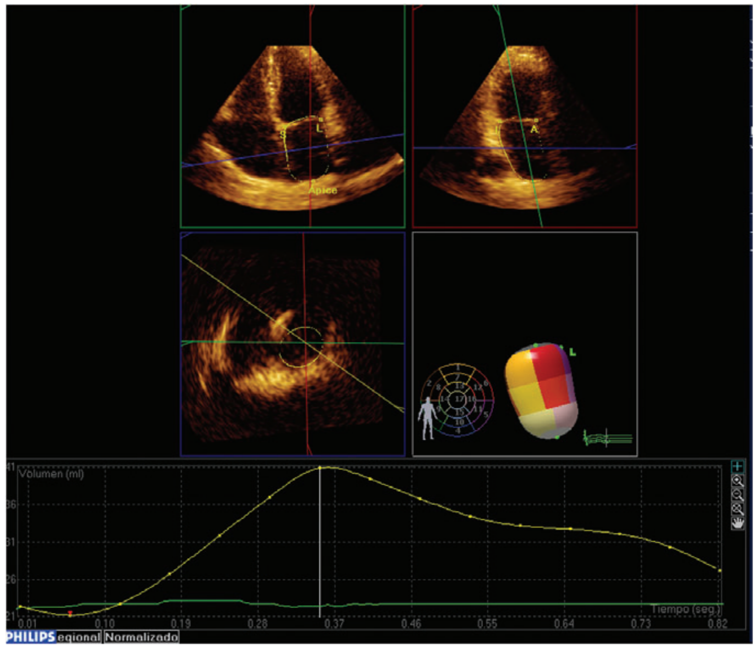

Figure 1 Three-dimensional echocardiography study to assess LA volumes. The post-processing of acquired full-volume images of the left atrial with a semiautomatic endocardial border detection software yields time–volume curves. The maximum volume is measured in the frame just before mitral valve opening, whereas the minimum volume is measured in the frame of mitral valve closure. The electrocardiogram (ECG)-gating also enables assessment of the LA volume at the point of auricular active contraction, which takes place at the same time as the *P*-wave on the surface ECG.

of the apex of the LV) at minimum and maximum LA volume, a semiautomatic algorithm of endocardial border detection provided time–volume curves.

The LA maximum volume ($Vmax_{3D}$) was defined as the largest volume just before mitral valve opening and LA minimum volume ($Vmin_{3D}$) as the smallest possible volume in ventricular diastole. Pre-contraction LA volumes (*V*p3D) were measured in the frame just prior to *P*-wave of the surface ECG (only in patients with sinus rhythm). Contractile, conduit, and reservoir functions were analysed using 3D Echo, measuring the following indices: (i) for LA contractile function, LA EF = $[(Vmax_{3D} - Vmin_{3D})/Vmax_{3D} \times 100]$, and LA active emptying fraction (ActEF%) = $[(Vp3D - Vmin_{3D})/Vp3D \times 100]$; (ii) LA conduit function = $[(Vmax_{3D} - Vp3D)/Vmax_{3D} \times 100]$, and (iii) LA reservoir or 'diastolic' function: LA expansion index = $[(Vmax_{3D} - Vmin_{3D})/Vmin_{3D} \times 100]$, as previously described extensively elsewhere.[17–20] Measurements were performed by an experienced observer, unaware of the outcomes after ablation of AF. Feasibility and inter- and intra-observer reproducibility of 3D LA volumes in our laboratory have been previously reported[19] with similar values than those reported by others.[17] In each patient, 5–10 sets of data were acquired for each patient. All measurements were taken as the average of three cardiac cycles if SR or of five cycles if AF was present.

