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Global Left Atrial Strain in the Prediction of Sinus Rhythm Maintenance after Catheter Ablation for Atrial Fibrillation

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Abstract

Background—Left atrial (LA) strain is a sensitive measure of LA mechanics. However, its relationship with rhythm outcomes after catheter ablation in patients with atrial fibrillation (AF) is not well established. The aim of this study was to evaluate whether baseline LA global longitudinal strain (LA ϵ) predicts rhythm outcomes in patients who undergo catheter ablation for AF.

Methods—In 256 patients with AF (paroxysmal, 204; persistent, 52), comprehensive echocardiography was performed with assessment of LA ϵ by using Velocity Vector Imaging to calculate average strain values from apical four- and two-chamber views before ablation (median, 41 days; interquartile range, 1–95 days).

Results—After a median of 8.0 months (interquartile range, 4.0–23.3 months) of follow-up, 149 patients (58%) had maintained sinus rhythm and 107 patients (42%) had recurrence of AF. In our study cohort (mean age 59 ± 11 years; mean left ventricular ejection fraction, $58 \pm 10\%$), impaired total LA ϵ (LA ϵ_{total}) was associated with greater left ventricular mass index ($r = -0.245$, $P < .001$) and worsening left ventricular diastolic function (ratio of transmitral flow peak early diastolic velocity to peak early diastolic velocity of the mitral annulus: $r = -0.357$, $P < .001$; maximal LA volume index: $r = -0.393$, $P < .001$). Patients with LA $\epsilon_{\text{total}} < 23.2\%$ showed a higher incidence of AF recurrence compared with patients with LA $\epsilon_{\text{total}} \geq 23.2\%$ (log-rank $P < .001$). In multivariate Cox proportional-hazards analysis, LA ϵ_{total} was independently related to rhythm outcomes (hazard ratio, 0.944; 95% confidence interval, 0.915–0.975; $P < .001$) after AF ablation. Moreover, LA ϵ_{total} provided incremental predictive value for rhythm outcomes over clinical features (increment in global $\chi^2 = 14.63$, $P < .001$).

Conclusions—In patients with AF, baseline LA ϵ_{total} was associated with rhythm outcome after catheter ablation.

Keywords

Atrial fibrillation; Echocardiography; Catheter ablation; Atrial function

During the past decade, catheter ablation for atrial fibrillation (AF) has evolved rapidly from an investigational procedure to its current status as a commonly performed ablation procedure at many major hospitals throughout the world.¹ However, catheter ablation is associated with a considerable AF recurrence rate.² In patients with a higher likelihood of recurrence, discontinuation of anticoagulation may be particularly risky. We previously reported that preexisting left atrial (LA) fibrosis evaluated by voltage mapping was associated with the recurrence of atrial arrhythmia.³ However, a noninvasive marker for LA fibrosis would be preferable for preablation patient selection.

Two-dimensional strain (ϵ) based on speckle-tracking is a recently developed, innovative method that provides insight into myocardial mechanics. The evaluation of LA mechanics using this technique has been widely accepted,^{4–8} and as assessed with cardiac magnetic resonance imaging, LA ϵ has been related to LA structural remodeling and fibrosis of the atrial wall.⁹ Deformation-based parameters of LA function provide incremental prognostic information over standard parameters in the general population or patients at risk for adverse cardiovascular events^{10–14}; however, the prognostic value of LA mechanics for rhythm outcomes in patients who undergo catheter ablation for AF has not been well established. Thus, we sought to examine the capability of LA global longitudinal ϵ (LA ϵ) to predict rhythm outcomes after catheter ablation for patients with AF.

METHODS

Study Population

We studied 319 patients with paroxysmal or persistent AF who underwent radiofrequency catheter ablation for AF from June 2008 to May 2010 and underwent preprocedural echocardiography <6 months before the procedure and were in normal sinus rhythm during echocardiography. Of this group, patients were excluded because of valvular heart disease or surgery ($n = 18$) or a history of cardiac surgery ($n = 9$), absence of clinical follow-up data ($n = 15$), and uninterpretable images ($n = 21$). This study was approved by the Cleveland Clinic Institutional Review Board.

