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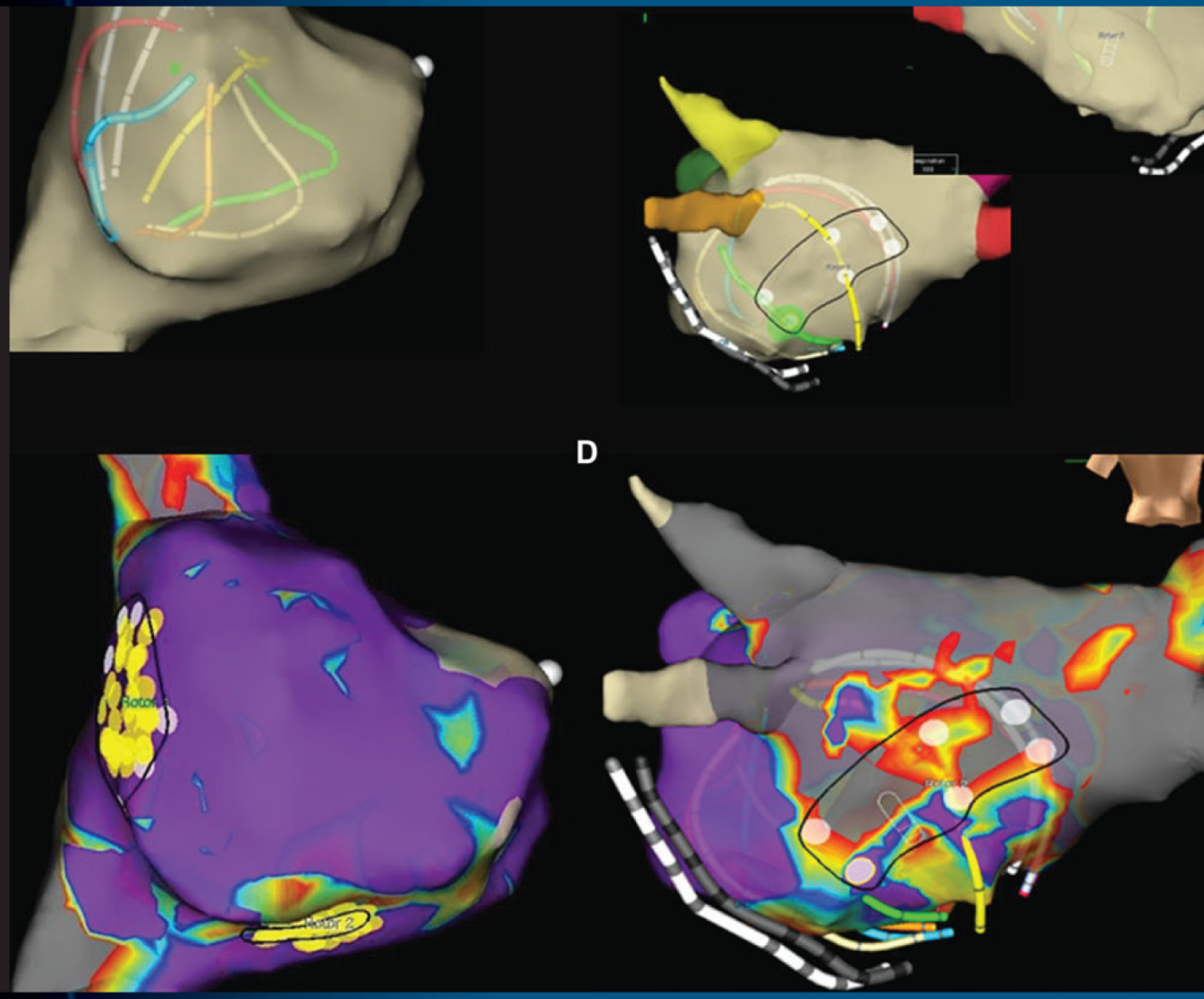

WILEY

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ORIGINAL ARTICLE

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Ablation of paroxysmal atrial fibrillation using a second-generation cryoballoon catheter or contact-force sensing radiofrequency ablation catheter: A comparison of costs and long-term clinical outcomes

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Abstract

Introduction: Although noninferiority of cryoballoon ablation (CBA) and radiofrequency catheter ablation for antral pulmonary vein isolation (APVI) has been reported in patients with paroxysmal atrial fibrillation (PAF), it is not clear whether contact force sensing (CF-RFA) and CBA with the second-generation catheter have similar procedural costs and long-term outcomes. The objective of this study is to compare the long-term efficacy and cost implications of CBA and CF-RFA in patients with PAF.

