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ORIGINAL ARTICLE
Arrhythmia/Electrophysiology

Is Incomplete Left Atrial Posterior Wall Isolation Associated With Recurrence of Atrial Fibrillation After Radiofrequency Catheter Ablation?

Takefumi Fujito, MD; Atsushi Mochizuki, MD, PhD; Naoyuki Kamiyama, MD; Masayuki Koyama, MD, PhD; Daigo Nagahara, MD, PhD; Tetsuji Miura, MD, PhD

Background: Complete left atrial posterior wall isolation (LAPI) is not always achieved. We examined whether incomplete LAPI has an effect on outcomes after catheter ablation (CA).

Methods and Results: This study enrolled 75 consecutive patients (mean [±SD] age 62.6±8.9 years, 74.7% male) who underwent LAPI by radiofrequency CA for persistent atrial fibrillation (AF). The median follow-up period was 541 days (interquartile range 338–840 days). Incomplete LAPI was defined as the presence of a successfully created roof or floor linear lesion. The rate of complete LAPI was 41.3% (31/75). Either a roof or floor linear lesion was created in 38 patients, whereas neither was created in 6. Multivariate Cox proportional hazards regression analysis revealed that female sex (hazard ratio [HR] 5.29; 95% confidence interval [CI] 1.81–16.8; P=0.002) and complete or incomplete LAPI (HR 0.17; 95% CI 0.03–0.79; P=0.027) were independent predictors of AF recurrence. Kaplan-Meier curves indicated that better outcome was associated with at least one rather than no successful linear lesion (86.5% vs. 50.0% at 1 year; P=0.043). There were no significant differences in outcomes between the complete LAPI and incomplete LAPI groups.

Conclusions: Complete LAPI is unachievable in a significant percentage of patients with persistent AF. However, incomplete LAPI, as a result of aiming for complete LAPI, may have a benefit comparable to that of complete LAPI.

Key Words: Atrial fibrillation; Catheter ablation; Left atrial posterior wall isolation

Pulmonary vein isolation (PVI) is the cornerstone of catheter ablation (CA) for atrial fibrillation (AF), a standard of care in AF patients. The increasing number of patients with AF has added further weight to CA; however, the frequency of recurrent AF after successful PVI is not negligible.[1] Recurrence of AF after PVI alone is more frequent in patients with persistent AF than in patients with paroxysmal AF.[2] To improve the benefit of CA, several adjuvant substrate modifications that are usually performed in combination with PVI in patients with persistent AF have been reported. These substrate modifications include linear ablation of the left atrial (LA) roof and/or LA isthmus,[3] ganglionated plexus ablation,[4] complex fractionated atrial electrogram (CFAE) ablation,[5] low-voltage area ablation,[6] and LA posterior wall isolation (LAPI).[7–15]

Of the strategies for substrate modification, LAPI has multiple advantages because the LA posterior wall is a considerable source of non-pulmonary vein (PV) triggers,[16] CFAE,[17] drivers,[18] and low voltage zones.[19] LAPI consists of the posterior lines of PVI, a roof line between the tops of the bilateral superior PVs, and a floor line that connects the bottoms of the bilateral inferior PVs, leading to electrical isolation of the LA posterior wall. However, it has not been determined whether complete LAPI is definitely required to reduce the recurrence of AF after CA or whether incomplete LAPI is also acceptable.

Complete LAPI is not always achieved due to a thick myocardial wall, unstable contact of the ablation catheter with the myocardium, and/or insufficient lesion formation because of the risk of myocardial perforation or esophageal injury.[7] An incomplete linear lesion with small gaps or recurrence of conduction could increase the incidence of reentrant atrial tachycardia (AT).[20] Although several investigators have shown the effectiveness of LAPI for persistent AF in meta-analyses,[10,11] the rates of recurrence of AF vary between investigations, and the relationship between the rate of AF recurrence after LAPI and procedural outcomes of LAPI remains unclear. Thus, in the present study, we examined the success rate of complete

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Department of Cardiovascular, Renal and Metabolic Medicine, Sapporo Medical University School of Medicine, Sapporo, Japan
Mailing address: Atsushi Mochizuki, MD, PhD, Department of Cardiovascular, Renal and Metabolic Medicine, Sapporo Medical University School of Medicine, South-1, West-16, Sapporo 060-8543, Japan. E-mail: a.mochizuki@sapmed.ac.jp

