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CLINICAL RESEARCH

Atrial fibrillation cryoablation is an effective day case treatment: the UK PolarX vs. Arctic Front Advance experience

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Aims Pulmonary vein isolation (PVI) is the cornerstone of catheter ablation for atrial fibrillation (AF). There are limited data on the PolarX Cryoballoon. The study aimed to establish the safety, efficacy, and feasibility of same day discharge for Cryoballoon PVI.

Methods and results Multi-centre study across 12 centres. Procedural metrics, safety profile, and procedural efficacy of the PolarX Cryoballoon with the Arctic Front Advance (AFA) Cryoballoon were compared in a cohort large enough to provide definitive comparative data. A total of 1688 patients underwent PVI with cryoablation (50% PolarX and 50% AFA). Successful PVI was achieved with 1677 (99.3%) patients with 97.2% ($n = 1641$) performed as day case procedures with a complication rate of <1%. Safety, procedural metrics, and efficacy of the PolarX Cryoballoon were comparable with the AFA cohort. The PolarX Cryoballoon demonstrated a nadir temperature of -54.6 ± 7.6°C, temperature at 30 s of -38.6 ± 7.2°C, time to −40°C of 34.1 ± 13.7 s, and time to isolation of 49.8 ± 33.2 s. Independent predictors for achieving PVI included time to reach −40°C [odds ratio (OR) 1.34; $P < 0.001$] and nadir temperature (OR 1.24; $P < 0.001$) with an optimal cut-off of ≤34 s [area under the curve (AUC) 0.73; $P < 0.001$] and nadir temperature of ≤−54.0°C (AUC 0.71; $P < 0.001$), respectively.

Conclusions This large-scale UK multi-centre study has shown that Cryoballoon PVI is a safe, effective day case procedure. PVI using the PolarX Cryoballoon was similarly safe and effective as the AFA Cryoballoon. The cryoablation metrics achieved with the PolarX Cryoballoon were different to that reported with the AFA Cryoballoon. Modified cryoablation targets are required when utilizing the PolarX Cryoballoon.

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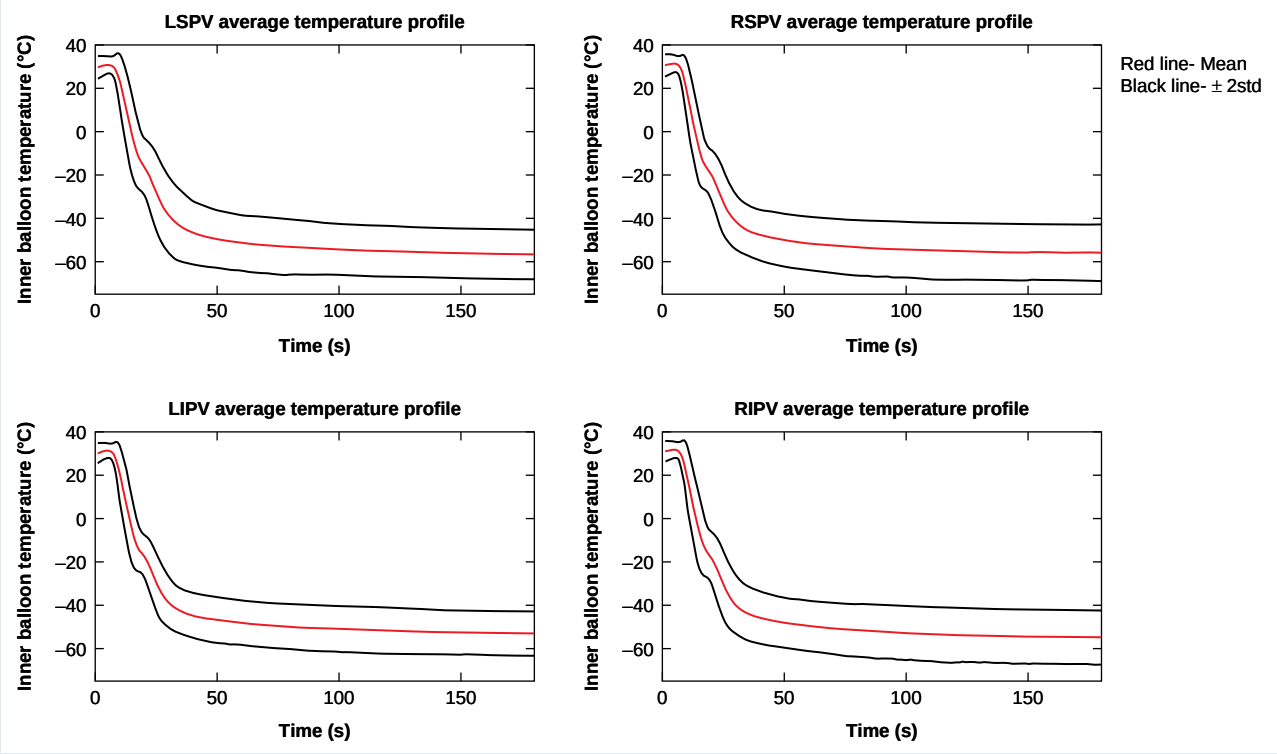
Graphical Abstract



Demonstrates the spread of temperature profiles on a per vein basis with the PolarX Cryoballoon for cryoablations with a TTI that demonstrated successful PVI.