Methods and results: A first APVI was performed in 146 consecutive patients (age: 63 ± 10 years, men: 95 [65%], left atrial diameter: 42 ± 6 mm) with PAF using CBA (71) or CF-RFA (75). Clinical outcomes and procedural costs were compared. The mean procedure time was significantly shorter with CBA than with CF-RFA (98 ± 39 vs. 158 ± 47 minutes, $P < 0.0001$). Despite a higher equipment cost in the CBA than the CF-RFA group, the total procedure cost was similar between the two groups ($P = 0.26$), primarily driven by a shorter procedure duration that resulted in a lower anesthesia cost. At 25 ± 5 months after a single ablation procedure, 51 patients (72%) in the CBA, and 55 patients (73%) in the CF-RFA groups remained free from atrial arrhythmias without antiarrhythmic drug therapy ($P = 0.84$).

Conclusions: The procedure duration was approximately 60 minutes shorter with CBA than CF-RFA. The procedural costs were similar with both approaches. At 2 years after a single procedure, CBA and CF-RFA have similar single-procedure efficacies of 72–73%.

KEYWORDS

atrial fibrillation, contact force, cryoballoon, procedural cost, radiofrequency ablation

1 | INTRODUCTION

Antral pulmonary vein isolation (APVI) is a common ablation strategy in patients with paroxysmal atrial fibrillation (PAF). Although prior studies have demonstrated the noninferiority of cryoballoon ablation (CBA) compared to radiofrequency ablation (RFA) with irrigated-tip catheters,[1–3] limited data are available comparing the procedural costs and long-term outcomes of APVI using exclusively the second-generation cryoballoon catheter versus an irrigated-tip force-sensing radiofrequency (RF) catheter. The purpose of this study was to compare the costs and long-term outcomes of APVI of CBA using the second-generation cryoballoon catheter and a contact

TABLE 1 Patient characteristics

Variables	CBA (n = 71)	CF-RFA (n = 75)	P
Age (years)	63 ± 10 (20–81)	62 ± 9 (39–80)	0.65
Male	53 (75)	42 (56)	0.02
Body mass index (kg/m^2)	31 ± 6 (19–46)	30 ± 5 (20–45)	0.71
AF history (months)	46 ± 33 (5–172)	52 ± 44 (6–204)	0.58
Left atrial diameter (mm)	42 ± 6 (29–55)	42 ± 6 (26–61)	0.99
Left ventricular ejection fraction	0.59 ± 0.06 (0.30–0.70)	0.60 ± 0.05 (0.45–0.70)	0.26
Hypertension	40 (56)	47 (63)	0.44
Structural heart disease	12 (17)	7 (9)	0.17
Coronary artery disease	10 (14)	5 (6)	
Nonischemic cardiomyopathy	0	1 (1)	
Hypertrophic cardiomyopathy	1 (1)	1 (1)	
Atrial septal defect	1 (1)	0	
Antiarrhythmic drugs	32 (45)	43 (57)	0.14
Beta-blockers	40 (56)	38 (51)	0.49
Calcium channel blockers	21 (30)	25 (33)	0.63
Warfarin	14 (20)	20 (27)	0.23
Novel oral anticoagulants	55 (77)	55 (73)	
Aspirin	2 (3)	0	
$CHADS_2$ score	0.9 ± 0.8 (0–3)	0.8 ± 0.7 (0–4)	0.23
CHA_2DS_2-VASc score	1.3 ± 1.1 (0–4)	1.3 ± 0.9 (0–5)	0.99
Prior cavotricuspid isthmus ablation	3 (4)	7 (9)	0.33

Data are shown as mean ± 1 standard deviation. Percent values are shown in parentheses.

force-sensing irrigated-tip ablation catheter (CF-RFA) in patients with PAF.

