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Left atrial strain is a powerful predictor of atrial fibrillation recurrence after catheter ablation: study of a heterogeneous population with sinus rhythm or atrial fibrillation

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Aims Accumulating data show the efficacy of catheter ablation (CA) for atrial fibrillation (AF); however, postoperative recurrence is not uncommon. The aim of this study was to identify predictors of AF recurrence in patients undergoing CA.

Methods and results We studied 100 patients with symptomatic paroxysmal (68) or persistent (32) AF who underwent CA preceded by transthoracic echocardiographic examination. Of these, 50 had sinus rhythm during echocardiography (Group NSR) and 50 had AF rhythm (Group AF). The left atrial (LA) strain was measured by two-dimensional speckle tracking echocardiography. Echocardiographic parameters were compared between the patients with AF recurrence and no recurrence. During 12 months of follow-up, 26 of 100 patients (11 in Group NSR and 15 in Group AF) had AF recurrence; these patients had significantly longer AF duration, a lower LA global strain (LA-GS), lower LA lateral total strain (LA-LS), and larger maximum LA volume index ($LAVI_{max}$) than those who maintained sinus rhythm. Multivariate logistic regression identified basal LA-LS and $LAVI_{max}$ as independent predictors of AF recurrence. Furthermore, receiver operating characteristic analyses revealed that basal LA-LS was the most useful parameter for predicting AF recurrence [area under the curve (AUC): 0.84 vs. 0.74 in $LAVI_{max}$]. Subanalyses showed that $LAVI_{max}$ was another independent predictor of AF recurrence in Group AF, but not in Group NSR, while basal LA-LS was a significant predictor in both groups.

Conclusion LA myocardial function assessed by basal LA-LS could predict AF recurrence after CA. Notably, such an assessment could be applicable even during AF rhythm, suggesting its convenience in the clinical setting without defibrillation before analysis.

Keywords LA strain • atrial fibrillation • catheter ablation

Introduction

Atrial fibrillation (AF) is one of the most common cardiac arrhythmias. AF worsens patient quality of life, particularly as it contributes to an increased risk of thromboembolic stroke and mortality. Catheter ablation (CA) is an effective treatment to restore sinus rhythm in AF patients,[1–6] but recurrence of AF after CA remains a major problem,[6–9] and advancing age, dilatation of the left atrium (LA), and long duration of AF are known predictors of low success for CA in terms of recurrence.[10,11] Recently, some studies suggested a relationship between LA strain analysis by two-dimensional speckle tracking echocardiography (2DSTE) and AF recurrence after CA;[12–15]

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however, these results remain controversial, because echocardiography was performed after restoring the sinus rhythm by electrical cardioversion, affecting the LA electrical properties.[12,15] Thus, such echocardiographic examinations should be performed without any electrical intervention. In the current study, we performed echocardiographic recordings in both sinus and AF rhythm at the time of the examination without restoring sinus rhythm. Our aim was to identify predictors of AF recurrence in patients undergoing CA.

Methods

The local ethics review committee approved the present study. We studied 100 patients with symptomatic paroxysmal (68 patients) or persistent (32 patients) AF who underwent transthoracic echocardiographic examinations (TTE) within a few days prior to CA from July 2010 to March 2012. We divided patients into two groups: with AF rhythm (Group AF, $n = 50$) or with sinus rhythm during TTE before CA (Group NSR, $n = 50$). The exclusion criteria were significant valvular heart disease, coronary artery disease, congenital heart disease, history of cardiac surgery, and failed acquisition of stable 2DSTE data with adequate tracking of the LA. *Table 1* details the clinical characteristics of the total population and each patients group. The average age was 59 ± 11 years, with 84 males and 16 females, and the average duration of AF was 6.0 ± 5.1 years in the total population (*Table 1*).

