

Long-Term Improvement in Left Ventricular Strain After Successful Catheter Ablation for Atrial Fibrillation in Patients With Preserved Left Ventricular Systolic Function

Laurens F. Tops, MD; Dennis W. Den Uijl, MD; Victoria Delgado, MD; Nina Ajmone Marsan, MD; Katja Zeppenfeld, MD, PhD; Eduard Holman, MD, PhD; Ernst E. van der Wall, MD, PhD; Martin J. Schalij, MD, PhD; Jeroen J. Bax, MD, PhD

Background—The effect of successful catheter ablation on left ventricular (LV) strain in patients with preserved LV systolic function is unknown. The aim of the present study was to assess the long-term effects of catheter ablation for atrial fibrillation (AF) on LV strain and strain rate in patients with preserved LV ejection fraction.

Methods and Results—In 78 patients undergoing catheter ablation for AF, speckle tracking strain imaging was performed to assess LV strain in 3 directions (radial, circumferential, and longitudinal) at baseline and after 12-month follow-up. The study population was divided into 2 groups, according to the maintenance of sinus rhythm (SR) during follow-up. After 13.8 ± 4.7 months of follow-up, 54 patients (69%) were in SR (SR group), whereas 24 patients (31%) had recurrence of AF (AF group). No significant changes in LV ejection fraction from baseline to follow-up were noted ($60 \pm 7\%$ versus $59 \pm 7\%$, $P = \text{NS}$). Circumferential strain improved significantly in the SR group ($-18.3 \pm 3.2\%$ versus $-20.4 \pm 3.8\%$, $P < 0.001$), whereas it remained unchanged in the AF group ($-18.9 \pm 3.5\%$ versus $-17.9 \pm 3.1\%$, $P = \text{NS}$). In the SR group, significant improvements in LV longitudinal strain and strain rate were noted, whereas in the AF group, LV longitudinal strain and strain rate deteriorated significantly at long-term follow-up.

Conclusions—After successful catheter ablation, LV circumferential and longitudinal strain and strain rate improve significantly in patients who maintain SR. In contrast, a decrease in LV longitudinal strain and strain rate is observed in patients with recurrence of AF. (*Circ Arrhythmia Electrophysiol.* 2009;2:249-257.)

Key Words: atrial fibrillation ■ catheter ablation ■ left ventricular function ■ strain echocardiography

Radiofrequency catheter ablation procedures are considered a reasonable option in the treatment of patients with highly symptomatic, drug-refractory atrial fibrillation (AF). It has been demonstrated that these procedures can effectively restore sinus rhythm and provide long-term relief of symptoms.¹ Furthermore, reverse remodeling and functional improvement of the left atrium (LA) has been reported after successful catheter ablation for AF.^{2,3}

Clinical Perspective on p 257

In addition, the restoration of sinus rhythm may result in an improvement in left ventricular (LV) systolic function. It has been demonstrated that LV ejection fraction improves after successful catheter ablation in patients with systolic heart failure.^{4–6} In patients with preserved systolic function, however, studies have failed to demonstrate a change in LV ejection fraction after catheter ablation.⁷ It is likely however, that LV ejection fraction does not reflect subtle changes in systolic LV function, and therefore the effect of catheter

ablation on LV systolic function cannot be detected by measuring LV ejection fraction. Recently, 2D speckle tracking strain imaging has been introduced.^{8,9} This novel technique may detect more subtle abnormalities in LV systolic function, as compared with conventional parameters such as LV ejection fraction.¹⁰ In addition, it allows angle-independent evaluation of LV systolic strain in 3 directions: radial, circumferential, and longitudinal.¹¹

Accordingly, the purpose of the present study was to assess the long-term effects of catheter ablation for AF on LV function and deformation properties. Two-dimensional speckle tracking strain imaging was used to study LV strain and strain rate in patients with maintenance of sinus rhythm and patients with recurrence of AF after radiofrequency catheter ablation.

Methods

Study Population and Study Protocol

The study population comprised selected patients with symptomatic drug-refractory AF who were referred for radiofrequency catheter

Received November 25, 2008; accepted April 7, 2009.

From the Department of Cardiology, Leiden University Medical Center, Leiden, The Netherlands.

The online-only Data Supplement is available at <http://circep.ahajournals.org/cgi/content/full/CIRCEP.108.838748/DC1>.

Correspondence to Jeroen J. Bax, MD, Leiden University Medical Center, Department of Cardiology, Albinusdreef 2, 2333 ZA Leiden, The Netherlands. E-mail j.j.bax@lumc.nl

© 2009 American Heart Association, Inc.

Circ Arrhythmia Electrophysiol is available at <http://circep.ahajournals.org>

DOI: 10.1161/CIRCEP.108.838748

ablation. Before the ablation procedure and after 12-month follow-up, an extensive echocardiographic evaluation was performed. To minimize the confounding effect of variations in heart rhythm on LV deformation properties, only patients with an available echocardiogram during sinus rhythm at baseline and at follow-up were studied. In addition, patients with moderate or severe valvular disease or patients with a history of heart failure or coronary artery bypass graft were excluded from the study. Of 98 patients who underwent radiofrequency catheter ablation, 20 patients were excluded because of the presence of AF during the baseline or follow-up echocardiogram. The remaining 78 patients formed the study population of the present study.

To study the effect of successful catheter ablation on LV function and deformation properties, the study population was divided into 2 groups, according to the maintenance of sinus rhythm during the 12-month follow-up. In addition, LV function and deformation properties were assessed in a group of 20 healthy control subjects matched for age, sex, and body surface area who were selected from an echocardiographic database.

Radiofrequency Catheter Ablation

The catheter ablation procedure was aimed at electrical isolation of all pulmonary veins from the LA and has been described in more detail elsewhere.¹² In brief, endocardial mapping and ablation was performed with a 4-mm quadripolar mapping/ablation catheter (7F Thermocool, Biosense Webster, Diamond Bar, Calif), using an electroanatomic mapping system (CARTO, Biosense Webster). A 6F diagnostic catheter placed in the right atrium served as a temporal reference. Radiofrequency current was applied outside the ostia of all pulmonary veins, using the ablation catheter with a 4-mm open-loop irrigated tip (maximum flow 20 mL/min; maximum temperature, 50°C; maximum radiofrequency energy, 30 W). At each ablation point, radiofrequency current was applied until a voltage <0.1 mV was achieved, with a maximum of 60 seconds per point. Pulmonary vein isolation was confirmed by recording entrance block during sinus rhythm or pacing in the coronary sinus.¹ All patients received heparin intravenously (activated clotting time, 300 to 400 seconds) to avoid thromboembolic complications.

