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Clinical outcomes of pulsed field versus radiofrequency ablation, incorporating posterior wall isolation, in persistent atrial fibrillation

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ABSTRACT

Background Persistent atrial fibrillation (AF) remains challenging to treat with catheter ablation. The left atrial posterior wall (PW) may represent an important non-pulmonary vein (PV) substrate; however, randomised trials have not demonstrated improved outcomes with adjunctive PW isolation (PWI), potentially reflecting technical limitations of thermal ablation rather than a lack of mechanistic relevance. Pulsed-field ablation (PFA) is a non-thermal ablation modality that selectively targets myocardial tissue and may enable safer and more consistent PWI. We compared real-world outcomes of PFA and radiofrequency ablation (RFA) for combined PV isolation and PWI in patients with persistent AF.

Methods 200 consecutive patients (100 PFA and 100 RFA) undergoing combined PVI and PWI were retrospectively followed for up to 12 months. Baseline characteristics were broadly similar; however, PFA patients had lower left ventricular ejection fraction (LVEF) (43.5% (35.5–55.5%) vs 47% (40–58), p=0.01) and higher CHA_2DS_2-VA risk score (3 (2–4) vs 2 (1–3), p=0.01). Primary outcomes were acute procedural success and freedom from recurrent atrial tachyarrhythmia (AT) at 6 and 12 months.

Results PFA achieved near-universal PWI compared with RFA (99% vs RFA: 65%, p<0.005), with shorter procedure duration (106 vs 143.5 min, p<0.005), reduced left atrial dwell time (62 vs 98 min, p<0.005), and faster time to PVI and PWI (all p<0.005). Major non-vascular complications were uncommon (1.5%) and similar between groups. At 12 months, freedom from recurrent AT was higher with PFA (70% vs RFA 54%, p=0.03), with lower odds of first detected AT recurrence in adjusted time-to-event analysis (OR 0.46 (0.26–0.82), p=0.009).

Conclusions In this real-world cohort, PFA was associated with a higher rate of acute PWI and greater freedom from AT compared with RFA, without a signal of increased complications. Prospective randomised studies are needed to define the role of PWI delivered with PFA in patients with persistent AF, including those with reduced LVEF.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Catheter ablation using radiofrequency thermal energy is an established treatment for atrial fibrillation; however, outcomes in patients with persistent AF remain suboptimal.
⇒ Randomised trials evaluating adjunctive posterior wall isolation (PWI) with radiofrequency ablation (RFA) have not demonstrated a consistent benefit beyond pulmonary vein isolation (PVI) alone, in part due to technical challenges in achieving effective PWI and concerns about collateral injury with thermal energy delivery.
⇒ Pulsed-field ablation (PFA) is a non-thermal ablation modality capable of selective myocardial ablation via electroporation and may address some of the limitations of RFA. However, comparative real-world data evaluating PFA against RFA for PWI in persistent AF remain limited.

INTRODUCTION

Over the past three decades, a deeper understanding of the underlying pathophysiological mechanisms, the refinement of electroanatomical mapping (EAM) and advancements in ablation technology have enabled effective and precise targeting of arrhythmogenic triggers during atrial fibrillation (AF) ablation. Pulmonary vein isolation (PVI) has established itself as the most effective strategy in this endeavour.[1] However, in patients with persistent AF, including longstanding persistent AF, the outcomes from PVI alone remain suboptimal,[2] and the underlying mechanisms are demonstrably more widespread.[3] Despite advances, the optimal ablation strategy for persistent AF remains to be defined.[4]

Interest in non-PV substrates has evolved as our understanding of left atrial (LA) anatomy has shifted from a two-dimensional plane to a three-dimensional (3D) structure.[5] Transmurality is understood to be essential

WHAT THIS STUDY ADDS

⇒ In a real-world cohort of 200 patients with persistent AF, PFA achieved near-universal PWI (99% vs 65% with RFA) with significantly shorter procedural duration.

⇒ Freedom from recurrent atrial tachyarrhythmia at both 6 and 12 months was higher following PFA, despite a higher baseline clinical risk for arrhythmia recurrence.

⇒ Major complications were uncommon and occurred at similarly low rates in both treatment groups, with no signal of increased procedural risk associated with PFA.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Our study demonstrates that PFA may facilitate more consistent endocardial PWI in patients with persistent AF, without an apparent increase in procedural risk.

⇒ The feasibility of performing PFA with reduced reliance on electroanatomical mapping highlights the potential for more efficient workflows and improved resource utilisation in selected, experienced centres.

⇒ Our data provide the rationale for prospective randomised trials to evaluate the clinical impact of PWI delivered with PFA, including in patients with persistent AF and concomitant heart failure.

for success,[6] with incomplete lesions increasing the risk of creating a pro-arrhythmogenic substrate,[7] particularly in this third plane.[8] Among non-PV targets, the posterior wall has attracted particular attention due to its unique embryological origin, distinctive electrophysiological properties[9] and susceptibility to endo-epicardial dissociation.[10] In contemporary practice, the decision to perform posterior wall isolation (PWI) is often guided by patient-specific features, including AF duration, LA myopathy and the presence of PW scar detected during EAM. Real-world data suggest its adoption is increasing, particularly in such patients. Registry data from over 20 centres in the United States reported its use in 24% of primary AF ablation cases between 2016 and 2018,[11] and in nearly 50% of cases between 2021 and 2022.[12] Furthermore, it is a key component in surgical, minimally invasive and hybrid AF ablation strategies, which have been reported to improve rhythm outcomes in persistent AF.[13 14]

Despite its widespread use in clinical practice, endocardial catheter ablation for PWI has not reliably demonstrated a benefit over PVI alone in randomised trials.[15] An explanation for the apparent disparity may lie in the lack of efficacy of the percutaneous strategies studied. Traditionally, AF ablation has utilised temperature-controlled destruction of atrial myocytes. Transmural PWI is often challenging with this approach due to anatomical complexities and the risk of collateral injury,[16] leading to the well-recognised suboptimal durability of PWI.[17] The advent of non-thermal pulsed-field ablation (PFA), which can selectively target atrial myocytes via electroporation,[18] theoretically permits safer and more consistent LA ablation.[19] However, despite these potential advantages, real-world head-to-head comparative data comparing PFA and radiofrequency ablation (RFA) are scarce. We aim to address this gap by comparing procedural characteristics, safety and arrhythmia outcomes of PFA and RFA in patients undergoing PVI and PWI for persistent AF.

