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Temporal dynamics of left atrial reverse remodeling predicts atrial fibrillation ablation outcome: A 3-year longitudinal study

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ABSTRACT

Background Long-term dynamic changes in the left atrium (LA) following radiofrequency catheter ablation (RFCA) for atrial fibrillation (AF) remain unclear. We aimed to unveil the temporary dynamics of LA reverse remodeling and the optimal echocardiographic indicator and timing for evaluating RFCA outcomes in this 3-year longitudinal study.

Methods Data were retrospectively collected from 400 consecutive patients undergoing RFCA for AF (paroxysmal 71%). Echocardiographic examinations were performed at 1 day, and 1, 3, 6, 12, 18, 24, 30, and 36 months after RFCA. Patients were classified into three groups based on RFCA outcomes. We constructed mean response curves to visualize the tendency between echocardiographic indicators and time across groups. Proportional odds models were built to determine the optimal echocardiographic indicator and follow-up time point for distinguishing the outcome group.

Results After a mean follow-up duration of 81 ± 24 months, free of AF was achieved in 357 patients. Mean response curves of echocardiographic indicators differed between patients with and without AF recurrence. A flat slope of mean response curves in the first 3 months and deterioration of echocardiographic indices starting 18 months after RFCA indicated higher risks of AF recurrence. LA linear ablation didn't affect the longitudinal trend of echocardiographic indicators in paroxysmal AF, but retarded LA reverse remodeling process in persistent AF. LAEF at 36 months had the highest c-index for predicting AF recurrence during a median follow-up period of 80 months.

Conclusions The longitudinal trend of echocardiographic indicators reflects long-term LA remodeling and can provide important information for individualized treatment strategies.

Atrial fibrillation (AF) is the most prevalent arrhythmia[1] and is associated with an increased risk of systemic thromboembolic events, heart failure, and mortality.[2] Although radiofrequency catheter ablation (RFCA) is an effective therapeutic option for patients with AF, AF recurrence remains a significant challenge. A meta-analysis showed that left atrial (LA) size as well as reduced LA function in the form of strain and LA emptying fraction (LAEF) are the most important predictors of AF recurrence, regardless of the type of AF and the technique used for AF ablation.[3] RFCA may improve LA structure and function in patients with AF by reverse remodeling; however, extensive LA scarring due to ablation may also impair LA function.[4] Changes in LA function after RFCA depend on the balance between the beneficial effects of LA reverse remodeling and deleterious effects of fibrosis. Wylie, *et al.*[4] reported that AF ablation decreased LA size

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but reduced LA systolic function 1 to 2 months after RFCA (paroxysmal 73%). Hwang, *et al*.[5] reported that LAEF increased within the first 24 h after ablation, decreased at 3 months, and then increased at 1 year (paroxysmal 60%). Rodrigues, *et al*.[6] noted an early reduction in LA function within the first 24 h after ablation, with subsequent improvement at 8 ± 2 months in paroxysmal AF patients. Liu, *et al*.[7] reported that there was no significant change in LA structure and function in paroxysmal AF; however, LA volume decreased and LAEF increased significantly in persistent AF within 1 week. In addition to the type of AF, the timing of the assessment (short- vs. long-term) may also be an important factor contributing to the inconsistent reports on changes in LA function after RFCA. As LA structure and function play crucial roles in the onset and persistence of AF, it is important to unveil the temporal dynamics of LA remodeling after RFCA for long-term outcome evaluation. Regarding the long-term dynamic changes in LA structure, we previously reported that LA diameter (LAD) decreased within the first three months and remained stable for up to 36 months; however, LAD reduction was not a sufficient indicator of RFCA success because LAD was reduced in both the success and failure groups.[8] The purposes of this 3-year longitudinal study were (1) to unveil the dynamic evolution patterns in echocardiographic indicators and assess the long-term effect of RFCA on LA structure and function between groups using mean response curve; and (2) to construct proportional odds models to identify statistically important echocardiographic indicators and the optimal follow-up time point for distinguishing the long-term outcome status of RFCA.

METHODS

Patient Population

We retrospectively evaluated 516 patients with symptomatic, drug-refractory AF undergoing RFCA at our institution between June 2017 and April 2022. Patients were excluded if the echocardiographic image quality was insufficient (n = 18) or if more than three of the nine follow-up echocardiographic data points were missing (n = 98). Thus, 400 patients were enrolled in this study. AF episodes that terminated spontaneously within 7 days were defined as paroxysmal AF, whereas AF episodes lasting longer than 7 days were defined as persistent AF. A detailed medical history of AF (including the duration of AF history) and associated cardiovascular and systemic diseases were recorded for all patients. All antiarrhythmic drugs (AADs) were discontinued for at least five half-lives, except amiodarone, which was discontinued at least three months before the ablation procedure. The potential predictors of AF recurrence were identified using clinical and echocardiographic data. Patients underwent cardiac computed tomography to evaluate the morphology and adjacent structures of the LA and pulmonary veins (PV). This study was approved by the Institutional Review Board of Chang Gung Memorial Hospital, Taiwan (IRB No. 202500701B0), and written informed consent was obtained from all patients.

Electrophysiological Study and Radiofrequency Catheter Ablation

All patients received RFCA procedure under general anesthesia with 1%-2% isoflurane. Heparin was administered to maintain an activated clotting time > 300 s. RFCA was performed using a three-dimensional electroanatomical mapping system (CARTO, Biosense-Webster, Diamond Bar, CA, USA) to support the creation and validation of ablation lesions. A 3.5-mm open-tip irrigated catheter (NaviStar ThermoCool or ThermoCool SmartTough, Biosense Webster) was percutaneously introduced through the right femoral vein for mapping and ablation. Bilateral circumferential pulmonary vein isolation (CPVI) was confirmed by the elimination or dissociation of all PV potentials recorded from a LASSO catheter, together with an exit block by pacing within the PV ostia in all patients. If AF persisted or left atrial tachycardia occurred after CPVI, additional LA linear ablation (LARF) was performed at the operator's discretion. The roof, posterior mitral, anterior mitral, posterior, and anteroseptal lines were potential targets. We prefer performing LARF within a low voltage area, especially at sites with complex-fractionated and/or high-frequency electrograms.[9] External cardioversion was performed to restore sinus rhythm if RFCA failed to convert AF.

Echocardiography

Two-dimensional echocardiographic images of the LA and left ventricle (LV) were obtained on the day after RFCA, and serial echocardiographic examinations were performed at 1, 3, 6, and12 months and then every 6 months after RFCA. Baseline echocardiographic exam-

inations were performed using a commercially available ultrasound scanner (Vivid 9, General Electric Medical Health, Waukesha, WI, USA) with a 2.5-MHz phased-array transducer. LA and LV measurements were obtained according to previously published methods[10] and the guidelines of the American Society of Echocardiography.[11] The LA volume was measured using an apical 4-chamber view. LA maximum volume (LAV_{max}) was defined as the largest volume just before mitral valve opening, and LA minimum volume (LAV_{min}) was defined as the smallest possible volume in ventricular diastole. LAEF was defined as $[(LAV_{max} - LAV_{min})/LAV_{max} \times 100]$.[10] The degree of mitral regurgitation (MR) was categorized into three grades (grade 0, none or trivial; grade 1, mild; grade 2, mild to moderate and above).

Follow-up and Definition of Recurrence

After discharge, patients were followed-up at 1 week and 1, 3, and 6 months, and then every 3 to 6 months after RFCA and whenever required owing to AF symptoms. At each visit, routine history taking, physical examination and 12-lead resting ECG were performed. Holter 24-h ambulatory ECG monitoring was performed in patients who reported symptoms suggestive of tachyarrhythmia. Recurrence was defined as the presence of self-reported typical palpitation episodes (> 30 s) or atrial tachyarrhythmia (AF or atrial tachycardia) on 12-lead ECG and/or 24-h Holter monitoring, or pacemaker/implantable cardioverter-defibrillator interrogation (where available) after a 3-month blanking period from the ablation procedure. AADs were prescribed for patients with recurrent atrial tachyarrhythmia if the patients preferred to avoid repeat RFCA. Repeat RFCA was suggested if atrial tachyarrhythmia was refractory to AADs. When patients who received repeat RFCA still experienced AF recurrence but responded to AADs, we also classified these patients into Group 2.

Statistical Analysis

Continuous variables were presented as the mean ± SD and categorical variables as number and percentage of the total. Based on the RFCA outcome, we divided patients into three groups: Group 1, no AF recurrence; Group 2, recurrence of atrial tachyarrhythmia responsive to AADs; and Group 3, recurrence of atrial tachyarrhythmia refractory to AADs. The potential predictors for AF recurrence included clinical and echocardiographic data. To assess the association between variables and the status of RFCA outcomes, we performed ANOVA for continuous variables and the chi-square test for categorical variables. $LAEF_d$ was defined as the difference between LAEF at baseline and 36 months post-ablation. A Spearman's rank-order correlation was conducted to assess the relationship between $LAEF_d$ and the total number of LARF lines and the baseline LAEF. To assess measurement reproducibility, LAEF, LAV_{max}, and LAV_{min} were reanalyzed in 45 randomly selected patients. Intra- and inter-observer reproducibility were evaluated using the intraclass correlation coefficient (ICC) with a two-way mixed-effects model and absolute agreement definition (single measure).

To identify the important echocardiographic indicators for differentiating the group, mean response curve was used to visualize the tendency between echocardiographic indicators (LAEF, LAD, LAV_{max}, LAV_{min}, and LV ejection fraction (LVEF)) and time across groups. Proportional odds models were then constructed to identify statistically important echocardiographic indicators and the optimal follow-up time point (baseline, and 1, 3, 6, 12, 18, 24, 30, and 36 months) for predicting the group, controlling for demographics (age and sex) and disease status. Cumulative odds were defined as the odds of severity. Variables that were significant in the bivariate analysis were included in the model,

Model fit was assessed by the receiver operating characteristic (ROC) curve. The concordance index (*c*-index) or the area under the ROC curve was used to summarize the ROC curve and was denoted as *c*.[12,13] Furthermore, the predicted group was assigned based on the largest predicted probability and was used to compute the percentage of correctly predicted groups and overall accuracy. Four accuracy indices were evaluated: Accuracy_1, Accuracy_2, Accuracy_3, and Accuracy_t, representing the percentage of correctly predicted Groups 1, 2, 3 and the overall accuracy, respectively.

Because of the imbalanced data, this study chose a sampling technique to balance the sample size in each group and set the sample sizes of Groups 1 and 2 to be equal to that of Group 3. To avoid potential selection bias, 500 random samples were randomly selected. The final model performance was then evaluated by the averaging *c*, Accuracy_1, Accuracy_2, Accuracy_3, and Accuracy_t over 500 samples. A two-tailed P value < 0.05 was considered indicative of statistical significance. Statistical analyses were performed using SAS version 9.4

(SAS Institute Inc., Cary, NC, USA).

