

ORIGINAL ARTICLE

Correlation of pulmonary vein reconnection patterns after cryoballoon and duty-cycled ablation of atrial fibrillation with the time of arrhythmia recurrence

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Email: drmwieczorek@t-online.de**Abstract**

Background: Pulmonary vein isolation (PVI) is safe and effective in the treatment of atrial fibrillation (AF). We compare and correlate pulmonary vein (PV) reconnection patterns at repeat ablation in patients with recurrent AF after PVI using duty-cycled radiofrequency (RF) technology (PVAC) or second-generation cryoballoon (CB) with the time of AF recurrence.

Methods and Results: In total, 85 PVAC and 66 CB patients undergoing a second ablation were enrolled 9.7 ± 3.4 months after initial PVI. PV reconnections were comparably high between both groups (93% PVAC and 92% CB patients). A mean of 2.79 ± 1.2 PVs/patient were reconnected after PVAC PVI compared with 1.97 ± 0.8 in CB patients, $P < .0001$. 33% PVAC patients, but no CB patient had 4 reconnected PVs ($P < .0001$). Early AF recurrences were more frequently observed in PVAC patients with ≥ 2 reconnected PVs, in CB patients with ≥ 3 reconnected PVs (both $P < .01$) and patients without PV reconnection, irrespective of the ablation technique. One reconnected PV was associated with late AF recurrence only in CB patients. The correlation between number of reconnected PVs and time of AF recurrence was -0.32 for PVAC and -0.52 for CB.

Conclusions: CB PVI was associated with greater durability and lesser PV reconnections/patient. There were negative correlations for both devices between extent of PV reconnections and time of AF recurrence. CB patients with early AF recurrences—although less frequently observed compared with PVAC patients—had more reconnected PVs than PVAC patients, suggesting additional effects for AF prevention after CB PVI.

KEYWORDS

atrial fibrillation recurrence, cryoballoon, duty-cycled radiofrequency, pulmonary vein isolation, pulmonary vein reconnection

1 | INTRODUCTION

Pulmonary vein isolation (PVI) has proven safety and efficacy in the treatment of atrial fibrillation (AF). However, recovery of pulmonary vein (PV) conduction is a frequent observation in patients with recurrence of AF after PVI.^{1,2} In this scenario, repeat PVI can result in a significant improvement of freedom from AF.³

Little is known about the relationship between the time of AF recurrence and the patterns of PV reconnection found at repeat ablation in patients with AF recurrences. In this retrospective study, we compared PV reconnection pattern in patients undergoing repeat ablation after successful PVI with multielectrode duty-cycled radiofrequency technology (PVAC) or second-generation cryoballoon (CB). Both have shown to be safe and effective in PVI procedures.^{4,5} We expected to find different PV reconnection patterns depending of the ablation technique and hypothesized that more extensive PV reconnections are correlated with an earlier onset of AF recurrence after PVI.

2 | METHODS

2.1 | Patients

All patients undergoing a second electrophysiology study in our institution for AF recurrences after completing a blanking period of three months. The basis for retrospective data collection were patients with a first PVI performed between May 2013 and June 2018. Their patterns of PV reconnections found at redo PVI were retrospectively analyzed. In addition, the time of first AF recurrence was calculated for each patient. Patients with long persistent AF (>1 year) were not part of this study. Energy sources for first PVI were multielectrode duty-cycled radiofrequency (PVAC or PVAC Gold, Medtronic) in 85 and second-generation CB (Arctic Front Advance, Medtronic) in 66 patients, respectively. Patients with a need for touch-up ablation during the first procedure were excluded from this study. The ablation technique used in the index procedure was at the operator's discretion. Only patients completing regular follow-up visits in our institution until recurrence of AF were recruited for data analysis. All procedures were performed after written informed consent.

Both patient groups presented in this comparative study were part of other studies, characterizing and correlating PV reconnection patterns at redo PVI with recurrence of AF for each technology.^{6,7}

2.2 | Index procedure

2.2.1 | Duty-cycled radiofrequency PVI

Our general ablation protocol for PVI using PVAC has been described in detail elsewhere.^{8,9} In brief, PVAC and PVAC GOLD are steerable, 9-F, over-the-wire circular mapping and ablation catheters used in combination with the multichannel RF generator (GENius, Medtronic). The system can synchronously apply duty-cycled

phased unipolar/bipolar RF energy over 10- (PVAC) or 9 (PVAC GOLD) electrodes, where bipolar refers to adjacent electrodes. PVAC was advanced into the left atrium (LA) using a long steerable 9Fr sheath (Greatbatch Medical™) and directed over a guidewire placed in each PV towards the PV antrum. We recorded bipolar electrograms of PV potentials from all electrodes. Under deep analgesedation, ablation was started with a 2:1 bipolar/unipolar ablation mode. It was at the operator's decision to switch to a 1:1 mode, if PVI failed. Overlapping RF applications, with a maximum duration of 60 seconds each, were made while repositioning the PVAC after each application, until all PV potentials were eliminated. PVAC was also used for validation of bidirectional PV conduction block after a waiting period of 30 minutes.