METHODS

Study design

The study was a physician-initiated, single-centre, retrospective analysis of 200 patients with persistent AF (defined as persistent or longstanding persistent AF per contemporary guidelines)[4], undergoing ablation at St. George's Hospital, UK, between October 2021 and October 2024. The study comprised 100 consecutive patients who underwent PVI and PWI with PFA and 100 consecutive patients who underwent PVI and PWI with RFA. Both PFA and RFA procedures were performed during overlapping time periods within the study window. All procedures were in accordance with the ethical standards outlined in the Declaration of Helsinki.

Patient and public involvement

Patients were not involved in the design or conduct of this study. All participants provided consent for their ablation procedure as part of standard clinical care in accordance with local requirements, and patient feedback on procedural experience contributes to ongoing quality improvement within the centre.

Patient selection

Consecutive patients undergoing catheter ablation (comprising PVI and PWI only) for persistent AF were included, provided they had completed a minimum of 6 months of clinical follow-up, which constituted the eligibility threshold for inclusion. Procedures could be first-time ablation (de novo) or repeat (redo) ablations; however, repeat ablation procedures were only eligible if the presenting rhythm was AF; any patients presenting with atrial tachycardia or atrial flutter were excluded. Patients were followed longitudinally for up to 12 months, with time-to-event analyses evaluated at 6-month and 12-month intervals. In all cases, the decision to proceed to PWI above PVI alone was planned a priori and guided by clinical assessment and individual patient characteristics, including AF chronicity, LA size and electroanatomical mapping (EAM) findings, suggesting advanced atrial remodelling or PW substrate. The approach to each strategy is detailed below:

Radiofrequency Ablation (RFA)

RFA procedures were performed under general anaesthesia (GA) on uninterrupted anticoagulation. Baseline transoesophageal echocardiography (TOE) was performed to exclude LA thrombus, and femoral access was gained under ultrasound guidance. Once LA access was established, intravenous heparin was administered to achieve an activated clotting time of ≥350 s. EAM was routinely used to facilitate ablation. PVI and PWI comprised wide-area circumferential ablation (WACA) and a posterior box (figure 1A) and were achieved using

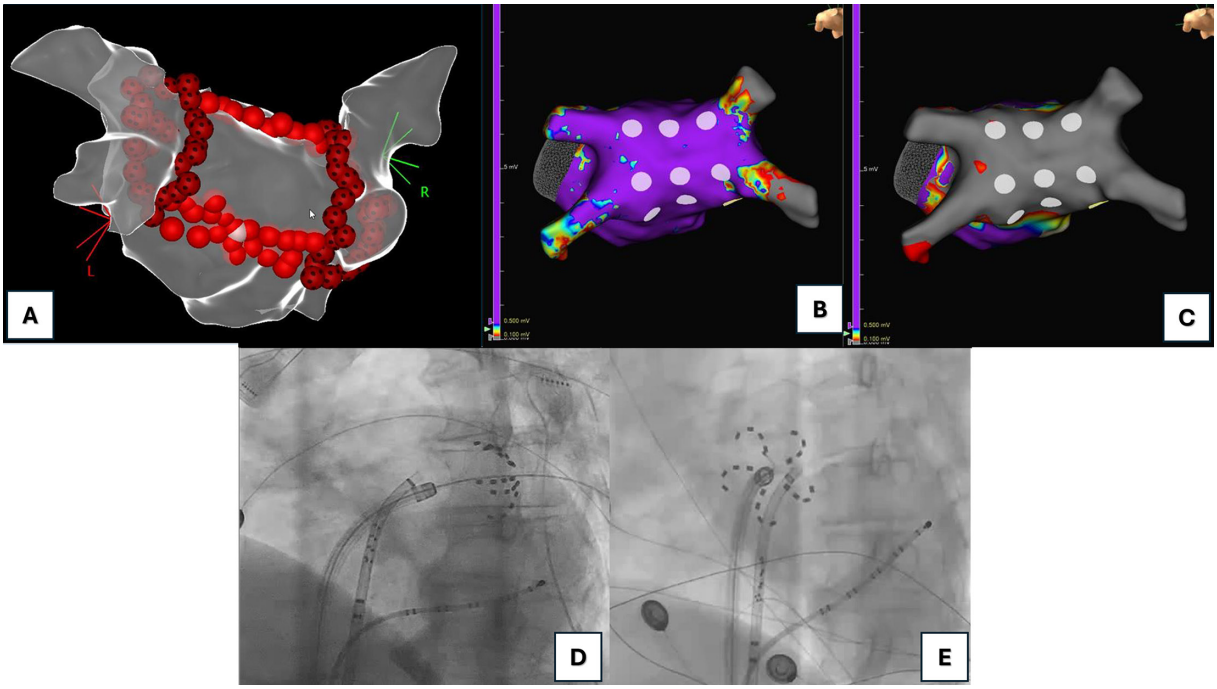

Figure 1 Examples of electroanatomical (EAM) and fluoroscopy-guided ablation intraprocedural images for combined pulmonary vein isolation and posterior wall isolation (A) – Radiofrequency ablation (Red dots = lesions). (B) - Pulsed-field (PFA) pre-ablation (EAM). (C) - PFA post-ablation (EAM): White dots = position of the centres of the posterior wall PFA lesions. (D) - Pentaspline PFA catheter during left lower pulmonary vein ablation with catheter in 'Basket' configuration (Left Anterior Oblique View). (E) - Pentaspline PFA Catheter during posterior wall ablation with catheter in 'Flower' configuration (left anterior oblique view).