Transthoracic Echocardiography

Comprehensive transthoracic echocardiography was performed by experienced sonographers using commercially available iE33 (Philips Medical Systems, Bothell, WA) and Vivid 7 and Vivid E9 (GE Medical Systems, Milwaukee, WI) machines. All images were stored digitally and were measured with offline software (Syngo Dynamics version 9.0; Siemens Medical Solutions, Malvern, PA). Standard techniques were used to obtain M-mode, two-dimensional, and Doppler measurements in accordance with American Society of Echocardiography guidelines.^{15,16} LA phasic volumes (maximal, minimal, and precontraction LA volumes) were obtained from the apical four- and two-chamber views by the method of disks and were indexed to body surface area.

LA ϵ Measurements

LA ϵ measurements were performed offline using dedicated software (Velocity Vector Imaging; Siemens Medical Solutions). We used the onset of the P wave as the reference point for the calculation of LA ϵ , as previously proposed.^{4,7,17} One cardiac cycle was selected for apical four- and two-chamber views, the endocardial border was traced manually in the end-systolic frame, and the software subsequently and automatically traced the borders in the other frames. Graphical displays of deformation parameters for each segment were then generated automatically and were used for the measurement of LA ϵ (Figure 1). The software calculated average ϵ values for six LA segments for apical four- and two-chamber views. We obtained LA ϵ only in the case of adequate tracking quality in at least five of the six segments per view. We identified peak negative LA ϵ , peak positive LA ϵ , and the sum of these values, total LA ϵ (ϵ_{total}).

Pulmonary Vein Isolation Procedure

Our pulmonary vein isolation protocol was previously described in detail.¹⁸ In brief, all antiarrhythmic drugs were stopped four to five half-lives before ablation, except for amiodarone, which was stopped a minimum of 4 to 5 months before the procedure. All pulmonary vein antra were isolated in all patients under intracardiac echocardiographic guidance. Electric isolation was confirmed by the absence of pulmonary vein potentials along the antrum or inside the veins by use of a circular mapping catheter. In all patients, the superior vena cava was mapped, and potentials were ablated when there was no phrenic nerve stimulation.

Follow-Up

Patients had scheduled clinical visits, 12-lead electrocardiography, and 48-hour Holter monitoring at 3, 6, and 12 months after ablation. Atrial arrhythmias that occurred during the first 2 months after catheter ablation were not counted as recurrences. Antiarrhythmic medications were generally continued during the 2-month period. These drugs included sotalol, dofetilide, propafenone, and flecainide, with the managing electrophysiologists making the choice. All patients wore rhythm transmitters for a minimum of 3 months after catheter ablation and were asked to record when they experienced symptoms as well as weekly, even when asymptomatic. Additional event recorder monitoring was obtained beyond the 3-month period if patients had atrial tachyarrhythmia within the first 3 months or developed symptoms consistent with arrhythmia. Interrogation of implanted devices was also used (when available) to confirm arrhythmia recurrence. Antiarrhythmic agents were discontinued in all patients during the third month after ablation unless continuing recurrent arrhythmias indicated the need for continued treatment. Patients with documented arrhythmias and those maintained on antiarrhythmic agents for control of AF beyond the blanking period were counted as experiencing recurrences. Arrhythmia recurrence was identified by electrocardiographic documentation of an atrial tachyarrhythmia lasting ≥ 30 sec on a 12-lead electrocardiogram, event recording, or Holter monitor recording. All success rates were determined in patients off antiarrhythmic medications.

Inter- and Intraobserver Variability

Inter- and intraobserver variability for $LA\epsilon_{total}$ was studied in a group of 10 randomly selected subjects by one observer repeated twice and by two investigators who were unaware of each other's measurements and of the study time point. Coefficient of variation, intraclass correlation coefficients, bias (mean difference), and limits of agreement ($1.96 \times$ standard deviation of difference) between the first and second measurements were determined.