Keywords Cryoablation • Atrial fibrillation • Pulmonary vein isolation • Novel technology

What's new?

This multi-centre study across 12 centres evaluated the safety, efficacy, and feasibility of same day discharge for cryoablation for atrial fibrillation using the PolarX and Arctic Front Advance (AFA) Cryoballoons. A total of 1688 patients underwent pulmonary vein isolation (PVI) (50% PolarX and 50% AFA). Successful PVI was achieved with 1677 (99.3%) patients with 97.2% ($n = 1641$) performed as day case procedures with a complication rate of <1%. Safety, procedural metrics, and efficacy of the PolarX Cryoballoon were comparable with the AFA cohort. Cryoablation metrics were different for the PolarX Cryoballoon compared with AFA Cryoballoon. Independent predictors for achieving PVI with the PolarX Cryoballoon included time to reach −40°C [odds ratio (OR) 1.34; $P < 0.001$] and nadir temperature (OR 1.24; $P < 0.001$). This large-scale UK multi-centre study has shown that Cryoballoon PVI is a safe, effective day case procedure and that alternative cryoablation metrics need to be considered with the PolarX Cryoballoon.

Introduction

Pulmonary vein isolation (PVI) is the primary ablation strategy for patients with symptomatic paroxysmal atrial fibrillation (PAF),[1,2] and with the findings from STAR AF II trial,[3] it is also the current primary ablation strategy for persistent atrial fibrillation (AF) patients. There are many technologies used to achieve this with an evolution of practice meaning safer and more effective procedures over time.

Currently, there are two Cryoballoon technologies available to achieve PVI, the PolarX Cryoballoon (Boston Scientific, MA, USA) and the Arctic Front Advance (AFA) (Medtronic, MS, USA). The AFA Cryoballoon system has been available for more than a decade. whilst the PolarX Cryoballoon has only been commercially available for a couple of years. Therefore, there remains a paucity of data regarding the safety and efficacy of the PolarX Cryoballoon relative to the more established AFA. It has been assumed that the safety and efficacy of these technologies are equivalent, but there are little data to substantiate this.

This multi-centre study aimed to establish the safety, efficacy, and feasibility of same day discharge for Cryoballoon PVI in a large contemporary cohort. We also compared procedural metrics, safety profile, and procedural efficacy of the PolarX Cryoballoon with the AFA Cryoballoon in a cohort large enough to provide definitive comparative data. All consecutive PolarX Cryoballoon AF ablation cases in the UK were included and compared with an equal number of consecutive AFA cases over the same period. Detailed data on the cryoablation metrics were also compiled for all PolarX cases to establish expected temperature profiles and ablation targets.

Methods

Study design

This was a multi-centre study incorporating data from separate nationally mandated institutional prospective registries. All UK centres that have

performed cryoablation using the PolarX Cryoballoon were included, aiming to capture all consecutive UK PolarX cases. A total of 12 UK centres were included. All patients underwent first time ablation for AF. Patients were enrolled consecutively from their first PolarX case (January 2020 until the end of July 2022). All patients underwent cryoablation using identical equipment: a Polarsheath (15.5F deflectable sheath), a PolarX 28-mm balloon catheter, and a Polarmap catheter (eight electrodes, 20 mm loop diameter, and 3F shaft diameter).

All patients provided written informed consent before the procedure. The study complied with the Declaration of Helsinki and was registered and endorsed by the Barts Health NHS Trust Clinical Effectiveness Unit (registration ID: 11690).

Procedure protocol

Patients underwent their procedure under conscious sedation (midazolam and diamorphine or fentanyl) or general anaesthetic depending on patient/operator preference. Femoral venous access was achieved using ultrasound guidance. All patients had two separate femoral venous access that was used for the 15F cryosheath and the 7F sheath that was used for the quadripolar catheter. All procedures were performed with uninterrupted anticoagulation therapy and intravenous heparin administration to achieve an activated clotting time of >300 ms throughout the procedure. Trans-septal punctures were either performed through the Polarsheath or FlexCath sheath using a Brokenbrough (BRK) or BRK1 89 cm needle (Abbott, IL, USA) and a Safe-sept trans-septal guidewire or with an SL1 sheath (Abbott, IL, USA) using a BRK or BRK1 71 cm and a Safe-sept trans-septal guidewire (Heart Medical Europe BV, Netherlands), which was then exchanged to the Polarsheath or FlexCath sheath. Right-sided PVs had cryoablation with phrenic pacing using a quadripolar catheter and monitoring diaphragmatic movement and compound motor action potentials for phrenic nerve compromise. For all PVs, prior to the cryoablation, the seal between the balloon and vein ostium was assessed with contrast injection to ensure there was no leak. If the seal was inadequate, the balloon was repositioned to achieve a better seal before the cryoablation.

Cryoablations were performed until PVI was achieved. Cryoablations were performed for 180 s as standard for all PVs. Cryoablations were abandoned if there was significant rapid drop in temperature (≥60°C within 30 s) or the temperature drop was limited with no PVI. A freeze with late isolation or moderate temperatures was extended to 240 s at the operator's discretion.

Attempts were made to visualize electrograms with the Polarmap at the start of the cryoablation. The metrics for the cryoablation and time to isolation (TTI) were recorded. If PVI was not achieved, then further applications were performed with PVI as the endpoint. Once PVI was achieved, additional consolidating cryoablation was performed as per the operator's discretion.