Follow-Up

After the catheter ablation procedure, patients were evaluated at the outpatient clinic on a regular basis. All medication, including antiarrhythmic drugs, was continued in all patients during the first 3 months after the ablation procedure. Thereafter, antiarrhythmic drugs were discontinued at the discretion of the physician. A surface ECG was acquired at every follow-up visit and 24 hours Holter monitoring was performed at 3- to 6-month intervals. A successful catheter ablation was defined as the absence of symptomatic recurrences lasting more than 3 minutes and/or the absence of AF episodes lasting more than 30 seconds detected with 24-hour Holter monitoring or surface ECG, after a blanking period of 1 month.¹

Subsequently, the study population was divided into 2 groups according to the absence or presence of AF during follow-up. The SR group comprised patients with maintenance of sinus rhythm during follow-up, whereas patients in the AF group had recurrence of AF during follow-up. Clinical and echocardiographic variables at baseline and at 12-month follow-up were compared between the 2 groups.

Echocardiography

Two-dimensional echocardiography was performed within 2 days before the ablation procedure and after 12-month follow-up. Images were recorded with patients in the left lateral decubitus position using a commercially available system (Vivid 7, General Electric Vingmed, Milwaukee, Wis).

Image acquisition was performed using a 3.5-MHz transducer at a depth of 16 cm in the standard parasternal and apical views (standard long-axis and 2- and 4-chamber images). Standard M-mode and 2D images including color Doppler data from 3 consecutive heart beats were saved in cine loop format. All analyses were performed off-line using commercial software (Echopac 6.1, General Electric Vingmed).

The anteroposterior diameter of the LA was measured at end-systole on the M-mode image obtained from the parasternal long-axis view.¹³ Left atrial volume was calculated using the biplane area-length method.¹³ In addition, LV end-diastolic and end-systolic diameters were acquired from the parasternal long-axis view.¹³ Left ventricular end-diastolic and end-systolic volumes were assessed from the apical 2- and 4-chamber images, and LV ejection fraction was calculated using the biplane Simpson rule.¹⁴ Finally, LV diastolic function was assessed using the mitral inflow pattern from the pulsed-wave Doppler images¹⁵ and tissue Doppler imaging. The ratio of early (E) to late (A) diastolic filling velocities (E/A), deceleration time of the E wave, the septal early diastolic mitral annular motion velocity (E'), and the E/E' ratio were assessed. Subsequently, LV diastolic function was classified as being normal, abnormal relaxation (mild diastolic dysfunction, grade 1), pseudo-normal filling (moderate diastolic dysfunction, grade 2) or restrictive filling pattern (severe diastolic dysfunction, grade 3).^{16,17}

Left Ventricular Strain Analysis

On standard gray-scale images (frame rate, 75±11 frames/s), 2D speckle tracking strain imaging was used to study LV deformation. Novel speckle-tracking software was used, as previously described.^{8,9,18} Briefly, this technique permits angle-independent measurement of myocardial strain in 3 different directions (radial, circumferential, and longitudinal). It tracks the characteristic pattern of natural acoustic markers present in the myocardial wall ("speckles") from frame to frame throughout the cardiac cycle. Myocardial strain is then calculated by the change in position of the speckle pattern with respect to the initial position.^{8,9}

Three distinct patterns of LV deformation were assessed: (1) radial strain, representing myocardial thickening/thinning in the short-axis plane; (2) circumferential strain, representing myocardial shortening/lengthening in the short-axis plane; and (3) longitudinal strain, representing myocardial shortening/lengthening in the long-axis plane. Peak systolic radial and circumferential strain/strain rate were calculated by averaging the peak systolic values of the 6 segments from the LV mid ventricular short-axis view. Peak systolic longitudinal strain/strain rate was calculated by averaging the peak systolic values of the 18 segments, derived from the 6 segments of the 3 apical views (2-chamber, 4-chamber, and apical long-axis views) (Figure 1). For myocardial strain, regional thickening or lengthening is expressed as a positive value and thinning or shortening as a negative value.¹⁹ Finally, strain rate (expressed in 1/s) was calculated in all 3 directions, representing the speed at which myocardial deformation occurs.¹⁹

Statistical Analysis

All continuous variables had normal distribution (as evaluated by Kolmogorov-Smirnov tests). Summary statistics for these variables are therefore presented as mean±SD. Categorical data are summarized as frequencies and percentages. Differences in clinical and echocardiographic variables between the SR group and the AF group were evaluated using unpaired Student *t* tests (continuous variables), χ^2 tests or Fisher exact tests (dichotomous variables), as appropriate. Changes in echocardiographic variables from baseline to follow-up were evaluated using paired Student *t* tests.

Intraobserver and interobserver reproducibility of strain and strain rate measurements by 2D speckle tracking strain analysis was determined by linear regression (Pearson correlation coefficient) and Bland-Altman analysis. Intraobserver reproducibility was determined by repeating the strain and strain rate measurements at 2 different time points by 1 experienced reader in 20 randomly selected patients. A second experienced reader performed the strain analysis in the same 20 patients, providing the interobserver reproducibility data.

Multivariate logistic regression analysis based on enter model was performed for the prediction of the maintenance of sinus rhythm at follow-up. The dependent variable was the maintenance of sinus rhythm. As independent variables, the number of antiarrhythmic drugs, LA remodeling (represented by the change in LA volume), change in mean arterial pressure and LV mass index, change in