Statistical Analysis

Continuous variables are summarized as mean $\pm$ SD if normally distributed and as medians and interquartile ranges if not normally distributed. Receiver operating characteristic (ROC) curves were generated to determine optimal cutoff values of continuous variable, and bootstrap estimation with resampling from 1,000 simulations was used to generate valid estimates of prediction accuracy. The best cutoff value was defined as the upper limit of the confidence interval of the Youden index. Kaplan-Meier plots were calculated from baseline to time of AF recurrence and compared using the log-rank test. The Cox proportional-hazards regression model was used to assess the clinical risk associated with increasing continuous increments of $LA\epsilon$. Covariate selection for model entry was based on clinical experience and identification of known correlates of AF recurrence. On the basis of an AF recurrence rate of approximately 40%, we anticipated being able to develop a stable model with 10 variables from a population of about 250 patients. The proportional-hazards assumption was verified with log (time) versus log ($-\log$ [survival]) plots. The incremental value of $LA\epsilon$ over baseline clinical and echocardiographic characteristics for assessing the risk for AF recurrence was determined by calculating the improvement in the global χ^2 statistic. For a sample size of about 250, the log-rank test was sufficiently powered (90%) for a hazard ratio of 2.0 and an average probability of 60% for event-free survival to end of follow-up.¹⁹ Statistical analyses were performed using SPSS version 20.0 (SPSS, Inc, Chicago, IL) and MedCalc version 12.3.0 (MedCalc Software, Mariakerke, Belgium). All P values reported are from two-sided tests, and P values $< .05$ were considered statistically significant.

RESULTS

Study Population

Of the 277 patients, 256 (92.4%) had $LA\epsilon$ that could be measured in both four- and two-chamber views. Echocardiography was performed a median of 41 days (interquartile range, 1–95 days) before catheter ablation. The average frame rate of the clips for $LA\epsilon$ analysis was 39 ± 12 frames/sec. The coefficient of variation for intraobserver variability for $LA\epsilon_{total}$ was $5.8 \pm 4\%$. The coefficient of variation of interobserver variability was $7.5 \pm 4.5\%$. The bias and limits of agreement of intra- and interobserver variability were $0.5 \pm 2.7\%$ and $0.7 \pm 3.9\%$, respectively. Intraclass correlation coefficients of intra- and interobserver variability were 0.940 and 0.876, respectively. The baseline clinical and echocardiographic parameters are summarized in Table 1. For the study population as a whole, mean peak negative $LA\epsilon$, peak positive $LA\epsilon$, and $LA\epsilon_{total}$ were $-7.6 \pm 4.0\%$, $15.9 \pm 6.6\%$, and $23.6 \pm 8.3\%$, respectively.

Relationship between LA ϵ , Clinical Features, and Cardiac Structure and Function

In univariate linear regression analysis, lower magnitude LA ϵ_{total} was correlated with age and CHADS₂ score (Table 2). More impaired LA ϵ_{total} was associated with greater left ventricular (LV) hypertrophy and worsening LV diastolic function. Worse LA ϵ_{total} was also associated with larger maximal LA volume index, more impaired total LA emptying fraction, and higher natural logarithm of B-type natriuretic peptide. In multivariate analysis with a forward stepwise algorithm, age, heart rate, LV mass index, ratio of transmitral flow peak early diastolic velocity to peak early diastolic velocity of the mitral annulus (E/e'), and total LA emptying fraction were significantly associated with LA ϵ_{total} (Table 2).

Predictors of Sinus Rhythm Maintenance

After a median of 8.0 months (interquartile range, 4.0–23.3 months) of follow-up, 149 patients (58%) had maintained sinus rhythm and 107 patients (42%) had recurrences of AF. The area under the ROC curve for LA ϵ_{total} was the greatest among LA ϵ_{total} , total LA emptying fraction, and maximal LA volume index (Figure 2). Using bootstrapping with 1,000 simulations, ROC curve analysis was used to select an LA ϵ_{total} cutoff of 23.2% for predicting sinus rhythm maintenance after catheter ablation with sensitivity of 76% and specificity of 66%. In Kaplan-Meier analysis, preserved baseline LA ϵ_{total} (< 23.2%) predicted long-term sinus rhythm maintenance (Figure 3) and remained a predictor of maintenance of sinus rhythm in patients with paroxysmal or persistent AF (Figure 4A) and with or without histories of AF ablation (Figure 4B). LA ϵ_{total} predicted rhythm outcomes after the procedure (Table 3). In multivariate Cox proportional-hazards analysis, LA ϵ_{total} predicted sinus rhythm maintenance after adjustment for age, sex, AF duration, AF type, history of AF ablation, CHADS₂ score, history of permanent pacemaker or cardioverter-defibrillator implantation, the natural log of B-type natriuretic peptide, and maximal LA volume index (Table 3). The incremental value of LA ϵ_{total} for predicting sinus rhythm maintenance is shown in Figure 5. LA ϵ_{total} provides an additional benefit over clinical features including age, sex, AF duration, AF type, history of AF ablation, CHADS₂ score, and permanent pacemaker or cardioverter-defibrillator implantation (increment in global χ^2 = 14.63, P < .001).

