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# Cryoballoon vs radiofrequency ablation of atrial fibrillation: insights from the Veterans Healthcare System

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# Cryoballoon vs radiofrequency ablation of atrial fibrillation: insights from the Veterans Healthcare System

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## Abstract

**Purpose** Catheter ablation is considered the mainstay treatment for drug-refractory atrial fibrillation (AF). The aims of our study were to compare the efficacy and safety of the most two currently approved approaches (point-by-point radiofrequency ablation (RFA), either with contact force (CF) or without contact force (nCF) catheters, and cryoballoon ablation (CBA)) in the Veterans Healthcare System.

**Methods** We performed a retrospective study of patients who underwent ablation for treatment of AF at the veterans affairs healthcare system between 2013 and 2018. Only the first reported ablation procedure was included.

**Results** We included 956 patients in the study (97.4% males, 91.5% Caucasians, 67% paroxysmal AF), with 682 patients in RFA-nCF, 139 in RFA-CF, and 135 in CBA. Thirty-day complication rates were comparable between the three groups with the exception of higher incidence of phrenic nerve injury in CBA group when compared to RFA-nCF (2.2% vs 0.0%, $p < 0.01$). Long-term recurrence rate of AF was significantly lower in the CBA group when compared to RFA-nCF (33.3% vs 47.7%, adjusted HR 0.60, 95% CI 0.44–0.83, $p < 0.01$). On the other hand, it was similar between RFA-CF and RFA-nCF groups (43.9% vs 47.7%, adjusted HR 1.01, 95% CI 0.76–1.33, $p$ 0.97). After stratifying patients based on AF type, these findings were only present in patients with paroxysmal AF.

**Conclusion** CBA for paroxysmal AF, in male dominant patients' population, was associated with lower incidence of AF recurrence rate while having a comparable safety profile to RFA independent of the use of CF catheters.

**Keywords** Atrial fibrillation · Radiofrequency ablation · Cryoballoon ablation · Contact force

## 1 Introduction

Atrial fibrillation (AF) is an endemic disease and age-related cardiac arrhythmia. In the recent 2017 expert consensus statement, catheter ablation of drug-refractory paroxysmal AF carries a class I level A indication, and pulmonary vein electrical isolation (PVI) is still the cornerstone approach [1].

The most common procedure for PVI is percutaneous catheter-based approach which is achieved by creating tissue necrosis and scar formation through circumferential lesions surrounding the pulmonary veins. The most two currently approved catheter approaches for PVI for paroxysmal AF in the USA are point by point radiofrequency ablation (RFA) and cryoballoon ablation (CBA) which is considered a "single-shot" approach. Prior randomized clinical trials showed comparable efficacy and safety profile between the two studies during overall short duration follow-up [2]. CBA has emerged as a novel treatment for pulmonary vein isolation (PVI) for patients with paroxysmal AF. The second-

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generation Arctic Front Advance (ADV) was redesigned with technical modifications aiming at procedural and outcome improvements. On the other hand, advancement in RFA catheter design resulted in the development of contact sensing catheters which, in theory, gives the operator the ability to assure adequate tissue contact prior to delivering the ablation lesions [3]. Few studies have compared the efficacy and safety of these three approaches. We aimed to evaluate the long-term outcome of the two types of RFA (contact force (CF) and non-contact force (nCF)) versus CBA in the Veterans Affairs (VA) healthcare system in our current retrospective multicenter study.

## 2 Methods

### 2.1 Data source and study population

Using data from CAPRI (Compensation and Pension Record Interchange) system, we identified patients who underwent AF ablation between January 2013 and January 2018. CAPRI is an electronic health record system holding national data for the VA system in the USA and allows electronic search as well as review of notes, procedures, imaging reports, and lab results across various VA hospitals. We initially narrowed our search by identifying patients with the procedure code CPT 93656. We used a combination of electronic data search (using ICD codes) and manual verification to identify demographic data and baseline clinical variables at the time of ablation. We manually reviewed each chart and excluded ablations for other forms of supraventricular tachycardias. The following information was collected: demographic data, co-morbidities, medications used, type of AF, type of ablation, complications in the first 30 days, time to first recurrence, re-ablation, direct current cardioversion (DCCV) post-ablation, and all-cause mortality. The Central Arkansas VA Health System's institutional review board approved the study.