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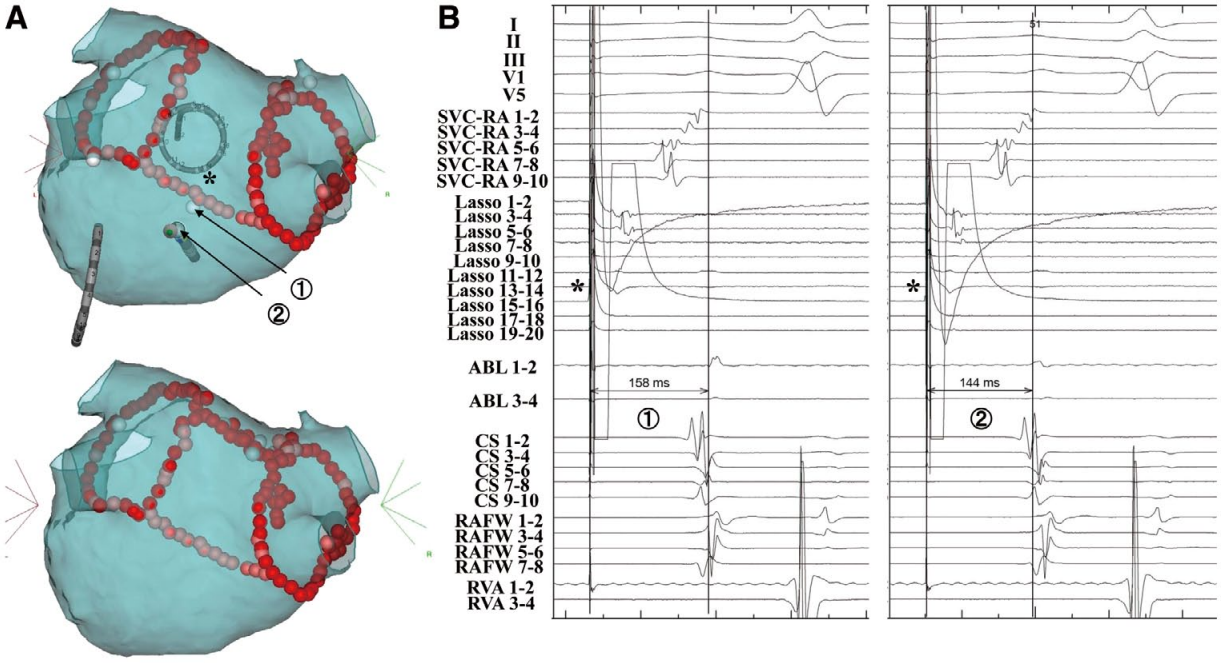

Figure 1. Three-dimensional electroanatomic map (CARTO image) and intracardiac electrocardiogram. (**A**) Images from a representative case undergoing left atrial posterior wall isolation (LAPI). Red tags indicate the sites of radiofrequency application. White tags (e.g., ① and ②) indicate the sites for assessment of successful creation of the floor line. The asterisk indicates the pacing site for the circular catheter. (**B**) A successful block line is demonstrated by differential pacing across the floor line. Atrial pacing is performed from the circular catheter (asterisk) and the interval between the pacing spike and atrial electrogram recorded at site ① is longer than that at site ②. ABL, ablation catheter; CS, coronary sinus; Lasso, Lasso circular catheter; RA, right atrium; RAFW, right atrial free wall; RVA, right ventricular apex; SVC, superior vena cava.

LAPI and whether the outcomes after CA were affected by completeness of the LAPI procedure in patients with persistent AF.

Methods

Study Patients

The present study was a single-center retrospective study conducted at Sapporo Medical University Hospital. The study population consisted of 75 consecutive patients with drug-refractory and symptomatic persistent AF who underwent first-time LAPI by radiofrequency (RF) CA at Sapporo Medical University Hospital between 2015 and 2018. Because follow-up data at the outpatient clinic were not available for one of the 75 patients, data for 74 patients were used in the analysis of the prediction of AF recurrence. Persistent AF was defined as continuous AF that was sustained beyond 7 days.[1]

The present study was approved by the Institutional Ethics Committee of Sapporo Medical University (Reference no. 312-73).

CA Procedure

Administration of antiarrhythmic agents was discontinued 2 days before the CA procedure. CA was performed in patients under deep sedation using continuous infusion of dexmedetomidine and propofol. Three long sheaths, including a steerable sheath (Agilis; St. Jude Medical, St. Paul, MN, USA), were inserted into the LA via the femoral vein, and 2 multipole catheters (i.e., 2 circular catheters or a circular catheter and a PENTARAY catheter; Biosense Webster, Diamond Bar, CA, USA) were introduced into the LA. RF ablation was performed under the guidance of a CARTO system using a 3.5-mm tip open-irrigated and contact force (CF)-sensing catheter (NaviStar ThermoCool SmartTouch; Biosense Webster). All patients underwent extensive encircling PVI, and balloon ablation technologies were not used. Although the basic RF energy setting was 30 W for 20–30 s for each point, the power and duration were reduced to 20 W and 10–15 s, respectively, at the left-sided posterior wall or at a site close to the esophagus. An esophageal temperature monitoring catheter was used, and RF energy delivery was stopped immediately if the temperature exceeded 39–40°C. The interlesion distance was set at 2–4 mm and target CF was aimed at >10 g. When the PV potential was not eliminated by a single circular line, detailed mapping along the lesion line and additional touch-up ablation at a residual conduction gap were performed. If AF was ongoing even after entrance block of all PVs was attained, sinus rhythm (SR) was restored by intracardiac or external electrical cardioversion. Pacing from the circular catheter within the PV was performed to evaluate the presence of the exit block.

