Research Article

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Economic impact of atrial fibrillation ablation with radiofrequency contact force catheter versus cryoballoon catheter

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Aim: To compare health utilization among atrial fibrillation (AF) patients undergoing ablation with a contact force-sensing (CF) catheter versus a cryoballoon (CB) catheter. **Methods:** AF patients who underwent ablation using the CF catheter (THERMOCOOL SMARTTOUCH® catheter) or CB catheter (Arctic Front™/Arctic Front Advance™ catheter) were identified from the Premier Healthcare database. Propensity score analyses were used to evaluate cost, length of stay and readmissions. **Results:** The CF catheter (n = 1409) was associated with significantly lower total (∼7%) and supply (∼13%) costs and a significantly lower likelihood of 4–12 month all-cause and CV-related readmission compared with the CB catheter (n = 2306). **Conclusion:** Differential health utilization outcomes are associated with the CF catheter versus the CB catheter in AF ablation.

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Atrial fibrillation (AF) is the most common sustained cardiac arrhythmia [1]. At least three million adults in the USA have been diagnosed with AF and as many as 7.5 million Americans are projected to have AF by 2050 [2]. Patients with AF have an increased risk of mortality [3,4] and significant morbidity [5,6], including an increased risk of stroke [7].

Catheter ablation is recommended as an effective treatment option for AF patients who are refractory or intolerant to pharmacotherapy treatments [8,9]. Radiofrequency catheter ablation (RFA) is a standard treatment for paroxysmal AF that involves electrical isolation of the pulmonary veins (PVs). Lesion formation remains the critical factor in PV isolation using RFA. The advent of contact force-sensing (CF) catheters, with the ability to provide real-time information on catheter–tissue interaction, has led to a significant improvement in the creation of durable lesions [10]. Studies have demonstrated CF technology to be associated with significantly lower rates of PV reconnection – a critical marker of ablation success [11,12]. In a prospective, parallel cohort study, drug refractory patients with paroxysmal AF who underwent ablation using the CF THERMOCOOL SMARTTOUCH® catheter (Biosense Webster, Inc., CA, USA) achieved higher rates of freedom from recurrent atrial arrhythmia (i.e., AF, atrial flutter or atrial tachycardia) at 1 year versus those who underwent ablation using a non-CF catheter (THERMOCOOLcatheter; Biosense Webster; 88 vs 66%, respectively; p = 0.0001) [11].

An alternative to RFA involves the use of cryoenergy for lesion formation with cryoballoon (CB) catheters. Few clinical studies have compared the use of CF-sensing THERMOCOOL SMARTTOUCH catheter with Arctic Front™/Arctic Front Advance™ CB catheter (Medtronic, MN, USA) [13,14]. In one multicohort study comparing outcomes among paroxysmal AF patients who underwent ablation using the THERMOCOOL SMARTTOUCH catheter versus Arctic Front Advance™ catheter, comparable rates of arrhythmia-free survival were demonstrated [14]. In another study comparing the two technologies at a single center, similar AF recurrence rates were reported among patients with paroxysmal AF who underwent AF ablation using the THERMOCOOL SMARTTOUCH catheter versus the Arctic Front Advance™ catheter [13]. Although providing useful information, the fact that these studies were based on data from a limited number of centers, restricts their generalizability. To the best of our knowledge, no study to date has compared outcomes among AF patients who undergo ablation using the CF (THERMOCOOL SMARTTOUCH catheter) versus the CB (Arctic Front™/Arctic Front Advance™) catheter in a real-world setting. Using a nationally generalizable multihospital US database, this study assesses the healthcare utilization differential in the two technologies. As AF prevalence increases and healthcare resources become scarce, it is imperative to better understand utilization differences among technologies used to treat AF.

The objective of this retrospective, observational study was to compare cost, length of stay (LOS) and readmissions among patients with AF who underwent ablation using the CF catheter versus the CB catheter in the real-world setting.

Methods

Data source

A retrospective analysis of the Premier Healthcare database was performed. The Premier Healthcare database contains complete clinical coding, hospital cost and patient billing data from more than 700 hospitals throughout the US. Although the database excludes federally funded hospitals (e.g., Veterans Affairs), the hospitals included in the Premier database are nationally representative based on bed size, geographic region, location (urban/rural) and teaching hospital status.