All patients underwent standard echocardiography, and 2DSTE was performed using a Vivid-7 or Vivid-E9 ultrasound system (GE Healthcare). Left ventricular (LV) dimensions were made in the parasternal long axis with the M-mode cursor positioned just beyond the mitral leaflet tips, perpendicular to the long axis of the ventricle. LV ejection fraction (EF) was obtained by modified biplane Simpson's method from four- and two-chamber views (CV). The LA diameters were measured from the parasternal long-axis view during end systole, and LA volumes were calculated from the apical 4CV and 2CV of the LA using the biplane discs method. LA volumes index was defined as LA volumes divided by body surface area. LA empting fractions were calculated as follows:

$$\frac{\text{maximum LA volume} - \text{minimum LA volume}}{\text{maximum LA volume}} \times 100\%$$

The mitral flow velocities were recorded by standard pulsed-wave Doppler ultrasound at the tips of the mitral valve leaflets in an apical 3CV. Tissue Doppler imaging was used to measure the peak during early (E') and late (A') diastolic phases of the cardiac cycle at the mitral annular septal and lateral corners. The E/E' was calculated as E divided by the average of septal and lateral E' velocity.

The global and regional LA myocardial strain was measured by 2DSTE. Greyscale imaging of the 4CV and 2CV was obtained with a frame rate of 60–80 Hz. Recordings were processed with acoustic-tracking software (EchoPAC, GE Healthcare), allowing off-line semi-automated speckle-based strain analysis. Briefly, lines were manually traced along the LA endocardium. An additional epicardial line was automatically generated by software, creating a region of interest (ROI). After manually adjusting the ROI shape, the software divided the LA region into six segments and generated the longitudinal strain curve (*Figure 1*). We set the zero strain point as that time from the beginning of the P wave in the Group NSR and the QRS wave in the Group AF. We measured positive peak strain during ventricular systole and negative peak strain during LA systole globally and for each of the 12 segments. The total strain was calculated as follows: positive peak strain − negative peak strain. Positive peak strain rate (SR) was measured during ventricular systole, early negative peak SR during early diastole, and late negative peak SR during late diastole. In the Group AF, measurements from the three consecutive beat recording were averaged. All data were digitally stored and analysed off-line with customized software blinded to any clinical information. Reproducibility of 2DSTE was tested in 15 randomly selected patients.

Table 1 Baseline characteristics of Group AF and Group NSR

	Total $n = 100$	Group AF $n = 50$	Group NSR $n = 50$
Age (year)	59 ± 11	57 ± 9.6	61 ± 12
Gender (male)	84	43	41
AF duration (year)	6.0 ± 5.1	6.3 ± 5.5	5.7 ± 4.6
HTN	42	16	26
CAD	4	1	3
CHF	8	7	1
DLP	29	11	18
DM	12	6	6
CVA	8	3	5
CHADS2	0.8 ± 0.9	0.7 ± 1.0	0.9 ± 0.9
CHADS2 ≧ 1	52	21	32
β-Blocker	45	26	19
Ca-blocker	30	16	14
ACE-I	9	4	5
ARB	27	9	18
AAD	55	27	28
Digitalis	12	9	3
Statin	20	9	11
Diuretics	9	6	3

AF, atrial fibrillation; NSR, normal sinus rhythm; HTN, hypertension; CHF, congestive heart failure; DLP, dyslipidaemia; DM, diabetes mellitus; CVA, cerebrovascular accident; ACE-I, angiotensin-converting enzyme inhibitor; ARB, angiotensin II receptor blocker; AAD, anti-arrhythmic drug.

CA and post-procedural follow-up

All anti-arrhythmic drugs (AADs) were discontinued for 5 half-lives before the procedure. Circumferential pulmonary vein (PV) isolation with a guidance of CARTO system (Biosense Webster, Inc., Diamond Bar, CA, USA) was performed as previously described.[16] Briefly, after taking simultaneous pulmonary venography of the superior and inferior PVs, a circular mapping catheter (Libero, Japan Lifeline Co. Ltd., Tokyo, Japan, or Lasso, Biosense Webster, Inc.) and a 3.5-mm saline-irrigated mapping catheter (Navi-Star Thermocool, Biosense Webster) were introduced. The PV isolation procedure was performed under the guidance of the CARTO system using the three-dimensionally reconstructed geometry of the LA obtained from MDCT images. Then, the ipsilateral superior and inferior PVs were circumferentially encircled by continuous RF lesions using an ablation catheter with an open-irrigation tip (Navistar Thermocool, Biosense Webster) with power of 25–35 W and irrigation rate of 17 or 30 mL/min and the maximal temperature of 42°C. The PV isolation was confirmed by the elimination of PV potentials as recorded by circular mapping catheters by the rapid infusion of 20 mg of adenosine triphosphate. Blockage of the conduction from the PVs to LA was also confirmed by applying 25 mA of output pacing from the PVs. The end points of the ablation procedure were different for paroxysmal and persistent AF. In addition to the circumferential PV isolation, focal ablation

