Cryoballoon ablation of the left atrial posterior wall reduces recurrence of persistent atrial fibrillation in patients with non-paroxysmal atrial fibrillation

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Abstract

Introduction: Detailed clinical outcomes of cryoballoon ablation of the left atrial (LA) posterior wall (LAPW) in patients with non-paroxysmal atrial fibrillation (AF) have not been fully examined. Methods: We analyzed the outcomes of 191 patients with non-paroxysmal AF, of whom 135 underwent cryoballoon ablation of the LAPW including the LA roof in addition to pulmonary vein isolation with a cryoballoon. Results: Complete conduction block at the LA roof was obtained in 97.0% (131/135) of patients and LAPW was isolated in 85.2% (115/135) of patients. Over 372 days (range, 182–450 days) of follow-up, atrial arrhythmia recurrence was observed in 55 (40.7%) patients, and atrial tachycardia (AT) recurrence accounted for 25.5% of cases. The prevalence of LA roof cryoballoon ablation tended to be higher in patients without recurrence than those with (74.3% vs. 61.8%, respectively; p=0.11), especially those with persistent AF recurrence (74.5% vs. 46.2%, p=0.01). Multivariate analysis revealed that cryoballoon ablation of the LA roof was a predictor of freedom from persistent AF recurrence and that it was not associated with AT recurrence. Durable LA roof lesions were confirmed in 18 (72.0%) of 25 patients who underwent redo ablation. Conclusion: Cryoballoon ablation of the LAPW leads to a sufficient acute success rate of complete conduction block and durable lesions of the LA roof without increasing the risk of AT recurrence. The prevalence of persistent AF recurrence decreases after additional cryoballoon ablation of the LAPW in patients with non-paroxysmal AF.

Introduction

The recurrence of atrial fibrillation (AF) can be controlled by the established treatment of pulmonary vein isolation (PVI)[1]; however, the effect of PVI seems to be insufficient in patients with non-paroxysmal AF. Additional strategies for AF catheter ablation have been considered in previous investigations, and linear ablation of the left atrial (LA) roof line and mitral isthmus (MI) line is one of the additional therapeutic methods of catheter ablation.[2] Atrial tachycardia (AT) recurrence has been reported as an undesirable outcome after catheter ablation for AF, which might be attributable to linear ablations.[3] Ablation of the LA roof with a cryoballoon in addition to PVI was investigated as a novel method for LA roof line ablation.[4] However, detailed clinical outcomes, including the type of recurrence, have not been fully examined. Thus, the present study aimed to clarify the details after catheter ablation in patients with non-paroxysmal AF, especially those who underwent cryoballoon ablation of the LA posterior wall (LAPW) including the LA roof.

Methods

Study patients

This single-center retrospective study included consecutive patients with non-paroxysmal AF who underwent cryoballoon ablation with PVI between January 2016 and December 2018. Patients who underwent heart surgery were excluded because the surgery could have contributed to the AT occurrence. Patients who underwent LA roof-line ablation using a radiofrequency (RF) catheter were also excluded because the effect of the ablation was considered to vary between LA roof-line ablation performed with a cryoballoon and that performed with an RF catheter. Patients who did not undergo clinical follow-up of more than 3 months were excluded from the analysis. We hypothesized that LA posterior wall (LAPW) ablation, including cryoballoon ablation of the LA roof in addition to PVI, is effective in reducing the recurrence of persistent AF in patients with non-paroxysmal AF without inducing AT. To compare the effect of additional LAPW ablation with that of only PVI, only patients who did not undergo MI ablation were analyzed; those who underwent only LA roof-line ablation without LAPW bottom line ablation were excluded. All patients underwent three-dimensional computed tomography and transthoracic echocardiography before ablation. Paroxysmal AF was defined as AF terminating within 7 days according to the previously reported definition[5]; hence, non-paroxysmal AF was defined as AF persisting for more than 7 days. Baseline demographic characteristics, comorbidities, and medications were recorded. Written informed consent was obtained from all patients prior to the ablation procedure. This study was approved by our local ethics committees and conform to the guiding principles of the Declaration of Helsinki.