2.2.2 | Cryoballoon PVI

After written informed consent, CB ablation was performed under mild conscious sedation, as described previously by our group.¹⁰ A 15- or 20-mm diameter inner lumen catheter (Achieve™, Medtronic) was placed in each targeted PV to record PV signals before, during and after ablation. Through a steerable sheath placed in LA (FlexCath™, Medtronic), the 28- or 23-mm CB (Arctic Front Advance™, Medtronic) was advanced over the Achieve catheter, inflated, and then directed to each PV ostium. Optimal vessel occlusion was assumed when contrast injection into the PV showed complete contrast retention without any backflow to the atrium. A single freeze protocol with a standard duration of 240 seconds at the beginning and later with 180 seconds duration was used with a target temperature of -40°C and/or PV isolation within 1 minute. Additional freezes, with different CB positions were applied if the first freeze was not successful or in the case of nadir temperature greater than -40°C . Phrenic nerve stimulation was performed during ablation of the right-sided PVs to minimize the risk of phrenic nerve palsy by a steerable multipolar catheter placed in the superior vena cava (cycle length 1000 ms, 15 mA/3.0 ms pulse width). To distinguish atrial far-field signals from PV potentials, coronary sinus pacing from different sites was performed, if necessary. PVI with verified entrance and exit block or absence of any electrical signal for ≥ 30 minutes was performed by the achieve catheter.¹⁰

2.2.3 | Definition and ablation strategy of left common trunk (LCPV)

A LCPV was defined as a bifurcated PV entering the LA contour together at a distance between the virtual border of the LA and the bifurcation of both PVs > 5 mm.

LCPV isolation with CB

If an antral occlusion of the LCPV, validated by contrast injection, could be obtained, a freeze was initiated. Otherwise, a sequential ablation approach targeting each PV branch was used.

LCPV isolation with PVAC

To avoid stenosis of the targeted LCPV, PVAC was always positioned antrally. Multiple PVAC rotations around the LCPV ostium followed by energy applications were performed, until LCPV isolation was achieved.

2.2.4 | Repeat ablation procedure

A hexapolar electrode catheter was placed in the coronary sinus (CS) for pacing and bipolar recordings. After transseptal puncture, a long steerable sheath (FlexCath or Greatbatch Medical) was inserted into the LA to delineate all PVs angiographically. All PVs were then assessed for PV-LA reconnection. PV reconnection was determined at the onset of the procedure using different multipolar circular catheters: 20 mm inner lumen mapping catheter Achieve (Medtronic), Lasso (Biosense Webster Inc) or Advisor (Abbott, St. Jude Medical), as preferred by the operator. The catheters were placed in each PV with evaluation for PV potentials. PVs ostia were divided into the segments superior, inferior, anterior, and posterior. Each segment covered with a mapping bipole was counted as conduction gap in case of a detectable PV signal. Electric isolation of PVs was confirmed by entrance and exit block for each PV, assessed by Achieve, Lasso or Advisor catheter positioned at the PV antrum and inside the PV, as necessary. All PVs with PV-LA reconnection were targeted for re-isolation with PVAC GOLD or CB. Point-by-point open-irrigated RF-energy was preferentially used for re-isolation of LCPVs.

2.3 | Follow-up strategy

All our patients underwent routine follow-up visits in an outpatient clinic every three months after the index ablation procedure or earlier in case of symptoms. In patients with early and/or recurrent symptomatic episodes of AF, antiarrhythmic drug (AAD) therapy was temporarily used and terminated again after completing the blanking period of three months or at least 1 week before the first follow-up visit. Amiodarone therapy was terminated immediately after re-ablation. At each follow-up interval, starting three months after the initial procedure, a 3-day Holter monitor recording was performed without AAD therapy. Patients were asked to contact our hospital in case of ongoing palpitations. We defined freedom from AF as the absence of AF lasting >30 seconds. Detection of regular atrial arrhythmias during follow-up was not counted as recurrence from AF. AF detection within 6 months after blanking (4–9 months) was arbitrarily defined as “early” recurrence, in contrast to “late” recurrence, occurring ≥10 months.

2.4 | Statistical analysis

All continuous variables are reported as mean ± standard deviation (SD) and were compared by student's *t* test, Mann-Whitney *U* test or

Wilcoxon test. Categorical variables were compared by chi-square or Fisher's exact method, as appropriate. A two-tailed *P* value <.05 was considered to be statistically significant. Correlation was calculated using Spearman's correlation coefficient. A linear regression model was used for significance analysis. All statistical analysis was performed using GraphPad Prism software, version 8.

3 | RESULTS

3.1 | Study population and first ablation data

A total of 151 patients were included in this study with a mean age of 60 ± 15 years, male dominance (63%), moderate LA enlargement (43 ± 5 mm), average CHA2DS2-VASc-score 2.3, paroxysmal AF in 65% and mean left ventricular ejection fraction of 56%. Hypertension was present in 53%, coronary artery disease in 25%, chronic obstructive pulmonary disease in 11%. No heart disease was diagnosed in 48% of the patients. Eighty-five patients were initially treated with PVAC (11 with PVAC, 74 with PVAC Gold), while 66 patients had received CB PVI. Baseline clinical characteristics were similar between both group (Table 1). Table 2 presents procedural data for both devices obtained during first ablation.

3.2 | Reconnection patterns at repeat ablation

Average time until recurrence of AF after ablation was 8.5 ± 3.1 months for all patients. Recurrence time was significantly shorter for PVAC patients compared with CB patients (8.1 ± 3.4 vs 9.1 ± 2.6 , $P = .0066$). A redo ablation procedure was performed in all 151 patients after a mean of 9.7 ± 3.4 months, with a shorter time interval for PVAC- (9.2 ± 3.8 months) compared with CB patients (10.4 ± 2.9 months), $P = .0063$. However, mean time delay between redetection of AF and re-ablation was comparable (1.1 ± 0.9 months for PVAC and 1.3 ± 0.9 for CB). Electrophysiological characteristics of both groups at the time of re-ablation are presented in Table 1. In both groups the percentage of patients with PV reconnection(s) was comparably high: 93% in the PVAC and 92% in the CB group. In the PVAC group, 237 out of 315 initially isolated PVs/LCPVs (75%) were reconnected to LA, while 130 out of 250 PVs/LCPVs (52%) were reconnected in the Cryo group ($P < .001$). As a result, a mean of 2.79 ± 1.2 PVs and LCPVs/patient were reconnected after PVAC PVI compared with 1.97 ± 0.8 in CB patients, $P < .0001$. 94% of the LCPVs -counted as 1 PV- in the PVAC group were reconnected, in contrast to 60% in the Cryo group ($P = .0473$). The distribution of patients with 0, 1, 2, 3, and 4 reconnected PVs is presented in Table 1 for each group. No patient in the CB group had 4 reconnected PVs, while this pattern of reconnection was observed in 33% of the PVAC group ($P < .0001$). As a result, the percentage of patients in the PVAC group with ≥3 reconnected PVs was significantly higher compared with CB patients (56 patients (66%) vs 17 patients (26%), $P < .0001$), while the percentage of patients with no PV reconnection was comparably

