Post–pulmonary vein isolation voltage remapping–guided incremental lesions: A feasible strategy to improve long-term outcomes

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BACKGROUND Pulmonary vein isolation (PVI) has demonstrated acceptable success rates; however, there is still potential for improvement. Pulmonary reconnection remains the main problem and the role of adjunctive strategies, such as repeat mapping to guide additional lesions to enhance durability of pulmonary vein isolation, remains uncertain.

OBJECTIVE This study aimed to evaluate the impact of post-PVI high-density remapping with guided incremental lesions on long-term recurrence-free survival.

METHODS This study included consecutive patients who underwent PVI between 2015 and 2023. Patients were divided into 2 groups based on whether they received post-PVI high-density remapping. Those in the remapping group with documented areas of incomplete ablation received incremental lesions to achieve complete ablation. The primary endpoint was recurrence-free survival.

RESULTS A total of 588 patients, with a mean follow-up of 25.8 months, were included. Post-PVI remapping was performed in 243 patients, while 345 patients underwent conventional PVI. Post-PVI remapping with guided incremental lesions improved recurrence-free survival compared with conventional PVI (adjusted hazard ratio 0.75, 95% confidence interval [CI] 0.57-0.99, $P = .04$). This benefit was especially notable in patients with paroxysmal atrial fibrillation (hazard ratio 0.69, 95% CI 0.49-0.96, $P = .027$). Complication rates and procedure times were comparable between the 2 groups. For patients undergoing their first radiofrequency ablation, 1-year success was higher in those who underwent PVI remapping (adjusted odds ratio 1.70, 95% CI 1.04–2.77, $P = .03$). However, long-term outcomes were comparable between the 2 groups.

CONCLUSION Postablation mapping effectively identifies and addresses proarrhythmic foci, potentially reducing atrial fibrillation recurrence and improving patient outcomes.

KEYWORDS Atrial fibrillation; Catheter ablation; Pulmonary vein isolation; Voltage mapping; Radiofrequency catheter ablation; Cryoballoon catheter ablation

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Introduction

Atrial fibrillation (AF) is the most prevalent arrhythmia in adults.[1,2] Pulmonary vein isolation (PVI) is the cornerstone of AF ablation, particularly for symptomatic patients who are refractory to antiarrhythmic drugs.[3] Although PVI has shown acceptable success rates,[4–6] there remains considerable potential for improvement, particularly regarding the use of adjunctive strategies such as repeat mapping to guide additional lesions.[7,8] Despite their potential, these strategies have not yet been incorporated into current guidelines.[3,9]

Incomplete atrial fibrosis due to incomplete ablation lesions with residual slow conduction contributes to a proarrhythmic environment.[10] Voltage remapping in sinus rhythm (SR) after initial ablation allows for the identification of these altered or incompletely ablated areas, guiding further ablation to address the arrhythmogenic substrate and prevent recurrence. This study aimed to evaluate the impact of voltage remapping and repeat ablation of previously targeted low-voltage and unablated areas on recurrence-free survival during long-term follow-up.

Methods

Study design

This was an observational, single-center, case-control, retrospective study. We reviewed patients who underwent PVI for

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KEY FINDINGS

- Post–pulmonary vein isolation voltage remapping guided by incremental lesions is a feasible strategy that improves recurrence-free survival during long-term follow-up.
- This strategy does not prolong the procedure or ablation times; however, it is associated with an increased number of ablation deliveries.
- Complication rates did not increase in patients who underwent this strategy.
- The benefits of this approach are particularly significant in patients presenting with paroxysmal atrial fibrillation.

atrial fibrillation between January 2015 and April 2024. These procedures were performed by operators who introduced post-PVI voltage remapping in SR with the delivery of incremental lesions in case of documentation of low-voltage zones or incomplete ablation of areas targeted in the first instance ablation as standard practice during this period. Patients older than 18 years of age, with a minimum follow-up period of 12 months, and those who presented the primary endpoints before this period were included in the study. The first PVI performed at our institution was considered the index procedure. Patients were divided into 2 groups: the first group included patients who underwent post-ablation remapping and the second group consisted of a historical cohort from the same operators prior to the introduction of this strategy (Figure 1). Baseline data, procedure characteristics, and outcomes were collected for further analysis. This study was conducted in accordance with the Declaration of Helsinki and was approved by the Institutional Review Board (21-011049). Written informed consent was obtained from all patients before the index procedure.

Pulmonary vein isolation

Before the procedure, all antiarrhythmic drugs were discontinued for 5 half-lives. During the procedure, heparin was administered with a target activated clotting time of 300 to 350 seconds.

AF ablation with radiofrequency or cryoballoon techniques was performed utilizing standard techniques. A 3.5-mm bidirectional irrigated-tip ablation catheter or the Arctic Front Advance System (Medtronic) was employed for radiofrequency ablation (RFA) or cryoablation, respectively. The standard radiofrequency energy settings included a default power of 30 W (ranging from 25 to 35 W), a radiofrequency application duration of 20 to 40 seconds, a contact force of 5 to 10 g, and an interlesion distance of <5 mm.