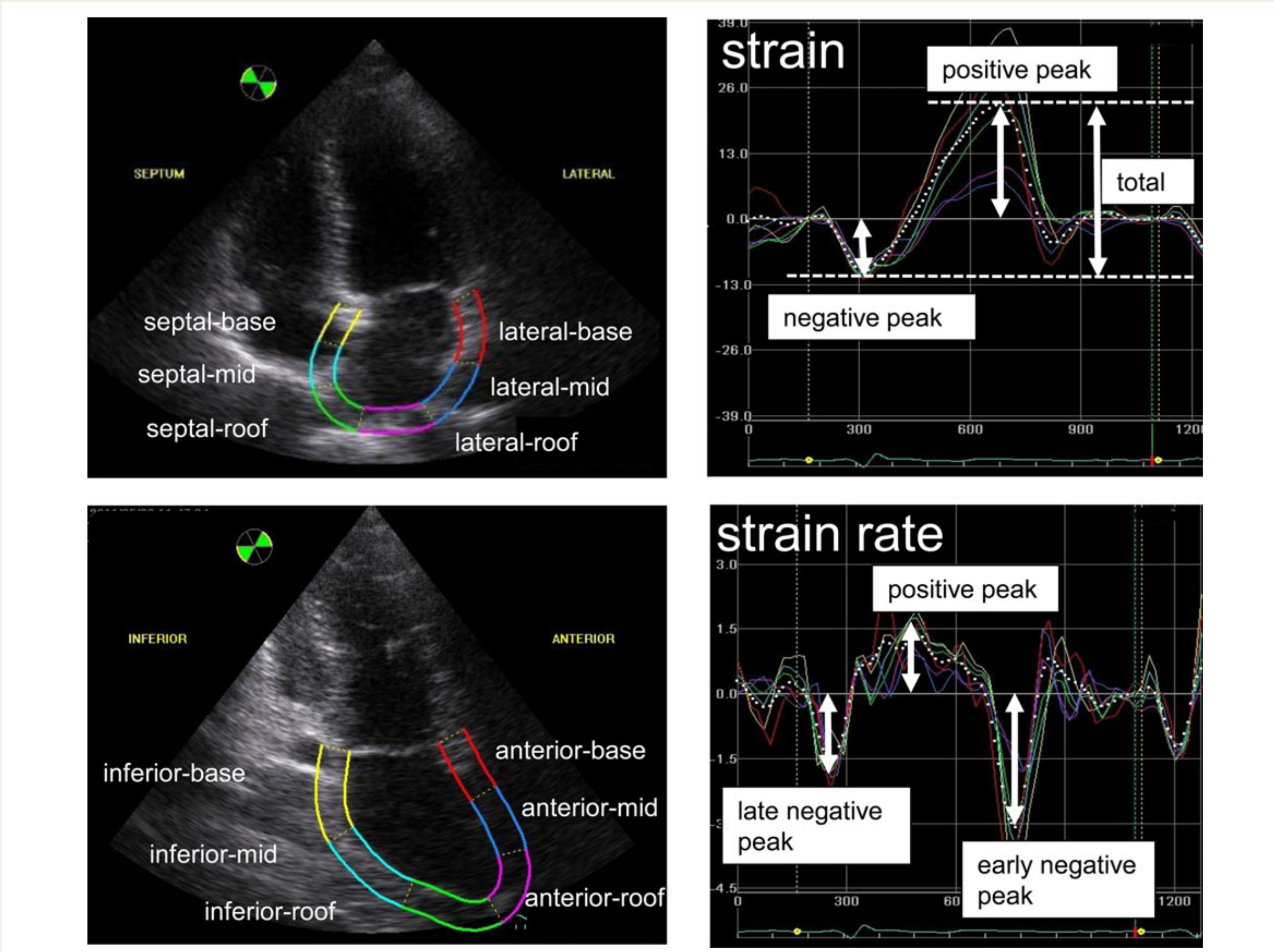


Figure 1 Analysis of longitudinal strain and SR of the left atrium using speckle tracking imaging. Analysis was performed from 12 segments (base, mid, and roof segments of LA lateral and septum wall in four-chamber view, and anterior and inferior wall in two-chamber view).

for paroxysmal AF with an extra PV origin, and the linear ablation or ablation for the complex, fractionated atrial electrograms in persistent AF, were added if they were necessary.

The patients remained hospitalized under continuous rhythm monitoring for ~1 week after the procedure. After discharge, each outpatient visit at 1, 3, 6, 9, and 12 months after ablation, 12-lead electrocardiography and Holter monitoring were performed. When there were arrhythmia-related symptoms such as palpitations or dizziness, the portable electrocardiogram (Nihon Kohden, Cardiophone) was performed. AF recurrence within 3 months after ablation was not counted as recurrence due to irritability of the atria immediately following ablation. Patients presenting with AF episodes by the above examinations between 3 and 12 months were placed in the 'AF recurrence group' and no AF episodes were placed 'No AF recurrence group'.

Statistical analysis

Baseline characteristics of patients within the AF and NSR groups, and by AF recurrence, were reported in the format 'mean ± standard deviation' for continuous variables and in the format 'count (percentage)' for categorical variables. *P*-values for baseline characteristics are not reported, and no corrections for multiple comparisons were made. From the available information on baseline characteristics, the following variables were of clinical interest in their relationship with the outcome AF recurrence: age, AF duration, LA-GS, basal LA-LS, $LAVI_{max}$, LVEF, *E/E′*, gender, and rhythm. These