TABLE 1 Clinical and electrophysiological characteristics of the enrolled patients (N = 151)

	PVAC N = 85	CB N = 66	P value
Age (y)	58 ± 17 [31-72]	63 ± 12 [29-83]	ns
Male	56 (66)	39 (59)	ns
CHA ₂ DS ₂ -VASc-score	2.2 [0-5]	2.4 [0-5]	ns
Left atrial diameter (mm)	43 ± 4 [37-50]	42 ± 6 [36-53]	ns
Implantable cardiac devices ^a	6 (7)	7 (11)	ns
Paroxysmal AF	58 (68)	40 (60)	ns
No. of antiarrhythmic drugs	1.4 ± 1.3 [0-3]	1.1 ± 1.2 [0-3]	ns
Amiodarone therapy	17 (20)	12 (18)	ns
Hypertension	42 (49)	38 (58)	ns
Coronary artery disease	22 (26)	15 (23)	ns
Chronic obstructive pulmonary disease	9 (11)	7 (11)	ns
No structural heart disease	44 (52)	28 (42)	ns
Left ventricular ejection fraction (%)	57 ± 8	54 ± 7	ns
Isolated PVs/ LCPVs at initial procedure	298/17	240/10	ns
Pts. with PV reconnections	79 (93%)	61 (92%)	ns
Reconnected PVs and LCPVs at redo procedure	237/315 (75%)	130/250 (52%)	<.0001
PV reconnections per patient ^b :	2.79 ± 1.2	1.97 ± 0.8	<.0001
Pts. with 4 reconnected PVs	28 (33%)	0 (0%)	<.0001
Pts. with 3 reconnected PVs	28 (33%)	17 (26%)	ns
Pts. with 2 reconnected PVs	18 (21%)	35 (53%)	.0001
Pts. with 1 reconnected PV	5 (6%)	9 (14%)	ns
Pts. without reconnected PVs	6 (7%)	5 (8%)	ns

Note: Data are numbers with mean ± SD, range [] and % in (); ns: no significant difference.

^aPacemaker, implantable cardioverter/defibrillator, event recorder, PTs patients, CB 2nd generation cryoballoon, PVs pulmonary veins, LCPVs left common PVs trunks.

^bIn patients with a reconnected LCPV, LCPV was considered and counted as one PV, ns not significant.

TABLE 2 Ablation Characteristics during First PVI

	PVAC/PVAC Gold
Cumulative energy until PVI/pt (J)	64 812 ± 1965 [3187-82644]
Energy applications/pt	26 ± 5 [9-41]
Activated electrodes/application	5 ± 3 [2-10]
Active electrodes/pt	134 ± 32 [101-177]
Energy transmission time (min)	24 ± 5 [11-42]
	CB2
Applications/pt until PVI	6 ± 1 [3-14]
Minimum CB temperature (°C)	-48 ± 8 [-41 to -65]
Freeze-cycle duration until PVI (s)	51 ± 21 [39-77]
Total freeze-cycle duration (s)	209 ± 35 [83-240]

low in PVAC and CB patients (7% and 8%, respectively). In 60 CB and 71 PVAC patients it was possible to determine the reconnection gap(s) with the achieve catheter, whereas in the remaining patients the exact location of the gap remained unknown. In total, 102 reconnection gaps were identified in 66 CB patients compared with 135

gaps in 85 PVAC patients. The location of the most frequently reconnected segment(s) for each group is presented in Figure 1."

3.3 | Time of AF recurrence and PV reconnection: All patients

The number of all *patients* with early AF recurrences (101/151) was higher compared with those having late recurrences (50/151), $P < .0001$ (Figure 2). This result was strongly influenced by a high number of PVAC patients with early recurrences (64/85), while a comparable effect was not observed for CB patients (37/66 patients with early AF recurrences, $P = .2229$). A comparison between early- and late AF recurrences for each PV subgroup is illustrated in Figure 3 for all patients: patients with 4, 3 or no reconnected PVs were more likely to experience AF recurrences in the early period after blanking compared with those with late recurrence ($P < .001$ for all). Patients with 1 reconnected PV had a trend for later AF recurrences ($P = .0570$), while patients with 2 reconnected PVs tended to have earlier recurrences during follow-up ($P = .0516$). Of note, 10/11 patients without PV reconnection had their first AF