LAPI was performed by adding a roof line between the tops of the bilateral superior PVs and a floor line between the bottoms of the bilateral inferior PVs to the posterior lines of the PVI (**Figure 1A**).[9,21] Completion of the first block line was confirmed by recording a wide double

Table 1. Baseline Clinical Characteristics in All Study Subjects and in Groups With and Without Complete LAPI

	All study subjects (n=75)	LAPI		P value
		Complete (n=31)	Incomplete or unsuccessful (n=44)	
Age (years)	62.6±8.9	64.0±8.3	61.5±9.2	0.240
Male sex	56 (74.7)	21 (67.7)	35 (79.6)	0.247
Body mass index (kg/m^2)	24.7 [22.8–27.6]	24.4 [22.2–26.6]	25.1 [23.1–28.9]	0.182
Duration of AF (months)	9 [5–19]	8 [5–25]	10 [5.3–18.8]	0.635
Structural heart disease	16 (21.3)	8 (25.8)	8 (18.2)	0.427
Hypertension	40 (53.3)	17 (54.8)	23 (52.3)	0.826
Diabetes	13 (17.3)	3 (9.7)	10 (22.7)	0.142
History of stroke or TIA	7 (9.3)	3 (9.7)	4 (9.1)	0.932
$CHADS_2$ score	1 [1–2]	1 [0–2]	1 [1–2]	0.452
CHA_2DS_2-VASc score	2 [1–3]	2 [1–3]	1 [1–3]	0.996
LA diameter (mm)	43.7±6.1	42.2±5.9	44.8±6.1	0.075
LA volume index (mL/m^2)	47.3±12.2	49.6±11.4	45.5±12.6	0.164
LVEF (%)	56.2 [51.0–61.8]	57.9 [53.3–62.4]	55.4 [47.3–61.3]	0.254
eGFR (mL/min/1.73 m^2)	65.0±14.1	65.3±12.0	64.9±15.5	0.890
BNP (pg/mL)	95.2 [66.3–212.5]	133.3 [74.2–361.5]	78.7 [62–192.2]	0.037*
NT-proBNP (pg/mL)	579.3 [359.4–992.1]	759.3 [448.7–1,060]	562.1 [252.3–851.8]	0.210
ACEI/ARB	34 (45.3)	12 (38.7)	22 (50.0)	0.333
Statin	18 (24.0)	6 (19.4)	12 (27.3)	0.429
Antiarrhythmic agents				
Before ablation	40 (53.3)	19 (61.3)	21 (47.7)	0.246
During blanking period	56 (74.7)	24 (77.4)	32 (72.7)	0.646
At the end of follow-up	6 (8.0)	3 (9.7)	3 (6.8)	0.653
Procedural data				
Cavotricuspid isthmus ablation	69 (92.0)	29 (93.6)	40 (90.9)	0.678
Superior vena cava isolation	46 (61.3)	19 (61.3)	27 (61.4)	0.995
Operation time (min)	298.4±49.2	291.5±42.2	303.3±53.5	0.310

Data are presented as the mean±SD for normally distributed variables, the median [interquartile range] for non-normally distributed variables, or as the number (%) of patients. *Indicates P<0.05. ACEI, angiotensin converting enzyme inhibitor; AF, atrial fibrillation; ARB, angiotensin II receptor blocker; BNP, B-type natriuretic peptide; eGFR, estimated glomerular filtration rate; LA, left atrial; LAPI, left atrial posterior wall isolation; LVEF, left ventricular ejection fraction; NT-proBNP, N-terminal pro B-type natriuretic peptide; TIA, transient ischemic attack.

potential along the ablation line and a compatible atrial activation sequence during differential pacing across the line (**Figure 1B**).[22] The order of linear lesion formation, whether the roof line or the floor line was formed first, was left to the discretion of individual operators. Complete LAPI was defined as: (1) the disappearance of atrial potentials within the posterior area and demonstration of local atrial capture without conduction to the LA; (2) observation of dissociated spontaneous activity within the posterior area; or (3) a lack of atrial capture by pacing within the posterior area.[21] If complete LAPI was not achieved despite 2 linear lesions, detailed mapping along the lesion and additional ablation at the site with contiguous or closely spaced double potentials were performed. If these additional multiple RF applications failed to achieve a successful block line, the attempt to make a linear lesion was discontinued at the operator's discretion to avoid complications.

Incomplete LAPI was defined as the presence of a successfully created roof or floor linear lesion, whereas unsuccessful LAPI was defined as the lack of both roof and floor linear lesions. Thus, incomplete LAPI and unsuccessful LAPI were failed attempts of complete LAPI.