point-by-point RFA guided by ablation index or with high-power short-duration lesions as recommended in guidelines.[4] Isolation was validated by recording electrical activity and using pacing manoeuvres to assess for electrical block. Adenosine testing was not routinely performed. Additional lesion sets such as mitral isthmus ablation, cavotricuspid isthmus (CTI) isolation, coronary sinus ablation or superior or inferior vena cava ablation were not routinely performed, and any such cases were excluded from the analysis. Areas of reconnection or gaps were targeted with supplementary ablation until isolation was achieved or deemed not possible.

Pulsed-Field Ablation (PFA)

PFA cases were performed under GA and followed the same preparation as RFA. PFA utilised the Boston Scientific Farawave™ ablation system (Marlborough, USA) with a pentaspline ablation catheter, assisted by EAM and fluoroscopy, or fluoroscopy alone. The mapping system and software utilised were at the operator's discretion. During EAM-guided PFA, a pre-ablation map was created. PVI and PWI followed well-reported protocols, sequentially ablating each PV utilising a combination of 'flower' and 'basket' lesions, with at least two rows of overlapping flower lesions for PWI, ensuring the PW was ablated, from the roof region inferiorly towards the coronary sinus (figure 1B-E).[20] Isolation was validated by creating an additional high-density map to assess residual electrical activity (>0.1 mV) and with pacing manoeuvres to assess for electrical block. In fluoroscopy-only PFA cases, PVI and PWI were confirmed with pacing manoeuvres to assess for block and by systematic roving of the pentaspline catheter into the PVs and across the PW to assess for local electrograms. Where residual electrical activity was identified, supplementary applications were delivered to achieve isolation, or until it was deemed impossible to do so. As in the RFA arm, adenosine testing for isolation was not routinely performed, and any cases where ablation beyond PVI and PWI was performed were excluded.

Post-ablation care and follow-up

Patients remained overnight and were discharged within 24 hours unless an extended admission was required. Same-day discharges were permitted after monitoring and exclusion of pericardial effusion on transthoracic echocardiography. Anticoagulation was restarted early, either on the same day or the next, unless there was concern about bleeding. All patients continued anticoagulation for 3 months, and eligible patients maintained it in accordance with the CHA_2DS_2-VA score recommendations.

Data collection & endpoints

Baseline patient demographics were recorded, including medical history, duration of AF and medication use. Procedural data and outcomes were collated in an anonymised centralised database, including anaesthesia use, mapping software, ablation

technique, procedural duration, fluoroscopy time and LA dwell time. In a predefined sample of patients (n=40; 20 per arm), the precise time to achieve PVI and PWI was prospectively recorded. Procedural efficacy was defined by assessing the acute success or failure in achieving PVI and PWI. Safety endpoints included major peri-procedural adverse events and late complications recorded during clinical follow-up. The primary efficacy outcome was time to first detected atrial tachyarrhythmia (AT) recurrence, defined as AF, atrial flutter or atrial tachycardia lasting >30 s, as recorded on ambulatory Holter rhythm monitoring (≥24 hours) or a 12-lead ECG. Time zero was the date of the index ablation. A standard 90-day blanking period was applied, during which arrhythmia recurrences were not considered events for the primary outcome. Rhythm surveillance was performed at prespecified 6- and 12 month time points as part of institutional follow-up practice and was uniform for both groups. Additional 12-lead ECGs or ambulatory ECG monitoring were performed if patients reported symptoms suggestive of arrhythmia recurrence during interim clinical review. All patients had clinical follow-up through 12 months, with analyses based on time to first-documented AT recurrence.

Statistical analysis

Patients were analysed according to ablation modality. The normality of continuous variables was assessed using the Shapiro-Wilk test and are reported as mean ± standard deviation (SD) or median (IQR 25%–75%) as appropriate. Between-group comparisons were performed using the Student's t-test or the Mann-Whitney *U* test. Categorical variables are presented as counts (n) and percentages (%) and compared using Fisher's exact test or χ^2 tests. Time-to-first detected AT recurrence was analysed using Kaplan-Meier (KM) survival methods. Patients were considered at risk until first detected at recurrence and were followed through 12 months. Follow-up was measured from the date of the index ablation procedure and included a standard 90-day blanking period, during which time arrhythmia recurrence was not counted as an event. Given that rhythm surveillance occurred at prespecified intervals rather than through continuous monitoring, recurrence timing reflects the time of detection rather than exact arrhythmia onset. To account for baseline imbalances and the interval-based structure of follow-up, an adjusted analysis was performed using a discrete-time survival framework aligned to the KM time-to-event analysis rather than a Cox proportional hazards model. Follow-up was divided into two clinically relevant intervals from the index procedure (0–6 and 6–12 months), with events occurring during the 90-day blanking period excluded. The discrete-time hazard was estimated using logistic regression incorporating ablation modality and a prespecified set of baseline covariates (age, sex, LVEF, CHA_2DS_2-VA score, AF duration, LAVi and baseline AAD use). An interval indicator was included to account for variation in baseline hazard over time, and cluster-robust standard errors were applied at the patient level. A two-sided p-value <0.05 was considered statistically significant.