RESULTS

Procedure Outcomes

Our study population comprised of 400 consecutive patients with AF (mean age 59.6 ± 11.5 years, mean duration of AF 3.29 ± 3.28 years, male 68.7%, and paroxysmal 71.0%). A total of 563 procedures were performed, and there were 273 (68.3%), 98 (24.5%), 24 (6.0%), 3 (0.75%) and 2 (0.5%) patients who received 1, 2, 3, 4 and 5 times RFCA procedures, respectively. After the last ablation, free of AF was achieved in 357 (89.3%) patients, including 287 patients (71.8%, Group 1) free of AADs and 70 patients (17.5%, Group 2) needing AADs treatment for AF control. Group 3 comprised of 43 patients (10.8%), including 22 patients (5.5%) with recurrence of left atrial tachycardia and 21 patients (5.3%) of AF. Among patients with paroxysmal AF, there were 226 (79.6%), 41 (14.4%) and 17 (6.0%) patients in Groups 1, 2, and 3, respectively; for persistent AF, there were 61 (52.6%), 29 (25.0%) and 26 (22.4%) patients in Groups 1, 2, and 3, respectively. LARF was performed in 196 patients (46.4% paroxysmal), including 44 (22.4%), 42 (21.4 %), 41 (20.9 %), 50 (25.5 %) and 19 (9.7 %) patients who received 1, 2, 3, 4 and 5 LARF lines, respectively. Among patients with LARF, there were 115 (58.7 %), 46 (23.5%) and 35 (17.9%) patients in Groups 1, 2, and 3, respectively; for patients without LARF (paroxysmal 94.6 %), there were 172 (84.3%), 24 (11.8%) and 8 (3.9%) patients in Groups 1, 2, and 3, respectively. The overall procedure-related major complication rate was 1.25 %, including three patients (0.75 %) with cardiac tamponade requiring pericardial drainage and two patients (0.5 %) with right phrenic palsy that resolved after several months.

Predictors of RFCA Success

Table 1 summarizes the clinical and echocardiographic characteristics of the three groups. Upon univariate analysis, old age, female, persistent AF, longer AF duration, LARF, tachycardia-bradycardia syndrome, more ablation time, hypertension, rheumatic heart disease, high CHA2DS2VASc score, chronic obstructive pulmonary disease, large LAD, LAV_{max} and LAV_{min}, lower LAEF and LVEF, and higher MR grade were found to be significant predictors of poor RFCA outcome. Body mass index and the presence of diabetes, dyslipidemia, coronary artery disease, end stage renal disease, or stroke did not confer a significant risk of AF recurrence.

Longitudinal Trends of Echocardiographic Parameters After RFCA

To elucidate whether the longitudinal trends of echocardiographic indicators differed according to the outcome of RFCA, mean response curves were constructed to visualize trends in the five echocardiographic indicators between the groups and over time, thereby distinguishing the groups. Figure 1 shows the mean response curves of the five echocardiographic indicators in the three groups of patients and Table 2 summarizes the results. For LAEF, mean response curves differed among the three groups. Group 2 had a steeper slope than Group 1 during the first 3 months. Group 3 had a flatter slope since the first month, and only Group 3 had a negative slope from 18 to 36 months. This implies that the improvement in LAEF was more evident in Groups 1 and 2 than in Group 3, and only Group 3 showed a downhill of LAEF starting 18 months after RFCA. For LAV_{max} and LAV_{min}, the longitudinal trend of Groups 1 and 2 was similar, declining in the first 3 months and then stabilizing (except for Group 2 at 30 months), while Group 3 showed a different trend with non-linear variation starting 3 months after RFCA. For LAD, mean response curves differed among the three groups. In Group 1, mean response curve declined during the first 12 months and then slightly elevated; in Group 2, the curve declined during the first 3 months, flattened out until 24 months, and then elevated; in Group 3, the curve declined during the first 6 months and then fluctuated with non-linear variation upward to 36 months. For LVEF, Groups 1 and 2 had similar longitudinal trend, but Group 3 showed a different trend with non-linear variation. Note that only Group 3 had a lower LAEF and LVEF, and a greater LAV_{max}, LAV_{min}, and LAD at 36 months than those at baseline. LA reverse remodeling remained relatively stationary for at least 36 months in patients whose AF was controlled (Groups 1 and 2).

Effects of LARF on Longitudinal Trends of Echocardiographic Indicators

To elucidate whether LARF influenced the longitudinal trends of echocardiographic indicators, mean response curves were constructed to visualize the tendencies of five echocardiographic indicators between the

Table 1 Clinical and echocardiographic data of the study groups.

	All patients	Group 1	Group 2	Group 3	*P*-values
Patient numbers	400	287 (71.75%)	70 (17.50%)	43 (10.75%)	
Age, yrs	59.6 ± 11.5	58.3 ± 10.7	62.3 ± 12.4	63.7 ± 13.0	0.002
Gender (males, %)	275 (68.7%)	204 (71.1%)	49 (70%)	22 (51.1%)	0.031
BMI, kg/m^2					0.335
< 25%	168 (42.0%)	129 (44.9%)	23 (32.9%)	16 (37.2%)	
25%-30%	174 (43.5%)	117 (40.8%)	35 (50.0%)	22 (51.2%)	
≥ 30%	58 (14.5%)	41 (14.3%)	12 (17.1%)	5 (11.6%)	
AF type					< 0.001
Paroxysmal	284 (71.0%)	226 (78.7%)	41 (58.6%)	17 (39.5%)	
Persistent	116 (29%)	61 (21.3%)	29 (41.4%)	26 (60.5 %)	
AFD, yrs	3.29 ± 3.28	2.85 ± 2.80	3.64 ± 3.39	5.66 ± 4.79	< 0.001
LARF	196 (49.0%)	115 (40.1%)	46 (65.7%)	35 (81.4%)	< 0.001
TBS, %	45 (11.3%)	25 (8.7%)	11 (15.7%)	9 (20.9%)	0.026
Ablation times	1.41 ± 0.68	1.36 ± 0.65	1.46 ± 0.67	1.63 ± 0.85	0.047
Hypertension	201 (50.3%)	134 (46.7%)	44 (62.9%)	24 (55.8%)	0.040
Diabetes mellitus	83 (20.8%)	53 (18.5%)	19 (27.1%)	11 (25.6%)	0.196
Dyslipidemia	149 (37.3%)	103 (35.9%)	31 (44.3%)	16 (37.2%)	0.429
CAD	17 (4.3%)	11 (3.8%)	5 (7.1%)	2 (4.7%)	0.487
ESRD	13 (3.3 %)	6 (2.1 %)	4 (5.7 %)	3 (7.0 %)	0.107
RHD	6 (1.5%)	2 (0.7%)	0 (0%)	4 (9.3%)	0.003
CHA2DS2VASc	2.81 ± 0.89	2.69 ± 0.80	3.03 ± 0.95	3.28 ± 1.14	< 0.001
Stroke	26 (6.5%)	15 (5.2%)	7 (10.0%)	4 (9.3%)	0.255
COPD	14 (3.5%)	8 (2.8%)	1 (1.4%)	5 (11.6%)	0.018
Echocardiographic data					
LAD, mm	42.5 ± 6.6	40.7 ± 5.7	46.3 ± 6.6	47.7 ± 6.9	< 0.001
LAV_{max}, mL	67.3 ± 30.1	59.6 ± 22.7	78.9 ± 37.8	96.6 ± 35.8	< 0.001
LAV_{min} (ml)	39.4 ± 26.4	31.9 ± 18.5	51.1 ± 32.8	67.3 ± 33.8	< 0.001
LAEF (%)	45.4 ± 12.9	49.1 ± 11.1	38.2 ± 12.8	32.7 ± 11.7	< 0.001
IVS (mm)	11.9 ± 2.5	11.7 ± 2.6	12.3 ± 2.0	12.4 ± 1.8	0.109
LVEF (%)	65.4 ± 8.3	66.4 ± 7.2	63.6 ± 9.7	62.0 ± 11.4	0.001
MR grade					< 0.001
None or Trivial	73 (18.25%)	64 (22.3%)	7 (10.0%)	2 (4.7%)	
Mild	231 (57.75%)	170 (59.2%)	38 (54.3%)	23 (53.4%)	
≥ Mild to moderate	96 (24.00%)	53 (18.5%)	25 (35.7%)	18 (41.9%)	

Data are presented as mean ± SD or *n* (%). AF: atrial fibrillation; Group 1: no AF recurrence; Group 2: recurrence of atrial tachyarrhythmia responsive to antiarrhythmic drugs; Group 3: recurrence of atrial tachyarrhythmia refractory to antiarrhythmic drugs. BMI: body mass index; AFD: AF duration; LARF: LA linear ablation; CAD: coronary artery disease; COPD: chronic obstructive pulmonary disease; ESRD: end stage renal disease; LAD: left atrial diameter; LAV_{max}: maximal left atrial volume; LAV_{min}: minimal left atrial volume; LAEF: left atrial emptying fraction; IVS: interventricular septum; LVEF: left ventricular ejection fraction; MR: mitral regurgitation; RHD: rheumatic heart disease; TBS: tachycardia-bradycardia syndrome.

groups of patients who did and did not receive LARF. As shown in Figure 2, patients with LARF (yellow lines) had lower LAEF and LVEF, and larger LAV_{max}, LAV_{min}, and LAD than those of patients without LARF (brown lines); however, the longitudinal trends of mean response curves were similar in both groups. Furthermore, patients with LARF had greater increases in LAEF and LVEF and greater decreases in LAD and LA volume than those without LARF, suggesting that patients with poorer baseline echocardiographic indices experienced a

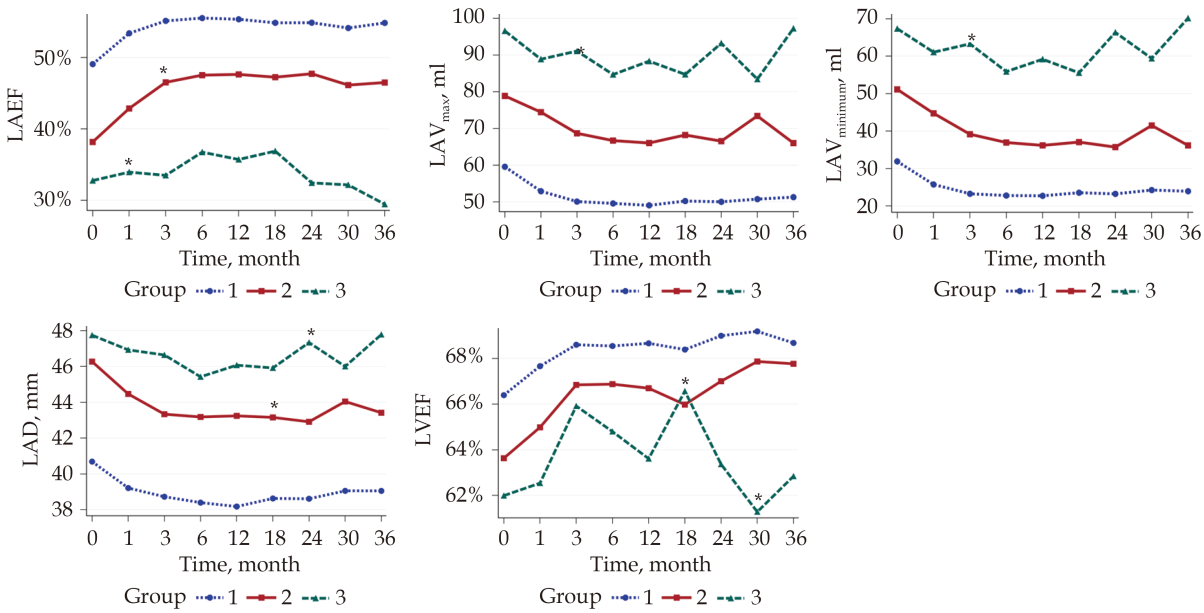


Figure 1 Mean response curves of five echocardiographic indicators in three groups. LAD: left atrial diameter; LAEF: left atrial emptying fraction; LAVmax: maximal left atrial volume; LAVmin: minimal left atrial volume; LVEF: left ventricular ejection fraction. Asterisks indicate $P < 0.05$ compared to Group 1.

greater degree of LA reverse remodeling, even when undergoing LARF. Table 3 summarizes the results of the statistical analyses of the mixed models controlling for LARF.