Additional touch-up ablation targeting the earliest activation site in the middle area of the enclosed posterior wall away from the lines[9] and adenosine challenge for dormant posterior wall conduction[14] were not performed. Cavotricuspid isthmus (CTI) ablation and superior vena cava (SVC) isolation were performed at the operator's discretion. Ablation of non-PV triggers was performed if atrial premature complexes were sufficiently frequent during the session; however, vigorous induction by isoproterenol infusion was not performed.[23,24]

Patient Follow-up

All patients underwent electrocardiography (ECG) and/or 24-h Holter monitoring at the outpatient clinic of Sapporo Medical University Hospital, or at the clinics of the physicians who referred the patients to Sapporo Medical University Hospital, at 3, 6, 9, 12, 18, and 24 months after CA or at any time when a patient was symptomatic. Administration of antiarrhythmic agents for AF was discontinued 3 months after CA. Discontinuation of oral anticoagulation (OAC) therapy was recommended if patients had maintained SR for 6 months and had a low risk of thromboembolism ($CHADS_2$ score <2) without other indications for OAC. Recurrence of AF was defined as AF or AT documented by 12-lead ECG or 24-h Holter monitoring (the cut-off duration was >30 s in cases documented by Holter ECG) after a blanking period of 3

months after the prior CA.[1]

Statistical Analysis

Continuous data are expressed as the mean±SD for normally distributed variables and as median values with the interquartile ranges (IQR) for non-normally distributed variables. Categorical variables are given as absolute counts and percentages. The significance of differences in continuous variables between 2 groups was assessed using Student's t-test for normally distributed variables and the Mann-Whitney U-test for non-normally distributed variables. Categorical variables were analyzed using the Chi-squared test, with Fisher's exact test used when appropriate. Recurrence-free survival rates were calculated by the Kaplan-Meier method and compared by the log-rank test across groups. To identify independent predictors of AF recurrence after CA, Cox proportional hazards regression analysis was used. Variables with $P<0.05$ in the univariate analysis were entered into a multivariate analysis. Two-sided $P<0.05$ was considered significant. Data were analyzed using JMP version 11.0.0 (SAS Institute, Cary, NC, USA).

Results

Baseline Clinical Characteristics of Study Subjects

Table 1 shows the baseline clinical characteristics of the study subjects. The mean age of the patients was 62.6±8.9 years, and 74.7% of patients were male. The median duration of AF was 9 months (IQR 5–19 months). Sixteen patients (21.3%) had structural heart disease. Forty patients (53.3%) had hypertension. In echocardiography, the LA diameter was 43.7±6.1 mm, the LA volume index was 47.3±12.2 mL/m^2 and the median left ventricular ejection fraction was 56.2% (IQR 51.0–61.8%). PVI was completed in all 75 patients. CTI linear ablation was performed in 69 patients (92.0%) and SVC isolation was performed in 46 patients (61.3%). Antiarrhythmic agents were used in 40 patients (53.3%) before ablation and in 56 patients (74.7%) during the blanking period. The administration of antiarrhythmic agents was continued in 6 patients (8.0%) at the end of follow-up: patients received amiodarone for concomitant ventricular tachyarrhythmia (n=3) or they were administered amiodarone (n=2) or bepridil (n=1) because of an expected higher probability of AF recurrence due to severe LA dilatation. Except for 1 patient with cardiac tamponade requiring drainage, there were no cases of major complications, such as symptomatic esophageal injury or ischemic stroke.

LAPI Success Rate

Of the 75 patients who underwent LAPI, a successful roof line was achieved in 36 (48.0%) and a successful floor line was achieved in 64 (85.3%), indicating that the floor line was easier to create than the roof line (**Table 2**). Ablation time was longer and ablation energy was higher in patients with unsuccessful linear lesions than in patients with successful linear lesions (**Table 3**). Lesion gaps were frequently located in the middle portion of the roof line and at a site close to the esophagus on the floor line. Complete LAPI was achieved in 31 patients (41.3%). Ablation of the floor

Table 2. Completeness of LAPI (n=75)

	No. patients (%)
Successful roof line	36 (48.0)
Successful floor line	64 (85.3)
Complete LAPI	31 (41.3)
Incomplete LAPI (either roof or floor line successful)	38 (50.7)
Successful roof line alone (unsuccessful floor line)	5 (6.7)
Successful floor line alone (unsuccessful roof line)	33 (44.0)
Unsuccessful LAPI (neither roof nor floor line successful)	6 (8.0)

LAPI, left atrial posterior wall isolation.

Table 3. Ablation Time and Ablation Energy for Creating a Linear Lesion and Location of the Lesion Gap (n=75)

	Successful	Unsuccessful	P value
Roof line			
No. patients	36	39	
Total no. RF applications	14.5 [12–17]	22 [16–30]	<0.001*
Total ablation time (s)	379.7 [302.6–427.9]	594.8 [385.8–655.5]	<0.001*
Total ablation energy (joules)	10,229.2 [8,321.0–12,002.8]	15,361.5 [10,783.2–18,641.5]	<0.001*
Location of lesion gap			
Right side		12 (30.8%)	
Middle portion		20 (51.3%)	
Left side		7 (17.9%)	
Floor line			
No. patients	64	11	
Total no. RF applications	18 (15–22)	25 (17–30)	0.016*
Total ablation time (s)	376.2 (317.9–418.7)	512.6 (388.4–681.6)	0.010*
Total ablation energy (joules)	8,518.1 (7,147.0–10,217.0)	11,379.0 (8,501.6–14,633.9)	0.043*
Location of lesion gap			
Close to the esophagus		9 (81.8%)	
Other sites		2 (18.2%)	

Unless indicated otherwise, data are presented as the median [interquartile range] or the number (%) of patients. *Indicates $P<0.05$. RF, radiofrequency.