Study sample

Patients with AF who had an ablation procedure between 1 January 2014 and 30 June 2017 were identified by either the Common Procedural Terminology (CPT) code 93656 with primary or secondary AF diagnosis, or by an ablation procedure coded by International Classification of Diseases, Ninth Edition (ICD-9) 37.34; International Classification of Diseases, Tenth Edition (ICD-10) equivalently listed with a primary diagnosis of AF. The first observed hospital admission meeting these criteria was designated as the index hospital admission. Eligible patients were required to be at least 18 years of age at the time of index admission. Patients with a catheter ablation procedure performed during the 12 months prior to the index admission were excluded from the study. Only those patients who electively underwent an index procedure in hospitals that had consistently provided inpatient and outpatient data to the Premier database in the 12-month pre-index period were considered for inclusion. Patients who underwent surgical ablation (i.e., ablation procedures that are performed concomitantly with open heart surgery for valvular, ischemic or congenital heart disease), valvular procedures or left atrial appendage occlusion during the 12-month pre-index admission were excluded. Patients with AF who underwent catheter ablation using either the CF THERMOCOOL SMARTTOUCH catheter or the Arctic Front™/Arctic Front Advance™ CB catheter without any additional point-to-point catheter use during an inpatient or outpatient hospital admission were then identified. The use of study devices was ascertained from hospital charge descriptors based on combination of device name or catalog identification numbers or model numbers. Among these patients, those who had cost (total cost, supply cost, or room and board cost) listed as $0 were excluded.

Study covariates

Patient & procedural characteristics

Patient characteristics including age (18–49 years, 50–59 years, 60–69 years, ≥70 years), gender (male, female), race (white, nonwhite) and marital status (married, single, other) were collected at index hospitalization. Comorbidities were assessed using the Charlson Comorbidity Index (CCI) score and the $CHADS_2$ score. Obstructive sleep apnea, obesity, diabetes, hypertension, chronic pulmonary disease, renal disease, congestive heart failure, atrial flutter, valvular heart disease, cardiomyopathy, cardiomegaly, ischemic heart disease, peripheral vascular disorders (PVDs) and pulmonary circulation disorders (PCDs) were assessed based on present on admission indicator. Pacemaker or defibrillator use was measured if the procedure occurred in the 12-month pre-index period. Payer type (commercial, Medicare, Medicaid, other) and year of procedure, were also evaluated.

Provider characteristics

Hospital characteristics including teaching status (teaching/nonteaching), hospital region (midwest, northeast, south, west), hospital bed size (under 300 beds, 300–399 beds, 400–499 beds and ≥500 beds), and the specialty (cardiovascular [CV]) of the physician performing the procedure were also determined. Volume of total ablation procedures (converted to categorical using median split: less than 330 ablations, ≥330 ablations) performed in the 12-month pre-index admission period were also assessed.

Study outcomes

Study outcomes included hospital costs (total, supply, and room and board), hospital LOS and readmissions (all-cause, CV-related and AF-related). Hospital costs (total and supply) costs were evaluated based on the index hospital admission for ablation procedure among patients with AF. Costs were adjusted for inflation and reported in 2017 US dollars. LOS and room and board cost were only evaluated for ablation procedures occurring in an inpatient hospital setting. All-cause, CV-related and AF-related readmissions were measured in the 4 to 12 month period after the discharge from the index admission, with the first 3 months being considered as a blanking period.

Secondary analysis

Considering the complexity of PV anatomy and the variability in shape and size of PVs, use of a CB catheter may not be able to ablate proximal antral region veins [15]. To better ablate these veins, an additional point-to-point catheter may be used along with CB ablation. Therefore, we conducted a secondary analysis to analyze outcomes in the CF catheter group versus those patients in the CB catheter group, with and without additional point-by-point catheter use.

Sensitivity analysis

It has been reported that outcomes associated with AF ablation tend to be better in centers that have performed 100 procedures or more [16,17]. To address this, we performed a sensitivity analysis wherein the study inclusion criteria were modified (in addition to inclusion/exclusion listed earlier) to include only those patients from both groups (CF catheter and CB catheter) who had ablation with a provider that had at least 100 total ablation procedures performed in the 12-month pre-index period. Outcomes assessment remained consistent with other analyses.