	PFA (n=100)	RFA (n=100)	P Value
DeNovo Procedure	86 (86%)	85 (85%)	1.00
Male	72 (72%)	70 (70%)	0.88
Age (years)	68 (62.5-73)	68 (60.5-76)	0.98
BMI (kg/m²)	30 [5.7]	29.6 [5.1]	0.64
CHA_2DS_2-VA Score	3 (2-4)	2 (1-3)	0.01
Tried / on AAD	50 (50%)	37% (37%)	0.09
AF Duration (months)	16 (10-30)	18 (13-32)	0.17
LVEF (%)	43.5 (35.5-55.5)	47 (40-58)	0.01
LAVi (mL/m²)	48.5 (42.8-55.5)	45.5 (39.1-55)	0.25

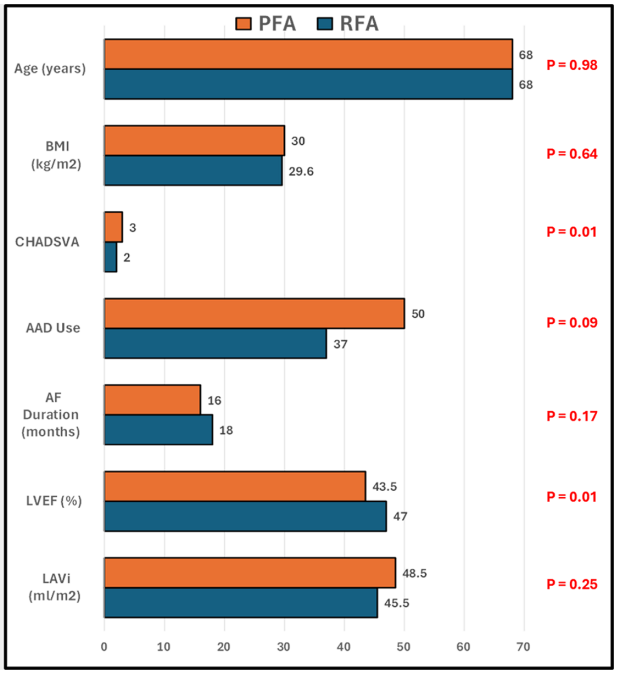

Figure 2 Baseline characteristics of all patients undergoing combined pulmonary vein isolation and posterior wall isolation by radiofrequency ablation (blue) or pulsed field ablation (orange), tabulated (left) and bar chart (right). Numbers to the right of the bar represent the average value. The red number to the right reports the p-value comparison between the two groups for the respective characteristic. Values are mean[SD], n(%) or median (Q1-Q3). AAD, Anti-arrhythmic drug; BMI, Body Mass Index; LAVi, Left Atrial Volume Index; LVEF, Left Ventricular Ejection Fraction.

A

		RFA (n=100)	PFA (n=100)	P value
EA Mapping Used		100 (100%)	89 (89%)	<0.005
EA Mapping (if used)	CARTO™	97 (97%)	23 (23%)	-
	ENSITE NAVX™	1 (1%)	57 (57%)	-
	RHYTHMIA™	0 (0%)	9 (9%)	-
	Fluoroscopy-Only	0 (0%)	11 (11%)	-
	Other	2 (2%)	0 (0%)	-
Successful PVI		100 (100%)	100 (100%)	-
Successful PWI		65 (65%)	99 (99%)	<0.005
Time for PVI (mins)[a]		65.9 [13.7]	19.3 [7.6]	<0.005
Time for PWI (mins)		23.3 [9.4]	6.0 [2.4]	<0.005
Procedure Duration (mins)		143.5 (114-184.5)	106 (82.5-128.5)	<0.005
Left Atrial Dwell Time (mins)		98 (79-183)	62 (48-80)	<0.005
Fluoroscopy Time (mins)[b]		10.5 (7.3-16.7)	19.5 (15.0-23.0)	<0.005
Length of Stay (days)		1 (1-1)	1 (1-1)	1.00
Complication (any)		2 (2%)	1 (1%)	1.00
- Stroke		1	0	-
- Pericardial Effusion		1	1	-
- Pseudoaneurysm		1	0	-

B

	RFA	PFA		
	EAM Mapping (n=100)	Fluoroscopy Only (n=11)	EA Mapping (n=89)	P value* (Fluoroscopy-only PFA Vs EAM PFA)
Acutely Successful PVI and PWI+	65 (65%)	11 (100%)	88 (99%)	1.00
Procedure Duration (mins)	143.5 (114-184.5)	87 (64-116)	110 (84-130)	0.03
Left Atrial Dwell Time (mins)	98 (79-183)	46 (39-50)	64 (53-81)	0.002
Fluoroscopy Time (mins)	10.5 (7.3-16.7)	15.2 (9.5-16.1)	19.5 (15.0-23.0)	0.002
Freedom from AT - 6 months (on or off AADs)	69 (69%)	9 (81.8%)	73 (82.0%)	0.70
Freedom from AT - 12 months (on or off AADs)	54 (54%)	7 (63.6%)	63 (70.8%)	0.73

Figure 3 Summary of ablation procedural data. (A) Procedural data of radiofrequency ablation (RFA) and pulsed field ablation (PFA) for combined pulmonary vein isolation and posterior wall isolation. Values are mean [SD], n (%) or median (Q1-Q3). EA, electroanatomical; PFA, pulsed-field ablation; PVI, pulmonary vein isolation; PWI, posterior wall isolation; RFA, radiofrequency ablation a n=40 (20 per arm) b PFA Fluoroscopy time included those using EAM-only (n=89). (B) Procedural data with PFA cases stratified by cases using fluoroscopy-only and those using electroanatomical mapping (EAM).
***P-Value represents PFA fluoroscopy-only versus PFA EAM. Comparisons are exploratory, given the small sample size of the fluoroscopy-only subgroup (n=11). +Combined PVI + PWI success was defined as the acute achievement of both PVI and PWI during the index procedure. Differences between groups reflect rates of PWI. PVI was achieved in 100% of cases.**