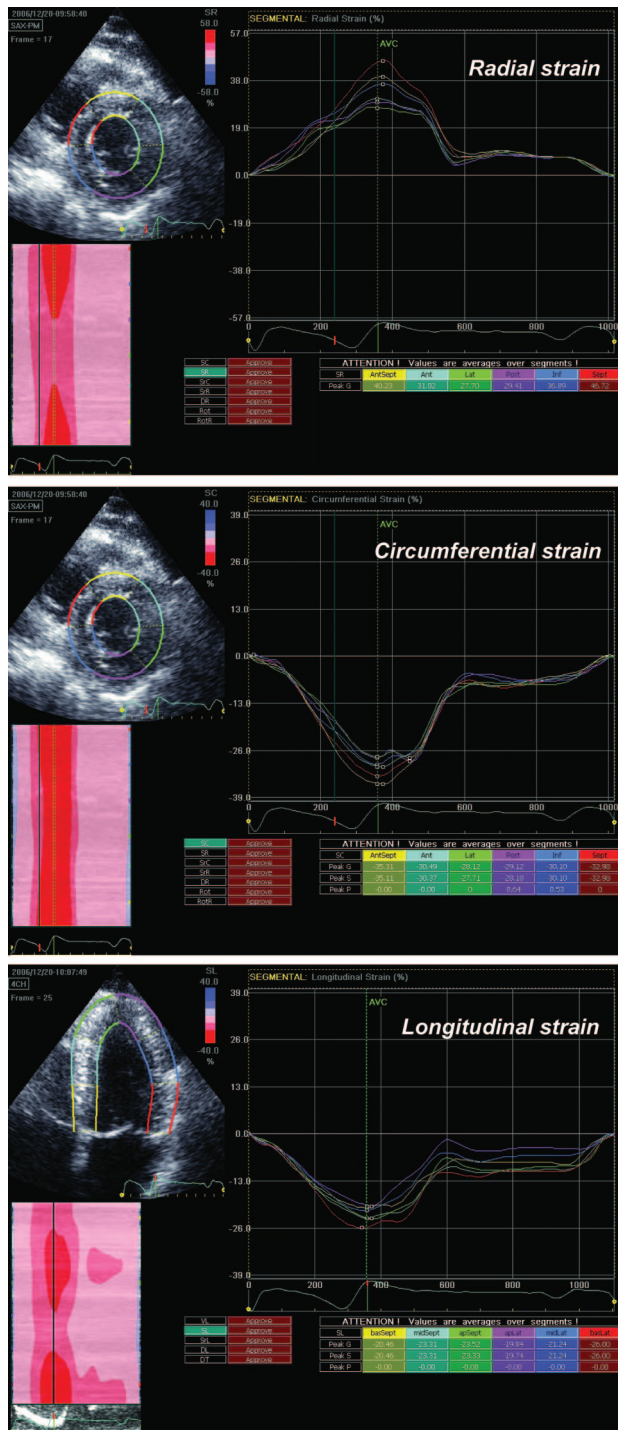


Figure 1. Assessment of left ventricular strain. LV strain was assessed in 3 directions. Radial strain (upper panel) and circumferential strain (middle panel) were assessed on short-axis images; longitudinal strain (lower panel) was assessed on standard apical images.

longitudinal strain, and change in circumferential strain after catheter ablation were entered in the model. Model discrimination was assessed using c-statistic.

All analyses were performed using SPSS software (version 12.0, SPSS Inc, Chicago, Ill). All statistical tests were 2-sided, and a probability value <0.05 was considered significant.

The authors had full access to the data and take responsibility for its integrity. All authors have read and agree to the manuscript as written.

Results

Study Population

The baseline characteristics of the study population are summarized in Table 1. The majority of the patients had paroxysmal AF (67 patients, 86%); in 11 patients (14%), persistent AF was present. Mean time from the first documented AF episode to the radiofrequency catheter ablation procedure was 5.9 ± 3.9 years. A mean of 3.4 ± 1.4 different antiarrhythmic drugs per patient had been used previously.

After a mean of 13.8 ± 4.7 months of follow-up, 54 patients (69%) were in sinus rhythm (SR group), whereas 24 patients (31%) had recurrence of AF (AF group). The study population was subsequently divided into 2 groups, according to the success of the catheter ablation procedure. No significant differences in baseline characteristics were noted between the 2 groups (Table 1).

In the total study population, no significant differences in heart rate between the baseline and follow-up echocardiogram were noted (baseline, 62 ± 11 bpm versus follow-up, 63 ± 20 bpm; $P=NS$). In addition, no differences between the 2 groups at the follow-up echocardiogram were noted (SR group, 64 ± 9 bpm versus AF group, 62 ± 10 bpm; $P=NS$). In the overall study population, no differences in mean systolic (from 133 ± 16 mm Hg to 131 ± 16 mm Hg, $P=NS$) or diastolic (from 81 ± 12 mm Hg to 80 ± 9 mm Hg, $P=NS$) blood pressure was noted during follow-up.

In addition, there were no differences between the SR group and the AF group with regard to the use of antiarrhythmic drugs at baseline (Table 1). At follow-up, 27 patients (35%) used β -blockers (including Sotalolol), 1 patient (1%) used a calcium channel blocker, 17 patients (22%) used a class IC antiarrhythmic drug, and 6 patients (8%) used amiodarone. At follow-up, there were no significant differences in the use of antiarrhythmic drugs between the SR group and the AF group, except for the use of β -blockers (SR group, $n=12$ [35%] versus AF group, $n=15$ [63%], $P<0.01$). By definition of the study protocol, all patients were in sinus rhythm during both echocardiographic evaluations.

Echocardiographic Changes During Follow-Up

In the overall study population, a decrease in LA diameter and LA volume was noted from baseline to follow-up (Table 2). Interestingly, this decrease in LA diameter was more pronounced in the SR group (baseline, 43 ± 5 mm versus follow-up, 40 ± 5 mm; $P<0.01$), as compared with the AF group (baseline, 45 ± 5 mm versus follow-up, 45 ± 5 mm; $P=NS$). Similarly, LA volumes decreased significantly in the SR group from baseline to follow-up (from 58 ± 18 mL to 51 ± 14 mL, $P<0.01$), whereas no changes in LA volumes were noted in the AF group (from 65 ± 17 mL to 64 ± 21 mL, $P=NS$).

In addition, an improvement in diastolic function was observed in the overall study population (Table 2). At baseline, 48 patients (62%) had normal diastolic function, whereas 21 patients (27%) had mild diastolic dysfunction and 9 patients (11%) had moderate diastolic dysfunction. At long-term follow-up, 16 patients improved in diastolic function: 59 patients (76%) had normal diastolic function, 12