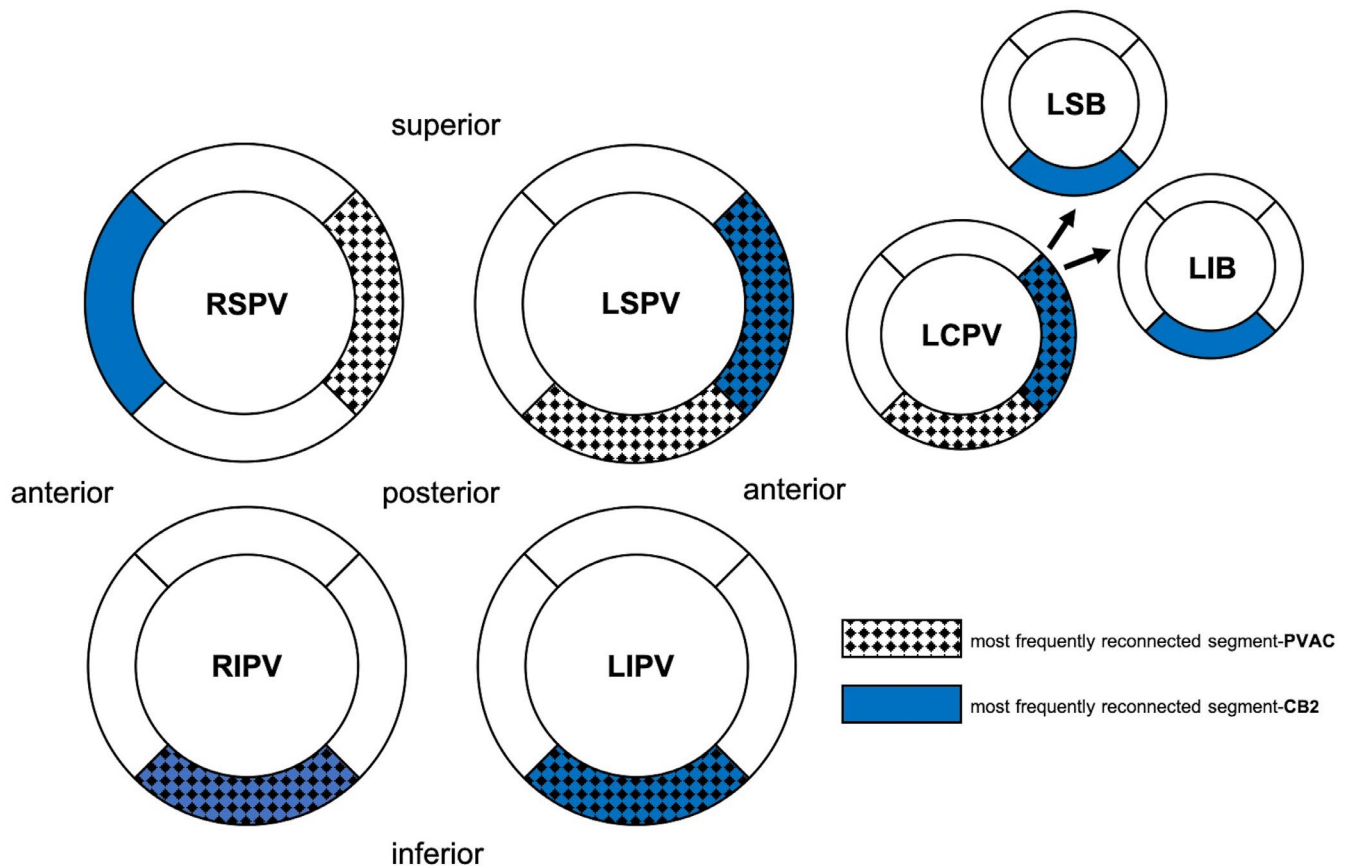


FIGURE 1 Distribution pattern of the most frequently reconnected PV segment(s) found at repeat ablation and calculated for each device. CB2, 2nd generation cryoballoon; LCPV, left common pulmonary vein; LIB, left inferior branch; LIPV, left inferior pulmonary vein; LSB, left superior branch; LSPV, left superior pulmonary vein; PVAC, pulmonary vein ablation catheter; RIPV, right inferior pulmonary vein; RSPV, right superior pulmonary vein

episode in the early period after blanking ($P = .0003$). For all 140 patients with proven PV reconnection(s), we observed a moderate, but significant negative correlation between extent of PV reconnection and time of first AF recurrence ($R = -.39$), which is presented in Figure 4.

3.4 | Time of AF recurrence and PV reconnection: PVAC patients

A total of 56/74 PVAC patients with 2, 3, or 4 reconnected PVs experienced AF episodes early after 4-9 months, compared with 18 patients with late recurrences ($P < .01$ for each subgroup). The same difference between early and late recurrences was observed for patients with 0-2 reconnected PVs ($n = 29$) or 3-4 reconnected PVs ($n = 56$), $P = .0001$ for each subgroup. No differences between early and late recurrences were found for patients with 1 or no reconnected PV (Table 3). The correlation between time of first AF recurrence after PVI and the pattern of PV reconnection at redo procedure is presented in Figure 4. There was a significant negative correlation in patients with proven PV reconnection between the number of reconnected PVs and the time of AF recurrence: more

reconnected PVs were correlated with earlier AF recurrences after completing the blanking period.

3.5 | Time of AF recurrence and PV reconnection: CB patients

No difference was observed between the number of CB patients with AF recurrences within the first 9 months and the time beyond (Figure 2).