To elucidate whether LARF had different effects on the longitudinal trends of echocardiographic indicators in different types of AF, mean response curves were constructed to visualize the tendency of the five echocardiographic indicators between patients with paroxysmal and persistent AF who did or did not receive RFCA. Figure 3 and Table 4 summarize the results. In paroxysmal AF, the baseline LAEF, LAV_{max}, LAV_{min}, and LAD were worse in patients with LARF (brown lines) than those without LARF (red lines), but the mean response curves of two groups were parallel. In persistent AF, patients with LARF (green lines) had worse baseline LAEF, LAV_{max}, LAV_{min}, and LAD, and the slopes of mean response curves were flatter than those without LARF (yellow lines). As shown in Figure 3, LARF resulted in a smaller and slower increase of LAEF in patients with persistent AF. Among these four groups, the best LA reverse remodeling occurred in persistent AF without LARF.

Roles of Echocardiographic Indicators and Timing in Model Performance

Table 5 summarizes the parameter estimates for proportional odds models of the association between predictive variables and ablation outcomes using different echocardiographic indicators and follow-up time points. Female, old age, AF duration, persistent AF, MR degree and hypertension were independent factors associated with AF recurrence after RFCA. By adding the values of sex, age, AF duration, AF type, MR grade, hypertension, and measured data of the echocardiographic indicators to the models, we can obtain the odds of having a severe outcome vs. a non-severe outcome.[10] Each echocardiographic indicator had its own model at a given follow-up time point. Figure 4 and Table 6 summarize the results of the model performance of all five indicators at nine follow-up time points. For LAEF, the mean *c*-index was 0.80 ± 0.02 at baseline and 0.91 ± 0.02 at 36 months; for LAV_{min}, the mean *c*-index was 0.81 ± 0.02 at baseline and 0.89 ± 0.02 at 36 months; for LAV_{max}, the mean *c*-index was 0.80 ± 0.02 at baseline and 0.86 ± 0.02 at 36 months; for LAD, the mean *c*-index was 0.79 ± 0.02 at baseline and 0.84 ± 0.02 at 36 months; for LVEF, the mean *c*-index was 0.77 ± 0.02 at baseline and 0.79 ± 0.02 at 36 months. All *c*-indices were better at month 36 than at baseline, and LAEF at 36 months had the best model performance, followed by LAV_{min}, LAV_{max}, LAD, and LVEF. The results of using accuracy to assess the model performance were similar to those obtained using *c*-index. The bottom panels of Figure 4 shows the results of accuracy for

Table 2 Mixed model controlling for the outcome group.

Models				LAEF			LAV_{max}			LAV_{min}			LAD			LVEF		
Variable			Variable	Est	SE	*P*	Est	SE	*P*	Est	SE	*P*	Est	SE	*P*	Est	SE	*P*
Intercept	–	–	Intercept	49.057	0.677	< 0.001	40.198	0.221	< 0.001	33.200	0.311	< 0.001	40.690	0.355	< 0.001	66.392	0.485	< 0.001
group * month	1	0	group * month			< 0.001			0.002			< 0.001			0.023			0.003
		1	group * month	0.000			0.000			0.000			0.000			0.000		
		3	group * month	0.000			0.000			0.000			0.000			0.000		
		6	group * month	0.000			0.000			0.000			0.000			0.000		
		12	group * month	0.000			0.000			0.000			0.000			0.000		
		18	group * month	0.000			0.000			0.000			0.000			0.000		
		24	group * month	0.000			0.000			0.000			0.000			0.000		
		30	group * month	0.000			0.000			0.000			0.000			0.000		
		36	group * month	0.000			0.000			0.000			0.000			0.000		
	2	0	group * month	0.000			0.000			0.000			0.000			0.000		
		1	group * month	−0.041	0.980	0.967	0.401	0.208	0.055	0.504	0.296	0.089	−0.483	0.399	0.227	0.241	0.856	0.779
		3	group * month	2.404	1.164	0.039	0.191	0.252	0.449	−0.037	0.370	0.919	−0.829	0.443	0.062	1.058	0.981	0.281
		6	group * month	2.946	1.219	0.016	0.032	0.283	0.909	−0.300	0.414	0.469	−0.659	0.465	0.157	1.207	0.936	0.198
		12	group * month	3.192	1.279	0.013	0.068	0.274	0.805	−0.355	0.415	0.392	−0.534	0.493	0.280	0.790	0.992	0.426
		18	group * month	4.081	1.349	0.003	0.103	0.286	0.719	−0.494	0.434	0.256	−1.051	0.462	0.023	0.462	1.005	0.646
		24	group * month	3.789	1.345	0.005	0.106	0.311	0.732	−0.397	0.468	0.396	−1.302	0.519	0.012	0.835	1.011	0.409
		30	group * month	3.820	1.374	0.006	0.446	0.325	0.172	−0.088	0.465	0.850	−1.270	0.542	0.020	0.713	1.185	0.548
		36	group * month	2.073	1.360	0.128	0.164	0.303	0.587	−0.021	0.462	0.964	−0.866	0.485	0.075	1.595	1.042	0.127
	3	0	group * month	0.000			0.000			0.000			0.000			0.000		
		1	group * month	−2.520	1.204	0.037	−0.028	0.256	0.914	0.572	0.364	0.117	0.476	0.491	0.333	−0.089	1.071	0.934
		3	group * month	−5.375	1.432	< 0.001	0.835	0.311	0.008	1.845	0.455	< 0.001	0.849	0.549	0.123	1.682	1.220	0.169
		6	group * month	−3.341	1.505	0.027	0.509	0.350	0.146	1.295	0.511	0.012	0.262	0.576	0.650	0.758	1.160	0.514
		12	group * month	−3.319	1.569	0.035	0.795	0.336	0.019	1.482	0.509	0.004	0.781	0.607	0.199	0.246	1.248	0.844
		18	group * month	−2.818	1.672	0.093	0.596	0.354	0.093	1.201	0.538	0.026	0.387	0.575	0.501	2.907	1.246	0.020
		24	group * month	−6.134	1.648	< 0.001	1.004	0.381	0.009	2.218	0.573	< 0.001	1.716	0.636	0.007	−1.748	1.257	0.165
		30	group * month	−7.897	1.685	< 0.001	1.104	0.399	0.006	2.695	0.570	< 0.001	1.346	0.662	0.043	−2.666	1.448	0.066
		36	group * month	−8.851	1.670	< 0.001	1.346	0.371	< 0.001	2.976	0.568	< 0.001	1.526	0.596	0.011	−0.918	1.302	0.481
AIC			AIC	20594.5			11569.9			13820.1			15525.4			18946.5		

AIC: Akaike Information Criterion; Est: estimate; LAD: left atrial dimension; LAEF: left atrial emptying fraction; LARF: left atrial linear ablation; LAVmax: maximal left atrial volume; LAVmin: minimal left atrial volume; LVEF: left ventricular ejection fraction.

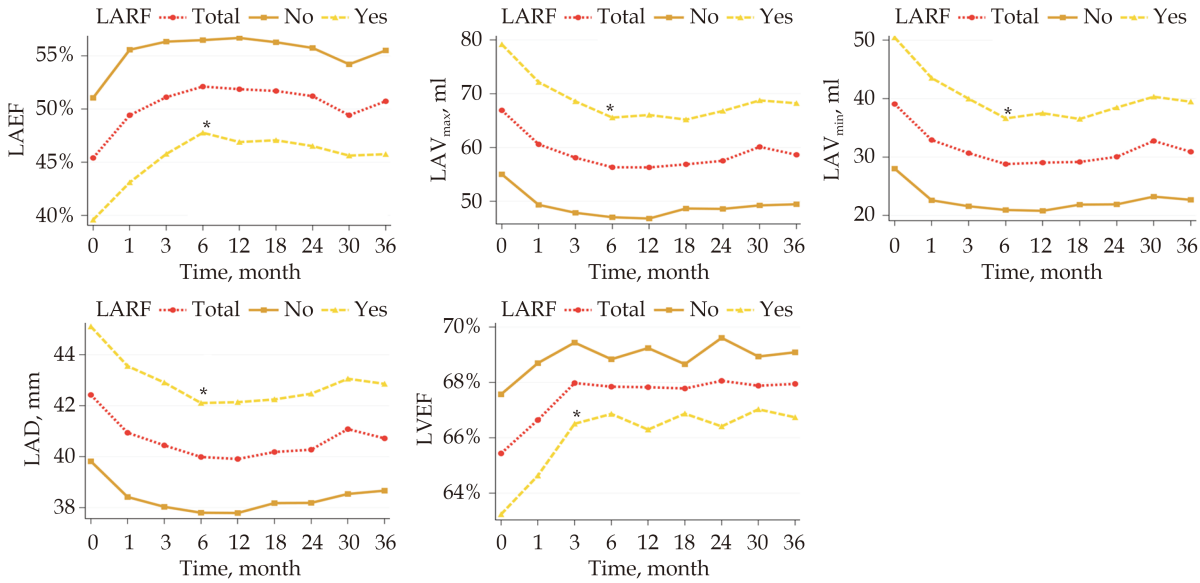


Figure 2 Mean response curves of five echocardiographic indicators in patients with (yellow line) and without (brown line) LARF. LAD: left atrial diameter; LAEF: left atrial emptying fraction; LAV_{max}: maximal left atrial volume; LAV_{min}: minimal left atrial volume; LVEF: left ventricular ejection fraction. Asterisks indicate $P < 0.05$ compared to Group 1. LAD: left atrial diameter; LAEF: left atrial emptying fraction; LARF: left atrial linear ablation; LAV_{max}: maximal left atrial volume; LAV_{min}: minimal left atrial volume; LVEF: left ventricular ejection fraction. Asterisks indicate $P < 0.05$ compared to patients without LARF.

Table 3 Mixed model controlling for LARF.