2 | METHODS

2.1 | Study subjects

The subjects of this study were 146 consecutive patients with PAF who underwent catheter ablation of atrial fibrillation (AF). Patients who had a prior ablation procedure were excluded from this study. There were 95 men and 51 women, and the mean age of the patients was 63 ± 10 years (Table 1). The mean left ventricular ejection fraction was 0.60 ± 0.06 and the mean left atrial diameter was 42 ± 6 mm. The clinical characteristics of the patients were similar in the two groups except for a higher proportion of men in the CF-RFA group.

2.2 | Electrophysiologic study and ablation

The study protocol was approved by the institutional review board of the University of Michigan. All patients provided informed written consent. Antiarrhythmic drug therapy was discontinued ≥5 half-lives before the electrophysiological study, except for amiodarone, which was discontinued >8 weeks before the procedure. Computed tomography or magnetic resonance imaging was not systematically obtained prior to RFA. The choice of CBA versus CF-RFA was based on operator preference. In patients taking warfarin with a target international normalized ratio of 2–3, warfarin was continued. In patients receiving one of the novel oral anticoagulants, the last dose of the drug prior to the procedure was held and resumed 4 hours after hemostasis was achieved. The catheter ablation procedure was performed in the fasting state under monitored anesthesia care. Vascular access was obtained through the femoral veins. A decapolar catheter (E-Z Steer CS Decapolar, Biosense Webster, Inc., Diamond Bar, CA, USA) was positioned in the coronary sinus. Transseptal catheterization was performed under intracardiac echocardiography guidance. In all patients, systemic anticoagulation was achieved with unfractionated heparin to maintain the activated clotting time between 300 and 350 seconds throughout the procedure. Bipolar electrograms were displayed and recorded at filter settings of 30 to 500 Hz (EPMed Systems, West Berlin, NJ, USA). Esophageal temperature was monitored with an orogastric temperature probe (Level 1®, Smith Medical, Inc., Dublin, OH, USA). APVI was performed to isolate all pulmonary veins (PVs). Cavotricuspid isthmus (CTI) ablation was performed in patients who had clinical or inducible CTI-dependent atrial flutter. After APVI, isoproterenol was infused up to 20 μg/minute at the discretion of the operator.

2.3 | Second-generation CBA

After the transseptal puncture, an 8.5 F sheath (SL0™, St. Jude Medical, Inc., St. Paul, MN, USA) was exchanged for a 15-F steerable sheath (FlexCath®, Medtronic, Inc., Minneapolis, MN, USA). A 28-mm Arctic Front Advance® cardiac cryoablation catheter was inserted into the left atrium over a spiral mapping catheter (Achieve®, Medtronic,

Inc.). A 3-dimensional electroanatomical mapping system was used to delineate PV anatomy and facilitate catheter navigation (EnSite™ Velocity™, St. Jude Medical, Inc.). Complete PV antrum occlusion was verified by radiocontrast injection. The freeze cycle duration was 3 minutes in all patients except in 4 patients who had 4-minute applications early in the study. To prevent phrenic nerve palsy during CBA of the right-sided PVs, the right phrenic nerve was stimulated with a decapolar catheter positioned in the superior vena cava. Phrenic nerve capture was confirmed by monitoring the diaphragmatic contraction, diaphragmatic compound motor action potentials recorded from a surface electrocardiogram lead positioned over the right diaphragm, and intermittent fluoroscopy. In case of attenuation or loss of diaphragmatic contraction, energy delivery was discontinued immediately. If PV isolation could not be achieved with CBA alone, CF-RFA was utilized. The completeness of APVI was assessed by demonstrating entrance and/or exit block in all PVs with a circular multielectrode catheter. Procedural characteristics including the number of cryoapplications, minimum inner balloon temperature, and the interval thaw time were recorded. Interval thaw time was defined as the time needed for the balloon to reach 0 °C after termination of cryoapplication.[4]

2.4 | Contact force (CF) guided RF catheter ablation

Ablation was performed with a 3.5-mm open irrigated-tip CF sensing catheter (ThermoCool®, SmartTouch™, Biosense Webster, Inc.) with the guidance of an electroanatomical mapping system (CARTO® 3, Biosense Webster, Inc.). PVs were mapped with a decapolar ring catheter (Lasso™, Biosense Webster, Inc.). The average CF was divided into four categories: low (>5 and <10 g), moderate (≥10 and < 15 g), high (≥15 and < 20 g), and very high (≥20 g).