Table 1. Baseline Characteristics of the Study Population

	All Patients (n=78)	SR Group (n=54)	AF Group (n=24)	P Value*
Age, y (range)	54±9 (31–77)	54±9 (31–77)	54±8 (39–72)	NS
Sex, M/F	63/15	43/11	20/4	NS
Body surface area, m ²	2.1±0.2	2.1±0.2	2.1±0.1	NS
Heart rate, bpm	62±11	61±9	63±15	NS
Blood pressure				
Systolic, mm Hg	133±16	133±16	135±16	NS
Diastolic, mm Hg	81±12	81±12	82±11	NS
LV mass index, g/m ²	111±24	109±26	117±20	NS
Type of AF				
Paroxysmal, n (%)	67 (86)	49 (91)	18 (75)	NS
Persistent, n (%)	11 (14)	5 (9)	6 (25)	NS
Duration of AF, y	5.9±3.9	6.0±4.2	4.2±3.0	NS
Antiarrhythmic drugs used per patient	3.4±1.4	3.6±1.4	3.1±1.3	NS
β-Blocker, n (%)	36 (46)	23 (43)	13 (54)	NS
Calcium channel blocker, n (%)	7 (9)	4 (7)	3 (13)	NS
Class IC antiarrhythmic drug, n (%)	27 (35)	19 (35)	8 (33)	NS
Amiodarone, n (%)	25 (32)	19 (35)	6 (25)	NS
ACE inhibitor/ATII, n (%)	40 (51)	27 (50)	13 (54)	NS
Statin, n (%)	20 (26)	14 (26)	6 (25)	NS
Hypertension, n (%)	36 (46)	22 (41)	14 (58)	NS
Diabetes mellitus, n (%)	4 (5)	3 (6)	1 (4)	NS
Coronary artery disease, n (%)	5 (6)	4 (7)	1 (4)	NS

NS indicates not significant; ACE, angiotensin-converting enzyme; ATII, angiotensin II receptor blocker.

*SR group versus AF group.

patients (15%) had mild, and 7 patients (9%) had moderate diastolic dysfunction.

Finally, LV dimensions, volumes, and ejection fraction were similar at baseline and at follow-up in the overall study population (Table 2). Both in the SR group and in the AF group, no significant changes were noted in LV volumes and LV ejection fraction from baseline to follow-up (Table 3).

Left Ventricular Strain and Strain Rate

Linear regression analysis demonstrated good intraobserver and interobserver agreement for the radial, circumferential and longitudinal strain and strain rate measurements (supple-

mental Table 1). In addition, Bland-Altman analysis showed a small bias for all strain and strain rate measurements performed by the same observer (intraobserver variability) and the 2 different observers (interobserver variability) (supplemental Table 1).

Strain and strain rate values for the overall study population at baseline were compared with a group of 20 healthy control subjects (mean LV ejection fraction, 60±7%). Radial strain and radial strain rate were not significantly different between the overall study population and the healthy control subjects (40.1±15.6% versus 40.8±11.7%, $P=NS$; and 1.8±0.6 1/s versus 1.9±0.6 1/s, $P=NS$, respectively). In contrast, both circumferential strain and circumferential strain rate were significantly reduced in the study population, as compared with the control subjects (−18.4±3.1% versus −20.1±3.3%, $P<0.05$; and −1.1±0.2 1/s versus −1.3±0.3 1/s, $P<0.05$). Similarly, both longitudinal strain and longitudinal strain rate were significantly lower in the overall study population, as compared with the healthy control subjects (−18.9±2.4% versus −20.4±2.1%, $P<0.05$; and −0.9±0.1 1/s versus −1.1±0.2 1/s, $P<0.01$).

In the overall study population, radial strain did not change significantly from baseline to follow-up (from 40.6±15.1% to 37.5±15.1%, $P=NS$). In addition, radial strain rate was similar at baseline and follow-up (1.8±0.6 1/s and 1.8±0.6 1/s, respectively; $P=NS$). Within the 2 groups, no differences were noted for radial strain and radial strain rate at baseline and at long-term follow-up (Table 3). Radial strain at long-term follow-up was comparable in the SR group and the AF group (Figure 2).

Table 2. Echocardiographic Parameters at Baseline and at Long-Term Follow-Up in the Total Study Population

	Baseline (n=78)	Follow-Up (n=78)	P Value*
LA diameter, mm	44±5	42±5	<0.05
LA volume, mL	60±18	55±17	<0.01
E/A ratio	1.3±0.5	1.4±0.5	<0.05
Deceleration time, ms	236±48	234±56	NS
E/E' ratio	8.8±3.4	8.8±4.2	NS
LV end-diastolic diameter, mm	54±5	54±5	NS
LV end-systolic diameter, mm	32±6	32±6	NS
LV end-diastolic volume, mL	124±29	124±28	NS
LV end-systolic volume, mL	49±17	50±15	NS
LV ejection fraction, %	60±7	59±7	NS

NS indicates not significant.

Table 3. Left Ventricular Systolic Function and Strain/Strain Rate at Baseline and Follow-Up in the SR Group and the AF Group

	SR Group (n=54)	AF Group (n=24)	P Value
LV end-diastolic diameter, mm			
Baseline	53±6	55±4	NS
Follow-up	53±6	55±5	NS
LV end-systolic diameter, mm			
Baseline	32±6	33±5	NS
Follow-up	32±5	34±7	NS
LV end-diastolic volume, mL			
Baseline	123±30	127±26	NS
Follow-up	124±30	123±23	NS
LV end-systolic volume, mL			
Baseline	49±17	49±17	NS
Follow-up	51±15	49±13	NS
LV ejection fraction, %			
Baseline	60±7	62±7	NS
Follow-up	59±7	61±6	NS
GRS, %			
Baseline	40.1±7.0	39.1±13.1	NS
Follow-up	37.2±15.2	38.3±15.3	NS
GRSr, 1/s			
Baseline	1.9±0.6	1.7±0.5	NS
Follow-up	1.9±0.6	1.7±0.4	NS
GCS, %			
Baseline	-18.3±3.2	-18.9±3.5	NS
Follow-up	-20.4±3.8‡	-17.9±3.1	<0.05
GCSr, 1/s			
Baseline	-1.1±0.3	-1.1±0.2	NS
Follow-up	-1.2±0.3‡	-1.1±0.2	<0.05
GLS, %			
Baseline	-18.8±2.7	-19.1±1.5	NS
Follow-up	-19.6±2.6‡	-17.9±1.8‡	<0.05
GLSr, 1/s			
Baseline	-0.9±0.1	-1.0±0.1	NS
Follow-up	-1.0±0.1‡	-0.9±0.1*	<0.001

NS indicates not significant; GCS, global circumferential strain; GCSr, global circumferential strain rate; GLS, global longitudinal strain; GLSr, global longitudinal strain rate; GRS, global radial strain; GRSr, global radial strain rate.

* $P<0.05$ versus baseline; ‡ $P<0.01$ versus baseline; † $P<0.001$ versus baseline.