Index ablation procedure

The ablation procedure was performed as previously described.[6] In brief, the procedure was performed under general anesthesia. A single transseptal puncture was made under fluoroscopic and intracardiac echocardiographic (Acuson and AcuNav; Biosense Webster, Diamond Bar, CA, USA) guidance. A 28-mm cryoballoon catheter (Arctic Front Advance; Medtronic, Minneapolis, MN, USA) was introduced into the LA through a steerable sheath (Flexcath Advance; Medtronic) with a circular mapping catheter (Achieve; Medtronic). Cryothermal energy was applied through a cryoballoon occluding each pulmonary vein (PV). The compound motor action potentials of the diaphragm provoked by phrenic nerve pacing were continuously monitored during ablation of the right PVs. When a successful PVI was not achieved solely by a cryoballoon, a touch-up ablation with an RF catheter (FlexAbility or TactiCath; Abbott, Abbot Park, IL, USA) was performed.

Additional ablations were performed according to the operator's decision. When LA roof cryoballoon ablation was performed, an Achieve catheter was inserted into the left and right superior PVs, and a cryoballoon was shifted along the LA roof by changing the direction of the steerable sheath and adjusting the position of the cryoballoon and sheath so that each cryoballoon location overlapped with the previous cryoballoon location. Cryoballoon ablation of the bottom line of the LAPW was performed in the same manner, with the Achieve catheter positioned in each inferior PV (Figure 1). Cryothermal energy was applied for 180 to 240 seconds according to the operator's decision. Touch-up ablation of the LAPW with an RF catheter was permitted. LAPW bottom line ablation was performed using an RF catheter. Cryoballoon ablation was performed under luminal esophageal temperature (LET) monitoring using esophageal temperature probes (Esophaster; Japan Lifeline, Tokyo, Japan) with a cutoff value of 15°C. RF applications were also prematurely interrupted when the LET reached 39°C. Linear ablation at the cavo-tricuspid isthmus (CTI) was performed by delivering RF energy from the tricuspid annulus to the inferior vena cava in a point-by-point fashion. After each linear ablation, the status of the conduction block was confirmed by an electrophysiological method, an activation map, and a voltage map created with an electrical impedance-based mapping system (Ensite NavX; Abbott). PVI was confirmed using a duo-decapolar circular mapping catheter (EPstar Libero; Japan Lifeline). All the procedures were performed by either of the two main operators skilled with the technique.

Clinical follow-up

Anti-arrhythmic drugs (AADs) were prescribed after ablation according to the discretion of the patient's attending cardiologist. Twelve-lead electrocardiograms (ECGs) were recorded at every follow-up visit or

an emergency visit due to symptoms suggestive of an arrhythmia recurrence. In addition, 24-hour Holter ambulatory ECG monitoring was performed to detect recurrence of paroxysmal arrhythmias. An arrhythmia recurrence was defined as any documented atrial arrhythmia lasting longer than 30 seconds after the initial 90-day blanking period.

Redo ablation procedure

The repeat ablation procedure was performed in a manner similar to the index one. When AT persisted at the beginning of the procedure, it was mapped using an EPstar Libero and Ensite NavX system. Along with electrophysiological findings, catheters and systems were used to confirm the status of the lesions created in the index ablation procedure. Based on the operator's judgment, ablation was performed for novel or recurring lesions.

Statistical analysis

Continuous variables are expressed as mean±standard deviation or median with the interquartile range. Categorical variables are reported as numbers and percentages. Comparisons were made using Fisher's test, Student's t-test, or Mann-Whitney U test. Cox regression analysis was also used to evaluate each type of recurrence after catheter ablation in the multivariate models. A p value of 0.10 was required for entry into the model, and a stepwise method was utilized for the detection of any predictors. A p value <0.05 was considered significant. All analyses were performed using the EZR software (Saitama Medical Center, Jichi Medical University, Saitama, Japan), which is a graphical user interface of R (The R Foundation for Statistical Computing, Vienna, Austria).