Baseline characteristics and procedural metrics were collected: the number of cryoablations required to achieve isolation, the temperature change over time (temperature at 30 and 60 s and rate of temperature change between 0 and 30 s), temperature at the time of isolation, TTI, nadir temperature for the cryoablation, and thaw time (time to reach 0°C). Safety outcomes were also recorded with regards to immediate procedural complications and 30-day complications.

PolarX Cryoballoon and Arctic Front Advance Cryoballoon comparison

An equal number of consecutive patients undergoing cryoablation with the AFA Cryoballoon, over the same period as cryoablation with the PolarX Cryoballoon, were included for the comparison analysis. Where there were no AFA Cryoballoon cases performed over the same period, an equal number of consecutive AFA Cryoballoon cases were taken prior to the start of the PolarX period. To ensure no operator or centre bias, all centres provided their own AFA Cryoballoon data. The cryoablation approach utilized for the AFA Cryoballoon was consistent to that utilized with the PolarX Cryoballoon.

Procedural metrics including procedure times, fluoroscopy times, dose area product (DAP), and complication rates were compared between the Cryoballoon cohorts.

Table 1 Baseline characteristics

Baseline characteristics	Cohort, *N* = 1688
Age, years, mean ± SD	61.9 ± 12.0
Male, *n* (%)	1119 (66.3)
Diabetes mellitus, *n* (%)	121 (7.2)
Hypertension, *n* (%)	547 (32.4)
TIA/CVA, *n* (%)	52 (3.1)
Ischaemic heart disease, *n* (%)	130 (7.7)
Cardiac surgery, *n* (%)	33 (2.0)
Cardiomyopathy, *n* (%)	176 (10.4)
Left ventricular EF ≥55%, *n* (%)	1281 (75.9)
LA size mm, mean ± SD	42.4 ± 5.7
AF type	
Paroxysmal, *n* (%)	1158 (68.6)
Persistent, *n* (%)	530 (31.4)
Current antiarrhythmic or rate-controlling strategy	
Beta-blockers including sotalol, *n* (%)	806 (47.7)
Amiodarone, *n* (%)	201 (11.9)
Flecainide, *n* (%)	413 (24.5)
Dronedarone, *n* (%)	41 (2.4)
Calcium channel blocker, *n* (%)	50 (3.0)
Digoxin, *n* (%)	42 (2.5)
Current anticoagulation strategy	
Warfarin, *n* (%)	39 (2.3)
Direct oral anticoagulants, *n* (%)	1649 (97.7)
Apixaban, *n* (%)	655 (38.8)
Edoxaban, *n* (%)	202 (12.0)
Rivaroxaban, *n* (%)	749 (44.4)
Dabigatran, *n* (%)	43 (2.5)

TIA/CVA, transient ischaemic attack/cerebrovascular attack; EF, ejection fraction; AF, atrial fibrillation; SD, standard deviation.

Same day discharge

Across all 12 centres, the aim was to perform all cryoablations as day case procedures with the intention to discharge patients the same day if possible. There were no specific exclusion criteria for same day discharge, and the inability to discharge the patient post-procedure was dependent on the procedural outcome and recovery post-procedure.

All patients had pre-procedural blood tests performed either at pre-assessment or on the day of the procedure. Patients were consented on the day of the procedure. Patients who required left atrial appendage thrombus excluded underwent transoesophageal echocardiogram prior and on the same day of the procedure.

To ensure early mobilization post-procedure, at the end of the procedure, a Z suture was placed, and heparin was routinely reversed with protamine. The Z suture was routinely removed after 3 h. Patients were monitored for around 4 h post-procedure and mobilized routinely at 3 h post-procedure with the intention to discharge patients the same day if possible.

Statistical analysis

All statistical analyses were performed using SPSS (IBM SPSS Statistics, Version 25 IBM Corp, NY, USA). Continuous variables are displayed as

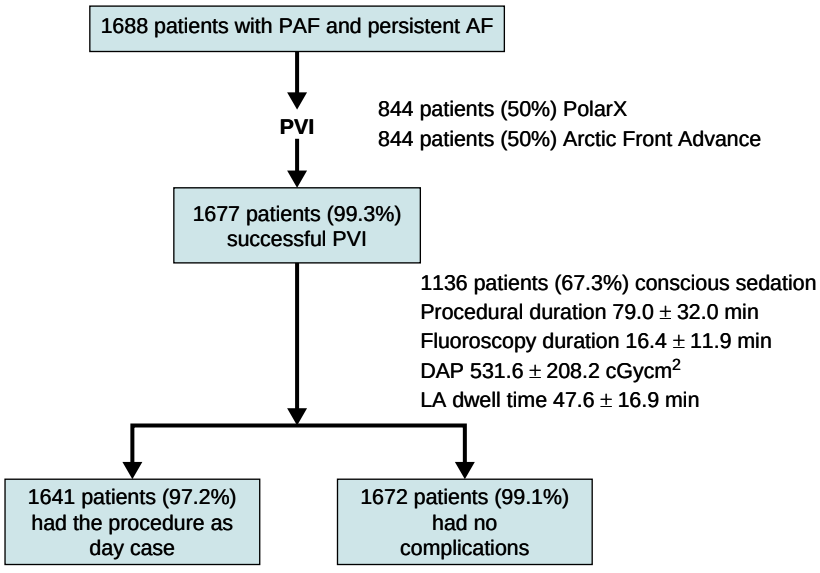


Figure 1 Consort flow diagram.