DISCUSSION

This study demonstrated the prognostic significance of LA ϵ for predicting sinus rhythm maintenance in patients with AF after catheter ablation. We showed that (1) baseline LA ϵ_{total} was an independent predictor of rhythm outcome after AF ablation; (2) LA ϵ_{total} was significantly associated with age, LV mass, and LV diastolic function; (3) LA ϵ_{total} < 23.2% predicted long-term sinus rhythm maintenance; and (4) the measurement of LA ϵ_{total} was highly feasible and showed good reproducibility.

Predictors of Maintenance of Sinus Rhythm

Several indicators have been reported as predictors of sinus rhythm maintenance after AF ablation, such as LA size and volume^{20–25} and calibrated integrated backscatter of the left atrium.²⁶ These studies were conducted on the basis of the same concept: LA structural remodeling and fibrosis might be a pathogenesis of AF recurrence after catheter ablation.

Previous studies using tissue Doppler imaging and two-dimensional speckle-tracking echocardiography found that maximal LA ϵ identified patients likely to maintain sinus rhythm after cardioversion or AF ablation. Our study involved a larger number of patients as well as sample size calculations and confirmed that LA ϵ_{total} provided incremental value over baseline clinical and echocardiographic characteristics. In terms of the evaluation of LA remodeling, the deformation-based parameter, LA ϵ , is a sensitive measure of LA ultrastructural changes, potentially affecting LA mechanics before LA dilatation occurs.^{27,28} Furthermore, our results indicated that it is useful even when LA dilatation has occurred. In this study, although maximal LA volume index was significantly associated with rhythm outcome in univariate Cox regression, it was not significant in the multivariate model. More variations of LA volume in our cohort might have improved the predictive value of LA volume; however, LA ϵ_{total} successfully predicted outcomes in the multivariate model in this population. Recently, myocardial mechanics have been reported to be a novel parameter with incremental prognostic value over anatomic parameters (i.e., LV ejection fraction) for predicting cardiovascular events.^{29,30} Myocardial ϵ is a sensitive parameter that reflects the physiologic mechanics of the myocardium and can be used to detect subclinical myocardial damage that is not detectable with volumetric parameters.³¹ Hence, the assessment of LA mechanics might be of more significant value than LA size and volume in guiding the treatment of patients with AF.

LA Deformation Imaging in AF Ablation

Recently, LA ϵ_{total} and ϵ rate were shown to be independent predictors of AF recurrence after catheter ablation.^{32–35} The present study strengthens and expands these previous observations by demonstrating the feasibility of noninvasive evaluation of LA mechanics as well as its usefulness in the prognostic stratification of patients with AF using a larger cohort and an angle-independent imaging technique. Our study confirms the prognostic significance of LA ϵ_{total} in AF after catheter ablation. The superior prognostic strength of LA ϵ_{total} with respect to the other echocardiographic parameters of LA function could be explained by hypothesizing that reduced LA ϵ_{total} better reflects a severe impairment of LA performance, because LA ϵ_{total} has been shown to be a noninvasive surrogate marker of LA fibrosis,^{9,36} which may serve as a substrate for slow conduction and intra-atrial reentry.^{37,38} Thus, LA ϵ_{total} may be useful for preablation patient selection in clinical settings.

LA Contractile and Conduit Functions

Here we briefly review other components of LA function, contractile and conduit function, in the prediction of rhythm outcome after AF ablation. Relative to LA ϵ_{total} , we found that peak negative LA ϵ provided comparable predictive value for AF recurrence after catheter ablation in ROC analysis (area under the ROC curve, 0.680 ± 0.034 [$P = .085$] vs LA ϵ_{total}), whereas peak positive LA ϵ did not (area under the ROC curve, 0.683 ± 0.034 [$P = .008$] vs LA ϵ_{total}). However, when we use contractile variables in the context of depressed LA contractile function, we cannot overlook the possibility that LA stunning³⁹ may prevent impaired contractility. Depressed LA contractile function does not necessarily reflect the ultrastructural remodeling of the LA wall. Because of the time lag between echocardiography and ablation, how well sinus rhythm had been maintained might affect contractile function before the procedure. On the other hand, there could be LV stunning

after AF termination, especially in patients who show rapid ventricular response during AF. In these patients, both LA contractile function and reservoir function can be impaired just after the termination of AF, but the latter perhaps less frequently because almost all contractile function is affected by AF. Furthermore, $LA\epsilon_{total}$ reflects the distensibility of the LA wall⁴⁰ and relates to fibrosis of the atrial wall.⁹ Thus, reservoir function variables might be preferable to contractile variables for assessing ultrastructural remodeling in clinical settings.