Models			LAEF			LA_{max}			LA_{min}			LAD			LVEF		
Variable	**Variable**		**Est**	**SE**	***P***	**Est**	**SE**	***P***	**Est**	**SE**	***P***	**Est**	**SE**	***P***	**Est**	**SE**	***P***
Intercept	–	–	51.049	0.814	< 0.001	39.469	0.261	< 0.001	32.080	0.367	< 0.001	39.823	0.427	< 0.001	67.570	0.566	< 0.001
LARF*month	No	0			0.004			0.136			0.040			0.049			0.023
		1	0.000			0.000			0.000			0.000			0.000		
		3	0.000			0.000			0.000			0.000			0.000		
		6	0.000			0.000			0.000			0.000			0.000		
		12	0.000			0.000			0.000			0.000			0.000		
		18	0.000			0.000			0.000			0.000			0.000		
		24	0.000			0.000			0.000			0.000			0.000		
		30	0.000			0.000			0.000			0.000			0.000		
		36	0.000			0.000			0.000			0.000			0.000		
	Yes	0	0.000			0.000			0.000			0.000			0.000		
		1	−0.770	0.737	0.296	−0.099	0.157	0.527	0.193	0.223	0.385	−0.249	0.299	0.406	0.530	0.646	0.413
		3	1.055	0.900	0.242	−0.067	0.192	0.727	−0.147	0.285	0.606	−0.349	0.338	0.302	1.513	0.743	0.042
		6	2.153	0.924	0.020	−0.450	0.212	0.034	−0.688	0.312	0.028	−0.936	0.348	0.007	1.865	0.701	0.008
		12	1.709	0.970	0.079	−0.373	0.206	0.071	−0.566	0.314	0.072	−0.965	0.369	0.009	1.365	0.743	0.067
		18	1.369	1.031	0.185	−0.442	0.215	0.040	−0.534	0.329	0.105	−0.925	0.348	0.008	2.653	0.747	< 0.001
		24	2.258	1.033	0.029	−0.566	0.233	0.016	−0.865	0.355	0.015	−1.002	0.393	0.011	1.140	0.762	0.136
		30	2.917	1.087	0.008	−0.332	0.251	0.187	−0.824	0.362	0.023	−0.797	0.421	0.059	2.658	0.931	0.005
		36	1.597	1.055	0.131	−0.490	0.229	0.033	−0.669	0.356	0.061	−1.078	0.364	0.003	1.820	0.778	0.020
AIC			20805.5			11633.2			13934.0			15592.2			18989.1		

AIC: Akaike Information Criterion; Est: estimate; LAD: left atrial dimension; LAEF: left atrial emptying fraction; LARF: left atrial linear ablation; LAVmax: maximal left atrial volume; LAVmin: minimal left atrial volume; LVEF: left ventricular ejection fraction; SE: standard error.

each group. Group 1 had the highest accuracy for all five echocardiographic indicators at baseline, whereas Group 3 had the highest accuracy for LAEF, LAV_{min}, and LAV_{max} at 36 months. All models had the weakest discriminatory ability to identify Group 2 at any follow-up time point.

Example: proportional odds model using LAEF at 36 months

When $j = 3$, $\log[\pi(\geq 3, z)/\pi(<3, z)] = \log[\pi(3, z)/\pi(1, z) + \pi(2, z)]$

$$\log\left(\frac{\pi_3(\boldsymbol{x}, z)}{\pi_1(\boldsymbol{x}, z) + \pi_2(\boldsymbol{x}, z)}\right) = 5.71 - 0.12x_1 + 0.01x_2 + 0.19x_3 + 0.65x_4 - 0.13x_{51} - 0.47x_{52} + 0.46x_6 - 0.20z$$

When $j = 2$, $\log[\pi(\geq 2, z)/\pi(<2, z)] = \log[\pi(2, z) + \pi(3, z)/\pi(1, z))]$

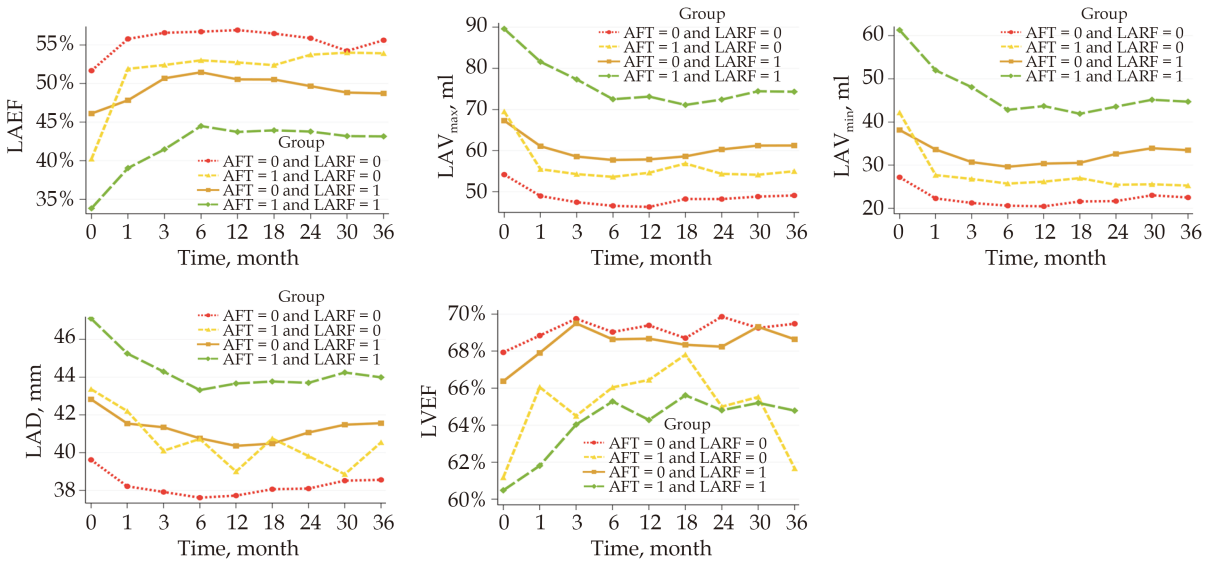


Figure 3 Mean response curves of five echocardiographic indicators in paroxysmal atrial fibrillation patients with (brown line) and without (red line) left atrial linear ablation (LARF) and in persistent atrial fibrillation patients with (green line) and without (yellow line) LARF. LAD: left atrial diameter; LAEF: left atrial emptying fraction; LAVmax: maximal left atrial volume; LAVmin: minimal left atrial volume; LVEF: left ventricular ejection fraction.

Table 4 Mixed model controlling for AF type and LARF.

Models			LAEF			LAV_{max}			LAV_{min}			LAD			LVEF		
Variable		Variable	Est	SE	*P*	Est	SE	*P*	Est	SE	*P*	Est	SE	*P*	Est	SE	*P*
Intercept	–	Intercept	51.668	0.767	< 0.001	39.321	0.257	< 0.001	31.809	0.352	< 0.001	39.620	0.424	< 0.001	67.935	0.559	< 0.001
group* month AFT= 0 and LARF = 0	0	group* month			< 0.001			0.002			< 0.001			0.023			0.003
	1	group* month	0.000			0.000			0.000			0.000			0.000		
	3	group* month	0.000			0.000			0.000			0.000			0.000		
	6	group* month	0.000			0.000			0.000			0.000			0.000		
	12	group* month	0.000			0.000			0.000			0.000			0.000		
	18	group* month	0.000			0.000			0.000			0.000			0.000		
	24	group* month	0.000			0.000			0.000			0.000			0.000		
	30	group* month	0.000			0.000			0.000			0.000			0.000		
	36	group* month	0.000			0.000			0.000			0.000			0.000		

Continued

Models			LAEF			LAV_{max}			LAV_{min}			LAD			LVEF		
Variable		Variable	Est	SE	*P*	Est	SE	*P*	Est	SE	*P*	Est	SE	*P*	Est	SE	*P*
AFT= 0 and LARF = 1	0	group* month	0.000			0.000			0.000			0.000			0.000		
	1	group* month	−1.950	0.920	0.035	−0.172	0.198	0.386	0.307	0.278	0.271	−0.087	0.382	0.821	0.774	0.818	0.345
	3	group* month	−0.021	1.131	0.985	−0.027	0.243	0.911	−0.002	0.359	0.995	0.192	0.424	0.651	1.150	0.948	0.226
	6	group* month	0.186	1.146	0.871	−0.181	0.267	0.497	−0.169	0.390	0.665	−0.241	0.436	0.582	0.941	0.881	0.287
	12	group* month	−0.811	1.200	0.500	−0.075	0.260	0.774	0.124	0.391	0.751	−0.600	0.465	0.197	0.752	0.942	0.425
	18	group* month	−1.121	1.270	0.378	−0.090	0.269	0.738	0.234	0.406	0.565	−0.482	0.437	0.271	1.463	0.935	0.118
	24	group* month	−0.651	1.267	0.608	−0.083	0.292	0.777	0.102	0.438	0.816	−0.284	0.493	0.564	0.111	0.965	0.908
	30	group* month	0.394	1.352	0.771	0.002	0.316	0.996	−0.168	0.452	0.710	−0.043	0.525	0.935	1.577	1.180	0.182
	36	group* month	−1.277	1.295	0.325	−0.146	0.288	0.611	0.136	0.440	0.757	−0.261	0.455	0.566	0.849	0.975	0.384
AFT= 1 and LARF = 0	0	group* month	0.000			0.000			0.000			0.000			0.000		
	1	group* month	6.767	2.272	0.003	−1.289	0.490	0.009	−2.400	0.689	< 0.001	−0.199	0.941	0.833	2.179	2.035	0.285
	3	group* month	6.113	2.765	0.028	−1.036	0.594	0.082	−2.025	0.878	0.022	−1.612	1.039	0.121	1.812	2.261	0.423
	6	group* month	7.492	2.779	0.007	−1.080	0.646	0.095	−2.376	0.944	0.012	−0.739	1.055	0.484	3.550	2.075	0.088
	12	group* month	7.249	2.932	0.014	−0.869	0.635	0.172	−2.185	0.954	0.023	−2.470	1.132	0.030	4.234	2.302	0.067
	18	group* month	9.062	3.179	0.005	−0.945	0.675	0.162	−2.753	1.017	0.007	−2.509	1.106	0.024	6.187	2.286	0.007
	24	group* month	9.293	3.096	0.003	−1.159	0.713	0.105	−2.851	1.069	0.008	−2.025	1.202	0.093	1.742	2.366	0.462
	30	group* month	8.572	3.243	0.009	−1.767	0.753	0.019	−3.176	1.084	0.004	−3.491	1.245	0.005	3.396	2.644	0.200
	36	group* month	9.789	3.157	0.002	−1.272	0.702	0.071	−3.286	1.074	0.002	−1.824	1.107	0.100	0.054	2.440	0.982
AFT= 1 and LARF = 1	0	group* month	0.000			0.000			0.000			0.000			0.000		
	1	group* month	0.938	0.876	0.285	−0.165	0.189	0.382	−0.144	0.265	0.586	−0.427	0.363	0.240	0.541	0.781	0.489
	3	group* month	2.618	1.082	0.016	−0.209	0.233	0.371	−0.482	0.344	0.161	−0.990	0.407	0.015	2.033	0.898	0.024
	6	group* month	4.643	1.098	< 0.001	−0.796	0.256	0.002	−1.386	0.373	< 0.001	−1.610	0.419	< 0.001	3.039	0.846	< 0.001
	12	group* month	4.653	1.148	< 0.001	−0.723	0.249	0.004	−1.393	0.374	< 0.001	−1.542	0.444	< 0.001	2.340	0.896	0.009
	18	group* month	4.458	1.219	< 0.001	−0.849	0.258	0.001	−1.484	0.390	< 0.001	−1.561	0.418	< 0.001	4.324	0.891	< 0.001
	24	group* month	5.746	1.212	< 0.001	−1.106	0.279	< 0.001	−1.999	0.419	< 0.001	−1.835	0.472	< 0.001	2.219	0.923	0.017
	30	group* month	6.010	1.282	< 0.001	−0.827	0.299	0.006	−1.751	0.428	< 0.001	−1.847	0.495	< 0.001	4.005	1.114	< 0.001
	36	group* month	5.113	1.239	< 0.001	−0.920	0.275	< 0.001	−1.712	0.421	< 0.001	−1.978	0.435	< 0.001	2.664	0.957	0.006
AIC		AIC	20681.0			11590.0			13852.4			15526.6			18892.4		

AIC: Akaike Information Criterion; Est: estimate; LAD: left atrial dimension; LAEF: left atrial emptying fraction; LARF: left atrial linear ablation; LAVmax: maximal left atrial volume; LAVmin: minimal left atrial volume; LVEF: left ventricular ejection fraction; SE: standard error.