Table 4. Univariate and Multivariate Cox Proportional Hazards Regression Analyses of Prediction of AF Recurrence After Catheter Ablation in All Study Subjects (n=74)

	Univariate analysis			Multivariate analysis		
	HR	95% CI	P value	HR	95% CI	P value
Age	0.99	0.94–1.04	0.643			
Female sex	5.91	2.32–16.1	<0.001*	5.29	1.81–16.8	0.002*
Body mass index	1.11	0.98–1.26	0.112			
Duration of AF	0.98	0.92–1.02	0.252			
Structural heart disease	1.80	0.62–4.65	0.260			
Hypertension	0.86	0.35–2.27	0.796			
Diabetes	1.10	0.26–3.35	0.877			
History of stroke or TIA	1.02	0.16–3.60	0.980			
$CHADS_2$ score	1.09	0.67–1.70	0.720			
CHA_2DS_2-VASc score	1.16	0.85–1.55	0.344			
LA diameter	1.07	0.99–1.16	0.094			
LA volume index	1.04	1.01–1.08	0.024*	1.02	0.97–1.06	0.427
LVEF	1.003	0.96–1.05	0.889			
eGFR	1.01	0.98–1.04	0.558			
BNP	0.9996	0.996–1.002	0.609			
NT-proBNP	0.9995	0.998–1.0004	0.621			
ACEI/ARB	1.98	0.78–5.39	0.151			
Statin	1.74	0.61–4.50	0.284			
Antiarrhythmic agents at the end of follow-up	0.64	0.04–3.12	0.641			
Procedural data						
Successful creation of roof and/or floor line	0.22	0.07–0.98	0.048*	0.17	0.03–0.79	0.027*
Cavotricuspid isthmus ablation	0.34	0.11–1.47	0.132			
Superior vena cava isolation	0.77	0.30–2.03	0.589			
Operation time (min)	1.01	0.996–1.01	0.264			

CI, confidence interval; HR, hazard ratio. *Indicates P<0.05. Other abbreviations as in Table 1.

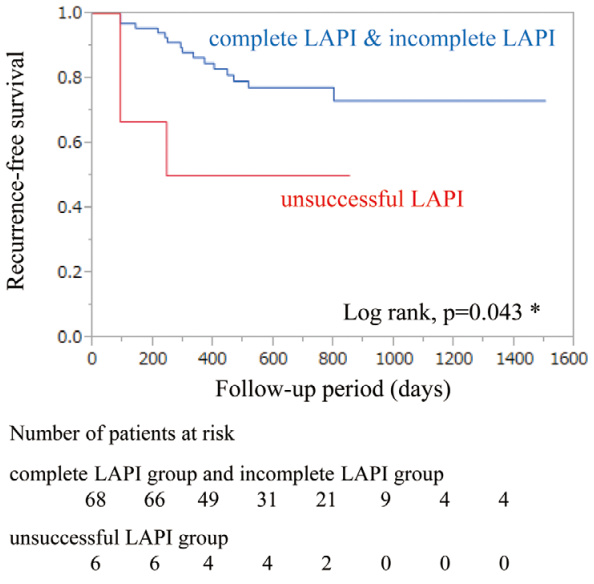

Figure 2. Kaplan-Meier recurrence-free survival curves for patients with persistent atrial fibrillation after catheter ablation showing comparisons between patients with at least one successful line (i.e., those with complete left atrial posterior wall isolation [LAPI] or incomplete LAPI) and those without a successful linear lesion (unsuccessful LAPI group). *Indicates P<0.05.

line prior to the roof line was performed in 60 patients (80.0%). Among patients in whom LAPI was not completed, either the roof line or the floor linear lesion was successfully created in 38 patients (50.7%) and neither linear lesion was created in 6 (8.0%). N-Terminal pro B-type natriuretic peptide (NT-proBNP) concentrations were higher in patients with a successful roof linear lesion than in those with an unsuccessful roof line (median [IQR] 817.3 [458.4–1,060] vs. 514.5 [200.3–704.8] pg/mL, respectively; P=0.044), and serum B-type natriuretic peptide (BNP) concentrations were higher in patients with complete than incomplete or unsuccessful LAPI (median [IQR] 133.3 [74.2–361.5] vs. 78.7 [62–192.2] pg/mL, respectively; P=0.037; **Table 1**). The reasons for the intergroup differences in NT-proBNP and BNP concentrations are unclear, but possibly reflect some effects of LA remodeling on susceptibility of the LA wall to ablation. Patients with a successful floor line were older than those with an unsuccessful floor line (63.7±8.6 vs. 56.2±7.8 years, respectively; P=0.009).