Results

Study population

Thirty patients were excluded because of a previous heart surgery (9 patients), LA roof-line ablation performed with an RF catheter (2 patients), and insufficient clinical follow-up after catheter ablation (19 patients). Of the remaining 340 patients, 131 underwent MI ablation and 18 underwent LAPW ablation without LAPW bottom line ablation. Finally, 191 patients with non-paroxysmal AF were analyzed. The baseline patient characteristics are shown in Table 1 and compared between patients who underwent cryoballoon ablation of the LA roof and those who did not (Table 2). Three patients had right middle PVs, and 15 patients had left common PVs.

Index ablation results

The procedural characteristics during the ablations are shown in Table 1. All PVs were successfully isolated in all patients, and touch-up ablation with RF energy was required in 32 (16.8%) of 191 patients (left superior PV, 2 patients; left inferior PV, 12 patients; right superior PV, 4 patients; right inferior PV, 20 patients; left common PV, 1 patient). Complete conduction block at the LA roof was obtained in 131 (97.0%) of 135 patients. Among those, one patient underwent LAPW bottom line ablation utilizing a RF catheter instead of a cryoballoon. The prevalence of complete conduction block at the LAPW bottom line, namely LAPW isolation, was 85.2% (115/135 patients). Touch-up ablation with RF energy was performed in six patients (4.4%) for the LA roof line and 29 patients (21.6%) for the LAPW bottom line. CTI ablation was performed in 186 patients, of whom 184 (98.9%) had complete conduction block. Of 340 patients, including those who underwent MI ablation or only LA roof-line ablation, transient and persistent phrenic nerve injuries were observed in 21 (6.2%) and 16 (4.7%), respectively. Phrenic nerve injury eventually recovered in all cases. Two patients (0.6%) had cardiac tamponade that required pericardiocentesis. One patient developed arteriovenous fistula requiring surgical repair. No other procedural complications, such as stroke or symptomatic esophageal complications, were observed.

Clinical outcomes

The median follow-up duration was 372 days [interquartile range, 182–450 days]. Atrial arrhythmia recurrence was observed in 55 (28.8%) of 191 patients, and the 12-month Kaplan–Meier event-free rate was 77.0%

(Figure 2). Of 191 patients, AT and AF recurrence were confirmed in 14 (7.3%) and 44 (23.0%) patients, respectively. The persistent type accounted for 59.1% of AF recurrences (26/44 patients). Table 1 shows the comparisons between the patients based on recurrence, with each recurrence pattern in addition to overall recurrence. The prevalence of LAPW ablation, including cryoballoon ablation of the LA roof, was higher in patients without recurrence than in those with recurrence, and the 12-month Kaplan–Meier event-free rate was 79.0% in patients who had undergone cryoballoon ablation of the LAPW and 72.2% in those who had not (p=0.15; Figure 3). When the recurrence rate was analyzed according to recurrence patterns, AF recurrence rate, particularly the persistent AF recurrence rate, was significantly lower in patients who had undergone cryoballoon ablation of the LAPW compared with those who had not, and the 12-month Kaplan–Meier event-free rate was 83.0% (AF recurrence) and 91.3% (persistent AF recurrence) in patients who had undergone cryoballoon ablation of the LAPW and 73.8% (AF recurrence) and 81.4% (persistent AF recurrence) in those who had not (AF recurrence: p=0.09, persistent AF recurrence: p=0.01; Figure 3). Moreover, multivariate analysis using Cox regression analysis identified LAPW cryoballoon ablation as a predictor for freedom of persistent AF recurrence in addition to AAD use and AF duration (Table 3). With regard to AT recurrence, multivariate analysis with Cox regression analysis revealed only AAD use as a predictor of AT recurrence (Table 3). LAPW ablation, including cryoballoon ablation of the LA roof, was not associated with AT recurrence. A wave velocity of trans-mitral flow was measured by transthoracic echocardiography in 94 out of 191 patients, and there was a significant difference between the patients who underwent cryoballoon ablation of the LAPW and those who did not (0.53±0.13 m/sec for the patients who underwent cryoballoon ablation of the LAPW vs. 0.64±0.24 m/sec for those who did not, p=0.01).