RESULTS

Patient population

200 patients were included (100 consecutive patients with PFA and 100 consecutive patients with RFA). Baseline characteristics are summarised in figure 2. Most ablations were first-time procedures (171/200 [85.5%]), with no significant difference between the groups (PFA: 86% and RFA: 85%, p=1.0). Most patients were male (PFA: 72% vs RFA: 70%, p=0.88). Age, BMI and AF duration were similar between the cohorts (p>0.05). Statistically significant differences were observed in baseline LVEF, which was lower in the PFA group (median 43.5% [35.5–55.5%] vs 47.0% [40–58%] in the RFA group, p=0.01), and in the corresponding CHA_2DS_2-VA score, which was higher in the PFA group (median 3 [2-4] vs 2 [1-3] in the RFA group, p=0.01). Left atrial indexed volume (LAVi) was comparable (PFA 48.5 mL/m^2 [42.8–55.5 mL/m^2] vs RFA 45.5 mL/m^2 [39.1–55 mL/m^2], p=0.25). Anti-arrhythmic drug (AAD) use at baseline was numerically higher in PFA patients (50% vs 37% in RFA), but the difference was not statistically significant (p=0.09).

Procedural data

Procedural data are summarised in figure 3 and online supplemental file 1. EAM was used in 100% of RFA cases and in 89% of PFA cases (p<0.005). During RFA, the most used software was CARTO™ (Biosense Webster) (97%). In contrast, EnSite NavX™ (Abbott) was most frequently used during PFA (57%), followed by CARTO™ (Biosense Webster) (23%) and Rhythmia™ (Boston Scientific) (9%). Fluoroscopy-only guidance was used in 11% (n=11) of PFA cases. Acute PVI was achieved in 100% of cases in both groups. In contrast, acute PWI was achieved more frequently with PFA (99% vs 65% in RFA, p<0.005). In a single PFA case, PWI could not be completed. Despite repeated endocardial PFA applications, persistent signals remained along the inferior PW adjacent to the coronary sinus region. These signals were low-amplitude and persisted despite supplementary ablation and were considered consistent with a substrate-related limitation rather than inadequate lesion delivery. The patient demonstrated marked LA hypertrophy on pre-procedural imaging, raising the possibility of increased myocardial thickness or epicardial connections contributing to the challenge in achieving PWI.

Procedural efficiency differed significantly between the groups: in PFA, the median procedure time was 106 [82.5–128.5] min compared with 143.5 [114–184.5] min with RFA (p<0.005). LA dwell time was also reduced with PFA: 62 [48-80] minutes vs 98 [79-183] minutes with RFA, p<0.005. Fluoroscopy time was higher in the PFA group: 19.5 [15.0–23.0] min vs 10.5 [7.3–16.7] min with RFA, p<0.005. PVI and PWI were more rapidly achieved with PFA. The mean time to PVI with PFA was 19.3±7.6 min vs 65.9±13.7 min with RFA, p<0.005, and the mean time to PWI with PFA was 6.0±2.4 min vs 23.3±9.4 min with RFA, p<0.005.

Three major complications occurred (3/200=1.5%). Two occurred in the RFA group (one mild stroke and one pericardial effusion requiring drainage) and one in the PFA group (a pericardial effusion requiring drainage). A major vascular complication occurred in one patient (1/200=0.5%) and comprised a pseudoaneurysm in the RFA group that required intervention. No signal of increased procedural risk was observed with PFA, although the study was not powered to detect differences in infrequent adverse events. No procedure-related mortality was observed. The length of stay was similar between the groups, with most patients discharged within one night (186/200 = 93%, PFA: 91 patients, RFA: 95 patients).

Sub-Analysis of PFA: EAM versus fluoroscopy-only

Figure 3 and online supplemental figures 1D and 2 summarise a sub-analysis comparing fluoroscopy-only-guided vs EAM-guided PFA. Of the 100 PFA cases, 89% (n=89) utilised EAM and 11% (n=11) were performed under fluoroscopy-only guidance. Acute PVI and PWI were achieved in all fluoroscopy-only PFA cases. Fluoroscopy-only PFA was associated with a shorter median procedure duration (87 [64–116] minutes) compared with EAM-guided PFA (110 [84–130] minutes, p=0.03), and shorter LA dwell time (46 [39-50] minutes vs 64 [53-81] minutes, p=0.002). Fluoroscopy time was lower in fluoroscopy-only PFA compared with EAM-guided PFA (15.2 [9.5–16.1] min vs 19.5 [15.0–23.0] min, p=0.002). Arrhythmia outcomes did not differ significantly between fluoroscopy-only and EAM-guided PFA, although event rates were low in the fluoroscopy-only subgroup. Freedom from AT at 6 months was 82% in both groups (p=0.70). At 12 months, 64% of fluoroscopy-only PFA patients were free from AT compared with 70.8% of EAM-guided PFA patients (p=0.73). When compared with RFA, PFA procedures with EAM were associated with longer fluoroscopy times (19.5 vs 10.5 min, p<0.005). However, fluoroscopy time did not differ significantly between RFA and fluoroscopy-only PFA procedures (15.2 vs 10.5 min, p=0.65).

Follow-up and arrhythmia outcomes

Follow-up data are summarised in figure 4. At 6 months, freedom from recurrent AT was observed in 82% of PFA patients compared with 69% of RFA patients (p=0.048). AAD use was similar during follow-up (PFA 19% vs RFA 17%, p=0.85). The difference persisted at 12 months, with 70% of PFA patients free from AT compared with 54% of RFA patients (p=0.03). No cardiovascular mortality occurred during follow-up in either group.

Adjusted analysis of arrhythmia recurrence

To address baseline imbalances between the groups and the prespecified interval-based rhythm surveillance, an adjusted discrete-time survival analysis was performed, aligned with the KM time-to-event framework (figure 4B). After adjusting for age, sex, LVEF, CHA_2DS_2-VA score, AF duration, LAVi, baseline AAD use and follow-up interval, PFA remained independently associated with greater freedom from recurrent AT compared with RFA (adjusted OR 0.46, 95% CI 0.26–0.82, p=0.009). The direction and magnitude of the association were consistent with those of the unadjusted analyses.