Clinical Implications

The analysis of $LA\epsilon$ using speckle-tracking enables the noninvasive assessment of atrial remodeling in patients with AF. Identifying predictors of AF recurrence makes it possible to differentiate patients on the basis of various probabilities of long-term success. Furthermore, noninvasive assessment of atrial remodeling based on $LA\epsilon$ analysis could be used to improve preablation patient selection. $LA\epsilon$ analysis may be beneficial in considering questionable candidates for ablation. Importantly, echocardiographic determination of $LA\epsilon$ using speckle-tracking is easy, reliable, and widely available and can be used in daily clinical practice.

Limitations

First, because of the retrospective nature of this study, the follow-up period was short, and the duration between echocardiography and catheter ablation was long. Second, we used two echocardiographic systems with a relatively low average frame rate (39 ± 12 frames/sec). Low frame rates and only a single measurement of $LA\epsilon$ might cause a missing peak value of $LA\epsilon$ as well as a wide variation of this measurement. Thus, the accuracy of $LA\epsilon$ for the prediction of procedural success was modest. A prospective study would increase predictive value by focusing specifically on image acquisition for $LA\epsilon$ measurements using higher frame rates and multiple heartbeats. In terms of the vendor difference, there was no significant difference in the distribution of $LA\epsilon$ between these two systems (iE33 and Vivid 7 or Vivid E9; $24.6 \pm 8.1\%$ vs $22.6 \pm 8.3\%$). Thus, the vendor difference did not play an important role in the relationship between depressed $LA\epsilon$ and AF recurrence. A previous study reported that machines from different vendors obtained varying values of global LV ϵ in the same patient, and these values were minimized by using non-vendor-specific software.⁴¹ In this study, we did not compare the two systems in terms of $LA\epsilon$ measured in the same patient; however, using non-vendor-specific software for measuring ϵ with different vendors' systems could minimize the variation in myocardial ϵ values.⁴¹ Third, asymptomatic episodes of AF might not have been detected during the follow-up period. Fourth, our population had preserved LV ejection fractions. Fifth, although the greatest area under the curve was obtained, the accuracy of $LA\epsilon_{total}$ for the prediction of sinus rhythm maintenance was modest. A future prospective study could show the prognostic significance of $LA\epsilon_{total}$ in a more balanced manner. Cutoff points determined using ROC curve analysis would be tested in a prospective manner. Sixth, our study population was heterogeneous; we enrolled patients regardless of whether they had paroxysmal or persistent AF, with or without histories of pulmonary vein isolation. The clinical impact of $LA\epsilon$ could be evaluated more accurately using a homogeneous cohort. Despite these limitations, $LA\epsilon$ analysis

proved a straightforward approach, with the promise of clinical utility for predicting sinus rhythm maintenance in patients after AF ablation.

CONCLUSIONS

In patients with AF, baseline $LA\epsilon_{total}$ was an independent predictor of sinus rhythm maintenance after catheter ablation. $LA\epsilon_{total}$ provided incremental predictive value for rhythm outcomes over clinical features. Further long-term prospective studies are needed to evaluate the clinical utility of $LA\epsilon$ analysis.

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Abbreviations

AF	Atrial fibrillation
ϵ	Strain
LA	Left atrial
$LA\epsilon$	Left atrial global longitudinal strain
$LA\epsilon_{total}$	Total left atrial global longitudinal strain
LV	Left ventricular
ROC	Receiver operating characteristic

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Figure 1.

Measurements of LA ϵ using Velocity Vector Imaging. We identified peak negative LA ϵ ($\epsilon_{\text{negative}}$), peak positive LA ϵ ($\epsilon_{\text{positive}}$), and the sum of these values, LA ϵ_{total} . LA ϵ_{total} was higher in a patient without AF recurrence (A) than in a patient with AF recurrence (B). ECG, Electrocardiogram.