RF energy was delivered at a maximum power of 20–25 Watts with a flow rate of 17 mL/minute near the PVs and along the posterior wall, and at a maximum power of 35 Watts with a flow rate of 30 mL/minute elsewhere in the atria. The maximum temperature was set at 48°C.[5,6]

2.5 | Procedure cost

The total procedure cost included the costs of equipment, anesthesia services, and hospital care. Due to contractual obligations and to account for the variability in pricing between centers, all cost data are presented as the ratio of the CBA to the CF-RFA group, using APVI only by CF-RFA without isoproterenol infusion as the base value.

2.6 | Follow-up

After the ablation procedure, patients were monitored overnight and discharged home the next day. Patients were seen in an outpatient clinic 3, 6, and 12 months after the procedure and every 12 months thereafter. They were instructed to call a dedicated nurse whenever they experienced symptoms. A 30-day autotriggered event monitor (Lifestar AF Express™, Life Watch Inc., Buffalo Grove, IL, USA) was routinely utilized at 8 ± 5 months after the ablation. A cardiac implantable electronic device was already present in 6 patients. The same antiarrhythmic regimen a patient was taking prior to the procedure was continued for 8–12 weeks after the ablation. Recurrence was defined as any symptomatic or asymptomatic atrial tachyarrhythmia lasting >30 seconds after the 3-month blanking period.

2.7 | Statistical analysis

In this retrospective analysis, continuous variables were expressed as mean ± 1 standard deviation and were compared using the Student's *t*-test. Sequential continuous variables were compared using one-way analysis of variance with repeated measures. Post-hoc comparisons were made with the Scheffe test. Categorical variables were compared using the Fisher's exact test. Linear regression analysis was performed to determine the relationship between procedure duration and cost. Kaplan–Meier analysis with the log-rank test was used to compare time to recurrent atrial arrhythmias after CBA and CF-RFA. A $P < 0.05$ indicated statistical significance.

3 | RESULTS

3.1 | PV isolation

In the CBA group, all four major PVs except for 1 right inferior PV and one anomalous left superior PV were isolated, including six left common and four right middle PVs. The mean number of cryoapplications was 2.1 ± 0.7 for the left superior PVs, 2.1 ± 0.8 for the left inferior PVs, 3.8 ± 1.2 for the left common PVs, 2.0 ± 0 right superior PVs, 2.0 ± 0.8 right inferior PVs, and 1.3 ± 0.5 for right middle PVs. The mean time to PV isolation was 39 ± 27 seconds. Additional focal applications with RFA were used to isolate one right superior and two right inferior PVs in three patients.

In the CF-RFA group, complete PV isolation was achieved in 74 of 75 patients (99%), 6 of whom had a left common PV. The mean CF during APVI was 18.7 ± 2.9 g and the median CF was 17.1 g. The mean proportion of CF values was 6 ± 8%, 32 ± 12%, 29 ± 8%, 34 ± 16% for low, moderate, high, and very high, respectively. Complete PV isolation was achieved more quickly in the CBA group than in the CF-RFA group (24 ± 5 vs. 41 ± 11 minutes, $P < 0.0001$; Table 2).

3.2 | Additional ablation after PV isolation

Prior to the first AF ablation, atrial arrhythmias other than AF were clinically documented in 16 patients (21%) in the CF-RFA group and 7 patients (10%) in the CBA group ($P = 0.06$). All 16 patients in the CF-RFA group and 6 patients in the CBA group had atrial flutter. One patient in the CBA group had a focal right atrial tachycardia, which was successfully ablated.

CTI ablation using CF-RFA was performed in 11 (15%) and in 24 patients (32%) in the CBA and the CF-RFA groups, respectively ($P = 0.02$, Table 2). After APVI, isoproterenol was infused in 10 patients (14%) in the CBA and in 59 patients (79%) in the CF-RFA groups, and induced frequent premature atrial depolarizations (n = 1) or an atrial tachycardia (AT) (n = 2) in the CF-RFA group and an AT in 1 patient in the CBA group. All inducible arrhythmias were successfully ablated