relationships were initially assessed through univariate logistic regressions of AF recurrence. Prognostic value of the variables of clinical significance on the risk of AF recurrence was assessed via univariate analysis, and the AUCs (area under the curve) of the receiver operating characteristic (ROC) curve for each variable were compared. Of LA-GS and basal LA-LS, basal LA-LS had a stronger relationship with AF recurrence; thus, to avoid multicollinearity issues due to the high correlation between these two measures, LA-GS was excluded from further analyses. Following univariate regression, variables whose relationship with AF recurrence was found to be marginally significant ($P < 0.05$) were chosen for inclusion in multivariate logistic regression models. All statistical analyses were performed using SAS version 9.2 (SAS Institute Inc., NC, USA).

The reproducibility of 2DSTE was tested in 15 randomly selected patients. The 95% confidence intervals for inter- and intra-observer variability were −0.8 to 1.4% and −1.0 to 2.9%, respectively.

Results

During 12 months of follow-up, 26 of 100 patients (11 in Group NSR and 15 in Group AF) had AF recurrence. *Table 2* details the clinical

Table 2 Baseline characteristics of patients with AF recurrence and no recurrence

	AF recurrence *n* = 26	No AF recurrence *n* = 74	*P*-value
Age (year)	61 ± 11.1	58 ± 10.7	<0.001
Gender (male)	21	63	0.601
Group AF	15 (paroxysmal 6/persistent 9)	35 (paroxysmal 12/persistent 23)	0.362
Group NSR	11	39	0.362
AF duration (year)	7.8 ± 6.5	5.3 ± 4.3	0.034
HTN	10	32	0.671
CAD	2	2	0.264
CHF	2	6	0.946
DLP	11	18	0.082
DM	3	9	0.933
CVA	4	4	0.107
CHADS2	0.9 ± 1.2	0.8 ± 0.8	0.542
CHADS2 ≧ 1	12	41	0.416
β-Blocker	12	33	0.891
Ca-blocker	3	27	0.017
ACE-I	1	8	0.286
ARB	6	21	0.600
AAD	16	39	0.436
Digitalis	6	6	0.043
Statin	9	11	0.033
Diuretics	2	7	0.787