Statistical analysis

Continuous variables are presented as the mean value ± standard deviation or median and interquartile range. To compare means of two variables, we used the Student's *t*-test and Mann–Whitney *U*-test as appropriate. Categorical variables were expressed as total number (percentages) and compared between groups using the χ^2 test. Logistic regression analysis was used to study the effects of baseline characteristics on procedure success in our sample. Univariate logistic regression models were fitted for each of the potential predictors. A *P*-value of <0.10 was used to screen covariates. Backward stepwise selection algorithms were used to select covariates included in the multivariate logistic regression model. At each step, the least significant variable was discarded from the model. Only covariates with a *P*-value of <0.10 and independent remained in the final model. Odds ratio and 95% confidence limit (95% CI) were calculated. We used receiver operating characteristic analysis and the likelihood ratio, defined as Sensitivity/(1 − Specificity), to evaluate the optimal cut-off value for predicting recurrence in our sample. A two-sided Type I error of 5% was used for all tests. Statistical analysis was performed using the R software for Windows version 2.14.1 (R project for Statistical Computing; Vienna, Austria).

Results

Table 1 summarizes the clinical and echocardiographic characteristics of the studied population. There were no significant differences between patients undergoing a first and a repeated procedure. At 6-month follow-up, RFCA was effective in 76 of 154 (49%) patients: 56 of 103 (54%) patients after a single RFCA and 20 of 51 (40%) after a redo procedure. Anti-arrhythmic drugs were completely suspended at a 6-month follow-up in 34 and 30% of patients undergoing a first and a repeated RFCA, respectively.

Table 2 reports the univariate and multivariate analyses of pre-procedural characteristics and echocardiographic variables after a first RFCA (Group I). In the univariate analysis, the non-indexed LA size (anteroposterior diameter, $Vmax_{3D}$, and $Vmin_{3D}$) and LA

Table 2 **Predictors of response after first RFCA (103 patients)**

	Successful RFCA54 patients (52%)	Recurrent AF49 patients (48%)	Univariate		Multivariate	
			OR (95% CI)	*P*-value	OR (95% CI)	*P*-value
Age (year old)	52 ± 11	54 ± 10	1.02 (0.98–1.06)	0.329		
Weight (kg)	81 ± 15	87 ± 17	1.02 (1.00–1.05)	0.092		
Height (cm)	173 ± 8	170 ± 10	0.97 (0.92–1.02)	0.187		
Hypertension (%)	**31**	**57**	**3.12 (1.37–7.11)**	**<0.01**	**2.60 (1.11–6.12)**	**0.028**
Persistent AF (%)	**36**	**59**	**2.74 (1.22–6.14)**	**0.014**		
Time of known AF (months)	54 ± 37	52 ± 32	1.00 (0.98–1.01)	0.808		
Mild mitral regurgitation (%)	6	9	1.58 (0.34–7.46)	0.562		
LVEF (%)	58 ± 10	59 ± 8	1.01 (0.96–1.05)	0.737		
AP diameter (mm)	**42 ± 6**	**45 ± 6**	**1.10 (1.02–1.18)**	**<0.01**		
Indexed AP diameter (mm/kg/m^2)	21.6 ± 3.6	22.3 ± 2.9	1.07 (0.94–1.23)	0.294		
LA maximum volume 2D (mL)	**65 ± 20**	**77 ± 34**	**1.02 (1.00–1.03)**	**0.045**		
LA maximum volume 3D (mL)	**56 ± 16**	**65 ± 22**	**1.03 (1.01–1.05)**	**0.020**		
Indexed LA volume max 3D (mL/m^2)	29.2 ± 8.8	31.4 ± 9.2	1.04 (0.99–1.09)	0.123		
LA minimum volume 3D (mL)	**34 ± 16**	**44 ± 20**	**1.03 (1.01–1.06)**	**<0.01**		
Indexed LA minimum volume 3D (mL/ m^2)	18.6 ± 9.1	21.6 ± 8.8	1.04 (0.99–1.09)	0.123		
LA EF (%)	**40 ± 19**	**32 ± 15**	**0.98 (0.95–0.99)**	**0.028**		
LA expansion index (%)	**78.9 (30.2–124.3)**	**48.9 (27.1–77.1)**	**0.99 (0.982–0.998)**	**0.016**	**0.99 (0.980–0.998)**	**0.019**
LA active contraction (%)	26 ± 14	21 ± 13	0.97 (0.92–1.02)	0.247		
LA conduit function (%)	30 ± 17	28 ± 11	0.99 (0.95–1.04)	0.742		
Baseline A-wave velocity (cm/s)	64 ± 21	60 ± 25	0.99 (0.97–1.02)	0.576		
Baseline A-wave VTI (cm)	9 ± 3.8	7.5 ± 3.2	0.88 (0.69–1.11)	0.267		