All five patients without PV reconnection had early AF recurrences. The same effect was observed for patients with 3 reconnected PVs: 14/17 patients had early AF episodes after the blanking period ($P = .0004$), while 8/9 patients with a single reconnected PV experienced late AF recurrences ($P = .0034$). Patients with 2 reconnected PVs showed equally distributed AF recurrence during follow-up (17 patients with early, 18 patients with late recurrence, respectively). As we did not observe a single patient with 4 reconnected PVs after CB PVI, subgrouping CB patients into categories with 0-2, 3-4, or 3-4 PVs was not performed (Table 3). After excluding patients without PV reconnection from analysis, a significant negative correlation between the number of reconnected PVs

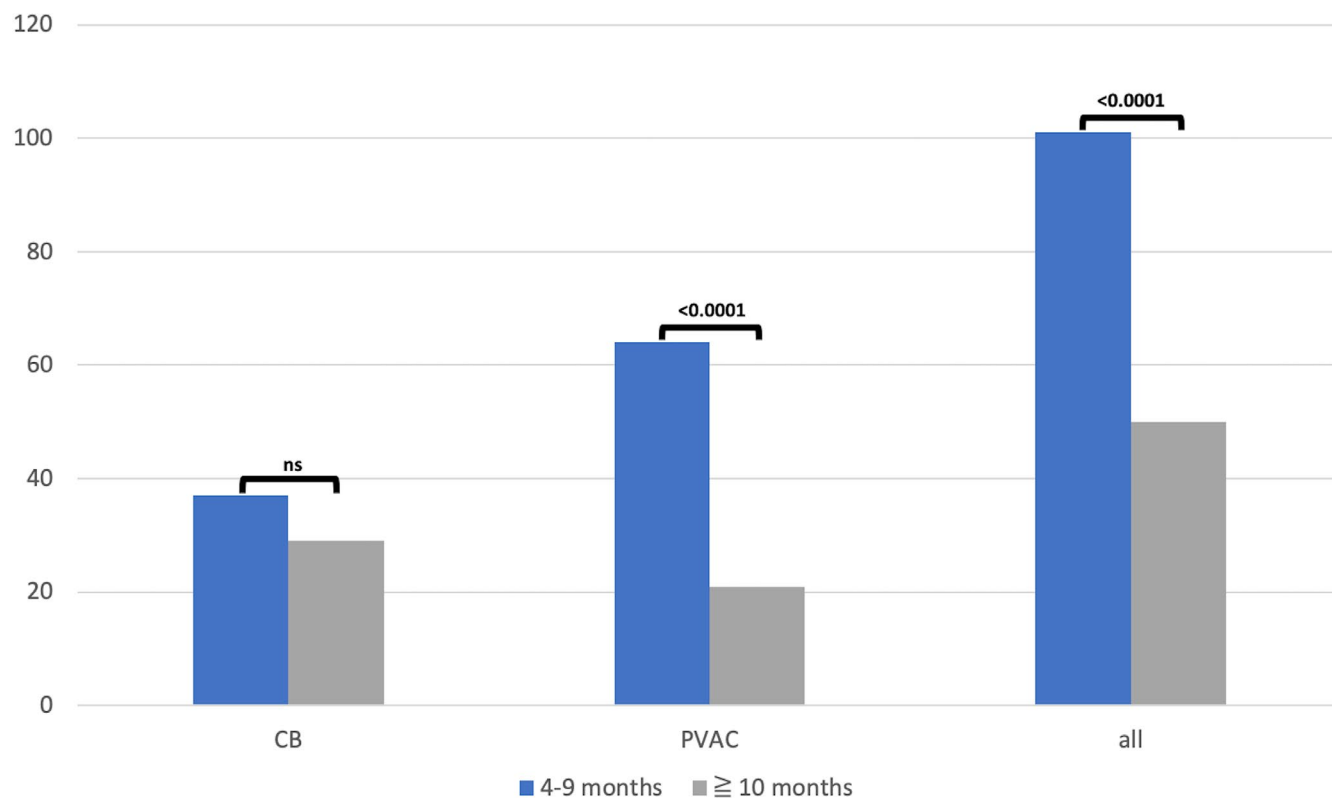


FIGURE 2 Number of pulmonary vein ablation catheter and cryoballoon patients with early (4-9 mo) and late (≥10 mo) recurrences of atrial fibrillation