Catheter position and left atrial anatomical mapping were performed with the NavX 3D (Abbott Cardiovascular) or CARTO 3 (Biosense Webster) mapping system. PVI was confirmed by demonstrating the entrance block of all the pulmonary veins (PVs) during coronary sinus pacing using a multipolar catheter, such as the Pentaray or Octaray (Biosense Webster), a Grid catheter (Abbott Vascular), or the Achieve catheter (Medtronic) in the case of cryoablation. After PVI, additional ablation lines were given at the discretion of the operator. Moreover, concomitant atrial flutter or atrial tachycardia was ablated.

Post-PVI voltage-guided incremental lesions

After the introduction of post-PVI remapping, all patients presenting for PVI were eligible. Both patients with complete isolation and those with persistent signals in the ablated area, as assessed by the ablation catheter, underwent remapping as part of this strategy.

After testing the entrance block of all the PVs, high-density voltage mapping of the left atrium was performed during the waiting period in SR using multipolar, small-diameter catheters. The fully ablated area was defined as <0.2 mV with no capture. Low-voltage areas (LVAs) included areas with a voltage between 0.2 mV and 0.4 mV at 3 or more adjacent points and unablated areas with a voltage >0.5 mV.

The following stepwise approach was implemented. If no LVAs or unablated areas were documented in areas targeted for first-instance ablation, the procedure was concluded. If there were uncomplete ablated areas, additional lesions were delivered, and confirmation of complete isolation on repeat mapping was performed (Figure 2). After complete ablation was achieved, the procedure was concluded. The endpoint of LVA modification was the reduction of local electrograms to <0.2 mV amplitude in all ablated areas with no capture at 10 mA.

Endpoints

As standard care practice, patients were followed up with 24-hour Holter monitoring 3, 6, and 12 months after the procedure and at any time that they presented symptoms during follow-up. If there was no atrial tachyarrhythmia recurrence, antiarrhythmics were discontinued after 90 days. Device interrogation data were also collected for patients who had a cardiac device. The primary endpoint was atrial tachyarrhythmia recurrence-free survival after a single procedure. Any documented episode of atrial fibrillation or flutter lasting more than 30 seconds after a blanking period of 3 months was considered a recurrence. Follow-up was defined as the period from the procedure to the first occurrence of the event of interest or to the last documented emergency room or office visit for patients without any event. Procedure complications were reported and categorized as severe if they were life-threatening, associated with organ failure, or required an additional invasive intervention; otherwise, they were categorized as mild. Postprocedural pericarditis was defined as chest pain with pleuritic characteristics that necessitated treatment with anti-inflammatory drugs or colchicine formulations.

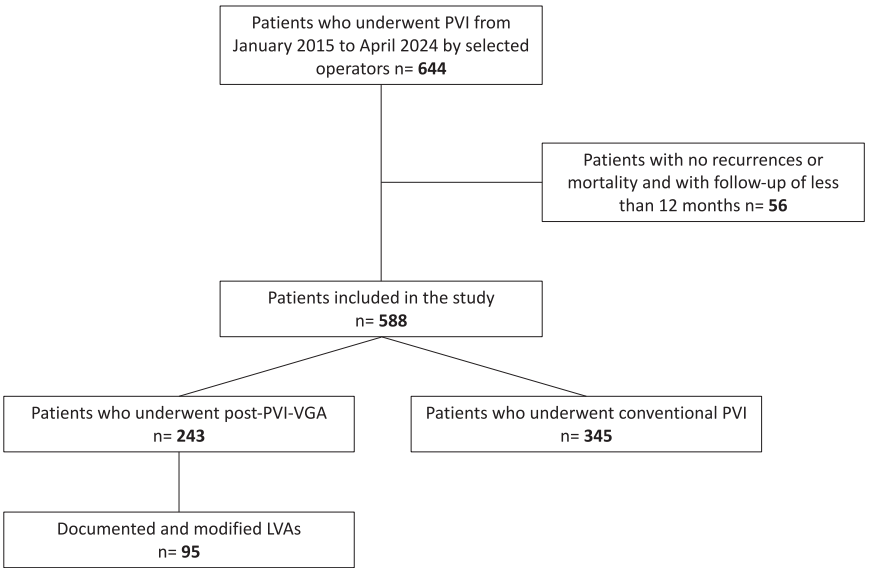


Figure 1 Study overview: participant flow chart. LVA = low-voltage area; PVI = pulmonary vein isolation; VGA = voltage guided ablation.