AF, atrial fibrillation; NSR, normal sinus rhythm; HTN, hypertension; CHF, congestive heart failure; DLP, dyslipidaemia; DM, diabetes mellitus; CVA, cerebrovascular accident; ACE-I, angiotensin-converting enzyme inhibitor; ARB, angiotensin II receptor blocker; AAD, anti-arrhythmic drug.

characteristics of the two patient groups, those with and without AF recurrence. The patients with AF recurrence were significantly older (61 ± 11.1 vs. 58 ± 10.7 years, $P < 0.001$), had a longer duration of AF (7.8 ± 6.5 vs. 5.3 ± 4.3 years, $P = 0.034$), and were more likely to receive digitalis (23.1 vs. 8.1%, $P = 0.043$) and statin (34.6 vs. 14.9%, $P = 0.033$) before CA than those without AF recurrence, whereas the patients without AF recurrence were more likely to receive calcium blockers (36.5 vs. 11.5%, $P = 0.017$) before CA. There were no significant differences between the groups in gender, Group AF or NSR, AF duration, the presence of hypertension, coronary artery disease, congestive heart failure, dyslipidaemia, diabetes mellitus, cerebrovascular accident, CHADS2 score, and the use of β-blockers, angiotensin-converting enzyme inhibitors, angiotensin II receptor blockers, AADs, and diuretics.

LA strain and SR with 2DSTE were compared between the patients with and without AF recurrence (*Table 3*). Patients with AF recurrence had significantly lower LA total strain as well as positive peak strain of global strain, lateral, and septal strain except for LA roof strain compared with no AF recurrence, which was almost identical to those with age-matched healthy control. In particular, both lower global and lateral strains were strongly correlated with AF recurrence ($P < 0.0001$). There was no significant difference in anterior and inferior strain or SR measured at apical 2CV.

Table 4 details the pooled data for the echocardiographic parameters except for strain and SR of the patients with AF recurrence and without AF recurrence. There were no differences in LA dimension (LAD), LA emptying fraction, LV dimensions, LVEF, mitral peak E wave, deceleration time of *E*, lateral *E′*, and *E/E′* ratio between groups with AF recurrence and without AF recurrence. $LAVI_{max}$ was significantly larger in the patients with AF recurrence than in those without AF recurrence (56.09 ± 16.34 vs. 43.07 ± 11.51 mL/m^2, $P = 0.0082$).

The multivariate logistic regression analysis showed that basal LA-LS and $LAVI_{max}$ were independent predictors of AF recurrence after CA (basal LA-LS: OR 0.81, 95% CI 0.73–0.89, $P < 0.0001$ $LAVI_{max}$: OR 1.07, 95% CI 1.03–1.12, $P = 0.0003$; *Table 5*).

Furthermore, the ROC analysis identified basal LA-LS as the most useful parameter for predicting AF recurrence after CA [area under the curve (AUC): 0.84 in basal LA-LS vs. 0.74 in $LAVI_{max}$; *Figure 2*]. The cut-off value of 25.27% in basal LA-LS showed 81% sensitivity and 72% specificity for predicting AF recurrence.

Next, we performed sub-analyses by dividing the patients into Group AF and Group NSR. In Group AF, LA-GS and basal LA-LS were significantly lower and $LAVI_{max}$ was larger in the patients with AF recurrence than in those without AF recurrence (LA-GS: $P = 0.003$, OR 0.75, 95% CI 0.38–0.82; basal LA-LS: $P = 0.002$, OR = 0.75, 95% CI 0.63–0.90; $LAVI_{max}$: $P < 0.0001$, OR 1.10, 95% CI 1.04–1.16). In contrast, LA-GS and basal LA-LS were significantly lower in the patients with AF recurrence than in those without AF recurrence in the Group NSR (LA-GS: $P = 0.004$, OR 0.34, 95% CI 0.16–0.71; basal LA-LS: $P = 0.003$, OR 0.75, 95% CI 0.63–0.91), while there was no significant difference in $LAVI_{max}$ ($P = 0.150$, OR 1.03, 95% CI 0.99–1.06). These results implicated $LAVI_{max}$ as an independent predictor for AF recurrence in Group AF, but not in Group NSR, although basal LA-LS was a significant predictor in both groups.