AP, anteroposterior; LA, left atrial; LV, left ventricular; EF, ejection fraction; VTI, velocity time integral; 2D, two-dimensional echocardiography; 3D, three-dimensional echocardiography.

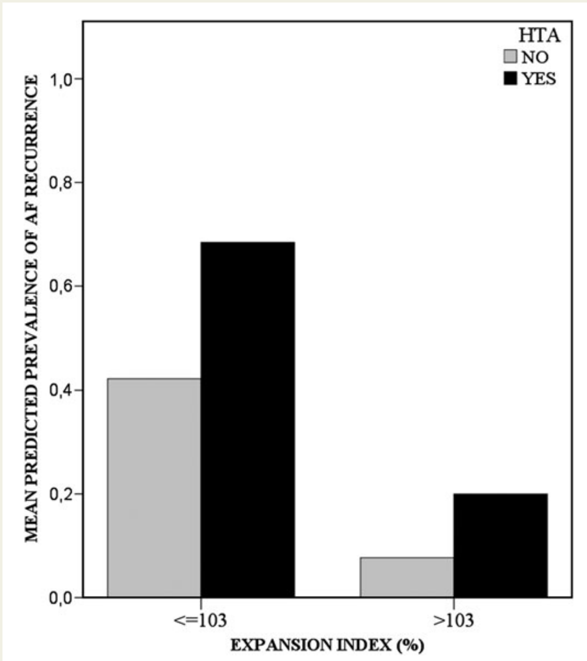

Figure 2 Hypertension and expansion index and risk of arrhythmia recurrence after a first RFCA. Patients with hypertension (HTA) and lower LA expansion index (≤103%) have the greatest risk of arrhythmia recurrence after first RFCA, whereas those without hypertension (non-HTA) and with higher LA expansion index (>103%) show the lowest.

function (LA EF and expansion index) were associated with non-recurrence of AF after a first RFCA. LA size showed high specificity but low sensitivity to identify patients in whom a single procedure of RFCA was ineffective: LA $Vmax_{3D}$ of >82.35 mL (19% sensitivity and 96% specificity), LA diameter of >51.5 mm (10% sensitivity and 98% specificity). Persistent AF and hypertension were also predictors of failed procedure. However, in the multivariate analysis, the only independent predictors of successful therapy were hypertension and LA expansion index, a surrogate of LA diastolic function (a higher index indicates better diastolic function). A cut-off value of the LA expansion index of >103% predicted non-recurrence of the arrhythmia after RFCA, with a 31% sensitivity, 94% specificity, positive predictive value of 85%, and negative predictive value of 55%.

Figure 2 shows the impact of combining the presence of hypertension and the value of the LA expansion index (using the cut-off of 103%) on prediction of success with a single RFCA. Patients with hypertension and a lower LA expansion index (≤103%) had a more risk of arrhythmia recurrence, whereas those with a higher LA expansion index (>103%) and without hypertension had fewer recurrences of AF after RFCA. Indeed, probability of non-recurrence of the arrhythmia at follow-up after RFCA was 8% in hypertensive patients with an LA expansion index of ≤103%, 20% in those non-hypertensive but with an expansion index of >103%, 42% in hypertensive but with an expansion index of ≤103%, and up to 68% in those non-hypertensive but with an expansion index of >103%.