### 2.2 Types of atrial fibrillation

We classified AF into two types: paroxysmal and non-paroxysmal. The non-paroxysmal group included patients with persistent and long-term persistent AF [4]. The patient assignment was based on documentation in the treating physician notes. If the type was not specified, the allocation was then performed by the reviewer based on the information available in the chart.

### 2.3 Type of ablation procedure

We divided patients into two groups based on ablation energy source: RFA ablation group and CBA group. The RFA group was further subdivided into two groups based on the use of contact force sensing catheters during the PVI ablation. We also identified the use of different ablation techniques, namely, PVI; superior vena cava (SVC) isolation; mitral valve and/or roof line; cavotricuspid isthmus (CTI) ablation; and complex fractionated atrial electrograms (CFAE) ablation. In patients who underwent a redo ablation procedure, if at least one PV showed evidence of reconnection that required additional ablation to achieve reisolation, they are considered to have undergone additional PVI.

### 2.4 Outcomes

We evaluated the incidence of complications and mortality in the first 30 days after ablation and first AF recurrence. AF recurrence was counted following 3-month blanking period after ablation. We also assessed the incidence and timing of re-ablation procedures or DCCV after the index ablation. Any detection of AF beyond the blanking period regardless of the duration was considered a recurrence. Mode of detection included ECG report showing AF, Holter, or event monitor, or implantable device interrogation with physician interpretation reporting AF or a physician note documenting recurrence.

### 2.5 Statistical analysis

Patients were classified into three groups based on the energy type used and the use of contact force sensing catheters: RFA-nCF, RFA-CF, and CBA groups. Categorical variables are reported as counts and percentages; differences were assessed with Chi-square test or Fisher exact test (if n less than 5 for one or more expected values). Continuous variables are presented as means with one standard deviation; differences were compared with two sample Student's $t$ test. Kaplan-Meier analysis and log-rank tests were used to compare the rates of AF recurrence and all-cause mortality for the unadjusted data. We then performed Cox-regression analysis to adjust for baseline variables and calculate the adjusted hazard ratios. The variables used in the Cox-regression analysis were age at ablation, gender, race, co-morbidities (congestive heart failure, coronary artery disease (CAD), history of atrial flutter, diabetes mellitus (DM), hyperlipidemia, hypertension, cerebrovascular accidents (CVA), peripheral vascular disease (PVD), chronic obstructive pulmonary disease, obstructive sleep apnea, and chronic kidney disease), ever smoking status, prior ablation, and body mass index. We chose the RFA-nCF group as the reference group for comparing the other two groups.

A two-sided $p$ value of equal to or less than 0.05 was considered significant. Analysis was performed using IBM SPSS statistics software.

## 3 Results

### 3.1 Baseline characteristics

A total of 956 patients who underwent first AF ablation in the time period specified above from 34 VA centers were included in this analysis. Of those, 682 patients had RFA ablation with nCF catheters, 139 had RFA with CF catheters, and 135 had CBA. More than 95% of patients in all groups were males. More than 65% of the patients had paroxysmal AF. Table 1 compares the baseline characteristics between the three groups. Compared to the RFA-nCF group, mean age in the RFA-CF group was higher (65.7 SD 7.0 vs 63.7 SD 8.2 years, $p$ 0.01), with a higher prevalence of prior CVA (26.6% vs 18.2% $p$ 0.02) and atrial flutter (62.6% vs 53.4%, $p$ 0.05). The CBA group had more patients with CAD (67.4% vs 54.4%, $p$ 0.01), DM (48.1% vs 38.0%, $p$ 0.03), hyperlipidemia (88.9% vs 82.1%, $p$ 0.05), and PVD (8.1% vs 3.5%, $p$ 0.02) when compared to the RFA-nCF group.