Statistical analysis

Continuous variables are presented as the mean ± SD and were compared with Student's *t* test. Categorical variables are presented as absolute and relative frequencies and were compared with the chi-square test or Fisher's exact test (if the frequency of observation was <5 in the contingency table). Binary outcomes were compared by odds ratios (ORs), and 95% confidence intervals (CIs) were reported. Recurrence-free survival was evaluated through Kaplan-Meier analysis. The time-to-event endpoints were analyzed with log-rank tests. The association between post-PVI remapping and event-free survival was tested using a multivariate Cox regression model, including variables with uneven distribution between the 2 groups, as demonstrated in the bivariate analysis ($P < .1$). For time-dependent variables, hazard ratios (HRs) and CIs are presented. To ensure more comparable groups, subgroup analyses were conducted based on the type of AF and source of energy, and for patients who underwent their first PVI with radiofrequency. Statistical significance was established with a P value of <.05. Statistical analyses were performed with R statistical software (version 4.2.3; R Foundation for Statistical Computing).

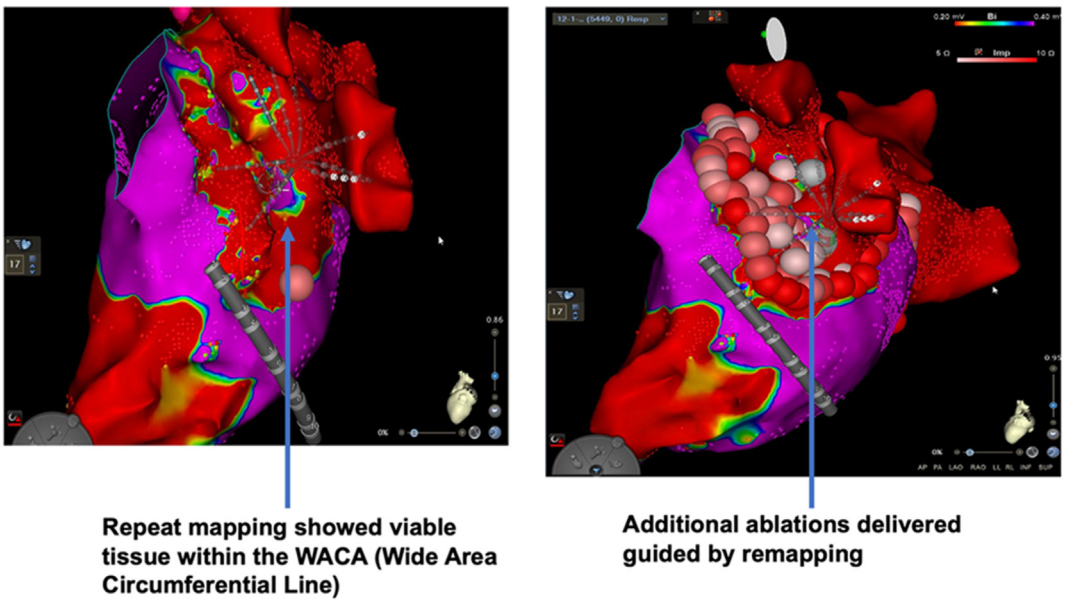


Figure 2 Post–pulmonary vein isolation remapping–guided incremental lesion strategy: Voltage mapping of a patient in whom we identified incomplete ablation areas (right) with posterior incremental lesion delivery (left).

Results

Population characteristics

A total of 588 patients were included in the study. The mean follow-up period was 25.8 months. Post-PVI remapping group included 243 patients, and conventional PVI was performed in 345 patients. The total and each group's baseline characteristics are summarized in Table 1. The mean age was 66.7 ± 9.6 years, with patients in the post-PVI remapping group being older than those in the conventional group (68.3 ± 8.4 years vs 65.6 ± 10.2 years; $P = .05$). Most of the patients presented with paroxysmal AF (n = 427 [73%]), and the distribution was similar among the 2 groups ($P = .3$). The mean left ventricular ejection fraction was 56.7 ± 9.5% and the left atrial volume index was 40.3 ± 14.1 mL/m^2. The index procedure was a "redo" PVI in 118 (20%) patients. Cryoablation was more frequent in the post-PVI remapping group (n = 25 [10.3%]) compared with the control group (n = 7 [2%]), with a P value <.01.

Procedure characteristics and outcomes

Procedure characteristics and outcomes are summarized in Table 2. The mean procedure time was shorter in the post-PVI remapping group (215 ± 64 minutes vs 261 ± 80 minutes; mean difference [MD] –46, 95% CI –57 to –34, $P <$ .01). In the same line, ablation time and fluoroscopy time were shorter in the post-PVI remapping group (ablation time: 38 ± 15 minutes vs 45 ± 22 minutes; MD –7, 95% CI –4 to –11, $P <$ .01; fluoroscopy time: 14 ± 12 minutes vs 18 ± 14 minutes; MD –4, 95% CI –7 to –2, $P <$ .01). However, the total number of ablations was higher in the post-PVI remapping group (142 ± 49 vs 122 ± 57; MD 20, 95% CI 10 to 29; $P <$ .01). A total of 592 (99%) patients underwent a successful procedure, with no significant differences among the analyzed groups.