DISCUSSION

Our real-world study compares procedural characteristics and arrhythmia outcomes of PFA and RFA for combined PVI and PWI in patients with persistent AF. To our knowledge, it represents the largest real-world direct comparison of these approaches, incorporating a substantial proportion of patients with impaired LV function. The findings are summarised in figure 5. Five key observations emerge:

1. **PFA was associated with a markedly higher rate of acute PWI while maintaining equivalent PVI success** (99% vs 65% with RFA), and both PVI and PWI were established more rapidly with PFA (p<0.005).
2. **Procedural efficiency was greater with PFA**, with shorter overall procedure duration and reduced LA dwell time, despite longer fluoroscopy time combined with EAM.
3. **Freedom from recurrent AT at both 6 months and 12 months was higher following PFA**, and this association persisted after adjustment for baseline clinical differences.
4. **EAM was required for all RFA cases, but not for all PFA cases**. In a small exploratory subgroup, fluoroscopy-only PFA was feasible and associated with shorter procedures without an observed reduction in acute procedural success.
5. **Major complications were uncommon and occurred at similarly low rates in both groups**.

Together, these findings indicate that PFA enables more consistent and efficient delivery of PVI and PWI and is associated with improved arrhythmia outcomes during follow-up. However, given the observational design, procedural heterogeneity and intermittent rhythm surveillance, these associations should not be interpreted as causal or as definitive evidence that PWI itself confers an incremental benefit. Rather, the data demonstrates that near-universal acute PWI was achievable with PFA

A

	Both Groups n=200	RFA n=100	PFA n=100	P value
Follow-up duration (months)	12.2 [3.5]	12.2 [2.8]	12.2 [4.0]	0.97
On AAD (during follow-up)	36 (18%)	17 (17%)	19 (19%)	0.85
Freedom from AT - 6 months (on or off AADs)	151 (75.5%)	69 (69%)	82 (82%)	0.048
Freedom from AT - 12 months (on or off AADs)	124 (62%)	54 (54%)	70 (70%)	0.03
Cardiovascular Mortality	0	0	0	NA

Values are mean[SD], n(%) or median(Q1-Q3). RFA = Radiofrequency Ablation, PFA = Pulsed-Field Ablation, AT = Atrial Tachyarrhythmia, AAD = Anti-arrhythmic drug

B

	Effect Estimate	Odds Ratio of First Detected AT Recurrence (95% CI)	P value
Unadjusted model (interval-indicator only)	PFA Vs RFA	0.52 (0.31–0.87)	0.012
Adjusted discrete-time survival model	PFA Vs RFA	0.46 (0.26–0.82)	0.009

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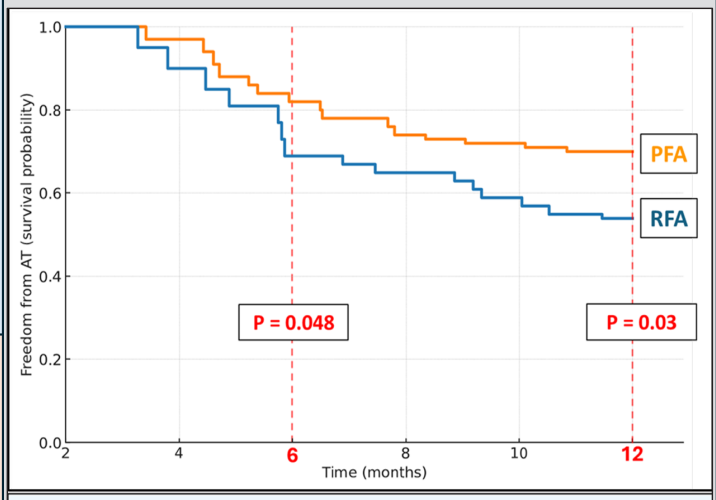

Numbers At Risk

Months	0	4	6	8	10	12
PFA	100	93	82	78	74	70
RFA	100	88	69	65	59	54

Figure 4 Summary of outcome data. (A) Freedom from AT after PFA and RFA for PVI and PWI at 6 and 12 months. (B) Adjusted discrete-time survival analysis of time to first detected AT recurrence. Results from an adjusted discrete-time survival analysis aligned to the Kaplan–Meier time-to-event framework. The model included ablation modality (PFA versus RFA) and prespecified baseline covariates (age, sex, left ventricular ejection fraction, CHA_2DS_2-VA score, AF duration, left atrial volume index, baseline AAD use and a follow-up interval indicator (0-6 vs 6-12 months). Cluster-robust standard errors were applied at the patient level. Odds ratios represent the odds of first-detected AT recurrence within each follow-up interval. (C) Kaplan-Meier curves showing time to first detected AT recurrence after PFA and RFA for PVI and PWI - PFA (orange) or RFA (blue). AT recurrence was defined as atrial fibrillation, atrial flutter or atrial tachycardia lasting >30 s occurring after a 90-day blanking period, detected on ≥24-hour ambulatory ECG monitoring or 12-lead ECG. Annotated p-values at 6 and 12 months reflect between-group comparisons at these time points; the overall group comparison was performed using the log-rank test. Numbers at risk are shown below the plot.

and was associated with favourable arrhythmia outcomes in this real-world cohort.