### 3.2 Ablation procedure characteristics

All patients (100%) in CBA group underwent successful PVI using the second-generation CB catheter (Arctic Front Advance®; Medtronic, Inc.). On the other hand, in the RFA groups, one patient in each group did not have PVI as they developed pericardial effusion requiring termination of the procedure. Nine patients (6.7%) in the CBA groups required additional RFA to complete the left atrial ablation. Mitral valve and/or roof line (5.2% vs 15.5%, $p < 0.01$) and CFAE (0.0% vs 5.9%, $p < 0.01$) were performed infrequently, as expected, in the CBA group compared to the RFA-nCF group; however, they were performed in similar frequency between the RFA-nCF and RFA-CF groups. There is no statistical difference in CTI line ablation between the three groups (Supplementary material online, Table S1). Additional ablation beyond PVI (other than CTI) was performed more frequently in patients with persistent AF compared to paroxysmal AF (28.8% vs 12.5%, $p < 0.01$). In patients with persistent atrial fibrillation, the frequency of ablation beyond PVI (other than CTI) was still lower in the CBA group when compared to

**Table 1** Baseline characteristics

| | Type of ablation | | | | |
|---|---|---|---|---|---|
| | RFA-nCF* (682) | RFA-CF (139) | $p$ value | CBA (135) | $p$ value |
| Age, years (SD) | 64 (8) | 66 (7) | 0.01 | 64 (7) | 0.72 |
| Male | 667 (97.8%) | 133 (95.7%) | 0.15 | 131 (97.0%) | 0.59 |
| Caucasian race | 624 (91.5%) | 125 (89.9%) | 0.55 | 126 (93.3%) | 0.48 |
| CHF | 275 (40.3%) | 52 (37.4%) | 0.52 | 52 (38.5%) | 0.70 |
| CAD | 371 (54.4%) | 77 (55.4%) | 0.83 | 91 (67.4%) | 0.01 |
| DM | 259 (38.0%) | 59 (42.4%) | 0.32 | 65 (48.1%) | 0.03 |
| HTN | 276 (40.5%) | 57 (41.0%) | 0.91 | 53 (39.3%) | 0.79 |
| Hyperlipidemia | 560 (82.1%) | 115 (82.7%) | 0.86 | 120 (88.9%) | 0.05 |
| PVD | 24 (3.5%) | 7 (5%) | 0.39 | 11 (8.1%) | 0.02 |
| CVA | 124 (18.2%) | 37 (26.6%) | 0.02 | 30 (22.2%) | 0.27 |
| COPD | 231 (33.9%) | 53 (38.1%) | 0.34 | 50 (37.0%) | 0.48 |
| OSA | 300 (44.0%) | 69 (49.6%) | 0.22 | 58 (43.0%) | 0.83 |
| Ever smoking | 240 (35.2%) | 55 (39.6%) | 0.33 | 52 (38.5%) | 0.46 |
| Atrial flutter | 364 (53.4%) | 87 (62.6%) | 0.05 | 81 (60.0%) | 0.16 |
| CKD† | 120 (17.6%) | 28 (20.1%) | 0.48 | 17 (12.6%) | 0.16 |
| Prior AF ablation | 129 (18.9%) | 18 (12.9%) | 0.10 | 20 (14.8%) | 0.26 |
| Paroxysmal AF | 455 (66.7%) | 87 (62.6%) | 0.35 | 98 (72.6%) | 0.18 |
| BMI ≥ 30 | 414 (60.1%) | 82 (59.0%) | 0.71 | 82 (60.7%) | 0.99 |

* Reference group

† *CKD* chronic kidney disease, defined as eGFR < 60 mL/min/1.73 $m^2$

*AF* atrial fibrillation; *BMI* body mass index; *CAD* coronary artery disease; *CBA* cryoballoon ablation; *CHF* congestive heart failure; *COPD* chronic obstructive pulmonary disease; *CVA* cerebrovascular accident; *DM* diabetes mellitus; *HTN* hypertension; *OSA* obstructive sleep apnea; *PVD* peripheral vascular disease; *RFA-CF* radiofrequency ablation-contact force; *RFA-nCF* radiofrequency ablation-non-contact force

the RFA-nCF group (10.8% vs 29.1%, $p$ 0.02) but was not different between the RFA-nCF and RFA-CF groups (29.1% vs 40.4%, $p$ 0.11).