Severe complications were present in 17 (3%) patients, with a nonsignificant difference in frequency among the analyzed groups (OR 0.58, 95% CI 0.2 to 1.71, $P = .3$). Fewer patients in the post-PVI remapping group presented mild complications (28 [8%] vs 8 [3%]; OR 0.37, 95% CI 0.16 to 0.84, $P = .01$). Sinus or atrioventricular node dysfunction after the procedure requiring pacemaker implantation was the most common severe complication (n = 6 [35%]), followed by pericardial effusion requiring pericardiocentesis (n = 5 [29%]). Each of the following complications was presented by 1 patient each: cardiac tamponade requiring sternotomy, esophageal perforation, atrial lead dislodgement, stroke, femoral fistula requiring ligation, and anaphylactic reaction to protamine (Supplemental Table 1).

During the blanking period, a total of 142 (24%) had documented atrial fibrillation episodes, which were less common in the post-PVI remapping group (48 [20%] vs 94 [27%]; OR 0.66, 95% CI 0.44-0.98, $P = .04$). Post-PVI remapping was associated with higher 1-year success rates, lower new atrial arrhythmia, and atrioventricular node ablation procedures (OR 1.51, 95% CI 1.01 to 2.25, $P = .04$, OR 0.36, 95% CI

Table 1 Baseline characteristics

	All patients (N = 588)	Post-PVI remapping (n = 243)	Conventional (n = 345)	*P* value
Age, y	66.7 ± 9.6	68.3 ± 8.4	65.6 ± 10.2	.005
Female	185 (31)	80 (33)	105 (30)	.5
Paroxysmal AF	427 (73)	171 (70)	256 (74)	.3
Persistent AF	161 (27)	72 (30)	89 (26)	.3
Hypertension	355 (60)	153 (63)	202 (59)	.3
Diabetes	101 (17)	33 (14)	68 (20)	.052
Obesity	234 (40)	93 (38)	141 (41)	.5
CAD	160 (27)	69 (28)	91 (26)	.6
CKD	152 (26)	68 (28)	84 (24)	.3
OSA	264 (45)	111 (46)	153 (44)	.7
Cardiac device	89 (15)	45 (19)	44 (13)	.054
BMI, kg/m^2	29.3 ± 5.7	29 ± 5.8	29.5 ± 5.7	.3
GFR, mL/min	73.1 ± 16.4	73.3 ± 14.8	72.9 ± 17.5	.7
LVEF, %*	56.7 ± 9.5	57.4 ± 8.6	56.2 ± 10.1	.1
LAVI, mL/m^2†	40.3 ± 14.1	41.2 ± 13.9	39.7 ± 14.3	.3
CHA_2DS_2-VASc	2.8 ± 1.6	2.9 ± 1.6	2.7 ± 1.7	.1
Redo PVI	118 (20)	52 (21)	66 (19)	.5
PV reconnection‡	95 (81)	43 (83)	52 (79)	.8
Cryoablation	32 (5)	25 (10)	7 (2)	<.01
PVI + CTI ablation	360 (61)	145 (60)	215 (62)	.5

Values are mean ± SD or n (%).

AF = atrial fibrillation; BMI = body mass index; CAD = coronary artery disease; CHA2DS2-VASc = congestive heart failure, hypertension, age ≥75 years, diabetes mellitus, prior stroke or transient ischemic attack or thromboembolism, vascular disease, age 65–74 years, sex category; CKD = chronic kidney disease; CTI = cavotricuspid isthmus; GFR = glomerular filtration rate; LAVI = left atrial volume index; LVEF = left ventricular ejection fraction; OSA = obstructive sleep apnea; PV = pulmonary vein; PVI = pulmonary vein isolation. rowhead.

*544 patients with LVEF data.

†450 patients with LAVI data.

‡Proportion of patients with a PV reconnection from the redo population.

Table 2 Procedure characteristics and outcomes

	All patients (N = 588)	Post-PVI remapping (n = 243)	Conventional (n = 345)	OR or MD (95% CI)	*P* value
Procedure time, min	242 ± 77	215 ± 64	261 ± 80	MD: −46 (−57 to −34)	<.01
Fluoroscopy time, min	16 ± 13	14 ± 12	18 ± 14	MD: −4 (−7 to −2)	<.01
Ablation time, min*	42 ± 19	38 ± 15	45 ± 22	MD: −7 (−4 to −11)	<.01
Number of ablations*	130 ± 55	142 ± 49	122 ± 57	MD: 20 (10 to 29)	<.01
Acute success	582 (99)	240 (99)	342 (99)	OR: 0.7 (0.1 to 5.3)	.7
Severe complications	17 (3)	5 (2)	12 (3)	OR: 0.58 (0.2 to 1.71)	.3
Mild complications	37 (6)	8 (3)	29 (8)	OR: 0.37 (0.16 to 0.84)	.01*
Post-PVI pericarditis	49 (8)	14 (6)	35 (10)	OR: 0.54 (0.28 to 1)	.06
<90-d recurrence	142 (24)	48 (20)	94 (27)	OR: 0.66 (0.44 to 0.98)	.04*
1-y success	441 (75)	193 (79)	248 (72)	OR: 1.51 (1.01 to 2.25)	.04*
New ablation	97 (17)	22 (9)	75 (22)	OR: 0.36 (0.21 to 0.6)	<.01*
AV node ablation	26 (4)	5 (2)	21 (6)	OR: 0.32 (0.12 to 0.89)	.02*

Values are mean ± SD or n (%).