Table 5 Parameter estimates for proportional odds models of the association between predicting variables and RFCA outcomes using LAD, LAEF, LAV_{max}, LAV_{min}, or LVEF at different follow-up times.

Measures	Variable	Category	Baseline			1 month			3 months			6 months			12 months		
Model	Variable	Category	Est	SE	%	Est	SE	%	Est	SE	%	Est	SE	%	Est	SE	%
LAD	Intercept	2	−6.01	1.91	98.20	−7.01	2.09	99.20	−7.43	2.09	100.00	−7.26	2.05	99.80	−8.19	2.06	100.00
		3	−7.99	1.98	100.00	−9.15	2.18	100.00	−9.63	2.18	100.00	−9.40	2.13	100.00	−10.30	2.15	100.00
	Sex	Male	−1.10	0.44	78.20	−1.11	0.46	75.80	−1.21	0.46	82.60	−1.07	0.46	69.00	−1.12	0.45	77.00
	Age		0.03	0.02	45.60	0.03	0.02	39.40	0.03	0.02	44.40	0.03	0.02	41.00	0.03	0.02	40.40
	AFD		0.17	0.05	98.80	0.18	0.06	97.20	0.14	0.06	72.20	0.18	0.06	93.40	0.16	0.06	88.80
	AFT	1	1.16	0.42	88.40	1.22	0.45	87.60	1.11	0.44	80.60	1.24	0.44	91.00	1.03	0.43	76.60
	MR grade	0	−0.56	0.70	3.80	−0.92	0.77	11.80	−0.50	0.72	2.60	−0.81	0.77	7.80	−0.61	0.71	3.20
		1	−0.09	0.43	0.60	−0.18	0.45	1.20	−0.22	0.44	0.80	−0.07	0.44	0.40	−0.06	0.44	0.40
	Hyperten-sion	Yes	−0.32	0.40	3.40	−0.32	0.42	4.00	−0.57	0.42	15.20	−0.50	0.43	8.80	−0.43	0.41	7.00
	LAD		0.11	0.03	100.00	0.14	0.04	100.00	0.16	0.04	100.00	0.15	0.04	100.00	0.17	0.04	100.00
LAEF	Intercept	2	1.84	1.44	10.60	3.93	1.64	75.60	5.64	1.76	98.40	5.18	1.84	91.00	5.39	1.80	93.80
		3	−0.16	1.43	0.20	1.71	1.60	7.60	3.25	1.69	45.80	2.87	1.79	29.40	3.13	1.75	41.20
	Sex	Male	−0.67	0.43	27.60	−0.58	0.46	14.80	−0.45	0.47	7.80	−0.22	0.48	2.20	−0.18	0.46	1.60
	Age		0.02	0.02	11.40	0.01	0.02	5.00	0.01	0.02	2.00	0.02	0.02	8.40	0.01	0.02	5.00
	AFD		0.17	0.05	98.40	0.16	0.06	89.00	0.14	0.06	66.60	0.15	0.06	70.00	0.17	0.06	92.00
	AFT	1	0.76	0.46	30.40	0.70	0.48	23.20	0.47	0.49	7.20	0.57	0.48	12.60	0.50	0.46	9.20
	MR grade	0	−1.02	0.71	22.80	−0.74	0.74	6.40	−0.54	0.75	4.60	−0.71	0.74	9.60	−0.80	0.72	10.40
		1	−0.29	0.42	1.60	−0.34	0.44	2.00	−0.24	0.46	1.40	−0.42	0.45	4.80	−0.40	0.44	4.80
	Hyperten-sion	Yes	0.11	0.39	0.20	0.13	0.42	0.20	−0.01	0.43	0.40	−0.16	0.43	0.80	0.14	0.41	0.00
	LAEF		−0.06	0.02	100.00	−0.09	0.02	100.00	−0.11	0.02	100.00	−0.11	0.02	100.00	−0.12	0.02	100.00
LAV_{max}	Intercept	2	−9.17	2.66	99.40	−9.54	2.75	99.60	−11.40	2.83	100.00	−11.00	2.81	100.00	−12.40	2.81	100.00
		3	−11.20	2.73	100.00	−11.60	2.82	100.00	−13.60	2.92	100.00	−13.20	2.90	100.00	−14.60	2.90	100.00
	Sex	Male	−0.86	0.43	51.40	−0.93	0.45	56.60	−0.81	0.46	42.00	−0.56	0.46	14.40	−0.67	0.45	26.20
	Age		0.03	0.02	39.40	0.03	0.02	42.40	0.04	0.02	51.40	0.04	0.02	55.40	0.03	0.02	44.20
	AFD		0.18	0.05	99.00	0.19	0.06	99.40	0.17	0.06	86.40	0.18	0.06	92.00	0.19	0.06	99.40
	AFT	1	0.94	0.44	62.80	1.10	0.46	74.80	0.89	0.46	51.60	1.01	0.45	66.80	0.84	0.43	48.40
	MR grade	0	−0.59	0.70	3.60	−0.47	0.71	2.40	−0.42	0.73	3.20	−0.89	0.73	14.40	−0.70	0.71	7.80
		1	−0.12	0.43	0.40	−0.15	0.45	0.60	−0.14	0.44	0.40	−0.27	0.44	1.00	−0.17	0.43	0.20
	Hyperten-sion	Yes	−0.17	0.39	1.60	−0.23	0.40	2.00	−0.37	0.41	5.60	−0.39	0.42	5.60	−0.18	0.40	1.60
	LAV_{max}		0.19	0.06	99.60	0.20	0.06	100.00	0.25	0.06	100.00	0.23	0.06	100.00	0.27	0.06	100.00
LAV_{min}	Intercept	2	−6.97	1.93	99.60	−7.70	1.99	100.00	−8.64	2.04	100.00	−8.40	2.04	100.00	−9.61	2.09	100.00
		3	−9.02	2.01	100.00	−9.87	2.08	100.00	−11.00	2.16	100.00	−10.70	2.15	100.00	−11.90	2.20	100.00
	Sex	Male	−0.75	0.44	37.80	−0.81	0.46	39.80	−0.60	0.47	17.00	−0.37	0.47	5.00	−0.41	0.46	7.00
	Age		0.03	0.02	29.00	0.03	0.02	24.60	0.03	0.02	27.80	0.03	0.02	36.00	0.03	0.02	24.80
	AFD		0.17	0.06	97.80	0.19	0.06	97.80	0.16	0.06	79.80	0.18	0.06	86.60	0.19	0.06	99.00
	AFT	1	0.65	0.46	20.60	0.73	0.48	26.60	0.50	0.48	7.80	0.69	0.47	22.00	0.46	0.46	6.00
	MR grade	0	−0.57	0.71	2.60	−0.34	0.73	1.00	−0.32	0.75	2.20	−0.68	0.75	7.00	−0.54	0.74	4.20
		1	−0.08	0.43	0.40	−0.08	0.45	0.20	−0.10	0.45	0.20	−0.27	0.45	1.20	−0.15	0.44	0.20
	Hyperten-sion	Yes	−0.09	0.39	0.40	−0.15	0.41	1.00	−0.30	0.42	3.20	−0.37	0.43	4.20	−0.09	0.41	0.40
	LAV_{min}		0.16	0.04	100.00	0.19	0.05	100.00	0.23	0.05	100.00	0.22	0.05	100.00	0.25	0.05	100.00

Continued

Measures	Variable	Category	Baseline			1 month			3 months			6 months			12 months		
Model	Variable	Category	Est	SE	%	Est	SE	%	Est	SE	%	Est	SE	%	Est	SE	%
LVEF	Intercept	2	0.70	1.71	0.40	0.51	1.95	0.20	0.40	2.04	0.00	1.52	2.16	1.00	0.81	2.02	0.00
		3	−1.17	1.71	1.80	−1.59	1.96	1.60	−1.54	2.04	1.60	−0.45	2.16	0.00	−0.99	2.02	0.00
	Sex	Male	−0.96	0.43	65.00	−0.78	0.47	35.20	−0.89	0.46	46.80	−0.92	0.47	49.20	−0.56	0.44	0.00
	Age		0.03	0.02	33.80	0.04	0.02	51.80	0.03	0.02	29.20	0.04	0.02	48.20	0.04	0.02	100.00
	AFD		0.18	0.05	99.20	0.20	0.06	99.60	0.16	0.06	91.20	0.17	0.06	92.00	0.17	0.06	100.00
	AFT	1	1.42	0.42	99.40	1.64	0.46	99.80	1.53	0.45	98.60	1.53	0.45	98.80	1.15	0.43	100.00
	MR grade	0	−1.04	0.67	31.20	−1.50	0.79	48.20	−1.06	0.76	27.00	−1.58	0.86	45.40	−0.89	0.83	0.00
		1	−0.41	0.41	6.00	−0.67	0.44	25.80	−0.47	0.44	7.60	−0.53	0.44	11.60	−0.53	0.42	0.00
	Hyperten-sion	Yes	−0.04	0.38	0.60	−0.19	0.42	1.60	−0.36	0.41	5.60	−0.36	0.43	5.00	0.02	0.41	0.00
	LVEF		−0.03	0.02	9.60	−0.03	0.02	12.40	−0.02	0.02	1.40	−0.04	0.03	24.80	−0.04	0.02	0.00