## 3.3 Outcomes

### 3.3.1 Thirty-day complication rates and all-cause mortality

There is no statistical difference in complication rates and all-cause mortality (Table 2) among the three groups at 30-day post-ablation with the exception of higher incidence of phrenic nerve injury (PNI) in CBA group when compared RFA-nCF (2.2% vs 0.0%, $p < 0.01$). All PNI recovered spontaneously during follow-up (two recovered prior to hospital discharge from the index ablation and one within 1-year of follow-up). There was a higher overall incidence of pericardial effusion in the RFA-CF when compared to RFA-nCF (3.6% vs 1.2%, $p$ 0.04), but there was no statistically significant difference in major pericardial effusion requiring interventions (2.9% vs 1%, $p$ 0.10).

### 3.3.2 Redo ablation, DCCV, and antiarrhythmic medication use after index ablation

During the blanking period post-ablation, atrial tachyarrhythmia rates were not different among the groups. However, fewer patients in the CBA group underwent DCCV compared to RFA-nCF (3.7% vs 9.2%, $p$ 0.03).

Over a median follow-up of 39.7 months, 120 patients underwent a redo ablation; PVI was reperformed in 96.7% of procedures. In RFA-nCF group, 92 (13.5%) patients underwent redo ablation, and almost all (98.9%) required additional PVI. On the other hand, 24 patients (16.5%) in RFA-CF group underwent a redo ablation and 87.5% required redo PVI. Only 4 (3.0%) patients underwent redo ablation in the CBA group, but all of them required additional PVI. Patients in CBA group less commonly underwent redo ablations when compared to the RFA-nCF group (3.0% vs 13.5%, $p < 0.01$). This difference was significant only in those with paroxysmal AF (1% vs 13%, $p < 0.01$), but not in those with persistent AF (8.1% vs 14.1%, $p$ 0.44). On the other hand, the difference in redo ablation rates between the RFA-CF and RFA-nCF was not statistically different, both in the overall cohort (17.3% vs 13.5%, $p$ 0.24) and in patients with paroxysmal AF (11.5% vs 13.0%, $p$ 0.71). However, in patients with persistent AF, the rate of redo ablation is higher in the RFA-CF group compared to RFA-nCF (26.9% vs 14.1%, $p$ 0.03) (Supplementary material online, Table S2). Atrial tachycardia or flutter was reported in 31 patients (25.8%) at time of the redo procedures, while the rest had only atrial fibrillation. The rates were not statistically significant between the three groups (22.8% vs 37.5% vs 25%, $p$ 0.34, nCF vs CF vs CBA, respectively).

Although there was no statistical difference among the three groups in regards to classes I and III antiarrhythmic medication use at hospital discharge, 12 months, 24 months, and 36 months from the index ablation, the RFA-CF group had a numerically lower rate of use of antiarrhythmic at discharge (63.3% vs 71.6%, $p$ 0.053) and at 36 months (7.1% vs