AV = atrioventricular; CI = confidence interval; MD = mean difference; OR = odds ratio; PVI = pulmonary vein isolation.

*For radiofrequency ablation.

0.21 to 0.6, $P < .01$; and OR 0.32, 95% CI 0.12 to 0.89, $P = .02$, respectively).

LVAs and incomplete ablation area prevalence and location distribution

LVAs and incomplete ablation areas were documented in 94 (39%) patients in the post-PVI remapping group. Posterior wall lines were the most common location, followed by the right superior PV, right inferior PV, left superior PV, and left inferior PV (Figure 3). A detailed description is presented in Supplemental Table 2.

Survival analysis

For the post-PVI remapping group, event-free survival was 80% at 1 year, 61% at 3 years, and 54% at 5 years. Two patients died during follow-up in this group, and 78 (32%) patients experienced recurrence. None of the patients who died presented with any recurrences. For the conventional PVI group, event-free survival was 72% at 1 year, 52% at 3 years, and 38% at 5 years. During the follow-up, 174 (50%) patients experienced recurrence and 19 (6%) died. Of the patients who died, 8 had previously documented atrial fibrillation recurrence.

The results of the Kaplan-Meier survival analysis are presented in Figure 4. The log-rank test demonstrated a significant difference between the analyzed groups ($P = .044$). Owing to the possible effects of confounders, a multivariate Cox regression model was performed (Supplemental Table 3). Post-PVI remapping was an independent predictor of increased event-free survival (HR 0.75, 95% CI 0.57 to 0.99, $P = .04$). Patients with a cardiac device had a lower event-free survival (HR 1.79; 95% CI 1.32 to 2.43, $P < .01$).

Subgroup analysis

Subgroup analysis was performed for patients with paroxysmal AF and persistent AF. Among patients with paroxysmal AF, the post-PVI remapping group had higher recurrence-free survival rates before and after adjustment for confounders (HR 0.72, 95% CI 0.52 to 0.99, $P = .048$; and HR 0.69, 95% CI 0.49 to 0.96, $P = .027$, respectively). For persistent AF, post-PVI remapping did not improve recurrence-free survival in the unadjusted or adjusted analysis (HR 0.87, 95% CI 0.54 to 1.39, $P = .55$; and HR 0.87, 95% CI 0.54 to 1.41, $P = .58$) (Figure 5).

Subgroup survival analyses for radiofrequency and cryoablation are presented in Supplemental Figures 1 and 2. For RFA (n = 556), a clear trend favoring higher recurrence-

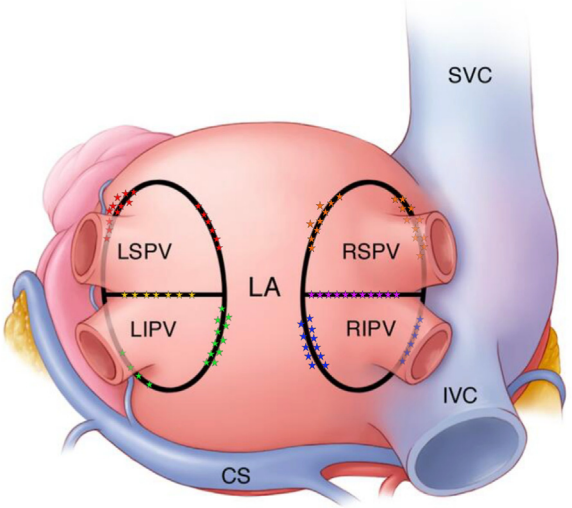
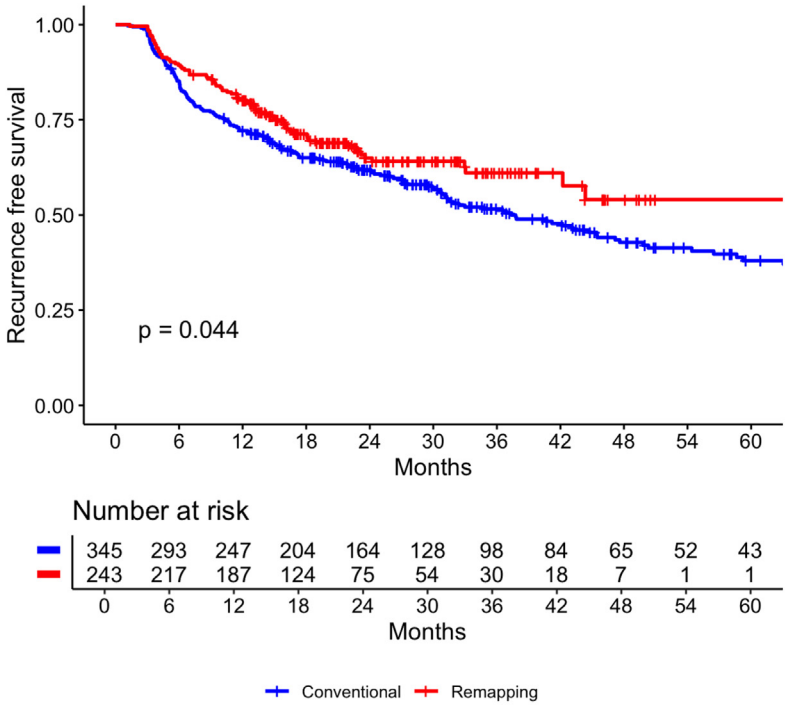