When comparing the potential of LA maximum volumes measured by 2D or 3D Echo to identify candidates for a first RFCA, there were significant differences in both 2D and 3D volumes in patients with or without recurrences: 2D LA maximum volume of 76 ± 33 vs. 64 ± 20 mL, $P = 0.03$ and 3D LA maximum volume of 65 ± 22 vs. 56 ± 16 mL, $P = 0.02$, respectively. However, in the predictive analysis of recurrence, a larger area under the curve was noted for 3D LA volumes (AUC = 0.62, $P = 0.03$) when compared with 2D LA volumes (AUC = 0.57, $P = 0.18$), suggesting a more powerful value of 3D Echo when compared with 2D Echo to predict outcome, at least after a first RFCA.

Table 3 presents the univariate analysis of pre-procedural characteristics and echocardiographic variables after a repeated RFCA (Group 2). After a second RFCA, age was the only predictor of successful ablation [odds ratio (OR) = 1.134, 95% CI = 1.052–1.222, $P = 0.001$]: a second RFCA was successful in >60% of patients younger than 54 years of age (the median age of the study group) but in only 13% of patients 54 years of age and older. Additionally, when the potential role of LA echocardiographic parameters was stratified according to the age of patients undergoing a repeated procedure, we found that, in patients ≤54 year old, LA maximum volume as measured by 3D Echo was significantly different in patients with or without AF recurrence; there was also a non-significant trend towards worse LA function in patients with arrhythmia recurrences (*Table 4*).

Discussion

The findings of the present study indicate that although larger LA size is moderately associated with worse success rates of RFCA in patients with AF, the analysis of LA function adds an independent predictive value to identify candidates for successful ablation. Using 3D Echo, we demonstrated that evaluation of LA reservoir function (i.e. expansion index) could identify patients without arrhythmia recurrence after a first procedure of RFCA; however, it did not predict success of the therapy after a repeated procedure. This underscores the need to find better indicators of anomalous atrial substrates that are not amenable to RFCA therapy and elimination of AF.

Role of LA size in predicting successful RFCA of AF

Using different measurement approaches, LA size has been related to worse RCFA success rates in patients with AF. Despite LA diameter being easy to obtain and widely available, volumetric approaches to determine LA size have been proposed as a better tool to evaluate the whole complex geometry of the LA, particularly when dilated, and having abnormal or fibrotic myocardial tissue. In this sense, patients with larger LA volumes measured with 3D imaging techniques, such as computed tomography, magnetic resonance, or echocardiography, had significantly higher arrhythmia recurrence rates.[5–7]

Even though most studies do not report excluding potential participants due to large LA diameter, most studies specifically include patients with an LA diameter of <55 mm.[12] Our patients have an LA diameter of ≤55 mm (29–55 mm), and we found a statistically significant association between a larger absolute LA diameter and higher rate of AF recurrence, similar to what has been reported in most of the univariate analysis in previous studies.[12] In fact, an LA

Table 3 Predictors of response after a repeated RFCA (51 patients)