In contrast, circumferential strain improved significantly from baseline to follow-up in the total study population (from $-18.6\pm3.2\%$ to $-19.7\pm3.6\%$, $P<0.01$). Similarly, circumferential strain rate improved significantly from baseline to follow-up (from -1.1 ± 0.2 1/s to -1.2 ± 0.3 1/s, $P<0.05$). Baseline values for circumferential strain and strain rate were comparable for the SR group and the AF group (Table 3). Importantly, circumferential strain and strain rate improved only in the SR group from baseline to follow-up, whereas no significant changes were noted in the AF group (Table 3). As a result, circumferential strain at long-term follow-up was significantly higher in the SR group, as compared with the AF group (Figure 2).

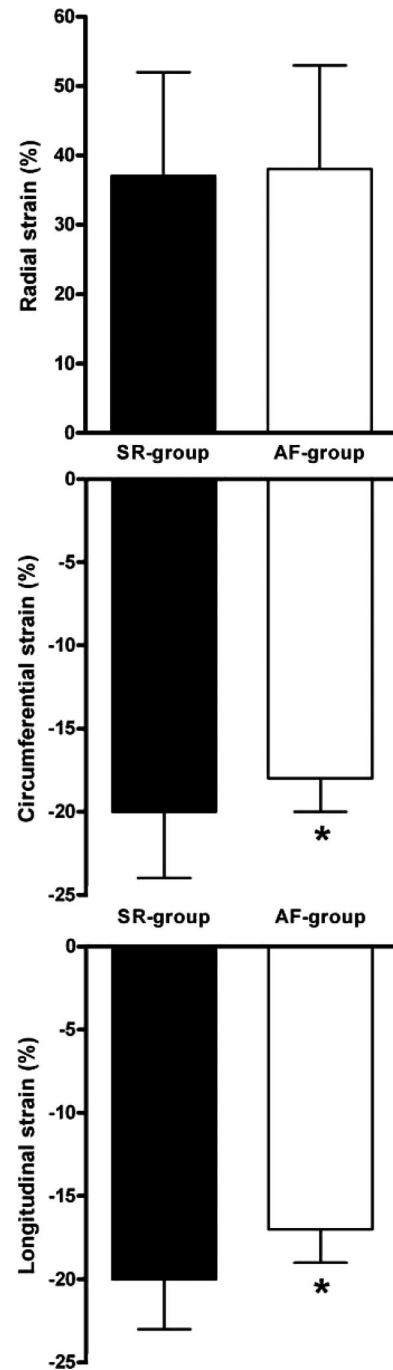


Figure 2. Strain values at long-term follow-up in SR group and AF group. The strain values at follow-up are demonstrated for both the SR group (black bars) and the AF group (white bars). After long-term follow-up, radial strain (upper panel) was comparable in the SR group ($37.2\pm15.2\%$) and the AF group ($38.3\pm15.3\%$). However, circumferential strain (middle panel) and longitudinal strain (lower panel) were significantly lower in the AF group ($-17.9\pm3.1\%$ and $-17.9\pm1.8\%$, respectively), as compared with the SR group ($-20.4\pm3.8\%$ and $-19.6\pm2.6\%$, respectively). * $P<0.05$.

Longitudinal strain was not significantly different at baseline and follow-up in the total study population ($-18.9\pm2.4\%$ and $-19.1\pm2.5\%$, respectively, $P=NS$). In addition, longitudinal strain rate was similar at baseline (-1.0 ± 0.1 1/s) and follow-up (-1.0 ± 0.1 1/s, $P=NS$). However, the changes in longitudinal