Discussion

The present study revealed that basal LA-LS measured by 2D speckle tracking could be useful as a predictor for AF recurrence after CA. The main findings of our study are as follows: (i) basal LA-LS and $LAVI_{max}$ were independent predictors in the heterogeneous population, including AF patients with sinus rhythm or AF when echocardiography was performed; (ii) only basal LA-LS was an independent predictor for AF recurrence in patients with sinus rhythm during echocardiographic examination (Group NSR), although $LAVI_{max}$ as well as basal LA-LS were significant predictors in patients with AF during echocardiography (Group AF). These results indicated that basal LA-LS could be a predictor for AF recurrence after CA, regardless of the rhythm during echocardiographic examination.

Previous reports have shown that LA size is a strong predictor of AF recurrence after CA.[10,11] Consistent with these results, our results also showed that $LAVI_{max}$ was an independent predictor for AF recurrence in the total study patient group (Group NSR + Group AF). However, the results of our sub-analyses did not support the previous results, especially in patients with sinus rhythm during echocardiographic examination (Group NSR). Since structural remodelling of LA (LA enlargement) is not induced in

Table 3 LA strain and strain rate of the patients with AF recurrence and no recurrence after catheter ablation

	Healthy controls, $n = 20$	AF recurrence, $n = 26$	No AF recurrence, $n = 74$	*P*-value
Global				
S-total (%)	23.0 ± 5.8	12.0 ± 4.3	19.4 ± 8.6	<0.0001
S-pos peak (%)	13.5 ± 5.3	8.8 ± 2.3	13.6 ± 5.4	<0.0001
SR-pos peak (s^{-1})	1.2 ± 0.4	0.8 ± 0.3	1.1 ± 1.0	0.029
SR-early neg peak (s^{-1})	−1.3 ± 0.4	−1.1 ± 0.4	−1.3 ± 0.5	0.058
Lateral-base				
S-total (%)	34.8 ± 10.9	19.8 ± 6.0	31.1 ± 10.8	<0.0001
S-pos peak (%)	24.5 ± 10.0	15.7 ± 5.8	23.3 ± 8.7	<0.0001
SR-pos peak (s^{-1})	2.0 ± 0.6	1.6 ± 0.4	1.9 ± 0.6	0.052
SR-early neg peak (s^{-1})	−2.0 ± 0.7	−2.0 ± 0.7	−2.4 ± 0.8	0.028
Lateral-mid				
S-total (%)	24.3 ± 8.3	12.3 ± 4.7	20.8 ± 9.0	<0.0001
S-pos peak (%)	14.9 ± 6.2	8.8 ± 3.9	14.3 ± 6.1	<0.0001
SR-pos peak (s^{-1})	1.5 ± 0.4	1.2 ± 0.4	1.4 ± 0.5	0.124
SR-early neg peak (s^{-1})	−1.4 ± 0.6	−1.4 ± 0.5	−1.6 ± 0.6	0.037
Septal-base				
S-total (%)	26.1 ± 7.6	16.6 ± 7.5	21.8 ± 10.5	0.022
S-pos peak (%)	16.2 ± 5.9	11.2 ± 4.7	15.4 ± 7.3	0.001
SR-pos peak (s^{-1})	1.4 ± 0.5	1.3 ± 0.4	1.4 ± 0.5	0.732
SR-early neg peak (s^{-1})	−1.3 ± 0.5	−1.3 ± 0.4	−1.5 ± 0.6	0.036
Septal-mid				
S-total (%)	28.0 ± 7.5	18.9 ± 8.5	23.6 ± 10.1	0.036
S-pos peak (%)	17.8 ± 5.6	13.2 ± 5.8	16.6 ± 7.0	0.028
SR-pos peak (s^{-1})	1.4 ± 0.4	1.3 ± 0.4	1.4 ± 0.5	0.477
SR-early neg peak (s^{-1})	−1.4 ± 0.5	−1.3 ± 0.5	−1.6 ± 0.6	0.094

LA, left atrial; AF, atrial fibrillation; S, strain; SR, strain rate; pos, positive; neg, negative.
P-value indicates statistical difference between AF recurrence and no AF recurrence.