TABLE 2 Procedural characteristics and clinical outcome

	CBA (n = 71)	CF-RFA (n = 75)	P
PV isolation			
Duration of ablation for PV isolation (minutes)	24 ± 5	41 ± 11	<0.0001
Isoproterenol infusion after PV isolation	10 (14)	59 (79)	<0.0001
Additional ablation			
Cavotricuspid isthmus ablation	11 (15)	24 (32)	0.02
Inducible atrial arrhythmias with isoproterenol	3 (4)	5 (7)	0.72
Procedure time			
Procedure duration after the transseptal puncture (minutes)	98 ± 39	158 ± 47	<0.0001
Procedure start-to-procedure end (minutes)	148 ± 41	207 ± 58	<0.0001
Anesthesia time (minutes)	204 ± 43	260 ± 62	<0.0001
Total fluoroscopy time (minutes)	30 ± 12	24 ± 10	<0.01
Periprocedural complications	1 (1)	3 (4)	0.62
Cardiac tamponade	0	2 (3)	
Phrenic nerve palsy	1 (1)	0	
Femoral arteriovenous fistula	0	1 (1)	
Sinus rhythm after a single procedure	51 (72)	55 (73)	0.84
Repeat ablation	14/20 (70)	13/20 (65)	0.74
Cryoballoon ablation	0/14 (0)	5/13 (38)	0.02

Data are shown as mean ±1 standard deviation. Percent values are shown in parentheses.

using CF-RFA. Two patients in each group had successful slow pathway ablation using CF-RFA for inducible slow-fast atrioventricular nodal reentrant tachycardia.

3.3 | Procedure duration

The mean procedure time after the transseptal puncture was significantly shorter in the CBA than in the CF-RFA group (98 ± 39 vs. 158 ± 47 minutes, P < 0.0001; Table 2). The mean total procedure duration was also significantly shorter in the CBA than in the CF-RFA group (148 ± 41 vs. 207 ± 58 minutes, P < 0.0001).

3.4 | Procedure cost

The equipment cost per patient was significantly higher in the CBA group than the CF-RFA group (1.57 ± 0.26 vs. 1.15 ± 0.27, P < 0.0001; Table 3). Because RFA had to be used to perform the CTI ablation, equipment cost significantly increased in the CBA group (2.01 ± 0.15 vs. 1.48 ± 0.18, P < 0.0001). The equipment cost in patients who had CTI ablation in the CF-RFA groups was not significantly different (1.16 ± 0.17 vs. 1.15 ± 0.31, P = 0.86).

Anesthesia cost was significantly lower in the CBA than in the CF-RFA group (0.96 ± 0.14 vs. 1.08 ± 0.16, P < 0.0001). There was a direct correlation between the anesthesia cost and the procedure duration in both CBA group (r = 0.79; P < 0.0001) and in the CF-RFA group (r = 0.89; P < 0.0001). Hospital-associated costs also were significantly lower in the CBA group than in the CF-RFA group (1.12 ± 0.21 vs. 1.18 ± 0.13, P = 0.02). Total cost was similar in the 2 groups (1.14 ± 0.20 vs. 1.17 ± 0.13, P = 0.26).

Isoproterenol infusion was associated with a higher hospital-associated cost both in the CBA, 1.32 ± 0.10 versus 1.03 ± 0.16 (P < 0.001), and in the CF-RFA groups, 1.19 ± 0.10 versus 1.00 ± 0.14, (P < 0.0001), respectively. CTI ablation after APVI was associated with a significantly higher total cost in the CBA than in the CF-RFA group (1.40 ± 0.12 vs. 1.22 ± 0.11, P < 0.0001; Table 3). The total procedural cost was similar among patients who underwent CBA and CF-RFA without isoproterenol infusion and/or CTI ablation (Table 3).

3.5 | Freedom from atrial arrhythmias after a single ablation procedure

At 25 ± 5 months after a single ablation procedure, 51 patients (72%) in the CBA group and 55 patients (73%) in the CF-RFA group remained free from recurrent atrial arrhythmias without concomitant antiarrhythmic drug therapy (P = 0.84, Table 2). On Kaplan–Meier analysis, freedom from atrial arrhythmias was similar in the CBA and CF-RFA groups (log-rank P = 0.82, Fig. 1). The mechanism of recurrence was an AT in 2 of 20 patients (10%) in the CBA group and in 3 of 20 patients (15%) in the CF-RFA group (P = 1.0). The probability of recurrence was similar among patients who did and did not have isoproterenol infusion after APVI (18 of 69 [26%] vs. 22 of 77 [29%], P = 0.74).