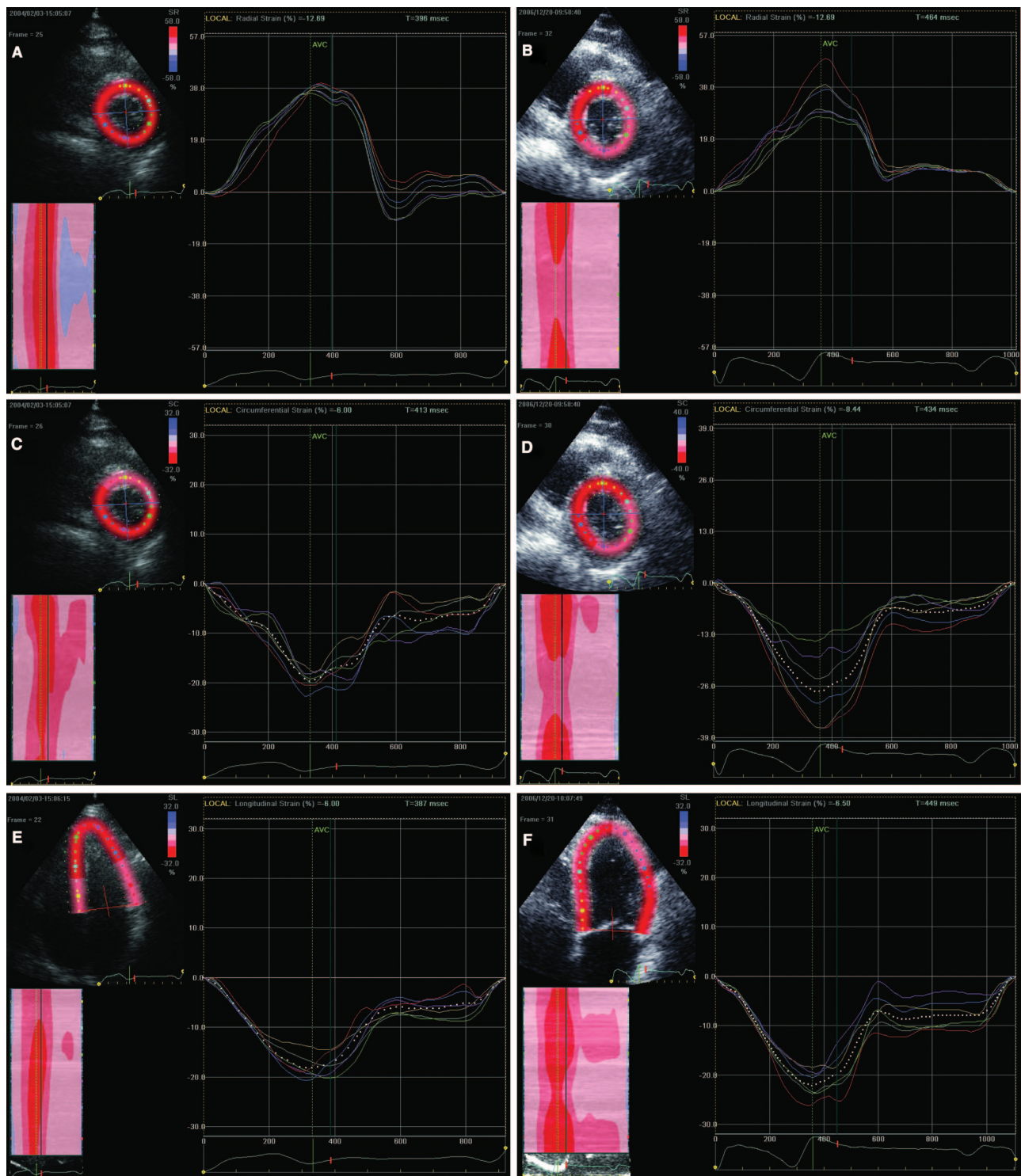


Figure 3. Patient example with increased strain after successful catheter ablation for atrial fibrillation. In this patient, global radial strain did not improve from baseline (38.1%, A) to 12-month follow-up (37.3%, B). In contrast, a significant improvement in global circumferential strain (baseline, -19.4% ; C; follow-up, -26.5% , D) and global longitudinal strain (baseline -17.3% , E; follow-up -22.5% , F) was observed.

strain and strain rate from baseline to follow-up were different in the 2 groups: Whereas longitudinal strain improved significantly in the SR group, it deteriorated significantly in the AF group (Table 3). At long-term follow-up, longitudinal strain was significantly different between the 2 groups (Figure 2). Similarly, longitudinal strain rate improved significantly in the SR

group, whereas it deteriorated in the AF group (Table 3). An example of a patient from the SR group demonstrating improvements in LV circumferential and longitudinal strain is shown in Figure 3.

A multivariate logistic regression analysis was performed to study the predictors of the maintenance of sinus rhythm

after catheter ablation. The results of the multivariate logistic regression analysis are shown in supplemental Table 2. Interestingly, the change in longitudinal strain and circumferential strain at follow-up were the only independent predictors for maintenance of sinus rhythm: Change in circumferential strain: odds ratio, 0.537, 95% CI, 0.339 to 0.849, $P=0.008$; change in longitudinal strain: odds ratio, 0.338, 95% CI, 0.155 to 0.737, $P=0.006$.

Discussion

In the present study, 78 patients with preserved LV systolic function, undergoing radiofrequency catheter ablation for AF, were studied. At long-term follow-up, a significant improvement in circumferential and longitudinal strain and strain rate was observed. Importantly, these improvements were only present in patients who maintained sinus rhythm during follow-up, whereas patients who had recurrence of AF did not exhibit improvements in circumferential and longitudinal strain.

Left Ventricular Function After Catheter Ablation

Significant improvements in LV strain were observed after successful catheter ablation in the current study in patients with preserved LV systolic function. The beneficial effect of catheter ablation on LV function has been demonstrated previously in patients with impaired LV systolic function.^{4–6} Interestingly, in patients with preserved LV systolic function, the favorable effects of catheter ablation on LV function are less clear. In 52 patients with an LV ejection fraction $>50\%$ undergoing catheter ablation, Lutomskey et al⁷ noted that LV ejection fraction remained unchanged after 6-month follow-up. It was concluded that successful catheter ablation may be less beneficial in patients with normal LV ejection fraction.⁷

However, it may well be that the positive effects of the restoration of sinus rhythm on LV systolic function are present but cannot be detected by conventional parameters such as LV ejection fraction. The evaluation of LV strain may detect more subtle abnormalities in LV systolic function,²⁰ which can improve after AF ablation. Indeed, preliminary data in 25 patients with normal LV ejection fraction suggest that LV deformation may improve after catheter ablation for AF.²¹ In the present study, 2D speckle tracking strain imaging was used to assess LV function after catheter ablation for AF in 78 patients. Similar to previous data,⁷ mean LV ejection fraction did not improve after long-term follow-up. However, significant changes in LV circumferential and longitudinal strain and strain rate were noted, in particular in the patients who maintained sinus rhythm during follow-up.

The improvement in LV function (according to strain and strain rate) after successful catheter ablation can be attributed to the normalization of the heart rate or to the restoration of sinus rhythm and subsequent more efficient LV filling. However, at present it remains unclear what mechanism contributes most.^{1,22} In the current study, the mean heart rate did not change significantly from baseline to follow-up. Per study protocol, both echocardiograms were acquired during sinus rhythm, and therefore the differences in LV strain cannot be attributed to changes in heart rhythm during image acquisition. Furthermore, significant changes in circumferential and longitudinal strain and strain rate were only noted in

the patients who maintained sinus rhythm during follow-up. Therefore, the current results suggest that the improvement in LV function after catheter ablation may be more related to restoration and long-term maintenance of sinus rhythm than to normalization of heart rate.

At the same time, it may also be that an improvement in LV function ultimately results in favorable reverse remodeling of the left atrium and subsequently in a reduced risk of recurrent AF.²³ Interestingly, in the present study, improvements in circumferential and longitudinal strain were the only predictors for maintenance of sinus rhythm during follow-up (supplemental Table 2). Although the restoration of sinus rhythm and the improvement in LV function after catheter ablation are clearly related, it remains unclear which factor is the exact cause and which is the consequence.

Left Ventricular Strain

In the present study, 3 distinct patterns of LV deformation were studied: radial, circumferential, and longitudinal strain. Interestingly, different responses during long-term follow-up were noted among the various strain patterns. Previously, several studies have demonstrated the effects of different clinical settings on these strain patterns.^{24–27} In an animal model of myocardial ischemia, it was noted that circumferential and longitudinal strain, as assessed with speckle tracking echocardiography, were most sensitive to reduced coronary flow.²⁴ In addition, in 53 patients with diabetes, Fang et al²⁵ demonstrated a significant impairment of longitudinal strain as compared with control subjects, whereas radial strain was compensatory increased. Finally, in patients with hypertrophic cardiomyopathy but normal LV systolic function, marked reductions in longitudinal strain have been demonstrated.^{26,27} From anatomic studies, it is known that there is a difference in orientation of the endocardial and epicardial myocardial fibers. It has been suggested that the LV myocardial architecture is a transmural continuum of 2 helical fiber geometries, with a right-handed helical geometry in the subendocardial region gradually changing into a left-handed geometry in the subepicardial region.²⁸ The discrepancy among the various strain patterns as found in the abovementioned studies may be explained by the fact that the longitudinal fibers located in the subendocardium, mediating the long-axis deformation, may be more susceptible to pathological changes.²⁹

In the present study, baseline values for LV strain were comparable in the SR group and the AF group and modestly reduced as compared with previously reported values for healthy control subjects.^{25,26} Interestingly, circumferential and longitudinal strain improved significantly in patients who maintained sinus rhythm after catheter ablation. In contrast, in patients with recurrence of AF, circumferential strain remained unchanged and longitudinal strain deteriorated. No significant changes in radial strain were noted in either group. It may be that, similar to detrimental effects of various pathological changes, the longitudinal fibers may be more prone to the beneficial effect of restoration of normal sinus rhythm and subsequent more efficient LV filling and contraction.