Measures	Variable	Category	18 month			24 month			30 months			36 months		
Model	Variable	Category	Est	SE	%	Est	SE	%	Est	SE	%	Est	SE	%
LAD	Intercept	2	−9.72	2.00	100.00	−8.79	2.11	100.00	−8.52	2.67	99.00	−9.91	2.23	100.00
		3	−11.80	2.10	100.00	−11.00	2.21	100.00	−10.80	2.79	100.00	−12.20	2.34	100.00
	Sex	Male	−1.16	0.44	100.00	−0.97	0.45	59.80	−0.93	0.59	32.00	−1.06	0.47	64.20
	Age		0.03	0.02	0.00	0.04	0.02	67.40	0.05	0.02	62.80	0.05	0.02	81.20
	AFD		0.16	0.06	100.00	0.17	0.06	97.40	0.16	0.07	61.00	0.19	0.06	98.60
	AFT	1	0.77	0.42	0.00	1.13	0.43	84.20	1.36	0.56	78.00	1.37	0.45	96.40
	MR grade	0	−0.03	0.71	0.00	−0.73	0.72	8.20	0.07	0.97	0.20	−0.33	0.75	1.20
		1	0.01	0.43	0.00	−0.14	0.44	0.40	0.36	0.54	2.20	−0.07	0.46	0.40
	Hyperten-sion	Yes	0.07	0.39	0.00	−0.46	0.42	8.40	−0.74	0.53	18.20	−0.58	0.43	16.80
	LAD		0.20	0.04	100.00	0.17	0.04	100.00	0.15	0.05	99.80	0.18	0.04	100.00
LAEF	Intercept	2	5.03	1.98	82.20	6.97	1.85	100.00	9.43	2.70	99.00	9.00	2.18	100.00
		3	2.77	1.94	21.80	4.43	1.77	77.80	5.82	2.47	70.40	5.71	2.01	85.40
	Sex	Male	−0.18	0.50	2.60	0.05	0.49	0.40	0.32	0.71	0.80	−0.12	0.55	1.20
	Age		0.01	0.02	1.60	0.01	0.02	1.80	0.03	0.03	12.40	0.01	0.02	4.00
	AFD		0.17	0.06	87.20	0.19	0.06	96.40	0.21	0.09	79.20	0.19	0.07	90.00
	AFT	1	0.49	0.51	9.00	0.48	0.46	8.20	0.58	0.63	6.40	0.65	0.51	17.40
	MR grade	0	−0.82	0.76	8.60	−0.72	0.75	9.00	−0.13	1.10	1.20	−0.13	0.81	1.00
		1	−0.39	0.46	4.80	−0.35	0.46	5.00	−0.39	0.64	2.80	−0.47	0.51	7.60
	Hyperten-sion	Yes	0.03	0.43	0.00	0.45	0.43	6.20	0.16	0.60	1.60	0.46	0.48	5.80
	LAEF		−0.11	0.02	100.00	−0.15	0.03	100.00	−0.23	0.04	100.00	−0.20	0.03	100.00
LAV_{max}	Intercept	2	−14.00	3.36	100.00	−13.80	2.96	100.00	−14.40	3.86	100.00	−17.20	3.30	100.00
		3	−16.20	3.46	100.00	−16.00	3.06	100.00	−16.80	4.01	100.00	−19.60	3.44	100.00
	Sex	Male	−0.64	0.49	19.20	−0.59	0.46	16.80	−0.56	0.60	6.80	−0.69	0.49	21.20
	Age		0.04	0.02	54.80	0.03	0.02	52.00	0.05	0.02	65.40	0.04	0.02	54.80
	AFD		0.21	0.06	99.40	0.20	0.06	99.20	0.19	0.08	79.60	0.21	0.06	99.40
	AFT	1	1.03	0.46	66.40	1.00	0.43	73.20	1.22	0.56	63.40	1.11	0.46	76.00
	MR grade	0	−0.49	0.75	1.80	−0.47	0.71	2.60	0.04	0.99	0.20	−0.19	0.76	0.40
		1	−0.02	0.46	0.40	−0.01	0.44	0.40	0.47	0.55	5.00	−0.10	0.47	0.40
	Hyperten-sion	Yes	−0.33	0.43	3.60	−0.27	0.41	2.40	−0.58	0.52	9.80	−0.41	0.43	5.40
	LAV_{max}		0.29	0.07	100.00	0.30	0.06	100.00	0.28	0.08	100.00	0.37	0.07	100.00

Continued

Measures	Variable	Category	18 month			24 month			30 months			36 months		
Model	Variable	Category	Est	SE	%	Est	SE	%	Est	SE	%	Est	SE	%
LAV_{min}	Intercept	2	−10.30	2.39	100.00	−11.20	2.23	100.00	−13.30	3.10	100.00	−14.10	2.53	100.00
		3	−12.60	2.51	100.00	−13.60	2.37	100.00	−16.10	3.32	100.00	−17.00	2.73	100.00
	Sex	Male	−0.42	0.50	6.20	−0.28	0.48	3.20	−0.29	0.63	1.00	−0.46	0.52	8.00
	Age		0.03	0.02	28.60	0.03	0.02	27.40	0.05	0.02	51.40	0.03	0.02	29.40
	AFD		0.20	0.06	98.20	0.20	0.06	98.40	0.21	0.08	82.40	0.21	0.07	97.40
	AFT	1	0.61	0.49	14.40	0.65	0.45	18.60	0.84	0.59	18.20	0.79	0.49	29.40
	MR grade	0	−0.44	0.78	1.20	−0.32	0.75	1.40	0.13	1.04	0.60	0.21	0.81	2.00
		1	−0.03	0.47	0.20	0.02	0.46	0.20	0.38	0.57	2.20	−0.05	0.49	0.40
	Hypertension	Yes	−0.23	0.43	1.80	−0.09	0.42	1.00	−0.50	0.55	5.40	−0.26	0.45	2.20
	LAV_{min}		0.26	0.05	100.00	0.28	0.05	100.00	0.31	0.07	100.00	0.36	0.06	100.00
LVEF	Intercept	2	0.81	2.02	0.00	0.81	2.02	0.00	6.02	3.50	32.00	1.26	2.09	0.40
		3	−0.99	2.02	0.00	−0.99	2.02	0.00	3.54	3.45	6.40	−0.74	2.09	0.00
	Sex	Male	−0.56	0.44	0.00	−0.56	0.44	0.00	−1.70	0.65	81.80	−1.08	0.48	63.80
	Age		0.04	0.02	100.00	0.04	0.02	100.00	0.07	0.03	71.60	0.03	0.02	32.60
	AFD		0.17	0.06	100.00	0.17	0.06	100.00	0.27	0.08	98.60	0.17	0.06	94.20
	AFT	1	1.15	0.43	100.00	1.15	0.43	100.00	2.10	0.65	98.40	1.70	0.49	100.00
	MR grade	0	−0.89	0.83	0.00	−0.89	0.83	0.00	1.06	1.06	8.80	−1.04	0.75	23.40
		1	−0.53	0.42	0.00	−0.53	0.42	0.00	0.51	0.61	5.00	−0.37	0.46	3.40
	Hypertension	Yes	0.02	0.41	0.00	0.02	0.41	0.00	−0.42	0.54	5.40	0.01	0.43	0.60
	LVEF		−0.04	0.02	0.00	−0.04	0.02	0.00	−0.15	0.05	99.80	−0.04	0.02	16.40

AFD: AF duration; AFT: AF type (paroxysmal = 0, non-paroxysmal = 1); Est: estimate; LAD: left atrial dimension; LAEF: left atrial emptying fraction; LAV_{max}: maximal left atrial volume; LAV_{min}: minimal left atrial volume; LVEF: left ventricular ejection fraction; MR: mitral regurgitation; SE: standard error; %: percentages of significance of the independent predictors during 500 times of split-sample cumulative cross-validation.

$$\log\left(\frac{\pi_2(\boldsymbol{x},z)+\pi_3(\boldsymbol{x},z)}{\pi_1(\boldsymbol{x},z)}\right)=9.00-0.12x_1+0.01x_2+$$
$$0.19x_3+0.65x_4-0.13x_{51}-0.47x_{52}+0.46x_6-0.20z$$

Where $\boldsymbol{x}=(x_1,x_2,x_3,x_4,x_{51},x_{52},x_6)'$ and $\pi_j(\boldsymbol{x},z), j=1,2,3$, represent the probability of the jth group controlling for $\boldsymbol{x}$ and z.

Variable: x_1: Sex: Male = 1; Female = 0 (reference); x_2: Age; x_3: AFD; x_4: AFT: non-paroxysmal = 1; paroxysmal = 0 (reference); x_{51}、x_{52}: MR grade: < mild = 0; mild = 1; ≥ Mild to moderate = 2 (reference); x_6: Hypertension: Yes = 1; No = 0 (reference); z: LAEF at 36 months.

Factors Affecting LA Functional Reverse Remodeling after RFCA

In addition to the longitudinal trend, factors influencing LA functional reverse remodeling were also evaluated. $LAEF_d$ were 5.74 ± 9.15%, 7.85 ± 13.65%, and -2.94 ± 9.75% in Groups 1, 2, and 3, respectively (P < 0.001), positing that AF recurrence played a pivotal role in the late decline of LAEF. $LAEF_d$ was negatively correlated with LAEF at baseline (r = -0.547, P < 0.001), suggesting that patients with lower baseline LAEF had a significantly greater LAEF improvement at 36 months. Furthermore, patients with persistent AF had a significantly greater $LAEF_d$ than patients with paroxysmal AF (9.45 ± 11.53% vs. 3.43 ± 9.57%, P < 0.001). The mean $LAEF_d$ of patients who received 0, 1, 2, 3, 4, and 5 LARF lines were 4.29 ± 10.14%, 4.61 ± 9.14%, 3.91 ± 8.53%, 10.88 ± 11.05%, 4.06 ± 10.98%, and 9.37 ± 14.87%, respectively. There was no significant correlation between the number of LARF lines and $LAEF_d$ (r = 0.078, P = 0.120).

Intra- and Inter-operator Reliability Analysis

The intra-operator ICCs were excellent for LAV_{max} (0.996; 95% CI: 0.992–0.998), LAV_{min} (0.996; 95% CI: 0.992–0.998), and LAEF (0.974; 95% CI: 0.953–0.986). Inter-observer reproducibility was also good-to-excellent, with ICCs of 0.994 (0.988–0.996), 0.969 (0.945–0.983), and 0.859 (0.759–0.920) for LAV_{max}, LAV_{min}, and LAEF, respectively.