Relationship Between at Least One Successful Linear Ablation and AF Recurrence

During a median follow-up period of 541 days (IQR 338–840 days), 18 of 74 patients (24.3%) had AF recurrence. Of those 18 patients, AF only was documented in 13 patients, AT only was documented in 2 patients, and both AF and AT were documented in 3 patients. The incidence of AT in patients with recurrence tended to be higher in the group with complete LAPI (3 of 7 patients) than in patients with incomplete or unsuccessful LAPI (2 of 11 patients),

Table 5. Baseline Clinical Characteristics in Groups With and Without at Least One Successful Linear Lesion

	Group with at least one successful line (n=69)	Group without a successful linear lesion (n=6)	P value
Age (years)	63.1±8.7	56.2±8.5	0.065
Male sex	52 (75.4)	4 (66.7)	0.639
Body mass index (kg/m^2)	24.7 [22.8–27.9]	25.4 [23.5–28.9]	0.733
Duration of AF (months)	9 [5–19]	14.5 [9.3–33]	0.145
Structural heart disease	16 (23.2)	0	0.184
Hypertension	36 (52.2)	4 (66.7)	0.495
Diabetes	12 (17.4)	1 (16.7)	0.964
History of stroke or TIA	7 (10.1)	0	0.413
$CHADS_2$ score	1 [1–2]	1 [0–1.3]	0.300
CHA_2DS_2-VASc score	2 [1–3]	1.5 [0–2.5]	0.391
LA diameter (mm)	43.7±6.3	44.5±3.5	0.737
LA volume index (mL/m^2)	47.1±12.3	49.1±12.6	0.701
LVEF (%)	56.1 [49.9–61.4]	61.1 [52.6–63.3]	0.287
eGFR (mL/min/1.73 m^2)	64.3±14.1	73.4±11.8	0.130
BNP (pg/mL)	93.5 [64.8–215.8]	128 [79.4–210]	0.617
NT-proBNP (pg/mL)	621.5 [428.2–1,048]	300.2 [200.3–535.9]	0.100
ACEI/ARB	31 (44.9)	3 (50.0)	0.811
Statin	17 (24.6)	1 (16.7)	0.661
Antiarrhythmic agents			
Before ablation	38 (55.1)	2 (33.3)	0.306
During blanking period	50 (72.5)	6 (100)	0.137
At the end of follow-up	6 (8.7)	0	0.451
Procedural data			
Cavotricuspid isthmus ablation	63 (91.3)	6 (100)	0.451
Superior vena cava isolation	43 (62.3)	3 (50.0)	0.552
Operation time (min)	295.3±46.1	334.8±72.3	0.058

Data are presented as the mean±SD for normally distributed variables, the median [interquartile range] for non-normally distributed variables, or as the number (%) of patients. Abbreviations as in Table 1.

although the difference was not statistically significant (42.9% vs. 18.2%; P=0.255). Recurrence-free survival rates 1 and 2 years after CA were 83.5% and 75.1%, respectively, in all patients.

In univariate analysis using a Cox proportional hazards regression model, female sex, LA volume index, and successful linear ablation in at least one of the lines (roof or floor line) during LAPI were associated with a lower rate of AF recurrence. In multivariate analysis, female sex (hazard ratio [HR] 5.29; 95% confidence interval [CI] 1.81–16.8; P=0.002) and success in at least one of the 2 linear ablations (HR 0.17; 95% CI 0.03–0.79; P=0.027) were independent predictors of the recurrence of AF (**Table 4**). In the group with incomplete LAPI, the number of RF applications, ablation time, and ablation energy were not associated with AF recurrence. As shown by Kaplan-Meier curves (**Figure 2**), the recurrence-free rate was higher in patients with at least one successful linear ablation (complete and incomplete LAPI groups) than in patients without successful linear ablation (unsuccessful LAPI group) (86.5% vs. 50.0% and 77.2% vs. 50.0% at 1 year and 2 years, respectively; P=0.043), although baseline clinical characteristics were comparable between the 2 groups (**Table 5**). The recurrence-free rates did not differ between the complete LAPI group and the incomplete or unsuccessful LAPI group (93.4% vs. 76.3% and 78.8% vs. 73.2% at 1 year and 2 years, respectively; P=0.501). Interestingly, there was no significant difference in recurrence-free rates