Limitations

Some limitations of the present study must be addressed. First, the study population was divided into 2 groups, based on recurrence of symptomatic AF episodes and/or detection of AF with surface ECG and 24-hour Holter monitoring on a regular basis. Asymptomatic AF recurrence during follow-up may therefore have been missed. Second, no data on the exact AF burden before the ablation procedure and during follow-up are available in the present study. Although potential asymptomatic AF recurrences may affect the results, and exact AF burden assessment may provide more information on the relation between improvement in LV function and AF recurrence, the definition of AF recurrence in the present study is according to the recommendations from the Heart Rhythm Society Expert Consensus Statement.¹

In addition, only a small number of patients with persistent AF were included in the study. Therefore, no comparisons between patients with paroxysmal and persistent AF could be performed. However, to minimize the confounding effect of variations in heart rhythm on LV deformation properties, only patients with an available echocardiogram during sinus rhythm at baseline and at follow-up were included in the present study. A larger population in future studies may allow comparison between paroxysmal and persistent AF patients.

Finally, in the present study, LV dyssynchrony was not routinely assessed. Future studies may investigate if LV dyssynchrony is present in patients undergoing catheter ablation, and if the improvement in LV function as demonstrated in the present study is associated with an improvement in LV dyssynchrony.

Conclusions

In patients with preserved LV systolic function undergoing catheter ablation for AF, improvements in LV strain were noted, without significant changes in LV ejection fraction. Longitudinal and circumferential strain and strain rate improved in patients who maintained sinus rhythm during follow-up. In contrast, patients who had recurrence of AF exhibited no improvements in circumferential or longitudinal strain.

Sources of Funding

This study was supported by the Research Fellowship of the European Society of Cardiology (Drs Delgado and Marsan).

Disclosures

Dr Schalij receives grants from Biotronik, Medtronic, and Boston Scientific. Dr Bax receives grants from Medtronic, Boston Scientific, BMS Medical Imaging, St Jude Medical, GE Healthcare, and Edwards Lifesciences.

References

1. Calkins H, Brugada J, Packer DL, Cappato R, Chen SA, Crijns HJ, Damiano RJ Jr, Davies DW, Haines DE, Haissaguerre M, Iesaka Y, Jackman W, Jais P, Kottkamp H, Kuck KH, Lindsay BD, Marchlinski FE, McCarthy PM, Mont JL, Morady F, Nademanee K, Natale A, Pappone C, Prystowsky E, Raviele A, Ruskin JN, Shemin RJ. HRS/EHRA/ECAS expert Consensus Statement on catheter and surgical ablation of atrial fibrillation: recommendations for personnel, policy, procedures and follow-up: a report of the Heart Rhythm Society (HRS) Task Force on catheter and surgical ablation of atrial fibrillation. *Heart Rhythm*. 2007;4:816–861.
2. Tops LF, Bax JJ, Zeppenfeld K, Jongbloed MR, van der Wall EE, Schalij MJ. Effect of radiofrequency catheter ablation for atrial fibrillation on left atrial cavity size. *Am J Cardiol*. 2006;97:1220–1222.
3. Reant P, Lafitte S, Jais P, Serri K, Weerasooriya R, Hocini M, Pillois X, Clementy J, Haissaguerre M, Roudaut R. Reverse remodeling of the left cardiac chambers after catheter ablation after 1 year in a series of patients with isolated atrial fibrillation. *Circulation*. 2005;112:2896–2903.
4. Hsu LF, Jais P, Sanders P, Garrigue S, Hocini M, Sacher F, Takahashi Y, Rotter M, Pasquie JL, Scavee C, Bordachar P, Clementy J, Haissaguerre M. Catheter ablation for atrial fibrillation in congestive heart failure. *N Engl J Med*. 2004;351:2373–2383.
5. Gentles PJ, Sauer WH, Gerstenfeld EP, Lin D, Dixit S, Zado E, Callans D, Marchlinski FE. Reversal of left ventricular dysfunction following ablation of atrial fibrillation. *J Cardiovasc Electrophysiol*. 2007;18:9–14.
6. Chen MS, Marrouche NF, Khaykin Y, Gillinov AM, Wazni O, Martin DO, Rossillo A, Verma A, Cummings J, Erciyes D, Saad E, Bhargava M, Bash D, Schweikert R, Burkhardt D, Williams-Andrews M, Perez-Lugones A, Abdul-Karim A, Saliba W, Natale A. Pulmonary vein isolation for the treatment of atrial fibrillation in patients with impaired systolic function. *J Am Coll Cardiol*. 2004;43:1004–1009.
7. Lutomsky BA, Rostock T, Koops A, Steven D, Mullerleile K, Servatius H, Drewitz I, Ueberschar D, Plagemann T, Ventura R, Meinertz T, Willems S. Catheter ablation of paroxysmal atrial fibrillation improves cardiac function: a prospective study on the impact of atrial fibrillation ablation on left ventricular function assessed by magnetic resonance imaging. *Europace*. 2008;10:593–599.
8. Leitman M, Lysyansky P, Sidenko S, Shir V, Peleg E, Binenbaum M, Kaluski E, Krakover R, Vered Z. Two-dimensional strain—a novel software for real-time quantitative echocardiographic assessment of myocardial function. *J Am Soc Echocardiogr*. 2004;17:1021–1029.
9. Reisner SA, Lysyansky P, Agmon Y, Mutlak D, Lessick J, Friedman Z. Global longitudinal strain: a novel index of left ventricular systolic function. *J Am Soc Echocardiogr*. 2004;17:630–633.
10. Edvardsen T, Helle-Valle T, Smiseth OA. Systolic dysfunction in heart failure with normal ejection fraction: speckle-tracking echocardiography. *Prog Cardiovasc Dis*. 2006;49:207–214.
11. Delgado V, Ypenburg C, van Bommel RJ, Tops LF, Mollema SA, Marsan NA, Bleeker GB, Schalij MJ, Bax JJ. Assessment of left ventricular dyssynchrony by speckle tracking strain imaging comparison between longitudinal, circumferential, and radial strain in cardiac resynchronization therapy. *J Am Coll Cardiol*. 2008;51:1944–1952.
12. Tops LF, Bax JJ, Zeppenfeld K, Jongbloed MR, Lamb HJ, van der Wall EE, Schalij MJ. Fusion of multislice computed tomography imaging with three-dimensional electroanatomic mapping to guide radiofrequency catheter ablation procedures. *Heart Rhythm*. 2005;2:1076–1081.
13. Lang RM, Bierig M, Devereux RB, Flachskampf FA, Foster E, Pellikka PA, Picard MH, Roman MJ, Seward J, Shanewise JS. 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.
14. Schiller NB, Shah PM, Crawford M, DeMaria A, Devereux R, Feigenbaum H, Gutgesell H, Reichek N, Sahn D, Schnittger I. Recommendations for quantitation of the left ventricle by two-dimensional echocardiography: American Society of Echocardiography Committee on Standards, Subcommittee on Quantitation of Two-Dimensional Echocardiograms. *J Am Soc Echocardiogr*. 1989;2:358–367.
15. Quinones MA, Otto CM, Stoddard M, Waggoner A, Zoghbi WA. Recommendations for quantification of Doppler echocardiography: a report from the Doppler Quantification Task Force of the Nomenclature and Standards Committee of the American Society of Echocardiography. *J Am Soc Echocardiogr*. 2002;15:167–184.
16. Ommen SR, Nishimura RA, Appleton CP, Miller FA, Oh JK, Redfield MM, Tajik AJ. Clinical utility of Doppler echocardiography and tissue Doppler imaging in the estimation of left ventricular filling pressures: a comparative simultaneous Doppler-catheterization study. *Circulation*. 2000;102:1788–1794.
17. Lester SJ, Tajik AJ, Nishimura RA, Oh JK, Khandheria BK, Seward JB. Unlocking the mysteries of diastolic function: deciphering the Rosetta Stone 10 years later. *J Am Coll Cardiol*. 2008;51:679–689.
18. Tops LF, Suffoletto MS, Bleeker GB, Boersma E, van der Wall EE, Gorcsan J III, Schalij MJ, Bax JJ. Speckle-tracking radial strain reveals left ventricular dyssynchrony in patients with permanent right ventricular pacing. *J Am Coll Cardiol*. 2007;50:1180–1188.