Table 4 Echocardiographic results of the patients with AF recurrence and no recurrence after catheter ablation

	AF recurrence $n = 26$	No AF recurrence $n = 74$	*P*-value
LAD (cm)	4.1 ± 0.6	3.8 ± 0.5	0.057
$LAVI_{max}$ (mL/m^2)	56.1 ± 16.3	43.1 ± 11.5	0.0082
$LAVI_{min}$ (mL/m^2)	37.0 ± 14.8	26.4 ± 9.4	0.051
LA emptying fraction (%)	36.4 ± 11.8	39.1 ± 11.3	0.305
LVEDD (cm)	4.9 ± 0.5	4.8 ± 0.4	0.267
LVESD (cm)	3.2 ± 0.7	3.1 ± 0.5	0.811
LVEF (%)	72.2 ± 10.8	71.5 ± 8.1	0.732
Mitral peak E wave (cm/s)	67.7 ± 14.0	69.0 ± 15.5	0.731
Deceleration time of *E* (ms)	201.2 ± 63.7	197.1 ± 43.8	0.777
Lateral *E′* (cm/s)	11.3 ± 3.8	11.7 ± 3.3	0.587
E/*E′* ratio	6.7 ± 2.5	6.3 ± 1.8	0.542

LAD, left atrial dimension; LAVI, left atrial volume index; LVEDD, left ventricular end-diastolic dimension; LVESD, left ventricular end-systolic dimension; LVEF, left ventricular ejection fraction.

patients with paroxysmal AF who can maintain sinus rhythm in early-stage disease, the other factors such as LA mechanical remodelling and electrical remodelling would be predominant factors for AF recurrence in these patients. Supporting this hypothesis, only LA strain, which may reflect the mechanical function of atrial muscle, was a significant predictor for AF recurrence in Group NSR. Furthermore, there was no significant difference in LAVI and LA empting fraction between AF recurrence and no recurrence in Group NSR, suggesting that the factor of primary importance in LA function for AF recurrence is contraction of atrial muscle, and that LA size and LA compliance may not be determinants of LA-LS.

In Group AF, which included persistent and paroxysmal AF patients with AF rhythm, $LAVI_{max}$ and basal LA-LS were both independent predictors for AF recurrence, indicating that LA structural remodelling (size and shape) could also affect LA-LS as well as the induction of AF in addition to the LA mechanical function in patients with long-lasting AF.

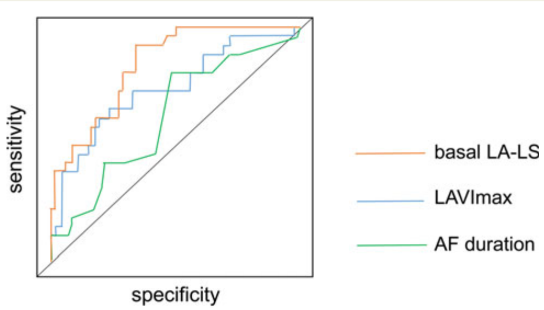
Usefulness of LA strain for prediction of AF recurrence

In addition to the present study, several previous studies have reported that LA strain is useful for predicting AF recurrence.[12–15,17] However,

Table 5 Univariate and multivariate predictors of AF recurrences after the catheter ablation