Figure 3 Low-voltage areas and incomplete ablation distribution in the wide-area circumferential ablation. Illustration of the left atrium (LA) from a posterior view. Stars represent the documented location of incomplete ablation in the wide area circumferential ablation. Red indicates the left superior pulmonary vein (LSPV), green the left inferior pulmonary vein (LIPV), orange the right superior pulmonary vein (RSPV), and blue the right inferior pulmonary vein (RIPV). Yellow and purple stars indicate the left and right carinas, respectively. Reprinted with permission from Kanitsoraphan et al.[21] CS = coronary sinus; IVC = inferior vena cava; SCV = superior vena cava.



	Post-PVI remapping event-free survival		Conventional event-free survival	
Time	Survival	95% CI	Survival	95% CI
12	80%	75-85%	72%	66-77%
24	65%	59-72%	62%	57-67%
36	61%	54-69%	52%	46-58%
48	54%	44-67%	43%	37-50%
60	54%	44-67%	38%	32-45%

Figure 4 Kaplan-Meier survival analysis. Kaplan-Meier curves illustrating recurrence-free survival in the post–pulmonary vein isolation (PVI) remapping group (red line) and in the conventional PVI group (blue line). CI = confidence interval.

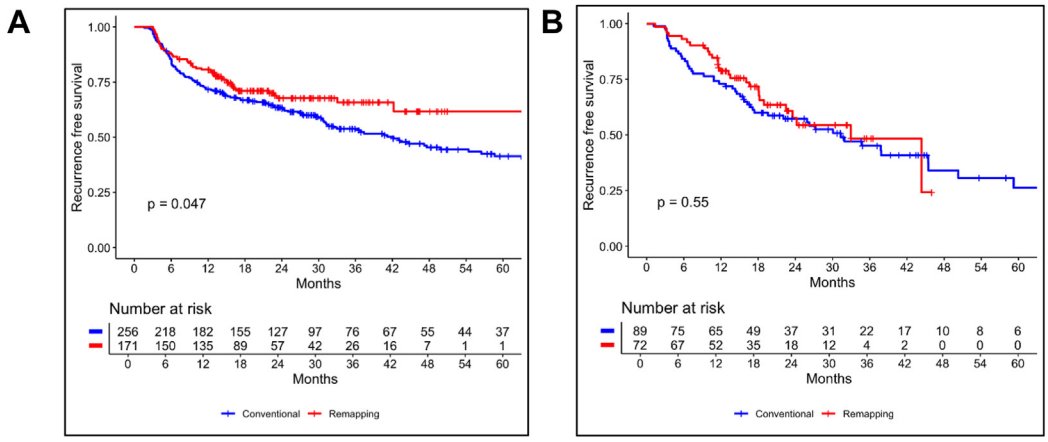
free survival in the remapping group was observed; however, significance was not reached (P = .05). For cryoablation (n = 32), no difference in recurrence-free survival was noted (P = .54). Subgroup analyses for first-time PVI and redo procedures did not demonstrate significant differences between the remapping and conventional groups (Supplemental Figures 3 and 4).

A subgroup analysis excluding redo procedures and cryoablation was conducted. For patients who underwent a first-time PVI with radiofrequency, baseline characteristics and procedure outcomes are summarized in Supplemental Tables 4 and 5. After adjusting for variables with uneven distribution between groups (age, presence of a cardiac device, and CHA_2DS_2-VASc [congestive heart failure, hypertension, age ≥75 years, diabetes mellitus, prior stroke or transient ischemic attack or thromboembolism, vascular disease, age 65–74 years, sex category] score), 1-year success was higher in the remapping group (adjusted OR, 1.70, 95% CI, 1.04 to 2.77, P = .03). However, Kaplan-Meier curves did not demonstrate significant differences in recurrence-free survival (Figure 6).