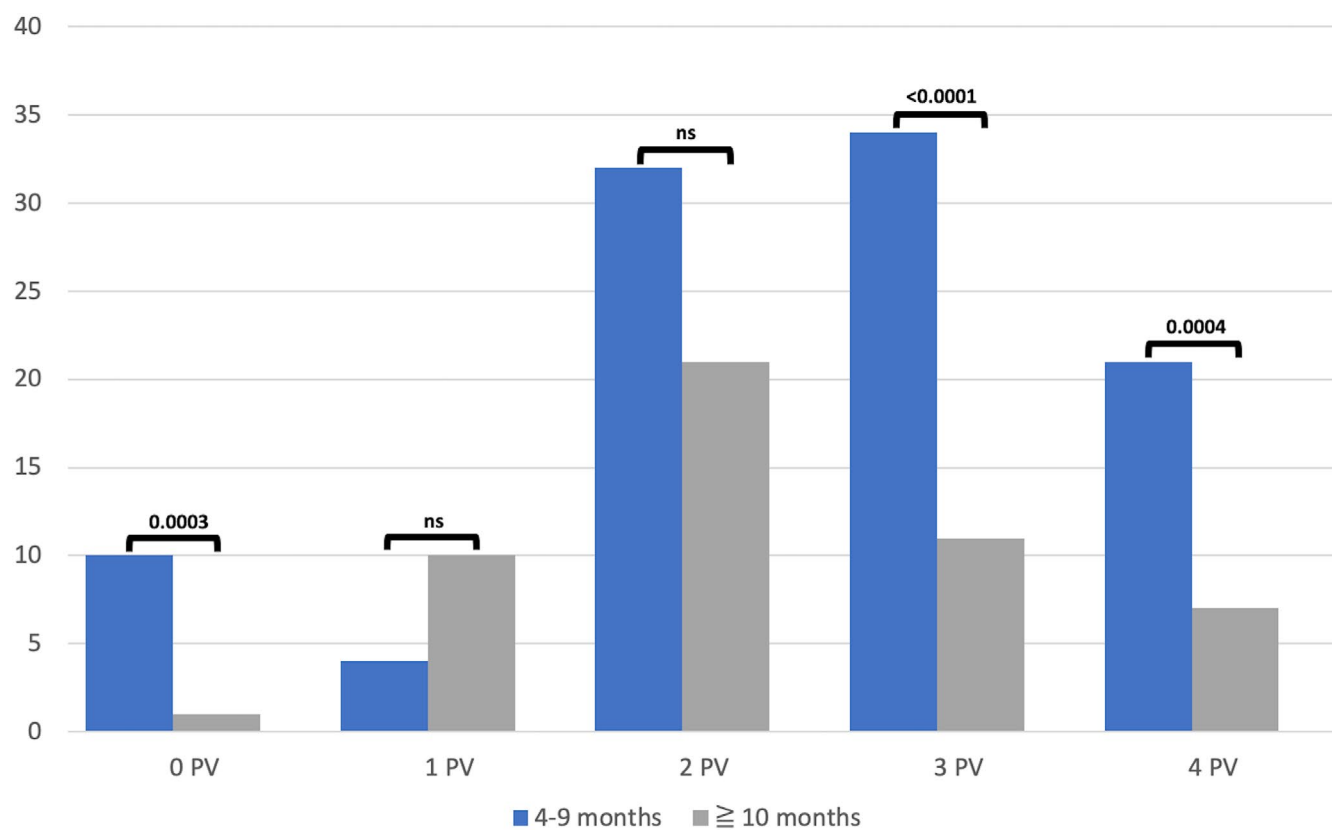
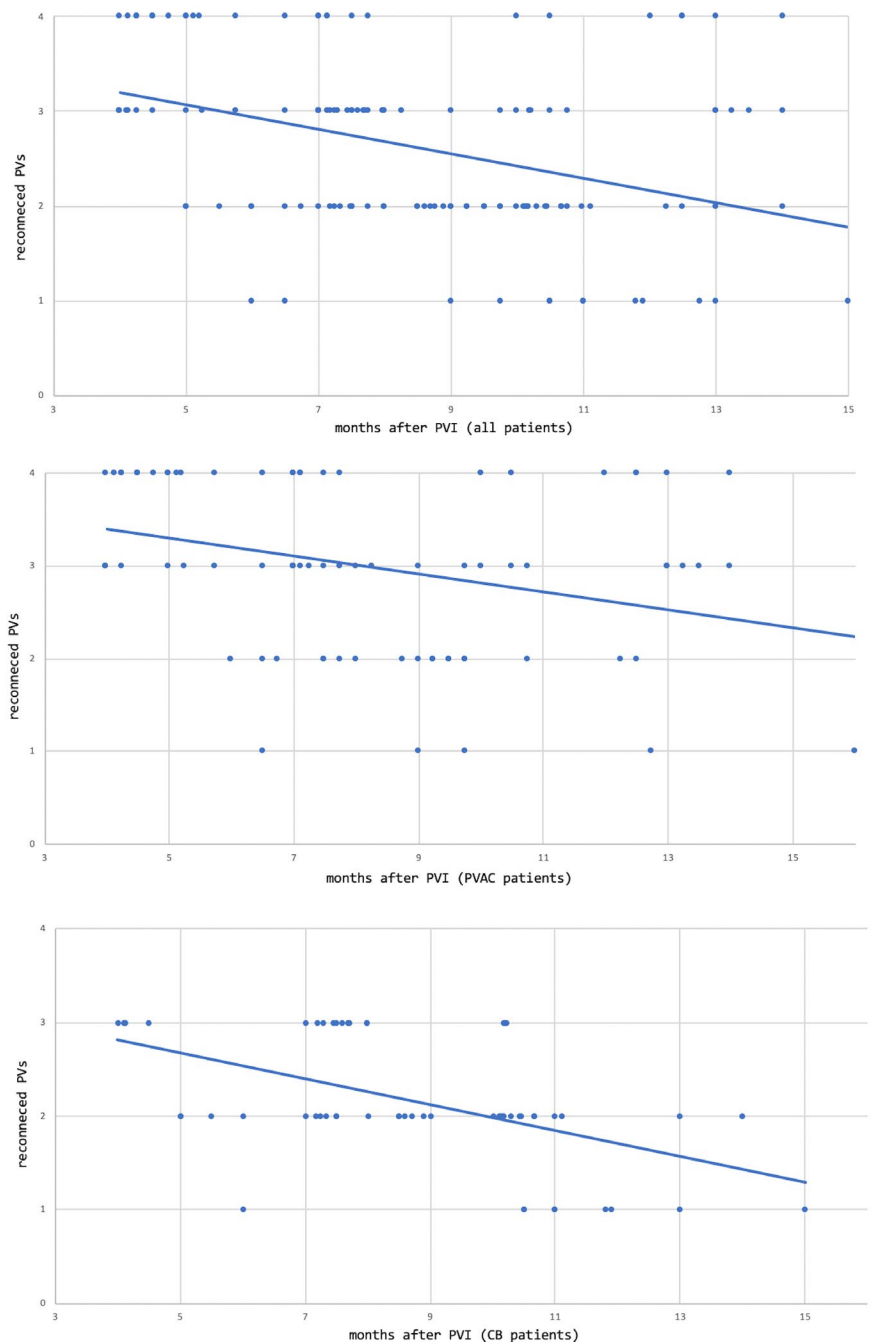


FIGURE 3 Number of reconnected pulmonary veins (PV) in 151 patients undergoing repeat pulmonary vein isolation and corresponding time period with first recurrence of atrial fibrillation

FIGURE 4 Correlation between time of first recurrence of atrial fibrillation and number of reconnected pulmonary veins (PVs) at repeat ablation calculated for all patients (upper panel), pulmonary vein ablation catheter patients (middle panel), and cryoballoon patients (lower panel). Solid lines represent linear regression lines



and the time of AF recurrence after blanking was found ($R = -.52$, $P < .001$) as presented in Figure 4.