Implications for pulsed-field ablation

As our understanding of LA anatomy and electrophysiology has evolved, the PW has emerged as a region of particular interest in AF. Several studies have examined percutaneous-only PWI, most notably the randomised CAPLA,[15] POBI-AF[21] and PEF-HOT[22] studies. These studies did not demonstrate a clear benefit of adjunctive PWI beyond PVI alone and, in some cases, reported longer procedure times and increased procedural risk. An important caveat has been the consistently reported limitation of safely establishing and maintaining PWI with thermal-based ablation. Across randomised studies, pooled acute PWI success with RFA has been reported at approximately 82.5%.[23] In CAPLA, PWI could not be completed in 13.5% of patients, most commonly (74%) due to rising oesophageal temperatures.[15] Furthermore, even when acute PWI is achieved with RFA, durability remains limited, with PW reconnection noted in 69% of redo procedures in CAPLA[15] and in 63% of cases reported in a meta-analysis.[24] In our series, acute PWI was achieved in 65% of RFA cases, consistent with rates reported in similar non-randomised and registry-based analyses (50.6–70.9%).[24 25] These lower success rates likely reflect the dynamic nature of real-world clinical decision-making, where ablation strategies are tailored to patient-specific substrate characteristics rather than delivered under tightly controlled trial protocols.

In contrast, minimally invasive surgical or hybrid ablation strategies targeting the PW epicardially have demonstrated improved rhythm outcomes, although with the increase in procedural risk that may be anticipated.[13 14 26] The apparent disparity may relate not only to study characteristics and design but also to the mode of energy delivery and lesion geometry.[27] Epicardial ablation permits effective treatment of the surface most likely to sustain arrhythmic potential when ablating from an endocardial-only approach.[28] Additionally, directing energy inward mitigates safety concerns, particularly the risk of increased oesophageal temperature, thereby enabling higher-energy applications.

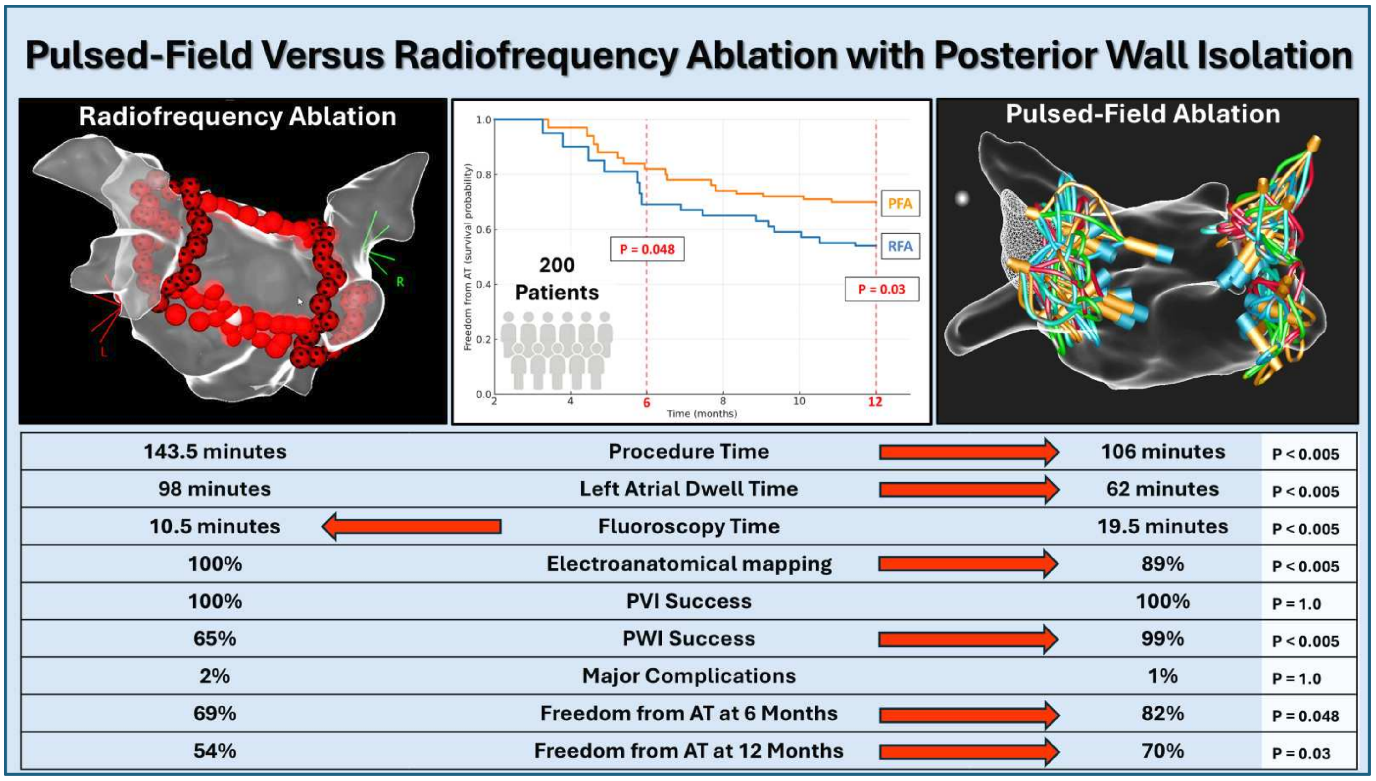

Figure 5 Central Illustration. This illustrates the study's key findings. PFA, pulsed-field ablation; RFA, radiofrequency ablation.

PFA has emerged as an endocardial ablation modality capable of selectively targeting myocardial tissue via electroporation, a property that may be particularly advantageous for safe and efficacious PW ablation. However, despite its rapid adoption, direct comparative real-world data evaluating PFA against RFA for PWI are limited, particularly in patients with persistent AF and impaired LV function. In the MANIFEST PFA registry, only a small number of patients with persistent AF underwent PWI, 24% (n=131/547),[29] with a sub-analysis of the same registry noting only 8.7% (n=120/1381) patients having impaired LV.[30] In our study, both treatment groups included patients with reduced LVEF, providing a clinically relevant comparison in a higher-risk population.