Figure 2.

ROC curves for the prediction of sinus rhythm maintenance. The area under the curve (AUC) for $LA\epsilon_{total}$ was greater than for total LA emptying fraction (LAEF) and maximal LA volume index (LAVi).

Figure 3. Kaplan-Meier analysis on the basis of $LA\epsilon_{total}$. Preserved baseline $LA\epsilon_{total}$ predicted long-term sinus rhythm maintenance.

Figure 4.

(A) Kaplan-Meier analyses according to $LA\epsilon_{total}$ in patients with paroxysmal or persistent AF. (B) Kaplan-Meier analyses in patients with or without histories of AF ablation.

Figure 5.

Incremental value of $LA\epsilon$ over conventional parameters. $LA\epsilon_{total}$ provides an additional benefit over clinical features, including age, sex, AF duration, AF type, prior AF ablation, CHADS₂ score, and permanent pacemaker or cardioverter-defibrillator implantation.

Table 1

Baseline characteristics

Variable	Overall (n = 256)	Sinus (n = 149)	AF recurrence (n = 107)	P
Demographics				
Mean age (y)	59 ± 11	59 ± 10	60 ± 13	.792
Male gender	179 (70%)	109 (73%)	69 (64%)	.192
Body mass index (kg/m ²)	29.5 ± 5.6	29.2 ± 5.5	30.0 ± 5.8	.286
Heart rate (beats/min)	61 ± 11	61 ± 11	62 ± 11	.407
Systolic blood pressure (mm Hg)	125 ± 18	125 ± 18	126 ± 18	.542
AF history				
Duration (mo)	48 (24–84)	48 (18–84)	46 (24–96)	.208
Paroxysmal	204 (80%)	128 (86%)	73 (68%)	.004
Number of failed AADs	1.4 ± 0.9	1.4 ± 0.9	1.5 ± 0.8	.162
Prior AF ablation	76 (30%)	39 (26%)	37 (35%)	.147
Comorbidities				
Congestive heart failure	38 (15%)	17 (11%)	21 (20%)	.068
Hypertension	138 (54%)	76 (51%)	62 (58%)	.272
Diabetes mellitus	29 (11%)	14 (9%)	15 (14%)	.250
Stroke/TIA	14 (5%)	6 (4%)	8 (7%)	.231
CHADS ₂ score	0.95 ± 0.94	0.83 ± 0.90	1.13 ± 0.97	.007
PPM/ICD	33 (13%)	12 (8%)	21 (20%)	.006
Coronary artery disease	37 (14%)	17 (11%)	20 (19%)	.102
Medications				
ACE inhibitors and/or ARBs	97 (38%)	59 (40%)	38 (36%)	.507
β-blockers	131 (51%)	75 (50%)	56 (52%)	.752
Class 1 or 3 AAD	196 (77%)	111 (74%)	85 (79%)	.357
Laboratory data				
BNP (pg/mL)	52 (22–117)	35 (19–84)	75 (32–135)	<.001
Echocardiographic data				
Global LAε _{total} (%)	23.6 ± 8.3	26.2 ± 7.9	19.9 ± 7.2	<.001
Global LAε _{negative} (%)	−7.6 ± 4.0	−8.7 ± 4.0	−6.2 ± 3.7	<.001
Global LAε _{positive} (%)	15.9 ± 6.6	17.6 ± 6.6	13.7 ± 6.0	<.001
Maximal LA volume index (mL/m ²)	41 ± 13	41 ± 11	47 ± 15	.002
Minimal LA volume index (mL/m ²)	23 ± 12	20 ± 10	26 ± 14	<.001
Precontraction LA volume index (mL/m ²)	32 ± 12	29 ± 10	35 ± 14	.001
Total LA emptying fraction (%)	50 ± 13	52 ± 13	46 ± 13	<.001
Active LA emptying fraction (%)	30 ± 15	32 ± 16	26 ± 13	.002
Passive LA emptying fraction (%)	28 ± 11	29 ± 11	27 ± 10	.062
LV EF (%)	58 ± 10	58 ± 9	57 ± 11	.415