Table 2 Demonstrates the cryoablation metrics of the cryoablations in the cohort with PV signals and confirmed PVI during the cryoablation

	All veins	LUPV	LLPV	RUPV	RLPV
Nadir temperature, °C, mean ± SD	−57.6 ± 6.3	−58.3 ± 5.8	−54.8 ± 5.7	−59.1 ± 6.5	−58.3 ± 6.4
Temperature at 30 s, °C, mean ± SD	−39.4 ± 7.7	−37.2 ± 9.6	−39.0 ± 6.5	−41.9 ± 5.9	−39.9 ± 6.9
Temperature at 60 s, °C, mean ± SD	−50.8 ± 5.9	−51.2 ± 6.5	−48.8 ± 5.0	−52.3 ± 5.9	−50.7 ± 5.5
Time to −40°C, s, mean ± SD	32.3 ± 12.6	33.2 ± 12.5	33.0 ± 13.0	30.8 ± 11.5	32.0 ± 13.4
Time to −50°C, s, mean ± SD	57.3 ± 30.4	54.9 ± 26.3	69.0 ± 37.1	48.9 ± 23.5	57.6 ± 31.0
Thaw time to 0°C, mean ± SD	22.2 ± 6.7	22.5 ± 6.6	19.8 ± 5.3	23.2 ± 7.0	23.5 ± 7.4
Thaw time to +15°C, mean ± SD	44.2 ± 14.7	45.7 ± 14.6	38.1 ± 12.4	46.5 ± 14.8	46.7 ± 15.5
TTI, s, mean ± SD	49.8 ± 33.2	51.2 ± 31.5	53.6 ± 36.9	43.8 ± 30.6	50.3 ± 32.9

TTI, time to isolation; PVI, pulmonary vein isolation; SD, standard deviation.

mean ± standard deviation or median [inter-quartile range (IQR)]. Categorical variables are presented as a number and percentage. Fisher's exact test was used for the comparison of nominal variables. The Student's *t*-test, or its non-parametric equivalent Mann–Whitney, was used for comparison of continuous variables. Binary logistic regression was performed with backward elimination of factors with a *P*-value >0.10 in a stepwise fashion to identify specific cryoablation metrics that were predictive of a successful PVI with the PolarX Cryoballoon. Receiver operating characteristic (ROC) analysis was performed to determine the association between the continuous variables studied and the outcome of PVI. Area under the curve (AUC) was determined, and optimal cut-off, sensitivity, and specificity were determined manually from ROC plots. A *P*-value of <0.05 was deemed significant.

Results

Across the 12 UK centres, 1688 patients underwent cryoablation with the PolarX ($n = 844$, 50.0%) and AFA ($n = 844$, 50.0%) Cryoballoons [mean age 61.9 ± 12.0 years and 1119 male (66.3%)]. The median number of patients from each centre was 32.5 (IQR 123.5) patients. Of these, 1158 (68.6%) underwent ablation for PAF and 530 (31.4%) for persistent AF. Of the 12 centres, 10 centres provided consecutive data for the AFA and PolarX Cryoballoons. Baseline characteristics are described in *Table 1*.

Most of the procedures were performed under conscious sedation ($n = 1136$, 67.3%) and were day case procedures ($n = 1641$, 97.2%). Of the 47 patients who were not discharged on the same day, which were unplanned, 14 (29.8%) were due to a complication, 20 (42.6%) were due to late lab finish, and 13 (27.7%) were due to the patient not having fully recovered post-procedure.

The average procedure duration was 79.0 ± 32.0 min with a fluoroscopy duration of 16.4 ± 11.9 min and a DAP of 531.6 ± 208.2 cGycm^2. The average LA dwell time was 47.6 ± 16.9 min. Of the 1688 patients, 16 (0.9%) patients encountered a procedural complication either acutely (at time of procedure or pre-hospital discharge) ($n = 14$, 0.8%) or within 30 days ($n = 2$, 0.1%). The procedural complications included groin haematoma ($n = 7$, 0.4%), cardiac tamponade requiring pericardial drain insertion ($n = 6$, 0.4%), phrenic nerve palsy ($n = 2$, 0.1%), and gastroparesis ($n = 1$, 0.06%). Of the 1688 procedures, 11 (0.7%) procedures were not successful as defined by not achieving