Redo ablation results

Among the 55 patients with recurrence after the index catheter ablation procedure, 42 patients underwent a redo ablation procedure. Of the 12 patients with AT recurrence who underwent a redo ablation, AT persisted at the beginning of the procedure in 8 (66.6%) patients, and the type of AT was identified in all patients. Perimitral AT circulating around the mitral annulus was the most frequently confirmed type (4 patients). Of these four patients with perimitral AT recurrence, cryoballoon ablation of the LA roof was performed in the index ablation procedure in three patients. Roof-dependent AT, which contained the LA roof in the reentrant circuit, was observed in two patients, who both underwent cryoballoon ablation of the LA roof in the index ablation procedure. PV gap-related AT was confirmed in the other two patients.

The durability of each lesion created in the index ablation procedure is described in Figure 4. The prevalence of the patients in whom all PVs were confirmed to be durable was 57.1% (24/42 patients). Complete conduction blocks at the LA roof, LAPW bottom, and CTI were confirmed to be durable in 72.2% (18/25), 38.1% (8/21), and 56.8% (21/37) of patients, respectively. The rates of lesion durability of the PVI and LA roof lines without touch-up ablations were 59.4% (19/32) and 73.9% (17/23) of patients, respectively. When the percentages of the lesion durability between the patients with AT recurrence (25.0%) and those without AT recurrence (29.4%) were compared, the prevalence of LA roof-line recurrence was comparable (p=1.00). At the beginning of the session, the ratio of scar area to LAPW area was significantly higher (p<0.01) in the patients who had undergone cryoballoon ablation (66.3 [45.8–83.1] %) of the LAPW in the index ablation as compared to those who had not (12.2 [2.1–26.3] %).

Additional linear ablation at the LAPW, including the LA roof line, was performed in 35 (97.2%) of 36 patients whose LAPW was not isolated at the beginning of the redo ablation procedure. MI ablation was performed in 19 (45.2%) of 42 patients. Of 41 patients who underwent follow-up after-redo ablation procedure, 26 (63.4%) were free from atrial arrhythmias after the redo ablation procedure.

Discussion

The present study investigated the details after catheter ablation in patients with non-paroxysmal AF, particularly those who underwent LAPW cryoballoon ablation including the LA roof. The main results showed that cryoballoon ablation of the LAPW was not associated with AT recurrence after the ablation procedure, but LA roof-dependent AT was observed in several patients (1.5%). Moreover, clinical outcomes

were improved after the ablation procedure compared with the strategy without LAPW ablation, especially regarding the recurrence of the persistent type of AF. The details of recurrence patterns, including the type of AT, and the durability of lesions created in the index ablation procedure, were also investigated in this single-center large cohort study.

PVI has been established as the gold standard for treating AF, and cryoballoon ablation has emerged as a novel ablation method instead of the conventional method utilizing RF energy[7]; however, its efficacy may be limited, especially in patients with non-paroxysmal AF. Various therapeutic approaches have been investigated for AF catheter ablation; linear ablation, such as LA roof line and MI line, is one such approach. In particular, linear ablation that targets the LAPW, including isolation of the LA roof line and LAPW bottom line, has been a prominent focus.[2] Recently, it has been demonstrated that a cryoballoon could be utilized for linear ablation at the LAPW, and this additional ablation could generate a broader isolated area after PVI with a cryoballoon.[4,8,9] Complete conduction block at the LA roof line was reportedly achieved in 81.0%–95.0% of ablations with RF energy[10,11] and in 88.0%–99.8% with a cryoballoon.[4,8] Regarding the chronic status of the lesions, the reported durability of the LA roof line was 37.5%–72.0% with RF energy[12,13] and 74.5% with a cryoballoon.[6] Indeed, several reports have shown additional LAPW ablation results in better clinical outcomes,[8,14] but the adjunctive value of LAPW ablation in addition to PVI is controversial.[15] In our study, the LA roof line was successfully ablated with a cryoballoon in 97.0% of patients, of whom 72.0% had confirmed durable lesions, which is consistent with previous reports. Moreover, further analysis regarding the recurrence type in this study revealed that LAPW ablation in addition to PVI could reduce the persistent type of AF recurrence, which seemed to be clinically important. A prior examination investigated the atrial substrate size by utilizing the parameter of conduction velocity, refractory period, and LA body area.[16] Considering the mechanism of reduced persistence of AF after ablation based on the reported theory, cryoballoon ablation of the LA roof might be effective in reducing the atrial substrate size because it could produce a broader scar area, as previously reported.[4,6,9] In this regard, cryoballoon ablation might be preferable to a conventional RF method for creating LA roof line. AF persistence seems to depend on the site of AF drivers, and it might be an important factor where AF drivers exist; however, findings regarding AF drivers were not examined in the present study. Moreover, A wave was significantly lower in the patients who underwent cryoballoon ablation of the LAPW in this study, although that of those who underwent cryoballoon ablation of the LAPW seems compatible according to the previous study[17]. Further studies might be required for assessing atrial function after the ablation more precisely, and selecting candidates who should undergo cryoballoon ablation of the LAPW.