**Table 2** 30-day complication rates

| | Type of ablation | | | | |
|---|---|---|---|---|---|
| | RFA-nCF* (682) | RFA-CF (139) | $p$ value | CBA (135) | $p$ value |
| Pericardial effusion | 8 (1.2%) | 5 (3.6%) | 0.04 | 4 (3.0%) | 0.12 |
| Tamponade or required drainage | 7 (1.0%) | 4 (2.9%) | 0.10 | 2 (1.5%) | 0.65 |
| Infection | 3 (0.4% | 1 (0.7%) | 0.53 | 0 (0.0%) | > 0.99 |
| Stroke/TIA | 3 (0.4%) | 0 (0.0%) | > 0.99 | 1 (0.7%) | 0.52 |
| Vascular bleeding | 31 (4.5%) | 2 (1.4%) | 0.10 | 6 (4.4%) | 0.96 |
| Non-vascular bleeding | 6 (0.9%) | 0 (0.0%) | 0.60 | 2 (1.5%) | 0.63 |
| Respiratory failure | 16 (2.3%) | 5 (3.6%) | 0.39 | 1 (0.7%) | 0.33 |
| Phrenic nerve injury | 0 (0.0%) | 0 (0.0%) | - | 3 (2.2%) | < 0.01 |
| Pericarditis | 14 (2.1%) | 5 (3.6%) | 0.27 | 0 (0.0%) | 0.14 |
| 30-day rehospitalization | 75 (11.0%) | 16 (11.5%) | 0.86 | 14 (10.4%) | 0.83 |
| 30-day mortality | 4 (0.6%) | 1 (0.7%) | > 0.99 | 0 (0.0%) | > 0.99 |

* Reference group

*CBA* cryoballoon ablation; *RFA-CF* radiofrequency ablation-contact force; *RFA-nCF* radiofrequency ablation-non-contact force; *TIA* transient ischemic attack

13.2%, $p$ 0.26) when compared to RFA-nCF group (Supplementary material online, Table S3).

### 3.3.3 Long-term atrial fibrillation recurrence rate

The follow-up duration of the RFA-nCF group was longer compared to RFA-CF group (41.2 SD 12.5 vs 31.8 SD 9.8 months, $p < 0.01$). On the other hand, there was no difference in follow up between the RFA-nCF and CBA groups (41.2 SD12.5 vs 41.4 SD 14.6 months, $p$ 0.81). AF recurrence rate for the whole cohort was 27.5% in the first year and 45.1% after long-term follow-up. Long-term recurrence rate of AF is significantly lower in the CBA group when compared to RFA-nCF and RFA-CF (33.3% vs 47.7% vs 43.9%, $p <$ 0.01) (Fig. 1a). This finding did not change after adjustment for baseline characteristics (Fig. 1b) or when analysis was performed in patients with paroxysmal AF (Supplementary material online, Fig. S1). On the other hand, in patients with non-paroxysmal atrial fibrillation, there was no difference in recurrence rate between the three groups. When analysis was restricted for first time ablation of paroxysmal atrial fibrillation (excluded patients with prior ablation for AF) and only PVI (excluded patients who underwent additional left atrial ablation to PVI), findings remained consistent, with long-term recurrence rate of AF being significantly lower in the CBA group when compared to RFA-nCF (22% vs 42%, HR 0.41, 95% CI 0.25–0.69, $p < 0.01$) and no difference in recurrence rate between RFA-CF and RFA-nCF (36% vs 42%, HR 0.86, 95% CI 0.55–1.34, $p$ 0.51) (Supplementary material online, Fig. S2).