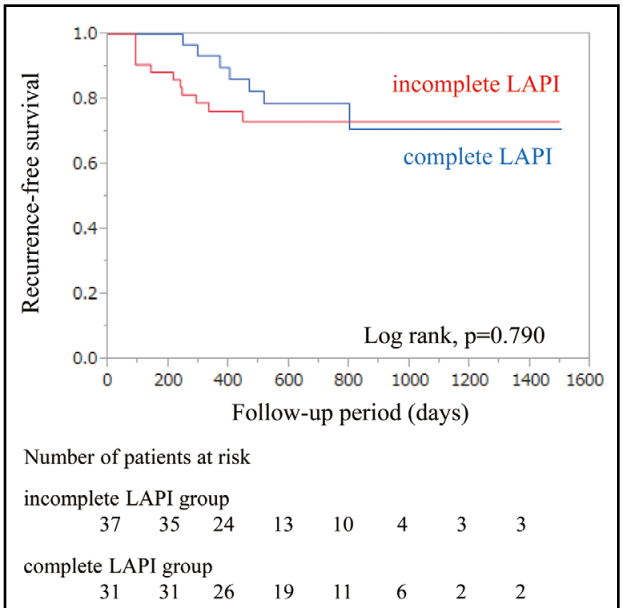

Figure 3. Kaplan-Meier recurrence-free survival curves for patients with persistent atrial fibrillation after catheter ablation showing comparisons between patients with complete left atrial posterior wall isolation (LAPI) and those with incomplete LAPI.

between the complete and incomplete LAPI groups (93.4% vs. 80.5% and 78.8% vs. 76.8% at 1 year and 2 years, respectively; P=0.790; **Figure 3**).

Of the 18 patients with AF recurrence, 11 underwent a redo procedure a median of 247 days (IQR 141–467 days) after the first CA: 6 patients in the complete LAPI group, 4 patients in the incomplete LAPI group, and 1 patient in the unsuccessful LAPI group. PV reconnection was observed in 5 patients (45.6%) and the median number of LA–PV conduction gaps was 0 (IQR 0–1) per patient. In 6 patients with complete LAPI, reconnection of roof line was observed in 2 patients and reconnection of both lines was seen in 1 patient; the remaining 3 patients were confirmed to have durable LAPI at the repeat procedure. All 4 patients with incomplete LAPI had a successful floor line, and no reconnection was observed at the redo procedure. Thus, of the 16 linear lesions (6 roof lines and 10 floor lines) that were successful in the first session, reconnection was observed in 3 roof lines (50.0%) and 1 floor line (10.0%).

Discussion

The present study showed that an attempt at LAPI often resulted in incomplete LAPI. It was more difficult to successfully create the roof line than the floor line, and this difficulty was primarily responsible for the failure to achieve complete LAPI. However, the results of the present study suggest that complete LAPI is not essential for reducing the rate of AF recurrence; the effect of incomplete LAPI (resulting after aiming for complete LAPI), with a successfully created roof or floor linear lesion, on AF recurrence was comparable to that of complete LAPI. Thus, the present study revealed, for the first time, that LAPI has a clinical benefit if there is sufficient modification of the LA posterior area and that a clinical benefit can be provided by successful creation of at least one of the lines even if complete LAPI is not achieved.

Difficulty Completing LAPI

There are specific problems that impede successful linear lesion formation for the roof line and floor line. One of the 2 major reasons why successful creation of the roof line is difficult is that the LA roof is the thickest area in the LA, reaching a wall thickness of 6.5 mm.[25,26] Continuous transmural lesions can be difficult to achieve for a thick myocardial wall. The other reason why creating a roof line is difficult is the technical difficulty in obtaining stable contact between the ablation catheter and the myocardium in the LA roof area.[9,27] Moreover, a high reconnection rate has been reported even if a successful roof line is achieved in the first CA session. For example, Rostock et al showed that electrical conduction across the roof line was recovered in 79% of cases, predominantly at a site close to the right PV, at the time of the repeat CA procedure.[28] In another study, the rate of reconnection observed in the second session was 79.2% in the roof line.[13]

Conversely, the wall thickness of the LA decreases in the inferior direction. The wall thickness of the LA has been reported to be 2.3±0.9 mm in the area between the superior PVs, and the wall becomes much thinner in the area between the inferior PVs;[29] this thinner myocardium makes it easier for the floor line to be successfully created. However, there are difficulties associated with creating the floor line. Careful attention should be paid to increases in the temperature of the esophagus to avoid esophageal injury; because the floor line traverses the esophagus in almost all patients, insufficient RF energy may be used.[30] Similarly, it had been reported that reconnection of the block line is more frequent at sites where the temperature of the esophagus rises than at other sites.[31]

Although we did not evaluate the actual wall thickness or stability of the catheter contact, complete and durable LAPI is not easy to achieve, even though there was a clear endpoint of electrical isolation from the LA. At least one successful linear lesion was sufficient to reduce the rate of AF recurrence in the present study, but creating 2 linear lesions, and not just the roof or floor line alone, is recommended because of the difficulty in achieving a successful and durable linear lesion.

The rate of complete LAPI in the present study was 41.3%. The rates of complete LAPI reported in previous studies vary widely, from 23.3% to 95.7%.[7,8] The difference in the success rates of LAPI depend, in part, on the ablation setting. The recommended ablation setting is a CF between 15 and 30 g, RF energy power of 30 W, and application duration of 60 s or until split or attenuation of local potential for each point when creating the roof line.[9] However, we used a less intense RF setting to avoid myocardial perforation or esophageal injury, and this may explain the lower rate of complete LAPI in the present study. Furthermore, it has been reported that LAPI is difficult to complete due to multiple conduction gaps if linear ablation is started in the setting of the other unsuccessful line.[9] Hence, the rate of complete LAPI differs among studies, and this difference may be caused by the settings for RF application and the order of creating the line, in addition to differences in anatomy among individuals.