Statistical analysis

Means and standard deviations were reported for continuous variables and means and percentages were reported for categorical variables. Bivariate statistical tests were conducted to examine and describe the differences between the two groups in potential confounding factors (e.g., patient demographics, clinical characteristics, procedural characteristics and hospital/provider characteristics).

Propensity score matching was used for study analyses. The propensity score was generated from a multivariable logistic regression equal to the predicted probability of undergoing ablation using the CF catheter or the CB catheter during the index hospital admission. Nearest neighbor technique without replacement, and with a 0.10 caliper, was used to match the two sets of patients. Standardized differences were used to assess the postmatch balance of the variables which were included in the propensity score model. Standardized differences, which is the difference in mean divided by pooled standard deviation, were used to assess the balance of covariates among the two groups postmatching. As standardized differences are not influenced by sample size [18], they offer a better approach to covariate imbalance assessment as compared with traditional (*t*-test, χ^2) statistical techniques. Considering the differential in outcomes assessment (total cost and supply cost were assessed for index admission including both inpatient and outpatient ablation, LOS and room and board cost were assessed for index admission occurring in an inpatient setting and readmission were assessed among patients who underwent index ablation with providers that continually contributed data to Premier Healthcare database for subsequent 12-month period), three separate propensity models (to assess total cost and supply cost, LOS and room and board cost, and readmissions) were run for primary and secondary outcome analysis.

Postpropensity matching, the impact of ablation technology on costs was assessed using a generalized estimating equations (GEE) model with an exchangeable correlation structure with log link and γ-distribution function. Impact on LOS was assessed using a GEE model with log link and negative binomial distribution. Impact on readmission rates were assessed using survey logistic regression analyses. Regression analyses accounted for potential hospital-level clustering. Any covariates with significant standardized differences (above 0.10 or below -0.10) postmatching were adjusted for in all the regression analysis.

Table 1. Patient attrition.

Step	Criteria	CF catheter versus CB catheter n	CF catheter versus CB catheter + point-by-point catheter use n
1	Patients with an ablation procedure listed with a primary diagnosis of AF during 1 January 2014–30 June 2017	37,643	
2	Patients ≥18 years	37,637	
3	Patients with an elective ablation procedure	25,602	
4	Patients with the index procedure at hospitals that provided data (inpatient and outpatient) for at least 12-months during the pre-index period in the Premier database	16,171	
5	Exclusion of patients with a procedural code for catheter ablation performed in the 12-month pre-index period	16,140	
6	Exclusion of patients with a procedural code for surgical ablation during the 12-month pre-index period	15,835	
7	Exclusion of patients with a procedural code for valvular procedures or atrioventricular node ablation during the 12-month pre-index period	14,877	
8	Exclusion of patients with a procedural code for left atrial appendage occlusion during the 12-month pre-index period	14,796	
9	Patients with either a CF THERMOCOOL SMARTTOUCH® catheter or Arctic Front™/Arctic Front Advance™ CB catheter device record	3721	4473
10	Patients who had total cost and supply cost >0 and for patients who had ablation in an inpatient setting, the room and board cost >0	3715	4466
Final study sample		3715 CF catheter = 1409 CB catheter = 2306	4466 CF catheter = 1409 CB catheter + point-by-point catheter use = 3057

AF: Atrial fibrillation; CB: Cryoballoon; CF: Contact force.

Results

Patient attrition

Patient attrition is presented in Table 1. The final study population consisted of 3715 patients with a primary diagnosis of AF who underwent a primary ablation procedure using the CF catheter (n = 1409) or CB catheter (n = 2306) during the index inpatient or outpatient hospital admission. For the secondary outcome analysis, patients receiving CF catheter (n = 1409) were compared with the CB catheter subgroup that had additional point-by-point catheter use (n = 3057 patients).