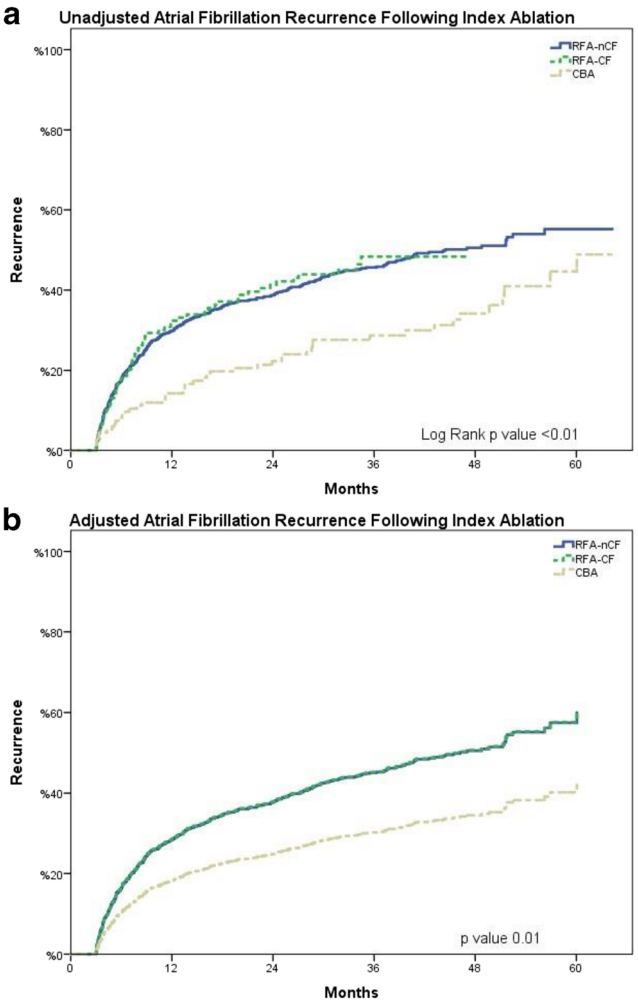


**Fig. 1** First recurrence after atrial fibrillation ablation. **a** Unadjusted Kaplan-Meier curves of atrial fibrillation recurrence. **b** Time to first recurrence curves adjusted for baseline characteristics using Cox-regression analysis

Table 3 summarizes the hazard ratios and confidence intervals for AF recurrence rate adjusted for follow-up time using Cox-regression analysis before and after adjustment for baseline characteristics. Long-term recurrence of AF was lower in CBA group compared to RFA-nCF (HR 0.60, 95% CI 0.44–0.83, $p < 0.01$). However, it was similar between the RFA-nCF and RFA-CF groups (HR 1.01, 95% CI 0.76–1.33, $p$ 0.96).

## 4 Discussion

In this contemporary, real-world chart review study comparing the three major AF ablation technologies available for percutaneous catheter PVI, the main findings were: (1) 30-day complication rate between CBA and RFA was comparable with the exception of higher incidence of transient PNI in CBA and higher incidence of pericardial effusion in RFA-CF group; (2) less DCCV was utilized in the blanking period for the CBA group; and (3) long-term recurrence of AF was significantly lower with CBA when compared to RFA with or without the use of CF, with a lower rate of redo ablation and similar rates of repeat DCCV. An important strength of this study is its use of the VA healthcare system, which provided important follow-up data on patients even when they changed cities or state; this level of follow-up is generally limited in other healthcare systems.

PVI is currently the standard strategy for any catheter-based treatment for patients with AF [1]. The standard point by point RFA technique has been utilized for the last two decades but still can be challenging and time-consuming. Cryoballoon ablation has emerged as a novel treatment for PVI as a single application for the last decade. CBA performed with the second-generation CB results in a shorter procedure with less catheter time in the left atrium when compared to RFA [5]. Contact sensing RFA catheters have also emerged as tools to allow for the optimization of each individual RF application that aims to maximize efficacy and procedural safety [3]. PVI has been used in the USA off label for persistent AF, and several studies showed similar outcome

**Table 3** Long-term outcomes compared to non-contact force radiofrequency ablation group

| | Unadjusted | | | | Adjusted | | | |
|---|---|---|---|---|---|---|---|---|
| | RFA-CF* | | CBA* | | RFA-CF* | | CBA* | |
| | HR (95% CI) | *p* value | HR (95% CI) | *p* value | HR (95% CI) | *p* value | HR (95% CI) | *p* value |
| AF recurrence | 1.05 (0.80–1.38) | 0.73 | 0.59(0.43–0.81) | < 0.01 | 1.01 (0.76–1.33) | 0.97 | 0.60 (0.44–0.83) | < 0.01 |
| Paroxysmal | 0.95 (0.66–1.37) | 0.78 | 0.51 (0.34–0.76) | 0.01 | 0.98 (0.67–1.44) | 0.93 | 0.56 (0.37–0.84) | 0.01 |
| Non-paroxysmal | 1.19 (0.79–1.80) | 0.41 | 0.82 (0.50–1.35) | 0.44 | 0.98 (0.64–1.51) | 0.93 | 0.64 (0.38–1.07) | 0.09 |

* Compared to RFA-nCF group

*AF* atrial fibrillation; *CBA* cryoballoon ablation; *CI* confidence interval; *HR* hazard ratio; *RFA-CF* radiofrequency ablation-contact force; *RFA-nCF* radiofrequency ablation-non-contact force

between CBA and RFA [6, 7]. Head to head comparisons of these three ablation approaches are sparse.