19. Kowalski M, Kukulski T, Jamal F, D'hooge J, Weidemann F, Rademakers F, Bijmens B, Hatle L, Sutherland GR. Can natural strain and strain rate quantify regional myocardial deformation? A study in healthy subjects. *Ultrasound Med Biol*. 2001;27:1087–1097.
20. Abraham TP, Dimaano VL, Liang HY. Role of tissue Doppler and strain echocardiography in current clinical practice. *Circulation*. 2007;116:2597–2609.
21. Reant P, Lafitte S, Jais P, Sacher F, Derval N, Deplagne A, Hocini M, Clementy J, Haissaguerre M, Roudaut R. Improvement of left ventricular deformation after catheter ablation for isolated paroxysmal atrial fibrillation in patients with normal ejection fraction: a 2-dimensional strain study. *Eur Heart J*. 2007;28(Suppl):1–250. Abstract.
22. Cha YM, Redfield MM, Shen WK, Gersh BJ. Atrial fibrillation and ventricular dysfunction: a vicious electromechanical cycle. *Circulation*. 2004;109:2839–2843.
23. Casaclang-Verzosa G, Gersh BJ, Tsang TS. Structural and functional remodeling of the left atrium: clinical and therapeutic implications for atrial fibrillation. *J Am Coll Cardiol*. 2008;51:1–11.
24. Reant P, Labrousse L, Lafitte S, Bordachar P, Pillois X, Tariosse L, Bonoron-Adele S, Padois P, Deville C, Roudaut R, Dos SP. Experimental validation of circumferential, longitudinal, and radial 2-dimensional strain during dobutamine stress echocardiography in ischemic conditions. *J Am Coll Cardiol*. 2008;51:149–157.
25. Fang ZY, Leano R, Marwick TH. Relationship between longitudinal and radial contractility in subclinical diabetic heart disease. *Clin Sci (Lond)*. 2004;106:53–60.
26. Serri K, Reant P, Lafitte M, Berhouet M, Le B, V, Roudaut R, Lafitte S. Global and regional myocardial function quantification by two-dimensional strain: application in hypertrophic cardiomyopathy. *J Am Coll Cardiol*. 2006;47:1175–1181.
27. Kato TS, Noda A, Izawa H, Yamada A, Obata K, Nagata K, Iwase M, Murohara T, Yokota M. Discrimination of nonobstructive hypertrophic cardiomyopathy from hypertensive left ventricular hypertrophy on the basis of strain rate imaging by tissue Doppler ultrasonography. *Circulation*. 2004;110:3808–3814.
28. Sengupta PP, Korinek J, Belohlavek M, Narula J, Vannan MA, Jahangir A, Khandheria BK. Left ventricular structure and function: basic science for cardiac imaging. *J Am Coll Cardiol*. 2006;48:1988–2001.
29. Jones CJ, Raposo L, Gibson DG. Functional importance of the long axis dynamics of the human left ventricle. *Br Heart J*. 1990;63:215–220.

CLINICAL PERSPECTIVE

Catheter ablation for atrial fibrillation (AF) is nowadays a good therapeutic option in patients with symptomatic, drug-refractory AF. However, the exact effect of catheter ablation on left ventricular (LV) strain in patients with preserved LV systolic function is unknown. In the present study, speckle-tracking echocardiography was used to assess the long-term effects of catheter ablation for AF on LV function. Three distinct strain patterns (radial, circumferential and longitudinal strain) were studied at baseline and after 12 months of follow-up in 78 patients with normal LV ejection fraction. In patients who maintained sinus rhythm during follow-up, circumferential and longitudinal strain significantly improved from baseline to follow-up. In contrast, in patients who had recurrence of AF, longitudinal strain and strain rate deteriorated significantly at long-term follow-up. These results demonstrate that successful catheter ablation for AF improves LV function, even in patients with preserved LV ejection fraction. In addition, it was noted that the change in circumferential strain and longitudinal strain were the only predictors for maintenance of sinus rhythm during follow-up. This study demonstrates that there is a close relation between the maintenance of sinus rhythm and the improvement in LV function after catheter ablation. However, future studies are needed to clarify if the maintenance of sinus rhythm precedes this improvement or, rather, is its consequence.