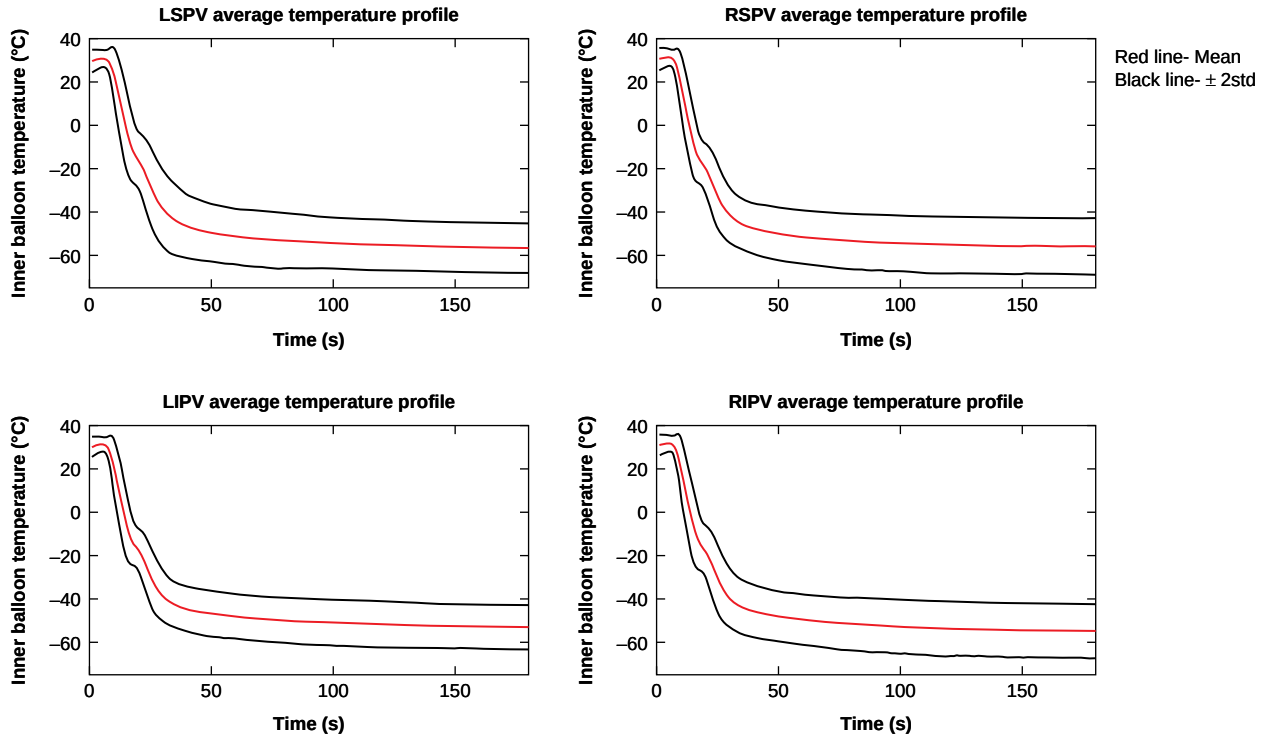


Figure 2 Demonstrates the spread of temperature profiles on a per vein basis with the PolarX Cryoballoon for cryoablations with a time to isolation (TTI) that demonstrated successful pulmonary vein isolation (PVI).

Table 3 Demonstrates differences in the cryoablation metrics with the cryoablations that resulted in PVI compared with the cryoablations that did not result in PVI

Cryoablation metrics	Cryoablations were vein isolated $n = 2742$	Cryoablations were vein did not isolate $n = 2262$	*P*-value
Nadir temperature, °C	−56.8 ± 6.7	−50.9 ± 7.7	<0.001
Temperature at 30 s, °C, mean ± SD	−39.5 ± 7.1	−37.1 ± 7.0	0.07
Temperature at 60 s °C, mean ± SD	−50.3 ± 6.1	−46.4 ± 6.6	0.14
Time to reach −40°C, s, mean ± SD	32.6 ± 12.3	36.8 ± 15.6	<0.001
Time to reach −50°C, s, mean ± SD	60.3 ± 34.0	71.4 ± 40.0	<0.001
Thaw time to 0°C, mean ± SD	21.47 ± 7.0	16.9 ± 6.3	<0.001
Thaw time to +15°C, mean ± SD	41.9 ± 14.8	31.2 ± 12.8	<0.001

PVI, pulmonary vein isolation; SD, standard deviation.

PVI ($n = 5$ cardiac tamponade, $n = 2$ procedure not tolerated due to patient discomfort, $n = 4$ despite optimal freeze parameters, PV signals remained). The procedure was deemed successful in the remaining 1677 (99.3%) procedures. *Figure 1* summarizes these findings.

Pulmonary vein isolation with PolarX

In the 844 patients who had cryoablation with the PolarX Cryoballoon, a total of 3373 veins underwent cryoablation to achieve PVI. In two patients, the left-sided veins were found to have a clear long common vein ostium based on contrast injections. In one patient, the right-sided veins were found to have common vein ostium based on contrast injections. Pulmonary vein (PV) signals were identified during cryoablation with 2064 of the 3373 veins (61.2%).

The average total cryoablation duration on a per patient basis was 22.7 ± 7.5 min to achieve PVI of all the veins. A total of 5.9 ± 2.2 cryoablations were applied to achieve PVI per patient; an average of 1.5 ± 0.9 cryoablations were applied per vein (1.7 ± 1.3 left upper PV (LUPV), 1.5 ± 0.9 left lower PV (LLPV), 1.6 ± 1.0 right upper PV (RUPV), 1.5 ± 0.9 right lower PV (RLPV)). Of the 3373 veins treated, 2177 (64.5%) veins isolated with a single cryoablation (2/2, 100% LCPV, 1/1, 100% RCPV, 543/842, 64.5% LUPV, 528/842, 62.7% LLPV, 550/

Table 4 Demonstrates the findings of the multivariate analysis

Cryoablation metrics	Univariate analysis		Multivariate analysis	
	P-value	Odds ratio (95% CI)	*P*-value	Odds ratio (95% CI)
Nadir temperature, °C	<0.001	0.93 (0.92–0.93)	<0.001	1.24 (1.18–1.29)
Temperature at 30 s, °C	<0.001	0.96 (0.95–0.97)	—	
Temperature at 60 s, °C	<0.001	0.90 (0.89–0.91)	—	
Time to reach −40°C, s	<0.001	0.98 (0.98–0.99)	<0.001	1.34 (1.24–1.38)
Time to reach −50°C, s	<0.001	0.99 (0.99–1.0)	—	

CI, confidence interval.