In the original FIRE and ICE study comparing CBA and RFA, there was no statistically significant difference of the primary outcome (first documented recurrence of AF > 30 sec, documented occurrence of atrial flutter or atrial tachycardia, prescription of antiarrhythmic drugs, or redo AF ablation after the 90-day blanking period) between the RFA and CBA approaches [2]. However, additional analysis including the blanking period and follow-up after the primary endpoint until exiting the study showed that patients treated with CBA had significantly lower redo ablation rates, DCCV, all-cause rehospitalizations, and cardiovascular rehospitalizations compared to RFA (11.8% in the CBA arm required a redo ablation procedure compared to 17.6% in RFA arm (*p* 0.03) after a mean follow-up of 1.5 years) [8]. In the current study, 3% in the CBA required a redo ablation in long-term follow-up. DCCV was required in 3.7% in the CBA group during the blanking period compared to 9.2% in the RFA-nCF group (Supplementary material online, Table S2) suggesting that CBA is less arrhythmogenic (less atrial arrhythmias during the blanking period) than RFA. However, in patients who underwent a redo procedure during follow-up, the rates of atrial tachycardia or flutter was similar between the three groups.

Ciconte et al showed that the rate of late PV reconnection in CBA was low (22%, average of 1.25 PVs/patient) [9]. A later study by Aryana et al. showed that CBA was associated with more durable PVI when compared to non-contact force-guided RF ablation [10]. In the current study, only 4 patients in the CBA group underwent redo ablation, and all of them required additional PVI; however, we did not have data on the number and laterality of the pulmonary veins that showed reconnections; thus, we cannot draw conclusions about the durability of PVI in this study. Nonetheless, it is important to note that PVI was less frequently performed in patients who underwent a redo ablation in the CF-RF group compared to the nCF-RF group (87.5% vs 98.9%).

Prior data suggests that PVI can be achieved with the second-generation CB alone in nearly all patients using the second-generation device [2, 11, 12]. In our study, however, additional RFA in left atrium was required in 6.7% undergoing CBA.

In the STOP AF post-approval study, which was a multicenter prospective study using second-generation CB for drug-resistant symptomatic paroxysmal AF [13], freedom from AF was 81.6% at 12 months, 73.8% at 24 months, and 68.1% (64.1%, from all atrial arrhythmias) at 36 months. The results of the current study are in line with these results (87% freedom from AF at one year and 72% with long-term follow-up).

An additional important finding in this study was the lack of difference in AF recurrence rate between non-CF and CF RFA ablations, with both being associated with higher recurrence when compared to CBA. Prior studies have largely suggested similar efficacy between CBA and nCF RFA, especially in randomized studies [2]. A meta-analysis comparing CF vs non-CF-guided ablation found that CF-guided therapy was associated with significant AF/atrial tachycardia-free survival benefit in patient with paroxysmal AF over a median follow-up of 12 months [3]. However, in a more recent meta-analysis by Virk et al., there was no difference in freedom from AF, independent of AF type, when analysis was restricted to randomized trials [14]. In a recent randomized trial, Buist et al. showed improved arrhythmia-free survival and more durable PVI with the use of second-generation CBA compared to RFA-CF in patients with drug-refractory paroxysmal AF, with similar complication rates [15]. In a recently published individual patient data meta-analysis, CBA was associated with less long-term failures in men but not in women when compared to RFA [16].