3.6 | Recurrences, CF, cryoballoon temperature and thaw time

The number of cryo applications per PV was similar among patients with and without recurrence (2.3 ± 1.0 vs. 1.9 ± 0.7, P = 0.29). The minimum balloon temperature was significantly higher (−42 ± 8 vs. −46 ± 6 °C, P < 0.01) and the interval thaw time was significantly shorter (8.2 ± 4.0 vs. 10.3 ± 4.2 seconds, P = 0.03) in patients with than without recurrence.

TABLE 3 Cost analysis

	CBA						CF-RFA					
		APVI Alone (n = 58)					APVI Alone (n = 49)					
	All (n = 71)	All (n = 58)	With Isoproterenol (n = 5)	Without Isoproterenol (n = 53)	CTI ablation (n = 11)	Ablation of Inducible Arrhythmias (n = 3)	All (n = 75)	All (n = 49)	With Isoproterenol (n = 39)	Without Isoproterenol (n = 10)	CTI Ablation (n = 24)	Ablation of Inducible Arrhythmias (n = 5)
Total	1.14 ± 0.20	1.08 ± 0.16*	1.32 ± 0.09*‡	1.06 ± 0.15	1.40 ± 0.12*†‡	1.37 ± 0.16†	1.17 ± 0.13	1.14 ± 0.13	1.18 ± 0.10‡	1.00 ± 0.14	1.22 ± 0.11†	1.28 ± 0.04†
Equipment	1.57 ± 0.26*	1.48 ± 0.18*	1.64 ± 0.09*‡	1.47 ± 0.17*	2.01 ± 0.15*†	1.73 ± 0.16*†	1.15 ± 0.27	1.15 ± 0.31	1.19 ± 0.30	1.00 ± 0.34	1.16 ± 0.17	1.09 ± 0.24
Anesthesia	0.96 ± 0.14*	0.92 ± 0.11*	1.01 ± 0.05	0.91 ± 0.11*	1.11 ± 0.11†	1.20 ± 0.28†	1.08 ± 0.16	1.03 ± 0.13	1.04 ± 0.15	1.00 ± 0.05	1.15 ± 0.18†	1.24 ± 0.12†
Hospital	1.12 ± 0.21*	1.06 ± 0.18*	1.32 ± 0.10*‡	1.03 ± 0.16	1.38 ± 0.13*†	1.35 ± 0.15†	1.18 ± 0.13	1.15 ± 0.14	1.19 ± 0.10‡	1.00 ± 0.14	1.23 ± 0.11†	1.30 ± 0.04†

Data are normalized by the mean unit cost of APVI using CF-RFA without isoproterenol and additional ablation. Data are shown as mean±1 standard deviation. APVI = antral pulmonary vein isolation; CBA = cryoballoon ablation; CF-RFA = contact force-guided radiofrequency ablation; CTI = cavotricuspid isthmus ablation. *P < 0.05 versus CF-RFA, †P < 0.05 versus APVI alone, ‡P < 0.05 versus without isoproterenol.

In the CF-RFA group, the mean CF during APVI was similar among patients with and without recurrent atrial arrhythmias (19.3 ± 2.6 vs. 18.4 ± 3.0 g, P = 0.25). No significant difference was observed in the mean proportion of CF values between patients with and without recurrence.

3.7 | Repeat ablation and cost

A repeat ablation procedure was performed in 14 patients (20%) in the CBA group and in 13 patients (17%) in the CF-RFA group (P = 0.71, Table 2) 10 ± 6 months after the index procedure. During the repeat ablation, CBA was used in 5 patients who underwent CF-RFA during the first procedure. CF-RFA was used in the remaining 22 repeat ablation procedures.

Recovery of conduction was observed in a mean of 2.4 ± 1.2 PVs per patient in the CBA group, including four left superior PVs, five left inferior PVs, three left common PVs, nine right superior PVs, and 10 right inferior PVs. In the CF-RFA group, a mean of 3.2 ± 1.1 PVs per patient had recovery of conduction, including nine left superior, 11 left inferior, seven right superior, and 11 right inferior PVs (P = 0.08). All of the PVs were reconnected in 4 of 14 patients (29%) in the CBA group and 7 of 13 patients (54%) in the CF-RFA group (P = 0.25).