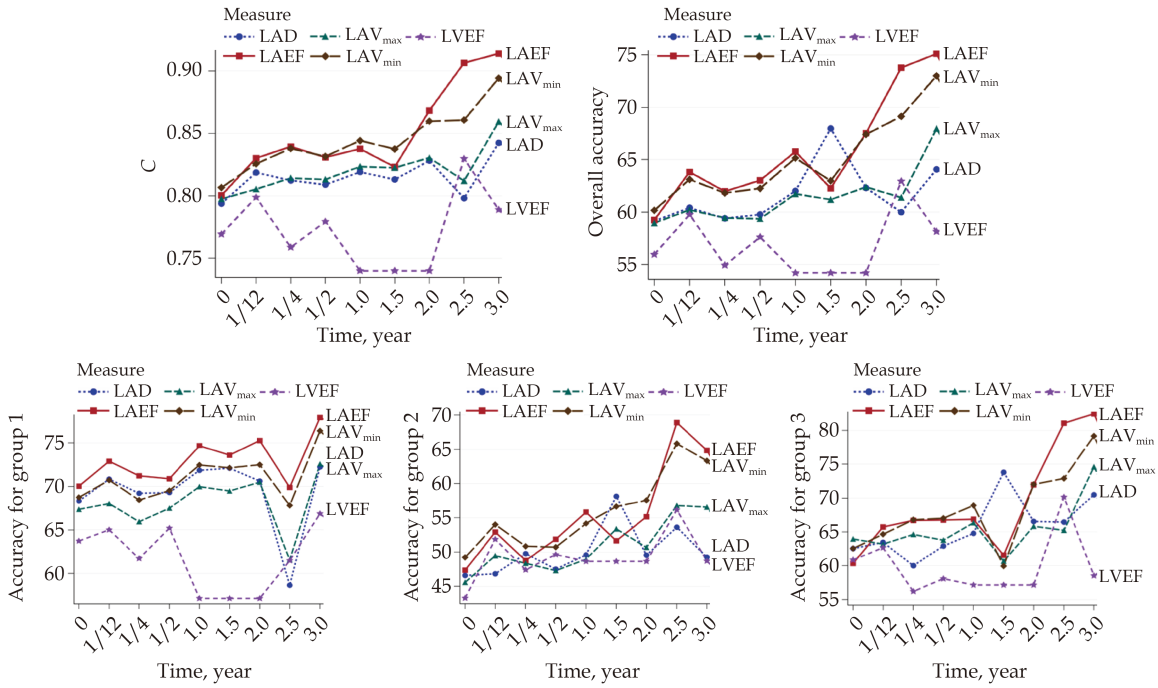


Figure 4 Summarized results of model performance using concordance index (c) and accuracy index of all five indicators at nine follow-up time points. The bottom subpanels summarized the result of accuracy indices in three groups. LAD: left atrial diameter; LAEF: left atrial emptying fraction; LAVmax: maximal left atrial volume; LAVmin: minimal left atrial volume; LVEF: left ventricular ejection fraction.

Table 6 Comparisons of accuracy and *c*-index of models' performance using LAD, LAEF, LAV_{max}, LAV_{min}, or LVEF at different follow-up times in the risk assessment of ablation outcome after ablation.

		Accuracy_t		Accuracy_1		Accuracy_2		Accuracy_3		*c*	
Variable	**Time**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
LAD	Baseline	59.15	3.33	68.33	5.32	46.60	6.53	62.53	3.95	0.79	0.02
	1 month	60.41	3.13	70.83	5.63	46.83	5.99	63.45	3.18	0.82	0.02
	3 months	59.39	3.17	69.21	5.74	49.77	6.00	59.99	4.11	0.81	0.02
	6 months	59.77	3.88	69.30	5.47	47.51	7.80	62.91	3.93	0.81	0.02
	12 months	62.01	3.50	71.84	5.03	49.59	6.49	64.77	3.98	0.82	0.02
	18 months	67.97	0.00	72.09	0.00	58.14	0.00	73.81	0.00	0.81	0.00
	24 months	62.31	3.52	70.61	5.47	49.55	6.53	66.53	3.36	0.83	0.02
	30 months	59.99	4.56	58.65	11.35	53.63	8.94	66.43	6.41	0.80	0.03
	36 months	64.07	3.16	72.23	5.14	49.26	6.09	70.49	3.06	0.84	0.02
	Predicted	62.22	3.31	71.91	5.14	48.12	6.41	66.64	3.54	0.83	0.02
LAEF	Baseline	59.24	3.17	70.02	5.47	47.36	5.69	60.33	4.76	0.80	0.02
	1 month	63.82	3.31	72.88	5.41	52.93	6.45	65.72	4.28	0.83	0.02
	3 months	61.97	3.42	71.21	5.86	48.77	6.22	66.69	3.93	0.84	0.02
	6 months	63.03	3.21	70.88	5.55	51.88	5.91	66.74	3.72	0.83	0.02
	12 months	65.77	2.99	74.67	5.01	55.84	5.86	66.85	3.16	0.84	0.02
	18 months	62.27	3.44	73.59	5.39	51.65	6.79	61.55	3.74	0.82	0.02
	24 months	67.52	3.06	75.27	4.69	55.15	5.48	71.97	3.27	0.87	0.02
	30 months	73.77	4.17	69.88	8.32	68.90	6.91	81.08	4.38	0.91	0.02
	36 months	75.10	2.98	77.92	4.68	64.84	5.29	82.45	3.26	0.91	0.02
	Predicted	68.87	3.09	76.27	4.65	57.32	5.59	73.02	2.96	0.88	0.02

Continued

		Accuracy_t		Accuracy_1		Accuracy_2		Accuracy_3		*c*	
Variable	**Time**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
LAV_{max}	Baseline	58.96	3.76	67.36	5.19	45.59	6.81	63.93	4.49	0.80	0.02
	1 month	60.21	3.71	68.01	5.36	49.47	7.15	63.19	3.83	0.81	0.02
	3 months	59.45	3.36	65.94	6.05	48.36	6.38	64.61	3.44	0.81	0.02
	6 months	59.36	3.77	67.49	5.58	47.30	7.06	63.76	4.84	0.81	0.02
	12 months	61.73	3.55	69.97	5.25	48.96	6.42	66.34	4.58	0.82	0.02
	18 months	61.19	3.47	69.48	5.77	53.38	6.78	60.65	3.68	0.82	0.02
	24 months	62.39	3.28	70.48	5.06	50.69	5.86	65.82	3.51	0.83	0.02
	30 months	61.39	4.45	61.56	10.33	56.79	8.74	65.21	6.26	0.81	0.03
	36 months	67.95	3.03	72.56	4.91	56.56	5.76	74.60	3.20	0.86	0.02
	Predicted	62.44	3.27	70.08	4.97	50.80	5.79	66.46	3.51	0.83	0.02
LAV_{min}	Baseline	60.17	3.56	68.73	5.14	49.23	6.76	62.53	4.00	0.81	0.02
	1 month	63.11	3.40	70.72	5.01	54.02	6.76	64.64	3.94	0.83	0.02
	3 months	61.83	3.30	68.44	5.66	50.85	6.59	66.78	3.71	0.84	0.02
	6 months	62.26	3.43	69.52	5.29	50.72	6.71	67.00	3.93	0.83	0.02
	12 months	65.16	3.12	72.45	5.19	54.18	5.77	68.90	3.43	0.84	0.02
	18 months	62.98	3.49	72.13	5.52	56.65	6.94	59.93	3.67	0.84	0.02
	24 months	67.40	3.10	72.49	5.17	57.56	5.90	72.02	2.81	0.86	0.02
	30 months	69.13	4.14	67.81	9.36	65.83	6.94	72.90	5.11	0.86	0.02
	36 months	72.99	2.88	76.38	4.60	63.32	5.47	79.17	2.66	0.89	0.02
	Predicted	67.17	2.79	73.18	4.87	58.31	5.30	70.01	2.54	0.86	0.02
LVEF	Baseline	55.96	3.13	63.73	5.48	43.31	6.26	60.85	4.60	0.77	0.02
	1 month	59.76	3.19	65.01	6.44	51.87	6.44	62.66	3.77	0.80	0.02
	3 months	54.93	3.30	61.71	6.81	47.40	6.90	56.19	4.77	0.76	0.02
	6 months	57.62	3.33	65.20	6.38	49.64	7.25	58.07	4.87	0.78	0.02
	12 months	54.21	0.00	57.14	0.00	48.65	0.00	57.14	0.00	0.74	0.00
	18 months	54.21	0.00	57.14	0.00	48.65	0.00	57.14	0.00	0.74	0.00
	24 months	54.21	0.00	57.14	0.00	48.65	0.00	57.14	0.00	0.74	0.00
	30 months	62.94	4.36	61.47	9.86	56.15	9.15	70.15	5.24	0.83	0.03
	36 months	58.15	3.68	66.86	5.82	48.70	6.88	58.51	5.30	0.79	0.02

Accuracy_t, Accuracy_1, Accuracy_2, and Accuracy_3: accuracy for all , Groups 1, 2, and 3, respectively; *c*: concordance index; LAD: left atrial dimension; LAEF: left atrial emptying fraction; LAV_{max}: maximal left atrial volume; LAV_{min}: minimal left atrial volume; LVEF: left ventricular ejection fraction; SE: standard error.

DISCUSSION

In this retrospective study, we demonstrated that: (1) the longitudinal trends of echocardiographic indicators differed between patients with and without AF recurrence after RFCA, and a flat slope of mean response curves in the first 3 months and deterioration of echocardiographic indices starting 18 months after RFCA were associated with a higher risk of AF recurrence; (2) LARF did not adversely affect the longitudinal trend of echocardiographic indicators in paroxysmal AF significantly, but resulted in slower and smaller LA reverse remodeling in persistent AF; (3) all echocardiographic indicators showed the best model performance at the 36-month time point among the nine time points, with LAEF at 36 months being the optimal predictor of AF recurrence during a median follow-up period of 80 months; and (4) LA functional reverse remodeling was significantly influenced by the baseline LAEF, AF type, and RFCA outcome, rather than by the number of LARF lines.

Factors Determining the Longitudinal Trend of Echocardiographic Indicators after AF Ablation

It is well known that AF-induced chaotic rapid elec-

trical activation has deleterious effects on the LA, including structural, functional, and electrophysiological remodeling.[14] Successful intervention to stop AF arrests the LA remodeling process, thereby promoting subsequent reverse remodeling to improve LA metrics. Although RFCA creates scarring in the LA, many clinical reports suggest that the benefits of maintaining sinus rhythm outweigh its drawbacks, leading to histological reverse remodeling and LA functional improvement.[15–17] Kawakami, *et al*.[18] reported that both LA structural and functional parameters were significantly improved by maintaining sinus rhythm after AF ablation (paroxysmal 52%) at 12-month follow-up. Masuda, *et al*.[19] reported that a larger baseline LA volume and impaired baseline LAEF were independently associated with LA reverse remodeling, and LAEF was improved only in patients (paroxysmal 80 %) with impaired baseline LAEF, whereas it was decreased in patients with preserved baseline LAEF at 3-month follow-up. We did not have a control group to determine whether patients with "normal" LAEF would experience downhill of LAEF after RFCA. However, in Group 1 patients with a mean baseline LAEF of 49.1%, the mean LAEF at 3, 12, 24, and 36 months were 53.4%, 55.3%, 54.8%, and 54.8%, respectively. The improvement in LAEF could reflect a predominance of reverse remodeling on RFCA fibrosis in AF patients with a relatively preserved LAEF around 50%. By using multi-time-point echocardiographic assessments, our data showed that improvements in echocardiographic indices occurred in the first three months and remained stationary for up to 36 months in patients whose AF was under control. However, these early responses were blunted, and echocardiographic indices declined starting 18 months after RFCA in patients with AF recurrence. Obviously, the main factor determining the longitudinal trend of echocardiographic indicators is the maintenance of sinus rhythm. Would the baseline echocardiographic indices influence their longitudinal trend? Our data also showed that patients with poorer baseline echocardiographic indices experienced a greater degree of LA reverse remodeling. It is consistent with the report by Antolini, *et al*.,[20] which stated that the beneficial effect of AF ablation was most evident in patients (paroxysmal 64%) with LAEF < 40 % at 9-month follow-up. The evidence of LAEF improvement after RFCA, even in patients with an impaired LAEF, may encourage physicians to consider ablation in this subgroup of patients. However, a lower baseline LAEF is also associated with worse AF ablation outcomes.[10] Our data showed that Group 2 experienced a rapid increase in LAEF within the first 3 months, whereas Group 3 did not, even though the mean baseline LAEF for both groups was below 40%. The blunted response of LAEF may reflect more advanced remodeling of the LA and a high fibrosis content that may not be reversed after RFCA.[21] Therefore, careful monitoring of long-term dynamic changes in LAEF, especially those below 40%, is needed. For patients with suboptimal improvement in LA indicators, enhanced follow-up to unveil occult AF recurrence may contribute to improving the long-term prognosis.