3.6 | Time of AF recurrence and PV reconnection: PVAC- vs CB patients

Sixty-four of 85 (75%) of the PVAC patients experienced early AF recurrences within 4–9 months after blanking, compared with 37/65 (56%) CB patients ($P = .015$), as shown in Figure 5. Table 3 shows the relationship between different PV reconnection patterns and

the time of first AF recurrence for PVAC and CB patients with the following results.

Most PVAC patients with more than 1 reconnected PV experience AF episodes within the first 9 months ($P < .01$ for 2, 3, or 4 reconnected PVs), while this effect was only observed for CB patients with 3 reconnected PVs ($P = .0004$). Differences in late AF recurrences were only observed in CB patients with 1 reconnected PV ($P = .0034$) but not in PVAC patients. We further found that all 5 CB patients without PV reconnection experienced early AF recurrences ($P = .0079$) compared with a trend for early recurrences observed in 5/6 PVAC patients ($P = .0801$).

4 | DISCUSSION

4.1 | Main findings

Most patients with AF recurrence after PVAC- or CB PVI had PV reconnection(s) at the time of repeat ablation with more reconnected

TABLE 3 Patterns of PV reconnections and AF recurrence time in PVAC and CB patients

	4-9 mo	≥10 mo	P value
PVAC			
0 PV	5	1	0.0801
1 PV	3	2	1.0000
2 PV	15	3	0.0002
3 PV	20	8	0.0029
4 PV	21	7	0.0004
0-2 PV	23	6	0.0001
3-4 PV	41	15	0.0001
All	64	21	<0.0001
CB			
0 PV	5	0	0.0079
1 PV	1	8	0.0034
2 PV	17	18	1.0000
3 PV	14	3	0.0004
0-2 PV	23	26	0.6864
All	37	29	0.2229

Bold values indicate significant differences for $P < 0.05$.

PVs/patient found after PVAC PVI. While the time of first AF recurrence after blanking was negatively correlated with the number of reconnected PVs for both technologies, most PVAC patients experienced AF recurrences early during follow-up in contrast to CB patients. Among patients with early AF recurrences, CB patients had more reconnected PVs than PVAC patients. Most patients without reconnected PVs experienced early AF recurrences, irrespective of the ablation technology.

4.2 | PV reconnection patterns after PVAC and CB PVI

PV reconnection is the characteristic finding in patients with recurrent AF after PVI.¹ In the past, diverging PV reconnection rates in patients with recurrent AF have been reported for different ablation strategies: after PVAC PVI, Rademakers et al found an average of 3.2 ± 0.7 reconnected PVs/patient and 46% of their patients had reconnections of three PVs.¹¹ Comparable results were reported by Balt et al after PVAC PVI: 98% of their patients showed PV reconnection(s) at repeat ablation with 34% exhibiting reconnections of 3 PVs.¹² Similarly, we detected PV reconnections in 93% of our patients and in 75% of the previously isolated PVs after PVAC PVI with a mean of 2.79 ± 1.2 reconnected PVs per patient and 66% of our patients had reconnections of 3 PVs. These results after PVAC PVI indicate that significant PV reconnections must be expected at repeat ablation. In contrast to PVAC PVI, Shah et al found an average