One of the reasons for hesitation in performing linear ablation was the possibility of iatrogenic AT occurrence after the ablation procedure. After PVI, including both RF energy and cryoballoon ablation, AT recurrence was observed in approximately 10% of patients according to previous reports.[18-20] In several studies that compared the prevalence of AT recurrence between patients who underwent PVI with RF energy and those who underwent PVI with a cryoballoon, the AT recurrence rate tended to be lower in those who underwent PVI with a cryoballoon.[18] Among recurrent ATs, perimitral AT was reportedly the most frequently observed, accounting for approximately 30% of AT recurrences in previous investigations.[19,20] Regarding linear ablation with RF energy, the recurrence of AT originating from the LA was reported to be 4% in patients.[21] Data regarding the prevalence of AT recurrence after linear ablation with a cryoballoon are limited. Aryana et al. investigated cryoballoon ablation of the LAPW and demonstrated that approximately 20% of patients experienced AT recurrence regardless of whether cryoballoon ablation of the LAPW was performed in addition to PVI; however, detailed descriptions regarding the type of recurrent ATs are lacking.[8] In our study, 7.4% (10/135) of the patients who underwent cryoballoon ablation of the LAPW had AT recurrence, which is comparable with previous reports, including RF ablation. We demonstrated that perimitral AT was the most frequent type of recurrent AT, accounting for half of the identified recurrent ATs in our study cohort. LA roof-dependent AT was confirmed in only two patients, who both underwent cryoballoon ablation for LAPW in the index ablation. However, considering previous reports in which the prevalence of LA roof-dependent AT recurrence was 1%–2% after PVI with a cryoballoon,[19,20] the recurrence rate of the LA roof-dependent AT in the present study might not be high. The high durability of the lesions created at the LAPW might

contribute to the low prevalence of LA roof-dependent AT recurrence.

Our study had a few limitations. First, this was a single-center, non-randomized retrospective study. Therefore, the results regarding additional cryoballoon ablation of the LAPW should be carefully interpreted, although there were no significant differences in patient characteristics such as left atrial diameter (LAD) or the existence of left common pulmonary vein (LCPV) or right middle pulmonary vein (RMPV) between the patients who underwent cryoballoon ablation of the LAPW and those who did not. Finally, the use of AADs after the index ablation was also different among study patients; thus, clinical follow-up data requires prudent interpretations. A randomized multicenter study with a fixed protocol is necessary to confirm the efficacy and impact of LAPW ablation with a cryoballoon. Nonetheless, we presented detailed data in terms of acute and long-term success rates and clinical outcomes after ablation, including the type of recurrence. We consider that these findings will contribute to further examinations regarding cryoballoon ablation of the LAPW in the future.