Variable	Overall (n = 256)	Sinus (n = 149)	AF recurrence (n = 107)	P
LV EDV index (mL/m ²)	55 ± 18	53 ± 15	56 ± 20	.199
LV mass index (g/m ²)	96 ± 29	93 ± 27	99 ± 30	.101
LA area (cm ²)	22 ± 6	21 ± 5	23 ± 6	.007
TMF E (cm/sec)	81 ± 20	80 ± 18	84 ± 23	.147
TMF A (cm/sec)	61 ± 22	64 ± 20	56 ± 23	.008
TMF E-DT (msec)	213 ± 57	213 ± 52	212 ± 62	.836
PVF S (cm/sec)	55 ± 14	58 ± 12	50 ± 14	<.001
PVF D (cm/sec)	57 ± 17	55 ± 15	59 ± 18	.034
PVF Ar (cm/sec)	25 ± 6	26 ± 5	24 ± 6	.004
S/D ratio	1.0 ± 0.4	1.1 ± 0.4	0.9 ± 0.4	<.001
DTI s' average (cm/sec)	7.9 ± 1.9	8.2 ± 1.8	7.6 ± 2.1	.028
DTI e' average (cm/sec)	9.1 ± 2.8	9.1 ± 2.5	9.2 ± 3.1	.863
DTI a' average (cm/sec)	8.0 ± 2.8	8.6 ± 2.5	7.1 ± 2.9	<.001

AAD, Antiarrhythmic drug; ACE, angiotensin-converting enzyme; ARB, angiotensin receptor blocker; BNP, B-type natriuretic peptide; DT, deceleration time; DTI, Doppler tissue imaging; EDV, end-diastolic volume; EF, ejection fraction; ICD, implantable cardioverter-defibrillator; PPM, permanent pacemaker; PVF, pulmonary vein flow; TIA, transient ischemic attack; TMF, transmitral flow.

Data are expressed as mean ± SD, number (percentage), or median (interquartile range).

Table 2

Univariate and multivariate linear regression associations with LAε

Variable	Univariate		Multivariate	
	r	P	β (95% CI)	Standardized β P
Age	−0.282	<.001	−0.091 (−0.163 to −0.019)	−0.111 .013
Heart rate	−0.206	.001	−0.117 (−0.184 to −0.050)	−0.149 .001
Systolic blood pressure	−0.104	.096		
CHADS ₂ score	−0.273	<.001		
Duration of AF	−0.077	.224		
LV EDV index	−0.074	.238		
LV mass index	−0.245	<.001	−0.039 (−0.065 to −0.013)	−0.131 .003
LV EF	0.177	.004		
E/e' average	−0.357	<.001	−0.367 (−0.563 to −0.171)	−0.168 <.001
Maximal LA volume index	−0.398	<.001		
Total LA emptying fraction	0.729	<.001	0.403 (0.350 to 0.456)	0.656 <.001
Natural log BNP	−0.469	<.001		

BNP, B-type natriuretic peptide; CI, confidence interval; EDV, end-diastolic volume; EF, ejection fraction.

Table 3

Univariate and multivariate Cox proportional-hazards analysis

Variable	Univariate		Multivariate	
	HR (95% CI)	P	HR (95% CI)	P
Age	1.005 (0.986 to 1.024)	.636	0.987 (0.969–1.007)	.197
Female gender	1.382 (0.926–2.062)	.113	1.288 (0.831–1.996)	.257
Duration of AF	1.002 (1.000–1.004)	.044	1.002 (1.000–1.004)	.109
Persistent AF	1.678 (1.102–2.556)	.016	1.182 (0.728–1.920)	.498
Prior ablation	1.505 (1.008–2.246)	.046	1.363 (0.881–2.109)	.164
CHADS ₂ score	1.198 (0.994–1.443)	.057	1.018 (0.814–1.272)	.878
PPM/ICD	2.050 (1.259–3.340)	.004	1.483 (0.859–2.561)	.157
Natural log BNP	1.297 (1.090–1.543)	.003	1.111 (0.905–1.365)	.315
LA ϵ _{total}	0.939 (0.916–0.962)	<.001	0.952 (0.921–0.983)	.003
Maximal LA volume index	1.014 (1.001–1.026)	.030	0.998 (0.983–1.014)	.822

BNP, B-type natriuretic peptide; CI, confidence interval; HR, hazard ratio; ICD, implantable cardioverter-defibrillator; PPM, permanent pacemaker.