843, 65.2% RUPV, and 553/843, 65.6% RLPV). There was no significant difference between PVs in the average number of cryoablations applied to achieve PVI ($P = 0.53$).

Reviewing the cryoablation metrics for all cryoablation applied regardless of identification of PV signals and whether effective PVI, the nadir temperature was −54.6 ± 7.6°C, the temperature at 30 s was −38.6 ± 7.2°C, the temperature at 60 s was −48.9 ± 6.5°C, the time to reach −40°C was 34.1 ± 13.7 s, the thaw time to 0°C was 19.7 ± 7.1 s, and the thaw time to +15°C was 38.1 ± 15.2 s (see Supplementary material online, *Table S1*). The cryoablation metrics per vein type are also demonstrated in Supplementary material online, *Table S1*.

When reviewing the cryoablations with confirmed PV signals and successful PVI during the cryoablation, the cryoablation metrics were as follows: the nadir temperature was −57.6 ± 6.3°C, the temperature at 30 s was −39.4 ± 7.7°C, the temperature at 60 s was −50.8 ± 5.9°C, the time to reach −40°C was 32.3 ± 12.6 s, the thaw time to 0°C was 22.2 ± 6.7 s, the thaw time to +15°C was 44.2 ± 14.7 s, and the TTI was 49.8 ± 33.2 s (*Table 2*). The cryoablation metrics per vein type are also demonstrated in *Table 2*. *Figure 2* also demonstrates the temperature profiles on a per vein basis for cryoablation with a TTI that demonstrated a successful PVI.

Comparing the cryoablation metrics between the cryoablation that resulted in effective PVI ($n = 2742$) with those that were not known to have achieved successful PVI ($n = 2262$), there was a significant difference in cryoablation metrics (*Table 3*). For the multivariate analysis, all data containing PV signals and thereby TTI were included with the remaining data excluded. In the multivariate analysis, time to reach −40°C [OR 1.34, 95% confidence interval (CI) 1.24–1.38; $P < 0.001$] and nadir temperature (OR 1.24, 95% CI 1.18–1.29; $P < 0.001$) were independent predictors of achieving initial PVI (*Table 4*). The optimal cut-off for the time to reach ≤−40°C was ≤34 s (AUC 0.73; $P < 0.001$) with a sensitivity of 75.4% (95% CI 73.1–82.1%) and specificity of 80.6% (95% CI 75.6–83.3%). The optimal cut-off for nadir temperature was ≤−54.0°C (AUC 0.71; $P < 0.001$) with a sensitivity of 74.3% (95% CI 70.3–78.4%) and specificity of 78.6% (95% CI 73.4–80.3%).

Comparison between PolarX Cryoballoon cohort and an Arctic Front Advance Cryoballoon cohort

Over the same period, 844 patients underwent cryoablation with the AFA Cryoballoon. In the AFA cohort, more patients were undergoing cryoablation for PAF compared with in the PolarX cohort (605/844, 71.7% vs. 553/844, 65.5%; $P = 0.01$). There was no difference in the other baseline characteristics between the PolarX Cryoballoon cohort and the AFA Cryoballoon cohort (*Table 5*).

In the AFA cohort, the majority of patients also had their procedure under sedation ($n = 570$, 67.5%, AFA cohort vs. $n = 566$, 67.1% PolarX cohort; $P = 0.88$) and as a day case procedure ($n = 819$, 97.0% AFA cohort vs. $n = 822$, 97.4% PolarX cohort; $P = 0.77$), and there was no significant difference to that in the PolarX cohort.

When comparing procedural metrics for the PolarX Cryoballoon cohort against the AFA Cryoballoon cohort, there was no significant difference in procedure times, fluoroscopy times, DAP, and complication rates between the two cohorts (*Table 6*). The number of cryoablations required to achieve initial PVI on a per patient (5.9 ± 2.2 cryoablations, Polar X vs. 6.0 ± 2.0 cryoablations, AFA; $P = 0.65$) and a per vein basis was also not significantly different (1.5 ± 0.9 cryoablations, PolarX vs. 1.6 ± 1.0 cryoablations, AFA; $P = 0.72$) (*Table 6*).

Discussion

This national multi-centre study that included all centres in the UK using the novel PolarX Cryoballoon evaluated this Cryoballoon for PVI in AF and compared it with the well-established AFA Cryoballoon. This is the largest study evaluating cryoablation for AF. It is also the largest study comparing the two commercially available Cryoballoon technologies with regards to procedural metrics and 30-day complication rates. This study also further established key cryoablation metrics achieved with the PolarX Cryoballoon that can be utilized to guided cryoablation with this technology.

The main findings were as follows:

- Contemporary cryoablation in experienced centres is a safe and effective method to achieve PVI in patients with AF, with procedural success in >99%, a major complication rate of <1%, and same day discharge in 97% of patients.
- Safety, efficacy, and procedural metrics for the PolarX Cryoballoon were comparable with that achieved with the AFA Cryoballoon.
- Cryoablation metrics achieved with the PolarX Cryoballoon is different to that reported with AFA Cryoballoon.
- The time to reach ≤−40°C and nadir temperature were predictive of PVI with the PolarX Cryoballoon.