	Successful RFCA20 patients (40%)	Recurrent AF31 patients (60%)	Univariate	
			OR (95% CI)	*P*-value
Age (year old)	**47.26 ± 8.8**	**57.1 ± 8.9**	**1.14 (1.05–1.23)**	**<0.001**
Weight (kg)	91.5 ± 12.9	83 ± 17	0.97 (0.92–1.01)	0.166
Height (cm)	176.8 ± 7.4	171.2 ± 10.2	0.94 (0.87–1.01)	0.103
Hypertension (%)	40	55	2.08 (0.65–6.21)	0.219
Persistent AF (%)	42	58	1.90 (0.60–6.05)	0.275
Time of known AF (months)	75.2 ± 74.6	67.8 ± 29.07	1 (0.99–1.01)	0.762
Mild mitral regurgitation (%)	5	7	1.24 (0.10–14.7)	0.864
LVEF (%)	56 ± 11.8	60.7 ± 18.5	1.05 (0.99–1.12)	0.134
LA anteroposterior diameter (mm)	42 ± 5	42 ± 6	0.99 (0.90–1.10)	0.894
LA maximum volume 2D (mL)	60 ± 22	73 ± 31	1.02 (0.99–1.04)	0.120
LA maximum volume 3D (mL)	51 ± 12	58 ± 19	1.03 (0.99–1.07)	0.133
Indexed LA maximum volume 3D (mL/m^2)	25 ± 5.6	28.9 ± 9	1.07 (0.98–1.18)	0.136
LA volume minimum 3D (mL)	32 ± 13	40 ± 18	1.03 (0.99–1.08)	0.101
Indexed LA minimum volume 3D (mL/ m^2)	16 ± 8.1	19.2 ± 8.1	1.07 (0.97–1.17)	0.830
LA EF (%)	38 ± 18	32 ± 16	0.98 (0.95–1.02)	0.311
LA expansion index (%)	57.4 (33.4–96.6)	46.1 (23.0–86.4)	0.99 (0.98–1)	0.227
LA active contraction (%)	23.6 ± 21.2	22.1 ± 12.8	0.99 (0.95–1.04)	0.825
LA conduit function (%)	29.4 ± 10.6	27 ± 17.2	0.99 (0.93–1.05)	0.667
Baseline A-wave velocity (cm/s)	45.4 ± 16.5	55.3 ± 15.5	1.04 (0.99–1.1)	0.127
Baseline A-wave VTI (cm)	6.2 ± 1.7	6.5 ± 2.7	1.06 (0.66–1.7)	0.807

LA, left atrial; LV, left ventricular; EF, ejection fraction; VTI, velocity time integral; 2D, two-dimensional echocardiography; 3D, three-dimensional echocardiography.

Table 4 Baseline characteristics of patients undergoing repeated RFCA dichotomized according to age (51 patients)

	Age ≤54 years old (*n* = 28)			Age >54 years old (*n* = 23)		
	Non-recurrence (*n* = 17)	Recurrence (*n* = 11)	*P*-value	Non-recurrence (*n* = 3)	Recurrence (*n* = 20)	*P*-value
Hypertension, *n* (%)	5 (30)	5 (45)	0.45	2 (67)	12 (60)	0.83
Persistent AF	7 (41)	7 (64)	0.31	1 (33)	11 (55)	0.49
AP diameter (mm)	41.9 ± 5.2	44.3 ± 6.2	0.29	41 ± 5.9	44.7 ± 3.2	0.29
LA maximum volume 2D (mL)	59 ± 23.2	80 ± 36.1	0.08	64.2 ± 15.7	68.2 ± 27.9	0.81
LA maximum volume 3D (mL)	**50.7 ± 12.9**	**67.7 ± 24.1**	**0.04**	52 ± 6.2	54.2 ± 17.4	0.82
LA minimum volume 3D (mL)	32.4 ± 13.4	47.4 ± 20.4	0.05	27.8 ± 11.8	35.7 ± 15.6	0.41
LA EF (%)	39.9 ± 17.8	30.4 ± 15.1	0.31	46.3 ± 21.6	35.1 ± 17.2	0.31
LA expansion index (%)	56.9 (31.1–95.6)	41.6 (24.2–61.3)	0.30	60.7 (43.5–243.7)	47.8 (19.4–90.2)	0.99
LA active contraction (%)	21.2 ± 20.8	21.4 ± 10.4	0.43	35.4 ± 26.5	22.3 ± 13.3	0.20

AP, anteroposterior; AF, atrial fibrillation; LA, left atrial; LV, left ventricular; EF, ejection fraction; 2D, two-dimensional echocardiography; 3D, three-dimensional echocardiography.

diameter of >51.5 mm predicted unsuccessful procedures of single RFCA in 98% of cases. However, the indexed value was not predictive when other parameters were included in the multivariate analysis, LA size did not show an independent prognostic value.