The EARNEST PVI trial suggested that additional LARF was superior to CPVI alone in suppressing of AF recurrence in patients with persistent AF.[22] While these linear lesions can be electrically effective in restoring sinus rhythm, they do so by creating more scar tissue, which may increase LA stiffness, thereby affecting LA performance.[23] In our patient population, LARF did not significantly affect the longitudinal trends of echocardiographic indicators in paroxysmal AF, but slowed the process and reduced the degree of LA reverse remodeling in persistent AF. Better LA reverse remodeling depends on a less advanced and more reversible form of atrial myopathy. Our data showed the baseline LAEF and AF type, rather than the number of LARF lines, were significant factors associated with the degree of LA functional reverse remodeling. As patients with persistent AF who underwent LARF had the lowest LAEF and largest LA volume, the injury caused by LARF might work additively with a more severe form of atrial myopathy, leading to a blunting response of LA functional reverse remodeling in this patient population.

Implications of Sequential Echocardiographic Monitoring in Outcome Prediction of AF Ablation

One of the unique features of this study was the observation that temporal changes in LA indicators differed between patients with and without AF recurrence by multi-time-point echocardiographic assessments for 3 years. In our measures, patients in Group 2 had worse baseline echocardiographic parameters than those in Group 1, but the longitudinal trend of echocardiographic parameters was similar in both groups; patients in Group 3 also showed early improvement in echocardiographic parameters, but the mean responses curves in Group 3 were flatter than those in Groups 1 and 2, and

began to decline 18 months after RFCA, with LAEF at 36 months being lower than the baseline LAEF. The late deterioration of LAEF could reflect progressive atrial cardiomyopathy, recurrent arrhythmia burden, and/or ablation-related atrial injury, and late-stage LAEF decline has been reported as the hallmark of long-term failure of AF ablation.[24] Thus, the early improvement in echocardiographic parameters may not guarantee a successful RFCA outcome. The baseline LAEF, its dynamics, and subsequent follow-up values should be considered for prognostic assessment.

Previous studies have revealed that the accuracy of baseline LAEF is better than that of LA volume or LAD in predicting the outcome of AF ablation.[10,25,26] Note that the volume and function of the LA exhibit dynamic changes during the post-ablation period. Khan, *et al.*[27] reported that LAV_{max} and LAV_{min} were reduced, and LAEF was increased at 3 and 12 months in patients with long-standing persistent AF undergoing RFCA. In these patients, LAEF was significantly higher in the sinus rhythm group than in the AF recurrence group. However, there were no differences in LAV_{max} and LAV_{max} between these two groups at 3 and 12 months, implying that LAEF is a more sensitive indicator for distinguishing the outcome groups. Zhang *et al.* also reported that the recovery rate of LA systolic strain at 1 month post-ablation was an independent predictor of AF recurrence.[28] Our data showed that the model using the LAEF at 36 months had the highest c-index and accuracy in distinguishing RFCA outcomes during a mean follow-up of 81 ± 24 months. While the baseline LAEF indicates the severity of the preexisting condition, the 36-month LAEF is a prognostic marker for the long-term success of RFCA by showing the extent of LA reverse remodeling and the heart's ability to maintain sinus rhythm. Repeated echocardiography to monitor changes in LA parameters allows clinicians to evaluate the effects of ablation and predict prognosis more accurately, especially for detecting patients with occult AF recurrence.

Limitations

Our study had limitations. First, this was a single center, retrospective study with a relatively small cohort size. Second, AF recurrence required ambulatory electrocardiogram documentation at specific time points or with symptoms; therefore, we might have missed asymptomatic AF cases or underestimated the recurrence rate.

Conclusion

The longitudinal trends of echocardiographic indicators differed according to the RFCA outcomes. In addition to the baseline values, the slope of mean response curve should be considered for long-term prognostic evaluation. LARF has no significant effects on the longitudinal trend of echocardiographic indicators in paroxysmal AF, but it reduced the degree and slowed the process of LA reverse remodeling in persistent AF. The late deterioration of LAEF was the hallmark of long-term failure of AF ablation. The model using LAEF at 36 months had the best performance in predicting long-term RFCA outcomes during a median follow-up period of 80 months.

DISCLOSURE

Data Availability

The de-identified participant data will be shared on a request basis. Please contact the corresponding author directly to request data sharing.

Ethics Approval

This study was approved by the Institutional Review Board of Chang Gung Memorial Hospital, Taiwan (IRB No. 202500701B0).

REFERENCES

[1] Chugh SS, Havmoeller R, Narayanan K, *et al.* Worldwide epidemiology of atrial fibrillation: a Global Burden of Disease 2010 Study. *Circulation* 2014; 129: 837–847.
[2] Benjamin EJ, D'Agostino RB, Belanger AJ, *et al.* Left atrial size and the risk of stroke and death: the Framingham Heart Study. *Circulation* 1995; 92: 835–841.
[3] Bajraktari G, Bytyci I, Henein MY. Left atrial structure and function predictors of recurrent fibrillation after catheter ablation: a systematic review and meta-analysis. *Clin Physiol Funct Imaging* 2020; 40: 1–13.
[4] Wylie Jr JV, Peters DC, Essebag V, *et al.* Left atrial function and scar after catheter ablation of atrial fibrillation. *Heart Rhythm* 2008; 5: 656–662.
[5] Hwang J, Park HS, Han S, *et al.* The impact of catheter ablation of atrial fibrillation on the left atrial volume and function: study using three-dimensional echocardiography. *J Interv Card Electrophysiol* 2020; 57: 87–95.
[6] Rodrigues ACT, Scannavacca MI, Caldas MA, *et al.* Left atrial function after ablation for paroxysmal atrial fibrillation. *Am J Cardiol* 2009; 103: 395–398.
[7] Liu Y, Liu Q, Yang Y, *et al.* Effect of radiofrequency catheter ablation on left atrial structure and function in patients with different types of atrial fibrillation. *Sci Rep*

2022; 12: 9511.
[8] Lee HL, Hwang YT, Chang PC, *et al*. A three-year longitudinal study of the relation between left atrial diameter remodeling and atrial fibrillation ablation outcome. *J Geriatr Cardiol* 2018; 15: 486−491.
[9] Liu HT, Yang CH, Lee HL, *et al*. Clinical Outcomes of low-voltage area-guided left atrial linear ablation for non-paroxysmal atrial fibrillation patients. *PLoS One* 2021; 16: e0260834.
[10] Chou C-C, Lee H-L, Chang P-C, *et al*. Left atrial emptying fraction predicts recurrence of atrial fibrillation after radiofrequency catheter ablation. *PLoS One* 2018; 13: e0191196.
[11] Lang RM, Bierig M, Devereux RB, *et al*. Recommendations for chamber quantification: a report from the American Society of Echocardiography's Guidelines and Standards Committee and the Chamber Quantification Writing Group, developed in conjunction with the European Association of Echocardiography, a branch of the European Society of Cardiology. *J Am Soc Echocardiogr* 2005; 18: 1440−1463.
[12] Hosmer DW, Lemeshow S. Applied logistic regression New York. NY: Wiley 1989; 33.
[13] LaValley MP. Logistic regression. *Circulation* 2008; 117: 2395−2399.
[14] Qiu D, Peng L, Ghista DN, Wong KK. Left atrial remodeling mechanisms associated with atrial fibrillation. *Cardiovasc Eng Technol* 2021; 12: 361−372.
[15] Beukema WP, Elvan A, Sie HT, Ramdat Misier AR, Wellens HJ. Successful radiofrequency ablation in patients with previous atrial fibrillation results in a significant decrease in left atrial size. *Circulation* 2005; 112: 2089−2095.
[16] Lemola K, Desjardins B, Sneider M, *et al*. Effect of left atrial circumferential ablation for atrial fibrillation on left atrial transport function. *Heart Rhythm* 2005; 2: 923−928.
[17] Verma A, Kilicaslan F, Adams JR, *et al*. Extensive ablation during pulmonary vein antrum isolation has no adverse impact on left atrial function: an echocardiography and cine computed tomography analysis. *J Cardiovasc Electrophysiol* 2006; 17: 741−746.
[18] Kawakami H, Inoue K, Nagai T, *et al*. Persistence of left atrial abnormalities despite left atrial volume normalization after successful ablation of atrial fibrillation. *J Arrhythm* 2021; 37: 1318−1329.
[19] Masuda M, Inoue K, Iwakura K, *et al*. The impact of atrial fibrillation ablation on left atrial function: association with baseline left atrial function. *Pacing Clin Electrophysiol* 2012; 35: 327−334.
[20] Antolini M, Brustio A, Morello M, *et al*. Left atrial function after Radiofrequency catheter ablation of Atrial Fibrillation–Can Pre-ablation function predict contractile improvement during Follow-up? *Circ J* 2015; 79: 2576–2583.
[21] Tops LF, Delgado V, Bertini M, *et al*. Left atrial strain predicts reverse remodeling after catheter ablation for atrial fibrillation. *J Am Coll Cardiol* 2011; 57: 324−331.
[22] Masuda M, Inoue K, Tanaka N, *et al*. Long-term impact of additional ablation after pulmonary vein isolation: results from EARNEST-PVI trial. *J Am Heart Assoc* 2023; 12: e029651.
[23] Park J-W, Yu HT, Kim T-H, *et al*. Atrial fibrillation catheter ablation increases the left atrial pressure. *Circ Arrhythm Electrophysiol* 2019; 12: e007073.
[24] Kim M-N, Lee JJ, Kim S-A, *et al*. The difference of predictors for recurrence after catheter ablation of non-paroxysmal atrial fibrillation according to follow-up period. *Int Heart J* 2014; 55: 312−318.
[25] Oka T, Tanaka K, Ninomiya Y, *et al*. Impact of baseline left atrial function on long-term outcome after catheter ablation for paroxysmal atrial fibrillation. *J Cardiol* 2020; 75: 352−359.
[26] Charitakis E, Karlsson LO, Papageorgiou J-M, Walfridsson U, Carlhäll C-J. Echocardiographic and biochemical factors predicting arrhythmia recurrence after catheter ablation of atrial fibrillation — An observational study. *Front Physiol* 2019; 10: 1215.
[27] Khan HR, Yakupoglu HY, Kralj-Hans I, *et al*. Left atrial function predicts atrial arrhythmia recurrence following ablation of long-standing persistent atrial fibrillation. *Circ Cardiovasc Imaging* 2023; 16: e015352.
[28] Zhang Q, Liu NN, Sun JS, *et al*. Echocardiographic assessment of left atrial structural and functional changes after catheter ablation in paroxysmal atrial fibrillation with preserved ejection fraction. *Sci Rep* 2025; 15: 28209.

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