Safety and efficacy of contemporary cryoballoon pulmonary vein isolation

The AFA Cryoballoon is a mature technology that has changed little over the last decade. Nevertheless, with increasing experience and evolution of practice, the complication rate has reduced overtime. The Fire and Ice trial reported major complication rates in 10% of patients undergoing Cryoballoon PVI.[4] Reports in recent years usually describe a major complication rate of ~3% comprised mostly of vascular complications in ~0.5%, tamponade in <1%, and rates of persistent phrenic nerve palsy of <1%.[2,5,6] However, recent reports have emerged with

Table 5 Demonstrates differences in baseline characteristics between the PolarX Cryoballoon cohort and the AFA Cryoballoon cohort

Baseline characteristics	PolarX cohort N = 844	AFA cohort N = 844	P-value
Age, years, mean ± SD	61.4 ± 12.8	62.3 ± 11.1	0.78
Male, *n* (%)	549 (65.0)	570 (67.5)	0.30
Diabetes mellitus, *n* (%)	56 (6.6)	65 (7.7)	0.45
Hypertension, *n* (%)	261 (30.9)	286 (33.9)	0.21
TIA/CVA, *n* (%)	29 (3.4)	23 (2.7)	0.48
Ischaemic heart disease, *n* (%)	62 (7.3)	68 (8.1)	0.65
Cardiac surgery, *n* (%)	15 (1.8)	18 (2.1)	0.73
Cardiomyopathy, *n* (%)	84 (10.0)	92 (10.9)	0.58
Left ventricular EF ≥55%, *n* (%)	631 (74.8)	650 (77.0)	0.31
LA size mm, mean ± SD	42.6 ± 4.7	42.1 ± 6.7	0.62
AF type			
Paroxysmal, *n* (%)	553 (65.5)	605 (71.7)	0.008
Persistent, *n* (%)	291 (34.5)	239 (28.3)	0.008
Current antiarrhythmic or rate-controlling strategy			
Beta-blockers including sotalol, *n* (%)	380 (45.0)	426 (50.5)	0.03
Amiodarone, *n* (%)	100 (11.8)	101 (12.0)	1.00
Flecainide, *n* (%)	200 (23.7)	213 (25.2)	0.50
Dronedarone, *n* (%)	21 (2.5)	20 (2.4)	1.00
Calcium channel blocker, *n* (%)	20 (2.4)	30 (3.6)	0.20
Digoxin, *n* (%)	16 (1.9)	26 (3.1)	0.16
Current anticoagulation strategy			
Warfarin, *n* (%)	15 (1.8)	24 (2.8)	0.19
Direct oral anticoagulants, *n* (%)	829 (98.2)	820 (97.2)	0.19
Apixaban, *n* (%)	330 (39.1)	325 (38.5)	0.84
Edoxaban, *n* (%)	103 (12.2)	99 (11.7)	0.82
Rivaroxaban, *n* (%)	374 (44.3)	375 (44.4)	1.00
Dabigatran, *n* (%)	22 (2.6)	21 (2.5)	1.00

TIA/CVA, transient ischaemic attack/cerebrovascular attack; EF, ejection fraction; AF, atrial fibrillation; SD, standard deviation; AFA, Arctic Front Advance.

very low complication rates indeed such as The STOP Persistent AF study of 165 patients in whom there were no major complications.[7] This large multi-centre study showed very low rates of major complications (<1%), with no deaths or strokes. Although there are now numerous reports of same day discharge for AF ablation,[8,9] the rate achieved in this cohort was very high at >98%.

Crucially, this study was comprised half of patients undergoing Cryoballoon PVI using the PolarX Cryoballoon. This included the first 844 consecutive patients undergoing Cryoballoon PVI in the UK. This showed that procedural learning and the evolution of techniques have extrapolated well to this newer technology as there was no difference in procedure parameters or safety between these technologies.

Ablation using the PolarX Cryoballoon

The design of the PolarX Cryoballoon was similar to the AFA Cryoballoon, and it has been assumed that the safety and efficacy are similar. There are some data reported on the PolarX Cryoballoon, but these are limited to either single or small multi-centre studies.[10–15] This novel Cryoballoon has yet not been evaluated with regards to safety and efficacy across a large cohort.

This study was demonstrated in 844 patients across 12 UK centres that the PolarX Cryoballoon achieves similar procedural metrics including procedural times, fluoroscopy times, and number of cryoablations required to achieve PVI to a cohort of 844 consecutive patients undergoing cryoablation with the AFA Cryoballoon. There were no safety concerns with the PolarX Cryoballoon with a majority of the cases performed as day case procedures with low procedural and 30-day complication rates (0.8%). These findings were also compatible to the AFA Cryoballoon cohort. This is consistent with that reported in previous small studies.[10–12]

Metrics associated with pulmonary vein isolation

Preliminary data have shown that the temperature drop and cryoablation profile are very different with the PolarX Cryoballoon and are ~10°C lower at 30 s, 60 s, and nadir temperature.[10–12,16] The temperature at 30 s and nadir temperature achieved with the PolarX were consistent with the temperatures reported in other studies and again shown to be ~10°C lower compared with that reported with the AFA Cryoballoon. The differences seen in the cryoablation metrics