Moreover, in patients treated with a repeated procedure, we could not find any association between LA size and the therapeutic success of RFCA, except in younger patients where LA maximum volumes measured with 3D Echo were predictors of arrhythmia suppression. Patients requiring a repeated RFCA procedure combine persisting symptomatic AF, which enlarges LA and decreased LA function, with the effect of scarring from the first ablation that, in turn, reduces atrial size.[20,22]

LA function as a surrogate of an anomalous atrial substrate: implications for patient selection for RFCA

Thus, LA size should not be incorporated as a unique factor to predict ablation success in patients with AF. Characterization of LA function could provide additional information on the status of the atrial myocardium and might help to better select patients for RFCA.

LA reservoir function with 3D Echo has been particularly useful as a powerful, independent predictor of new-onset AF and flutter in the community[23] and of post-operative cardiac surgery.[24] The LA index expansion derived from 3D Echo is an indicator of the reservoir function of the LA and depends on both left ventricular systolic function and LA wall stiffness.[25] Since left ventricular systolic function was preserved in most patients included in our study (88% in Group 1 and 86% in Group 2), the difference in the expansion index mostly represents changes in LA wall stiffness and compliance in our patients. Myocardial fibrosis results in stiffer and less compliant atria and secondary less expansion index; in addition, the extent of LA fibrosis determined by magnetic resonance is related to the success of RFCA.[26] Therefore, the LA expansion index, as a surrogate of LA fibrosis, identifies patients with poorer outcomes after a first RFCA in terms of arrhythmia suppression. However, in patients treated with a repeated procedure, we could not find any association between LA function derived from 3D Echo and the therapeutic success of RFCA, likely because of the presence of scar tissue caused by the first procedure.

Our finding that hypertension is a risk factor for AF recurrence after RFCA is consistent with previous studies.[4] In clinical practice, therefore, clinical evaluation of hypertension, age, and LA function could improve the selection of patients with RFCA, especially before a first procedure.

Finally, evaluation of LA contractile, reservoir, and conduit function is also possible with new technologies, such as LA strain and strain rate derived from Velocity Vector Imaging and 2D speckle-tracking echocardiography.[8,9] These new techniques, which were not specifically evaluated in the present study, could also help to better select candidates for repeated procedures of RFCA.

Study limitations

Despite technological developments, the spatial and temporal resolution of 3D Echo may be too limited for routine use in the clinical setting; however, we only included patients with at least good-quality scans, in whom measurements could always be reliably obtained. Inter-observer reproducibility for 3D LA volume at our centre has been previously reported,[19] with similar values than others.[17] Certainly, further technological improvements in 3D Echo, such as improving temporal resolution and border delineation, will lead to more reproducible evaluations and will allow for establishing more robust cut-off values of LA size and functional parameters. LA volume measured by 2D Echo was only measured from the four-chamber apical view; consequently, cut-off values might slightly vary if biplane methods are used; however, excellent correlation was found between 3D and 2D derived LA volumes ($r = 0.73, P = 0.000$). Different ablation strategies were used and recurrence may also be related to the techniques used; however, none of the specific ablation sites (LA roof, mitral isthmus, and CAFE) were predictive of AF recurrence. The software used in the study is not only specific for the analysis of the LA, but rather a surrogate of LV function analysis modified by changing the starting point of the ECG (*P*-wave instead of QRS onset); however, we think that despite inaccuracies in absolute values might exist, relative values for the comparison of groups should be reliable. Finally, the small sample population especially for the repeated RFCA group could account for the negative results of the study in this subgroup; further larger studies must be performed to confirm our findings.

Conclusions

LA function, assessed with 3D Echo, is related to the success of ablation procedures for AF, beyond LA size. Additionally, combining clinical parameters such as age and hypertension, with imaging evaluation of LA function, improves the prediction of successful therapy.

Conflict of interest: None declared.