Relationship Between LAPI Completeness and AF Recurrence

Kumar et al reported that the recurrence-free rate did not differ between patients with complete and those with incomplete LAPI.[7] In that study, the definition of "incomplete LAPI" was different from that of the present study, i.e., "incomplete LAPI" included both incomplete LAPI and unsuccessful LAPI of the present study, and Kumar et al presumed that the drivers at the roof or floor area may be interrupted despite incomplete LAPI.[7] However, detailed evaluation of the relationship between completeness of LAPI and AF recurrence was not undertaken. Verma et al included patients with PV reconnection in the second ablation, and reported that sufficient LA-PV conduction delay was associated with a lower rate of AF recurrence (i.e., the conduction delay was smaller in patients with than without AF recurrence).[32] The authors of that study concluded that significant conduction delay brought about by the prior CA resulted in the suppression of rapid conduction, leading to a decrease in the triggers of AF.[32] Although conduction delay in the LA posterior area was not evaluated in the present study, the same mechanism as that proposed by Verma et al[32] may be applied to incomplete LAPI. Therefore, even if either the roof line or the floor linear lesion is not created successfully during LAPI, a significant conduction delay in the LA posterior wall may contribute to modification of the arrhythmogenic nature of the LA posterior area, leading to a decreased risk of AF recurrence. In addition, successful creation of either the roof or floor line prevents roof-dependent macroreentrant AT, which is thought to contribute considerably to

the reduction in the risk of AT or AF recurrence.

In the present study, procedural outcomes of LAPI attempts were heterogeneous, and the successful creation of at least either the roof line or floor line during LAPI was actually associated with a better outcome after CA (**Table 4**; **Figure 2**). However, the findings in the present study do not prove the effectiveness of a strategy of a single roof or floor line,[22,33] and further studies in which such a single-line strategy is compared to incomplete LAPI are needed. Nevertheless, the results of the present study support the notion that LAPI is beneficial for the prevention of AF recurrence unless both roof and floor lines are not successfully created.

In the present study, female sex was also found to be an independent predictor of AF recurrence. It is well known that the outcome of CA for AF differs between the sexes, and female sex has been shown to be strongly associated with arrhythmia recurrence.[34–36] Possible explanations for the poor outcome in females include less-durable ablation lesions in women,[34] more symptomatic status in woman than in men,[35] a more advanced LA substrate in women,[36] and a propensity for the development of non-PV triggers in women.[36]

Study Limitations

This study has several limitations. First, the study was a single-center retrospective study and the number of patients was relatively small, limiting the study's statistical power. Thus, data for some factors that may affect procedural outcomes of LAPI, such as LA wall thickness and stability of the contact between the ablation catheter and atrium, were not available, and the statistical power may not have been sufficient to detect factors associated with successful creation of a linear lesion, completion of LAPI, and AF recurrence. Second, we did not perform additional touch-up ablation in the middle area of the enclosed posterior wall even when LAPI was incomplete in the period when the subjects underwent ablation. If this strategy had been adopted in the incomplete LAPI group, the success rate of complete LAPI and the rate of AF recurrence may have been different. Third, an ambulatory ECG monitor or implantable cardiac monitor was not used in the present study. Therefore, asymptomatic or short-lasting AF may have been overlooked, resulting in a higher recurrence-free rate than in previous studies.[12,13,15] Fourth, although general practitioners were recommended to discontinue antiarrhythmic agents 3 months after CA, several patients were on antiarrhythmic agents during the follow-up period, which may have modified the clinical outcomes. However, antiarrhythmic agents were not associated with the recurrence of AF in the present study. Fifth, patients with severe valvular heart disease were not included in this study. LA dilatation was mild and the duration of AF (median 9.0 months) was relatively short. It is possible that there was a selection bias towards AF patients with mild LA remodeling at the time of assessing indications for CA. Sixth, the precise mechanism underlying AF recurrence was not assessed. SVC isolation was not performed in approximately 40% of subjects and we did not perform aggressive induction of non-PV triggers by isoproterenol infusion. Therefore, non-PV triggers originating from the SVC may have affected the clinical outcomes. Thus, it is difficult to evaluate the relationship purely between the completeness of LAPI and AF recurrence because possible reconnection of linear lesions, PV reconnection,[37] and non-PV triggers[23] may also have been responsible for AF recurrence.

Conclusions

Complete LAPI is not achievable in a significant proportion of patients in whom RF CA is performed for persistent AF. However, if at least either the roof or floor linear lesion is created successfully, even incomplete LAPI resulting after aiming for complete LAPI has benefits comparable to those of complete LAPI in terms of the suppression of AF recurrence.

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The authors have no conflicts of interest to disclose.

IRB Information

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