Conclusions

In this study, the efficacy of cryoballoon ablation for the LAPW, especially at the LA roof was demonstrated. A sufficient success rate of complete conduction block at the LA roof, including the chronic durability of the lesions can be expected. AT recurrence after ablation does not increase in patients who undergo cryoballoon ablation of the LAPW. The recurrence rate of the persistent type of AF after ablation becomes lower when cryoballoon ablation of the LAPW is performed.

The conversion from the persistent to the paroxysmal type after ablation may have various benefits. The risk of stroke or heart failure might be reduced, and complete elimination of AF might be possible after an additional trigger-based ablation. Therefore, the strategy of LAPW ablation could lead to better clinical outcomes after ablation in patients with non-paroxysmal AF who would not benefit from PVI alone. However, identifying suitable candidates for additional LAPW ablation remains to be clarified.

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Table 1

Patient characteristics and index ablation results

	All	Study cohort	Recurrence	Recurrence	Recurrence	AT re
	(n=340)	(n=191)	– (n=136)	+ (n=55)	p	– (n=
Age (years)	65.1±10.1	65.3±9.9	64.6±9.5	67.2±10.6	0.09	65.0±
Male sex	268 (78.8)	149 (78.0)	108 (79.4)	41 (74.5)	0.45	140 (
Body mass index (kg/m^2)	25.2±3.9	25.0±4.1	25.1±4.2	24,7±4.0	0.57	25.0±
AF duration (months)	3.0 [2.0–12.8]	3.0 [2.0–15.0]	3.0 [2.0–10.3]	6.0 [2.0–35.0]	0.048	3.5 [2

	All	Study cohort	Recurrence	Recurrence	Recurrence	AT re
Hypertension	168 (49.4)	84 (44.0)	63 (46.3)	21 (38.2)	0.34	81 (45
Diabetes	51 (15.0)	28 (14.7)	17 (12.5)	11 (20.0)	0.26	25 (14
Chronic heart failure	40 (11.8)	24 (12.6)	16 (11.8)	8 (14.5)	0.63	20 (11
Prior stroke/TIA	26 (7.7)	17 (8.9)	14 (10.3)	3 (5.5)	0.40	17 (9.
LVEF (%)	60.8±10.9	60.6±10.9	60.5±10.7	61.0±11.4	0.77	61.2±
LA diameter (mm)	44.3±6.0	44.1±6.2	43.6±6.3	45.4±6.0	0.07	43.9±
LCPV or RMPV	29 (8.5)	18 (9.4)	12 (8.8)	6 (10.9)	0.79	15 (8.
Treatment with AADs	91 (26.8)	47 (24.6)	22 (16.2)	25 (45.5)	<0.01	40 (22
Roof line	265 (77.9)	135 (70.7)	101 (74.3)	34 (61.8)	0.11	125 (7
Bottom line	239 (70.3)	135 (70.7)	101 (74.3)	34 (61.8)	0.11	125 (7
Touch up ablation for LAPW isolation	48 (14.1)	31 (16.2)	21 (15.4)	10 (18.2)	0.67	27 (15
CTI ablation	334 (98.2)	186 (97.4)	134 (98.5)	52 (94.5)	0.15	173 (9
MI ablation	131 (38.5)	0 (0.0)				

Values are presented as mean±standard deviation, n (%), or median [interquartile range].

AADs, anti-arrhythmic drugs; AF, atrial fibrillation; AT, atrial tachycardia; CTI, cavotricuspid isthmus; LA, left atrial; LAPW, left atrial posterior wall; LCPV, left common pulmonary vein; LVEF, left ventricular ejection fraction; MI, mitral isthmus; RMPV, right middle pulmonary vein; TIA, transient ischemic attack.