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IMAGE FOCUS

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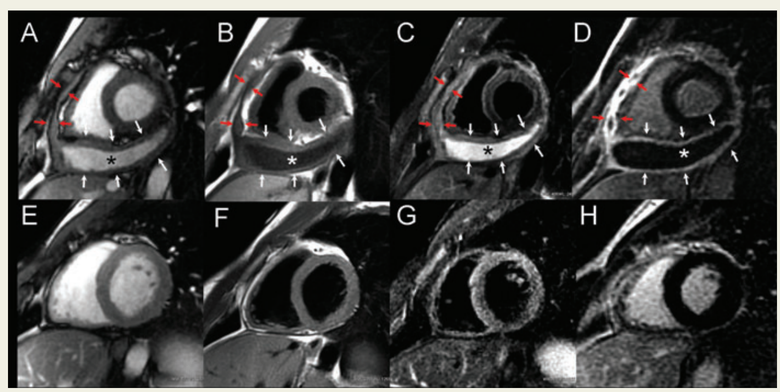
Comprehensive cardiovascular magnetic resonance for monitoring the response to therapy in pericardial tuberculosis

Chrysanthos Grigoratos[1], Massimiliano Mariani[2], Andrea Barison[2], Massimo Lombardi[2], and Pier Giorgio Masci[2]*

[1]Cardiac, Thoracic and Vascular Department, University of Pisa, Pisa, Italy and [2]Fondazione CNR/Regione Toscana 'G.Monasterio' Pisa & Massa, Via Moruzzi 1, 56124 Pisa, Italy

* Corresponding author. Tel: +39-0503152824; Fax: +39-0503152166; Email: masci@ftgm.it, pgmasci@tiscali.it



A Caucasian 25-year-old man with cardiac tamponade underwent urgent pericardiocentesis with the removal of 100 ml of siero-ematic essudative fluid. Smear microscopy detected acid-fast bacilli, and pericardial tuberculosis was confirmed by positive culture for *Mycobacterium tuberculosis*. One-week after pericardiocentesis, cardiovascular magnetic resonance (CMR) was performed (upper panel). Short-axis cine steady-state free precession (*Panel A*), black-blood T_1-weighted (*Panel B*), and T_2-weighted, short-TI-inversion-recovery (*Panel C*) fast spin-echo images showed markedly thickened pericardial layers, which were fused anteriorly (red arrows, maximum thickness 10 mm), while remained separated by abundant pericardial effusion (asterisks) inferiorly (white arrows). Diffuse oedema and late gadolinium enhancement (LGE) were visualized on T_2-weighted (*Panel C*) and post-contrast T_1-weighted fast gradient-echo inversion-recovery (*Panel D*) images, respectively. Horizontal long-axis cine images showed diastolic 'bouncing' of interventricular septum, indicating an increased ventricular interdependency (Supplementary data online, *Video S1*). CMR using the same protocol was repeated after 1 year of anti-tuberculosis regimen including isoniazid, rifampicin, pyrazinamide, and ethambutol (lower panel). Cine (*Panel E*) and morphological (*Panels F* and *G*) images disclosed the resolution of structural and tissue abnormalities of pericardial layers in association with disappearance of pericardial effusion. In particular, oedema and LGE of pericardial layers were not any longer visualized on T_2-weighted (*Panel G*) and post-contrast T_1-weighted (*Panel H*) images, respectively. These changes were paralleled by the normalization of diastolic motion of interventricular septum on cine horizontal long-axis images (Supplementary data online, *Video S2*), indicating an improved compliance of the pericardium. Pericardial tuberculosis is a rare extrapulmonary manifestation in immunecompetent patients with multi-facet presentations ranging from acute pericarditis to cardiac tamponade and constrictive pericarditis. CMR is useful in monitoring the response to therapy with particular respect to the morphological, tissue and functional abnormalities.

Supplementary data are available at *European Heart Journal – Cardiovascular Imaging* online.