The total repeat ablation cost of CF-RFA was 1.18 ± 0.16 compared to initial CF-RFA (P = 0.83). The total cost of CBA during repeat procedures was 1.17 ± 0.12 compared to the initial CBA (P = 0.74). The total cost of first and repeat procedures was similar among patients who underwent both CBA and CF-RFA (2.22 ± 0.24) or only CF-RFA (2.36 ± 0.39, P = 0.26).

After a mean of 1.2 ± 0.4 procedures, and 24 ± 6 months after the last procedure, 63 patients (89%) in the CBA group and 67 patients (89%) in the CF-RFA group remained free from recurrence without antiarrhythmic drugs (P = 0.91). The probability of remaining in sinus rhythm was similar in patients who underwent only CBA (52 of 58 [90%]), only CF-RFA (62 of 70 [89%]) or both CBA and CF-RFA (16 of 18 [89%], P = 0.98).

3.8 | Complications

There was no significant difference in the prevalence of perioperative complications between the CBA and CF-RFA groups (1 of 71 [1%] vs. 3 of 75 [4%]; P = 0.62, Table 2). Pericardial tamponade occurred in 2 patients in the CF-RFA group, and was successfully treated with pericardiocentesis including the patient who had perforation during ablation in a recess along the CTI. In the other patient, the real-time CF showed a transient increase in CF of 110.5 g (>100 g for 200 milliseconds) during APVI. A left-sided phrenic nerve paralysis was diagnosed in a patient who presented with dyspnea 1 week after CBA.

4 | DISCUSSION

4.1 | Major findings

The results of this study demonstrate that: (1) At 2 years of follow-up after a repeat ablation in 20% of the patients, freedom from atrial

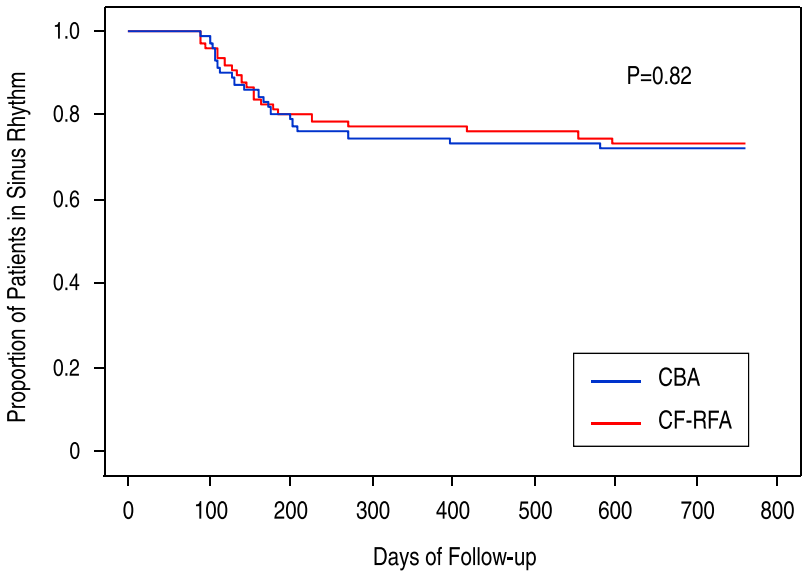

FIGURE 1 Kaplan–Meier analysis showing the atrial tachyarrhythmia-free survival rate after a single ablation procedure. A blanking period of 3 months was applied

arrhythmias was maintained in ~90% of the patients in both groups without antiarrhythmic drug therapy; (2) the overall procedure duration was approximately 60 minutes shorter with CBA than CF-RFA; and (3) the total procedure cost was similar between the CBA and CF-RFA groups, despite a higher catheter cost in the CBA group. This was driven primarily by the lower anesthesia costs attributable to a shorter procedure duration in the CBA group.

4.2 | CBA versus CF-RFA

The most common cause of recurrence after an initially successful ablation is recovery of conduction over the PV fascicles. CF-sensing catheters have been introduced to improve the durability of the lesions.[7] Based on prior studies,[8] an effort to maintain a CF > 10 g was made and almost always achieved by all operators. Nevertheless, clinical efficacy was still similar to CBA, and recovery of conduction was observed in a similar proportion of patients after CBA or CF-RFA.[1,2] The main difference between CBA and CF-RFA for APVI was a shorter overall procedure time of approximately 60 minutes.