Discussion

Main findings

Our study revealed that compared with conventional PVI, the post-PVI remapping–guided incremental lesions strategy significantly improved recurrence-free survival during long-term follow-up. This benefit was particularly pronounced in patients with paroxysmal AF, as evidenced by the subgroup analysis but was not observed in those with persistent AF. Importantly, the complication rates between the 2 groups were comparable, and the additional mapping and ablation did not result in increased procedure



A: Paroxysmal

	Post-PVI remapping event-free survival		Conventional event-free survival	
Time	Survival	95% CI	Survival	95% CI
12	81%	75-87%	72%	67-78%
24	68%	61-76%	64%	58-70%
36	66%	58-75%	54%	48-61%
48	62%	52-74%	45%	39-53%
60	62%	52-74%	41%	34-50%

B: Persistent

	Post-PVI remapping event-free survival		Conventional event-free survival	
Time	Survival	95% CI	Survival	95% CI
12	79%	70-89%	73%	64-83%
24	58%	45-73%	57%	48-69%
36	48%	34-69%	45%	35-58%
48			34%	23-50%
60			26%	15-45%

Figure 5 Subgroup analysis for paroxysmal and persistent atrial fibrillation (AF). Kaplan-Meier curves illustrating recurrence-free survival. Patients with paroxysmal AF (A) and patients with persistent AF (B). The red line indicates the post–pulmonary vein isolation (PVI) remapping group and the blue line indicates in the conventional PVI group.

time. For patients who underwent a first radiofrequency PVI, postprocedural remapping improved 1-year success but did not have a documented impact on long-term follow-up.

Reported data on the prevalence of incomplete ablation areas after PVI vary across studies. This variation may be attributed to factors such as the type of catheter used for remapping, the ablation strategy employed, and the conventional practices for assessing success. In cryoablation, where PVI is confirmed with an octopolar inner lumen mapping catheter, remapping with conventional circular catheters has shown a reported prevalence of residual PV potentials in 4.3% of PVs and 12% of patients.[11,12] However, these numbers can increase to 22% to 24% in patients who underwent remapping with high-density mapping.[13,14]

For RFA, when PVI is confirmed by exit block using a circumferential mapping catheter, 20% to 82% of the

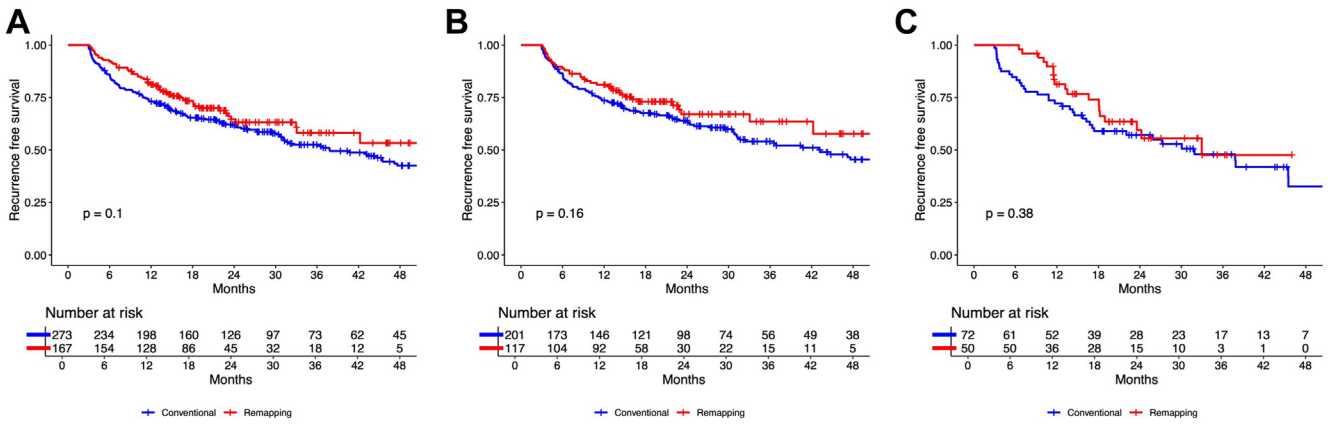


Figure 6 A: Kaplan-Meier (KM) curve for 440 patients who underwent a first radiofrequency pulmonary vein isolation (PVI). B: KM curve for 318 patients with paroxysmal atrial fibrillation who underwent a first radiofrequency PVI. C: KM curve for 122 patients with persistent atrial fibrillation who underwent a first radiofrequency PVI. *P* values for the log-rank test.

patients presented gaps in the high-density remapping.[13,15] When PVI was confirmed using a technique of pacing the ablation lines, gaps in the high-density remapping were reported to be present in 68% of the patients.[13] In our study, we performed a high-density remapping, with 39% of the patients presenting with incomplete ablation areas. This rate is consistent with previously reported data.