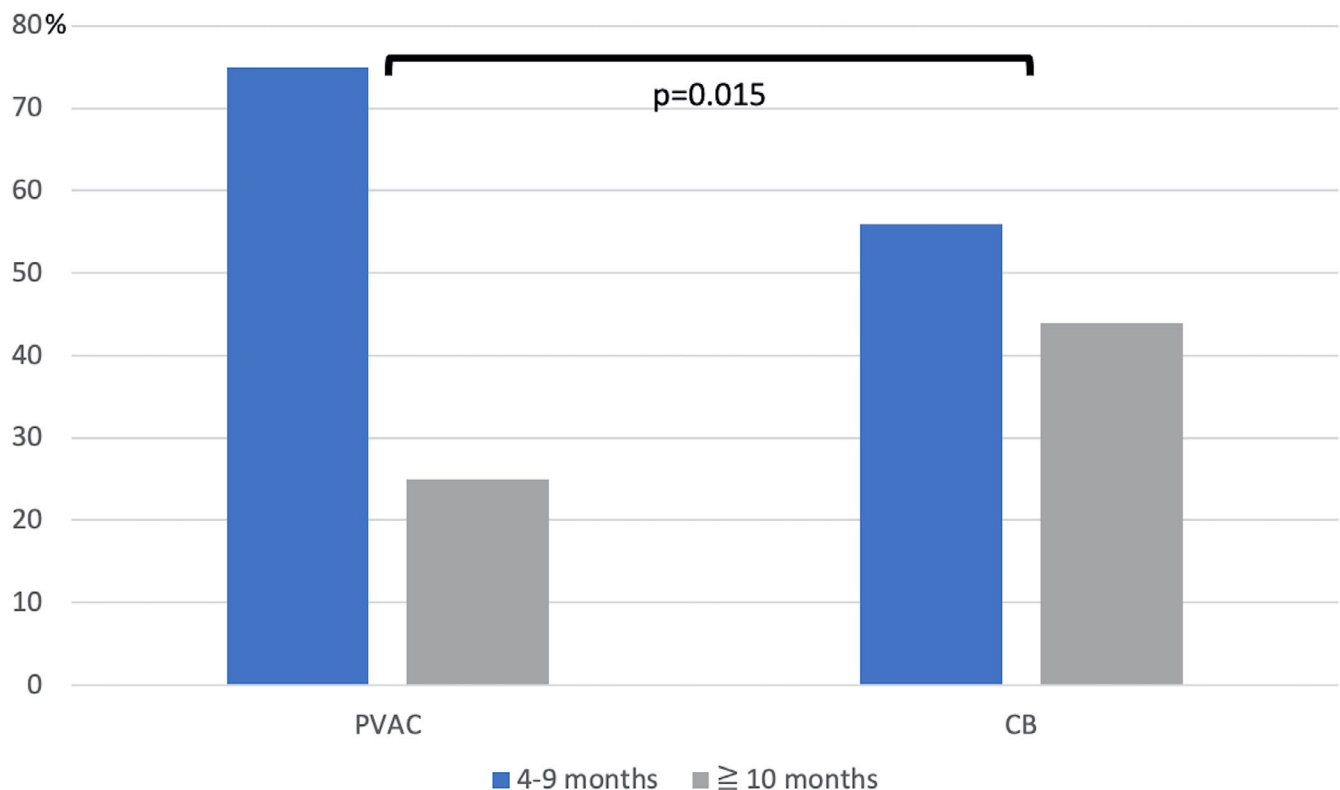


FIGURE 5 Comparison of percentage of patients with first recurrences of atrial fibrillation early (4-9 mo) and late (≥10 mo) after pulmonary vein ablation catheter and cryoballoon pulmonary vein isolation

PV reconnection rate after CB PVI of 2.1 ± 0.8 PVs/patient, which is comparable with our data of 1.97 ± 0.8 reconnected PVs/patient.¹⁰

While the number of patients with PV reconnections was not different between both groups, more PVs and PVs/patient were found reconnected after PVAC PVI. Our data suggest, that duty-cycled RF energy for PVI creates less durable lesions compared with CB ablation. The reported higher PV reconnection rates after conventional radiofrequency PVI compared with CB ablation, observed by other authors^{13,14} can be explained by the mechanism of cryoablation, which in case of optimal vein occlusion, creates more uniform lesions surrounding pulmonary veins ostia.

4.3 | Patterns of PV reconnection and time of AF recurrence

Prior studies could demonstrate that most patients with AF recurrences after PVI had PV reconnections at the time of redo PVI and that PV re-isolation can increase freedom from AF.³ There are data suggesting that PV reconnections patterns of patients with- and without AF recurrence after PVI are not significantly different.^{15,16} This would be in favour of other catheter interventions besides redo PVI possibly resulting in improved clinical outcome. For both, PVAC- and CB patients with PV reconnection(s) at redo PVI, we found negative correlations between the extent of PV reconnection and the time of recurrence of AF. To the best of our knowledge, this is the first study to compare and associate the time of AF recurrence after PVI for different technologies with patterns of PV reconnection. We observed that multiple PV reconnections (≥ 3 PVs) were associated with earlier AF recurrences compared with less extensive PV reconnections. The only subgroup of patients with later AF recurrences during follow-up were CB patients with a single reconnected PV at redo PVI. Of note, in both PVAC- and CB patients, we found that the majority of patients without PV reconnection had early AF recurrences. These findings could be explained as follows: with a higher number of silently reconnected PVs the probability for reconnection of an arrhythmogenic PV causing AF increases. The possibility of triggering silent arrhythmogenic foci inside a reconnected PV by other rapidly firing reconnected PVs is enhanced with an increasing number of reconnected PVs, resulting in a dynamic interaction of firing and triggering between multiple reconnected PVs, as described by Kumagai et al.¹⁷ Rapid focal activation arising from PVs may be important not only as a trigger of onset, but also in the maintenance of AF. Using an empirical ablation approach when targeting all electrically connected PVs for ablation, the individual mechanism of AF initiation and/or perpetuation is generally not identified. This could explain the observation in our study, that the majority of PVAC- and CB patients without PV reconnection had early AF recurrences, as the mechanism of AF in these patients may not be rooted in the PVs. Other ectopic sources triggering AF have been identified outside the PVs and can be located in the crista terminalis, vena cavae, coronary sinus, ligament of Marshall, the appendages and others.^{18,19}

The fact that CB patients with early AF recurrence showed more extensive PV reconnections compared with PVAC patients

suggests additional protective effects after PVI using second-generation 28-mm CB compared with PVAC: multiple antral PVAC lesions around the PV ostium to achieve PVI are expected to be less homogeneous compared with CB lesions created with 28-mm second-generation CB, which might have contributed to the observed difference.

5 | STUDY LIMITATIONS

As our study is a retrospective, nonrandomized, and single-center analysis of AF patients undergoing a second procedure following an index PVI with PVAC or CB unadjusted confounders may have been present and influenced our findings. The treatment allocation was nonrandomized, so we cannot exclude unknown factors which may have influenced either treatment arm. Patients with asymptomatic AF recurrence during follow-up may have been undetected and thus not recruited for this study. However, it seems unlikely that this would have served as a significant source of bias between the two treatment arms. The exclusive use of different circular catheters in our study for detection of PV reconnections might have underestimated its true incidence, as no 3D mapping system was used at the time of redo ablation to compensate for this limitation. There was no control group of patients without AF recurrences after PVI. Therefore, the pathophysiological impact of our findings with the view of AF recurrences resulting from PV reconnection alone remains unclear.

6 | CONCLUSION

At redo ablation most patients after PAVC- and CB PVI had PV reconnection. But the extent and patterns of reconnected PVs were different in many aspects. CB PVI was associated with greater durability and lesser PV reconnections/patient compared to PVAC ablation. There were significant negative correlations for both devices between extent of PV reconnections and time of AF recurrence. CB patients with early AF recurrences although less frequently observed compared with PVAC patients had more reconnected PVs than PVAC patients, suggesting additional effects for AF prevention after CB PVI.

CONFLICT OF INTEREST

All authors declare no conflict of interests for this article.

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