Our real-world findings add to the growing body of evidence supporting PFA as an AF ablation strategy that can be delivered efficiently, with high acute success rates for PVI and PWI,[31–34] and acceptable safety in patients with persistent AF, including those with reduced LVEF. While near-universal acute PWI was associated with improved arrhythmia outcomes in our cohort, the absence of systematic remapping and the presence of confounding procedural and temporal factors precludes attributing the benefit specifically to PWI. Whether improved acute isolation with PFA results in durable lesions and sustained rhythm control remains uncertain. Prospective randomised trials comparing PVI alone vs PVI plus PWI using PFA, incorporating systematic remapping and atrial functional assessment, are required to determine whether PWI confers incremental benefit when delivered with non-thermal energy.

Arrhythmia outcomes

An important observation from this study is the higher freedom from AT observed in patients undergoing PFA (PFA 70% vs RFA 54%, p=0.03), despite the cohort having a lower average LVEF and a higher CHA_2DS_2-VA score. Patients with impaired LV function and greater comorbidities, as indicated by a higher CHA_2DS_2-VA score, are less likely to maintain sinus rhythm after index catheter ablation and more likely to need repeat procedures.[1 4 35] In such patients, EAM at repeat procedures frequently demonstrates non-PV triggers and complex arrhythmia-sustaining mechanisms,[36] highlighting the limitations of PVI alone in such cohorts. In this context, the ability to achieve more consistent acute PWI with PFA may be particularly relevant. However, the present study cannot determine whether PWI itself accounts for the observed arrhythmia outcomes.

Resource usage

Another relevant finding relates to procedural resource utilisation. EAM was used in all RFA cases, whereas it was not required for all PFA procedures and was used in 89% of cases. RFA is inherently dependent on EAM, which increases procedural complexity, catheter burden and the need for specialist technical physiology support. In contrast, PFA incorporating PVI and PWI can be performed using fluoroscopic guidance alone in selected cases. Consistent with prior reports, fluoroscopy-only PFA in our series was feasible and did not compromise acute procedural success or outcomes at follow-up.[37] Notably, fluoroscopy-only PFA was associated with

lower fluoroscopy exposure than EAM-guided PFA, and fluoroscopy time did not differ significantly from that observed in RFA procedures (p=0.65). However, the findings should be interpreted cautiously given the small sample size of the fluoroscopy-only group (n=11). In this series, fluoroscopy-only PFA ablations were performed later (cases 65 onwards), once procedural confidence had been gained using EAM-guided PFA, consistent with a procedural learning curve and published data demonstrating improvements in PFA procedural efficacy with experience.[38] In addition, the clinicians performing fluoroscopy-only cases were high-volume fluoroscopy-guided AF cryoablation operators, which may have influenced procedural efficiency. While exploratory, these findings suggest that selective reduction in reliance on EAM may be achievable with PFA in experienced centres, with potential implications for procedural efficiency and resource utilisation, particularly in high-volume or publicly funded healthcare systems.

LIMITATIONS

This study represents a real-world comparison of two contemporary percutaneous AF ablation strategies and is limited by its retrospective, single-centre, non-randomised design. Accordingly, causal inferences cannot be drawn. Baseline differences between groups were present, with lower LVEF and higher CHA_2DS_2-VA score in the PFA group. Although these characteristics are typically associated with a higher risk of arrhythmia recurrence and would be expected to bias against improved outcomes, residual confounding cannot be excluded. Rhythm follow-up was based on routine clinical care, including scheduled ECGs, intermittent ambulatory monitoring and symptom-driven or clinician-driven assessment. Consequently, asymptomatic, brief or sporadic episodes of AT may have been under-detected, and event timing reflects time of detection rather than actual arrhythmia onset. Although an adjusted discrete-time survival analysis was performed, this approach cannot fully mitigate limitations related to intermittent rhythm surveillance. The study was not powered to detect differences in infrequent adverse events, and conclusions regarding comparative safety should be interpreted with caution. All procedures were performed under GA at a high-volume tertiary centre for AF ablation and a quaternary referral centre for AF and heart failure, which may limit external validity and procedural era effects and evolving operator experience, particularly with PFA, may have influenced procedural efficiency and outcomes. LA compliance, myocardial thickness and epicardial substrate were not systematically assessed. As a result, the potential impact of PWI on atrial compliance, including the development of stiff left atrial physiology, as well as substrate-related resistance to PWI, could not be evaluated beyond procedural and imaging observations. Finally, because systematic remapping was not performed, the relationship between acute PWI success and long-term lesion durability cannot be determined. Prospective randomised studies with PFA comparing PVI alone with PVI and PWI that incorporate systematic remapping and atrial functional assessment are required to define the role of PFA and PWI in persistent AF, including in patients with reduced LVEF.

CONCLUSION

In this real-world cohort of patients with persistent AF, PFA was associated with higher rates of acute PWI success and greater freedom from recurrent atrial tachyarrhythmia at 6 and 12 months compared with RFA. These associations were observed despite a higher baseline clinical risk profile in the PFA group (lower LVEF and a higher CHA_2DS_2-VA score) and were consistent in adjusted analyses. Procedures performed with PFA were shorter and associated with reduced LA dwell time, and a fluoroscopy-only approach was feasible in a small, selected subset without compromise in acute procedural success. Given the observational design and lack of systematic remapping, these findings should be interpreted as associative rather than causal. Randomised studies are required to determine whether PWI using PFA confers incremental benefit beyond PVI in patients with persistent AF, including those with reduced LVEF.

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Contributors OA and RAK designed the study, and collected, analysed and monitored the data. IZ provided supplementary data and analysis. OA generated the initial draft. RAK revised the draft paper. AL, AB, ZZ, MN, LL, MJS, MSo and MSa provided data and reviewed the final manuscript. EB supervised the study and writing. MSa and RAK are joint senior authors. RAK is the guarantor.

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