4.3 | Cost implications

CBA has a higher cost than the CF-RFA system. However, this increase in the equipment cost was negated by a shorter procedure duration. Procedure duration directly affects the time dependent cost elements such anesthesia services, use of the electrophysiology laboratory, and postanesthesia recovery units. Therefore a decrease in the procedure duration directly reduces the anesthesia service costs and hospital-associated costs.

Because it is likely that there are variations in operator preference, and expertise with one technique than the other even within the same institution, it is possible to model cost structures as described in this study based on the relative procedural efficacy, and duration for an operator and the cost of equipment, anesthesia, and hospital services at a given center. This should allow a cost effective decision to be made by factoring in these critical variables.

Switching to CF-RFA after CBA for ablation of atrial flutter or other arrhythmias is associated with a substantial increase in the total cost. Therefore from a cost perspective, it may be preferable to start with CF-RFA when the patient is known to have other arrhythmias, particularly atrial flutter, prior to the procedure.

Although anesthesia services are routinely used during catheter ablation of AF in most centers, ablation might be performed without anesthesia staff based on the availability of resources at certain centers. Because anesthesia service is a major determinant of procedural cost, the cost structure will have to be modeled differently for these centers.

Isoproterenol is a costly drug and has been used to assess the inducibility of residual arrhythmias. Isoproterenol was infrequently used in the CBA group based on operator preference in this study. However, overall clinical efficacy was similar among patients who were and were not administered isoproterenol after PVI. It is possible that after wide antral PV isolation, there will be fewer residual antral foci. Nevertheless, isoproterenol may still be helpful to identify both residual triggers and other arrhythmias in a small subset of the patients in a larger study population. Therefore, use of isoproterenol should be carefully determined by the operator considering the patient characteristics, likelihood of identifying residual arrhythmias, alternative approaches, and potential cost implications.

4.4 | Prior studies

To our knowledge this is the first study that systematically compared the costs of APVI by CBA and CF-RFA. In a registry from four

centers, CBA with a second-generation catheter and CF-RFA using two different catheter systems was compared in patients with PAF.[1] Single procedure efficacy was similar between the two groups. Although procedure duration with CBA was shorter by only 13 minutes, fluoroscopy exposure was similar between the two groups. The recently published multicenter FIRE and ICE trial that randomized patients with PAF to cryoballoon (378) versus RFA without CF sensing ability (384) demonstrated noninferiority of CBA to RFA.[3] However, there have been improvements both in cryoballoon (second generation) and RF catheters (CF sensing ability) since the start of this trial. In a recent randomized trial, 237 patients with PAF were randomized to RFA versus CBA versus combined RFA and CBA.[9] At 1 year of follow-up, 47% in the RFA, 67% in the CBA, and 76% in the combined group were free from atrial arrhythmias without antiarrhythmic drug therapy. CBA was quicker, and both CBA and combined approaches were superior to RFA. However, a first-generation cryoballoon was used and the RF catheter did not have CF sensing capability. In a nonrandomized study, 150 patients with PAF underwent CBA with a second-generation cryoballoon and CF-RFA.[2] However, operators were assigned to perform only the type of ablation approach with which they had extensive experience. The duration of the procedure was shorter in the CBA group. AF recurrence rate, 12–15%, at 12 months was similar in both groups. Lastly, a recent study demonstrated that the individualized cryoapplications guided by the time to PV isolation were associated with approximately 60 minutes shorter total procedure time as compared to the conventional cryoablation strategy. This reduction in procedure duration may lower the anesthesia and hospital associated costs associated with CBA.[10] However, a RFA catheter had to be used in 15% of the patients, which may negate some of the cost reductions due to the shorter procedure duration.

4.5 | Limitations

The main limitation of this study is that the use of CF-RFA versus CBA was not decided on a random basis but was based on operator discretion. CTI ablation was performed more frequently in the CF-RFA group. It is likely that a history of atrial flutter may have prompted the choice of CF-RFA. Another limitation is that all of the operators had many more years of experience with RFA than with CBA, which may have created a bias in favor of RFA.

5 | CONCLUSIONS

Both CBA and CF-RFA in patients with PAF have a similar procedural efficacy and safety. However, the CBA procedure is significantly shorter than CF-RFA. Despite a higher equipment cost, CBA for APVI appears to have a similar total cost to CF-RFA primarily driven by lesser anesthesia and hospital associated costs and infrequent use of isoproterenol.

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