Table 6 Procedural, freedom from AF/AT during follow-up and cryoablation metric differences between PolarX Cryoballoon cohort and AFA Cryoballoon cohort

Procedural and cryoablation metrics	PolarX cohort $n = 844$	AFA cohort $n = 844$	*P*-value
Procedural metrics			
Procedural duration, min, mean ± SD	78.6 ± 38.1	79.4 ± 25.8	0.55
Fluoroscopy time, min, mean ± SD	16.1 ± 12.3	16.7 ± 11.4	0.68
Dose area product, cGycm^2, mean ± SD	531.2 ± 216.3	532 ± 200.1	0.45
Complications, *n* (%)	7 (0.8)	9 (1.1)	0.80
Immediate complications, *n* (%)	6 (0.7)	8 (0.9)	0.79
Cardiac tamponade, *n* (%)	3 (0.4)	3 (0.4)	1.00
Groin haematoma, *n* (%)	3 (0.4)	4 (0.5)	1.00
Phrenic nerve palsy, *n* (%)	0 (0)	1 (0.1)	1.00
30-day complications, *n* (%)	1 (0.1)	1 (0.1)	1.00
Gastroparesis, *n* (%)	1 (0.1)	0 (0)	1.00
Phrenic nerve palsy, *n* (%)	0 (0)	1 (0.1)	1.00
Cryoablation metrics			
Number of cryoblations to achieve PVI per patient, *n*, mean ± SD	5.9 ± 2.2	6.0 ± 2.0	0.65
Number of cryoablations to achieve PVI per vein, *n*, mean ± SD	1.5 ± 0.9	1.6 ± 1.0	0.72

PVI, pulmonary vein isolation; AF, atrial fibrillation; SD, standard deviation; AFA, Arctic Front Advance; AT, atrial tachycardia.

with the PolarX Cryoballoon are likely due to the differences in the PolarX Cryoballoon design to the AFA Cryoballoon such as differences in the position and injection orientation of the nitrous oxide injection coil relative to the front of the balloon, different refrigerant flow, and closer proximity of the thermocouple to the outflow of the cold gas proximally (5 mm with PolarX and 10 mm with AFA).[17] Thereby, the differences in balloon design and the differences seen in cryoablation metrics between the PolarX and AFA Cryoballon emphasize that the well-established targets used with the AFA Cryoballoon[18] cannot be readily transferable to the PolarX Cryoballoon and modified metrics needs to be targeted to achieve effective PVI with the PolarX Cryoballoon. We have previously demonstrated in a small study that nadir temperature and time to reach −40°C are predictive of effective PVI with the PolarX Cryoballoon.[10] This study has also shown that the time to reach ≤−40°C and the nadir temperature are independent predictors of PVI with the PolarX Cryoballoon. These cryoablation metrics can guide the use of the PolarX Cryoballoon. Even though these metrics have shown to be predictive of effective PVI with AFA Cryoballoon, the optimal targets were ∼10°C lower than that reported using the AFA Cryoballoon.[19,20] These findings give clear guidance on metrics that can be utilized by clinicians when performing cryoablation with the PolarX Cryoballoon.

Since TTI is not always visualized, it is useful to consider targets excluding TTI analysis. Where a temperature of ≤−40°C was achieved at 30 s, first pass PVI was more likely. If this is paired with a nadir temperature of ≤−54°C, then there is a further likelihood of achieving PVI. If the temperature is >−35°C at 30 s, then the vein is unlikely to isolate, and consideration could be given to abandoning the cryoablation and repositioning. If a temperature between −35 and −40°C is achieved at 30 s, then a consolidating cryoablation ought to be considered.

Limitations

The focus of this study was to evaluate procedural metrics and safety profile with regards to immediate and 30-day complication rates using Cryoballoon ablation. Thereby the impact on clinical outcomes was not evaluated. Further studies using robust follow-up are required to evaluate differences in long-term outcomes achieved with these two Cryoballoons. Further to this, the impact of freeze targets and metrics on long-term outcomes needs to be evaluated particularly for the PolarX.

In this study, efficacy and safety with the PolarX Cryoballoon were compared with the consecutive AFA Cryoballoon cohort. Further studies, ideally randomized trials, remain desirable to compare these technologies.

In this study, the reporting of a complication within 30 days of the procedure was reliant on the patient reporting any complications post-discharge from hospital. However, all patients were reviewed at 3 months post-procedure, and any complications encountered during the 30-day period post-procedure were recorded.

Conclusion

This large-scale UK multi-centre study has shown that contemporary Cryoballoon PVI is a safe, effective day case procedure. PVI using the novel PolarX Cryoballoon was similarly quick, safe, and effective as the AFA Cryoballoon. However, the cryoablation metrics achieved with the PolarX Cryoballoon were different to that reported with the AFA Cryoballoon. PolarX cryoablation metrics including time to reach ≤−40°C and nadir temperature ≤−54°C were independent predictors of effective PVI. Modified cryoablation targets are required when utilizing the PolarX Cryoballoon. Prospective testing of these targets and ultimately outcome studies are needed to define the best ablation approach with the PolarX Cryoballoon and compare it with the AFA.

Supplementary material

Supplementary material is available at *Europace* online.

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Data availability

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

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