In patients with persistent atrial fibrillation, there was no difference in AF recurrence rate between the three groups after the index ablation even though the percentage of patients undergoing ablation beyond PVI was lower in CBA group compared to the other two groups. This finding is consistent with the results of the STAR-AF II trial that showed no added

reduction in the rate of AF recurrence when mitral or roof linear ablation or CFAE was performed alongside PVI. [17]

In our study, the 30-day complication rate was generally comparable to what was reported in previous studies [2, 18] and among the three groups with the main exception of transient PNI that was significantly higher in CBA group. However, the reported rate in our study (2.2%) was similar to the FIRE and ICE study (2.7%) [2] and is much less compared to what has been reported in elsewhere (11.0% and 13.5% in some studies) [19]. One other interesting finding was the higher incidence of pericardial effusion in the RFA-CF group when compared to the RFA-nCF group; however, it was not statistically significant when only effusions requiring intervention or causing tamponade were evaluated. This could reflect the somewhat stiffer nature of the CF catheters and the variable level of expertise of the operators in regard to the required CF for the ablation. This finding supports the results of a recent study which demonstrated a higher incidence of cardiac tamponade in CF compared to non-CF ablation [20]. In our study, the incidence of pericardial effusion in CBA was not better than RFA and was higher than reported in a recent meta-nalysis [21].

## 5 Limitations

Our study has several limitations. Data collection relied on retrospective chart review of the VA health records system. However, it still provides important patient level data that cannot be obtained in studies based only on ICD codes. As in any retrospective study, selection and other bias may have impacted the results. Adjudication of type of AF and AF recurrence rate was based on record review, and the true recurrence rate (especially asymptomatic) may be underestimated. Although we could not account for any follow-up that happened outside the VA system, we believe the impact of this is likely much lower when compared to other healthcare systems as veterans tend to stay in the VA system even after moving to a different city or state. Type of monitoring for arrhythmia recurrence after the PVI was not standardized but reflects real-world practice. As expected of an older US veteran population, the vast majority of patients was male, and results may not be applicable to females. In fact, female gender has been associated with more failed ablations and higher incidence of complications and cardiovascular rehospitalization post-PVI [22]. Ablations were performed in 34 centers and by operators of varying experience especially with newer technologies. Variation in the learning curve among newer ablation technologies could also have affected the procedure outcome. We could not adjust for these operator characteristics both due to the low numbers per site and operator due to using only one procedure CPT code as well as the practical observation that most operators within the VA system often perform ablations at affiliated academic medical centers. The last two factors likely resulted in underestimation of the actual number of AF ablation procedures performed per site and operator. Due to the reliance on medical records, we could not assess the difference in radiation and intravenous contrast exposure among these techniques as well as balloon inflation times and freeze duration in CBA group. Finally, we were unable to determine if stable and recommended CF was achieved during the CF RFA procedures [18]. This may have affected the efficacy of this procedure since recent studies suggested better outcome when ablation index was used in the CF RFA [23, 24].

## 6 Conclusion

In our real-world study of a predominantly male patient population, CBA for paroxysmal AF was associated with lower incidence of AF recurrence and redo ablation rates during long-term follow-up while having a comparable safety profile compared to RFA independent of the use of CF catheters. These results should be validated in a prospective manner to evaluate if outcomes will be different based on gender and type of AF.

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**Authors' contributions** Waddah Maskoun: Conceptualization, methodology, original draft, review, and editing

Amjad Abualsuod: Data collection, statistical analysis, original draft, review, and editing

Fuad Habash: Material preparation, data collection, review, and editing.

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Zaid Gheith: Data collection, review, and editing.

Bilal Alqam, MD: Data collection, review, and editing.

John M. Miller: Review and editing.

Srikanth Vallurupalli: Supervision, review, and editing

**Data Availability** Available upon reasonable request

## Compliance with ethical standards

**Conflict of interest** W. Maskoun, Medtronic grant; J. Miller, Medtronic, Boston Scientific, Biosense-Webster, Biotronik, Abbott Electrophysiology—training grants and lecture honoraria. The remaining authors have nothing to disclose.

**Code availability** Not applicable

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