Table 2

Comparison of patient characteristics and index ablation results of patients with and without cryoballoon ablation of the LA roof

	Patients with cryoballoon ablation of the roof line (n=135)	Patients without cry
Age (years)	64.2±9.7	68.0±10.0
Male sex	109 (80.7)	40 (71.4)
Body mass index (kg/m^2)	25.2±4.1	24.7±4.1
AF duration (months)	3.5 [2.0–24.0]	3.0 [2.0–10.3]
Hypertension	60 (44.4)	24 (42.9)
Diabetes	20 (14.8)	8 (14.3)
Chronic heart failure	16 (11.9)	8 (14.3)
Prior stroke/TIA	11 (8.1)	6 (10.7)
LVEF (%)	60.4±11.1	61.2±10.4
LA diameter (mm)	43.6±6.1	45.4±6.5
LCPV or RMPV	15 (11.1)	3 (5.4)
Treatment with AADs	33 (24.4)	14 (25.0)
Touch-up ablation for LAPW isolation	31 (23.0)	0 (0.0)
CTI ablation	135 (100.0)	51 (91.1)

Values are presented as mean±standard deviation, n (%), or median [interquartile range].

AADs, anti-arrhythmic drugs; AF, atrial fibrillation; CTI, cavotricuspid isthmus; LA, left atrial; LAPW, left atrial posterior wall; LCPV, left common pulmonary vein; LVEF, left ventricular ejection fraction; RMPV, right middle pulmonary vein; TIA, transient ischemic attack.

Table 3

Univariate and multivariate analysis results for persistent AF recurrence and AT recurrence

Predictors of persistent AF recurrence	Univariate	Univariate	Univariate	Univariate	Multivariate	Multivariate
	HR	95% CI	p	HR	HR	95% CI
LAPW ablation	0.37	0.17–0.80	0.01	0.31	0.31	0.14–0.70
AF duration	1.02	1.01–1.03	<0.01	1.01	1.01	1.01–1.02
Treatment with anti-arrhythmic drugs	3.94	1.81–8.60	<0.01	2.61	2.61	1.09–6.22

AF, atrial fibrillation; CI, confidence interval; HR, hazards ratio; LA, left atrial; LAPW, left atrial posterior wall; LCPV, left common pulmonary vein; RMPV, right middle pulmonary vein.

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Figure 1

Fluoroscopic images during cryoballoon ablation of the (top) left atrial (LA) roof and (bottom) left atrial posterior wall (LAPW) bottom (PA view). The cryoballoon is shifted gradually on the LA roof or the LAPW bottom from the left superior pulmonary vein to the right superior pulmonary vein or from the left inferior pulmonary vein to the right inferior pulmonary vein in an overlapping manner.

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Figure 2

Kaplan–Meier curve of atrial arrhythmia recurrence after index ablation

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Figure 3

Kaplan–Meier curves of (A) overall atrial arrhythmia recurrence, (B) AF recurrence, (C) persistent AF recurrence, (D) atrial tachycardia recurrence, and (E) persistent AF recurrence adjusted with several factors (AAD use, age, body mass index, AF duration, LAD, and AF duration) after the index ablation. The clinical outcomes for each recurrence pattern were compared between patients with and without additional LA roof cryoballoon ablation. The 12-month Kaplan–Meier event-free rate estimates were the following: 79.0% vs. 72.2% (overall recurrence), 83.0% vs. 73.8% (AF recurrence), 91.3% vs. 81.4% (persistent AF recurrence), and 93.9% vs. 96.4% (AT recurrence). AADs, anti-arrhythmic drugs; AT, atrial tachycardia; AF, atrial fibrillation; LA, left atrial; LAD, left atrial diameter

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Figure 4

Percentage of durable lesions confirmed at the beginning of the redo ablation procedure.

The analysis of PV durability was performed in 42 patients including three patients with an LCPV who underwent redo ablation procedures. PV recurrence was confirmed in 4, 4, 9, and 11 patients at the LSPV, LIPV, RSPV, and RIPV, respectively. The durability of the LA roof line, LAPW bottom line, and CTI line was analyzed in patients who had obtained complete conduction block in the index ablation procedure (25 patients for the LA roof line, 21 patients for the LAPW bottom line, and 37 patients for the CTI line). CTI, cavotricuspid isthmus; LA, left atrial; LAPW, left atrial posterior wall; LCPV, left common pulmonary vein; LIPV, left inferior pulmonary vein; LSPV, left superior pulmonary vein; PV, pulmonary vein; RIPV, right inferior pulmonary vein; RSPV, right superior pulmonary vein.