The right and left superior PVs in their septal and anterior aspects and right PV carina have been reported as the most common locations of incomplete ablation areas in high-density mapping after RFA.[13,15] For remapping performed with circular mapping catheters, the most reported location is around the bottom portion of the right inferior PV after cryoablation.[11] These data are consistent with our study location distribution.

To the best of our knowledge, this is the largest study assessing post-PVI voltage remapping and the first one comparing long-term outcomes with conventional PVI. One-year success rates for patients who underwent cryoballoon PVI with remapping and residual potential elimination ranged from 80% to 88%.[11,14] In our population, recurrence-free survival rates are consistent with previously reported data, and they were higher than the ones for patients who underwent conventional PVI, particularly for patients with paroxysmal AF. We hypothesize that the lack of significance in the persistent AF population may be due to the small sample size of this specific group in our study.

The adverse event rates reported in our population are consistent with those reported in other studies that included post-PVI remapping.[16–18] Furthermore, post-PVI remapping was not associated with an increased risk of adverse events in our study.

Regarding procedure time, the remapping was performed during the waiting period and therefore did not add to the overall procedure duration. We hypothesize that the reduction in procedure time is due to minor variations in the operators' protocols, even though no major modifications were made to the institutional protocol during the enrollment period.

Significance of the results

The findings of this study provide compelling evidence for the potential benefits of incorporating immediate postablation voltage mapping into AF management. By focusing on the detection of incomplete ablation lesions, which may later develop into arrhythmogenic foci, this approach presents a proactive strategy to optimize ablation procedures and enhance patient outcomes. The identification and subsequent ablation of these prearrhythmic areas resulted in a statistically significant improvement in recurrence-free survival, demonstrating the clinical value of this technique.

The concept of immediate postablation mapping represents a promising avenue for future research in AF management. Our findings indicate that post-PVI remapping is a viable strategy that maintains procedure efficiency and safety. It improves 1-year outcomes and long-term results, particularly in patients with paroxysmal AF, and merits consideration for integration into the routine practice of centers performing this procedure. This step can be effectively incorporated during the recommended waiting period.

Although newer technologies, such as pulsed field ablation, have recently emerged as promising alternatives for PVI, thermoablation techniques still play a significant role, particularly in cost-sensitive healthcare systems. This strategy suggests an improvement in long-term clinical outcomes using commonly available technologies.

Limitations

Our study has several limitations, and the results should be interpreted with caution. This is a retrospective study, which implies selection bias. Our control group was a historical cohort, meaning that most procedures in this group were performed earlier than those in the post-PVI remapping group. Although this raises concerns about

the effects of the operator's learning curves, most of the included operators had extensive prior experience before the initial inclusion date, which can minimize this effect. However, learning curves are difficult to quantify precisely. Another limitation associated with the historical cohort is the potential risk of bias due to the introduction of new technologies and improved techniques beyond the tested strategy. To address this limitation, we restricted the historical cohort to procedures performed until 2015, excluding older ones. The newer technologies and strategies during this period primarily focused on reducing procedural times and improving safety, rather than enhancing long-term outcomes.[19] Aside from the strategy described in this manuscript, no other major modifications to the PVI protocol were introduced by the participating operators. The absence of standardized criteria for determining the delivery of additional ablation lines was a further limitation of this study.

A differentiation between endocardial conduction gaps and nonendocardial connections has been proposed.[20] Determining the proportion of each condition in the remapped population could contribute to a better understanding of their role during PVI. Unfortunately, due to insufficient data for a significant proportion of patients, this assessment could not be performed in this study.

We did not analyze the proportion of patients who achieved an entrance/exit block and who had LVAs identified due to a lack of data for a significant proportion of those who underwent remapping. This analysis could provide valuable insights into the role of this strategy. Additionally, we did not evaluate the effect of this strategy on outcomes related to quality of life or symptom burden, which would provide a more comprehensive understanding of its impact. Further randomized trials, and studies evaluating not only recurrence rates, but also symptom burden—ideally with follow-up periods exceeding 5 years—are needed to establish definitive guidelines in this field.

Conclusion

The evidence suggests that immediate postablation mapping is an effective method for detecting and addressing immature prearrhythmic foci, potentially reducing AF recurrence and enhancing patient outcomes. While larger, multicenter studies are needed to confirm these findings, the results underscore the potential benefits of individualized treatment plans and advanced mapping techniques in AF management. Continued research in this area will be crucial to fully understanding the clinical implications and maximizing the benefits of this approach.

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Patient Consent: Written informed consent was obtained from all patients before the index procedure.

Ethics Statement: This study was conducted in accordance with the Declaration of Helsinki and was approved by the Institutional Review Board (21-011049).

Data Availability: The data underlying this article will be shared on reasonable request to the corresponding author.

Appendix

Supplementary Data

Supplementary data associated with this article can be found in the online version at https://doi.org/10.1016/j.hroo.2024.12.015.

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