Variables	OR	Univariate analysis		OR	Multivariate analysis	
		95% CI	*P*-value		95% CI	*P*-value
Age (year)	1.02	0.98–1.07	0.293			
AF duration (year)	1.1	1.01–1.20	0.034	1.09	0.97–1.22	0.137
LA-GS (%)	0.8	0.71–0.89	<0.0001			
Basal LA-LS (%)	0.81	0.73–0.89	<0.0001	0.83	0.75–0.92	0.0005
$LAVI_{max}$ (mL/m^2)	1.07	1.03–1.12	0.0003	1.06	1.01–1.11	0.014
LVEF (%)	1.01	0.96–1.06	0.729			
E/E′	1.07	0.87–1.31	0.542			
Gender	0.73	0.23–2.36	0.602			

AF, atrial fibrillation; LA-GS, left atrial global strain; LA-LS, left atrial lateral strain; LAVI, left atrial volume index; LVEF, left ventricular ejection fraction.



	AUC	Cut-off	Specificity	Sensitivity
basal LA-LS (%)	0.84	25.27	0.72	0.81
LAVImax (ml/m^2)	0.74	50.02	0.77	0.65
AF duration (year)	0.62	4.5	0.51	0.81

Figure 2 ROC curve showing the left atrial lateral strain (LA-LS), maximum left atrial volume index (LAV_{max}), and AF duration for predicting AF recurrence after catheter ablation.

there have been several differences in the details of these results. Schneider *et al.*[17] reported that LA strain and SR measured by tissue Doppler imaging (TDI) were important predictors of recurrence during 3 months of follow-up in patients who underwent AF ablation. However, measures of strain and SR using TDI suffer from some limitations due to angulation error caused by myocardial translational motion and variable reproducibility. Hwang *et al.*[13] subsequently measured LA strain and SR by 2DSTE, and reported that average values of LA systolic strain and SR for each segment were independent predictors of AF recurrence after CA for paroxysmal AF patients. Mirza *et al.*[15] also reported LA lateral strain as the only independent predictor of AF recurrence for paroxysmal and persistent AF patients, while Machino *et al.*[15] reported that lower global LA strain was associated with AF recurrence, although a multivariate analysis identified only the LA stiffness index and AF duration as independent predictors of AF recurrence.

In the present study, LA strain on the lateral side was the most useful parameter for predicting AF recurrence, although LA-GS was also a significant predictor. The lateral side of LA is the only segment without the influence of right atrium and PV, and this may reflect the pure contractile function of the atrial muscle. We believe this is why lateral strain was a superior predictor to the other segments.

Clinical implications

In previous studies, LA strain was measured after converting AF rhythm to sinus rhythm by cardioversion in patients with AF rhythm. However, the LA function immediately after cardioversion might not be recovered and thus underestimated, suggesting that cardioversion only would not be clinically applicable for predicting AF recurrence. Thus, we performed echocardiographic examination without any intervention, such as cardioversion. Our results demonstrated that basal LA-LS could predict AF recurrence regardless of the rhythm during echocardiographic examination, although $LAVI_{max}$ could not in patients with sinus rhythm. These results support the possible clinical application of LA strain measurement for predicting AF recurrence during routine echocardiographic examinations.

Based on these results, we believe that this non-invasive imaging technique can improve therapeutic guidance in patients with AF. Earlier CA therapy as well as the optimal antiarrhythmic drug therapy would therefore be recommended in high-risk patients with lower LA strain. In such patients, close follow-up, such as by portable electrocardiogram as used in the present study, might be needed so as not to miss the AF recurrence.

Study limitation

There are several limitations to the present study. First, in some cases it was difficult to obtain enough views of the LA for speckle tracking. This was probably due to the thinner breadth of LA compared with LV, and the lack of wall around the vessel connection. The reason why LA roof strain was not a predictor of AF recurrence could be that the PV directly connected to the LA might disturb the contraction of LA roof muscles.

Next, a decrease in LA strain might be attributable to increased wall stress, because the patients with AF recurrence had larger LA than those without recurrence. Further study is needed to investigate the effect of wall stress on LA strain.

In conclusion, LA myocardial function assessed by LA lateral strain using speckle tracking echocardiography is a strong predictor for AF recurrence after CA. Notably, this type of assessment is applicable even during AF rhythm, suggesting its usefulness in the clinical setting without defibrillation before analysis.

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