Patient & hospital characteristics

Patient and hospital characteristics are presented in Table 2. Among both groups prematching, a majority of patients were 60–69 years of age, male, white and married. Medicare/Medicaid was the most common payer type among all groups and the majority of ablations occurred in the South, at hospitals with teaching status and in an outpatient setting. A significantly higher proportion of patients in the CF catheter group versus the CB catheter group in the prematch sample had sleep apnea (26.90 vs 20.69%; $p < 0.0001$), obesity (16.96% vs 9.24%; $p < 0.0001$), chronic pulmonary disease (16.18 vs 13.57%; $p = 0.0287$), renal disease (6.10 vs 4.55%; $p = 0.0379$), congestive heart failure (19.87 vs 15.57%; $p = 0.0007$), atrial flutter (32.65 vs 18.86%; $p < 0.0001$), valvular disease (18.45 vs 14.44%; $p = 0.0012$) and cardiomyopathy (7.38 vs 4.90%; $p = 0.0018$). The mean CCI score was significantly higher ($p = 0.0002$) in the CF catheter group (0.90 ± 1.18) as compared with the CB catheter group (0.75 ± 1.12). Tables 2, 3 and 4 depict the prematch and postmatch characteristics and standardized differences for the underlying sample for the total cost and supply cost, LOS and room and board cost, and readmission comparisons, respectively.

Table 5 presents the patient and hospital characteristics for the overall sample for the secondary analysis. Similar to the primary analysis, the CF catheter group demonstrated a greater comorbidity burden than the CB catheter group that included patients with additional point-by-point catheter use. The CF catheter group had a significantly higher CCI score (0.90 ± 1.18) as compared with the CB catheter group that included patients with additional point-by-point catheter use (0.78 ± 1.14; $p = 0.002$).

Table 2. Study characteristics before and after propensity score matching for the total cost and supply cost assessments among patients in the overall sample.

Characteristic n (%)	Before propensity score matching			After propensity score matching		
	CF catheter n = 1409	CB catheter n = 2306	Standardized difference	CF catheter n = 1056	CB catheter n = 1056	Standardized difference
Age, (mean [SD], yrs)	63.21 (10.21)	64.52 (10.76)	-0.1254	63.38 (10.27)	63.58 (10.52)	-0.0192
Age group						
18–49 yrs	142 (10.08%)	193 (8.37%)	0.0591	107 (10.13%)	97 (9.19%)	0.0321
50–59 yrs	307 (21.79%)	462 (20.03%)	0.0431	225 (21.31%)	220 (20.83%)	0.0116
60–69 yrs	567 (40.24%)	842 (36.51%)	0.0767	415 (39.30%)	422 (39.36%)	-0.0136
≥70 yrs	393 (27.89%)	809 (35.08%)	-0.1553	309 (29.26%)	317 (30.02%)	-0.0136
Female gender	502 (35.63%)	878 (38.07%)	-0.0507	396 (37.50%)	384 (36.36%)	0.0235
White race	1220 (86.59%)	2156 (93.50%)	-0.2323	948 (89.77%)	943 (89.30%)	0.0155
Marital status						
Married	993 (70.48%)	1637 (70.99%)	-0.0113	747 (70.74%)	748 (70.83%)	-0.0021
Single	352 (24.98%)	615 (26.67%)	-0.0386	276 (26.14%)	279 (26.42%)	-0.0065
Other	64 (4.54%)	54 (2.34%)	0.1209	33 (3.13%)	29 (2.75%)	0.0224
Payer						
Commercial	614 (43.58%)	941 (40.81%)	0.0561	446 (42.23%)	448 (42.42%)	-0.0038
Medicaid	49 (3.48%)	74 (3.21%)	0.0149	41 (3.88%)	33 (3.13%)	0.0412
Medicare	628 (44.57%)	1198 (51.95%)	-0.1481	499 (47.25%)	506 (47.92%)	-0.0133
Other	118 (8.37%)	93 (4.03%)	0.1807	70 (6.63%)	69 (6.53%)	0.0038
Year						
2014	310 (22.00%)	701 (30.40%)	-0.1918	244 (23.11%)	245 (23.20%)	-0.0022
2015	557 (39.53%)	852 (36.95%)	0.0532	415 (39.30%)	395 (37.41%)	0.0390
2016	382 (27.11%)	458 (19.86%)	0.1717	263 (24.91%)	270 (25.57%)	-0.0153
2017 (until the end of June)	160 (11.36%)	295 (12.79%)	-0.0441	134 (12.69%)	146 (13.83%)	-0.0335
CCI score						
0	671 (47.62%)	1289 (55.90%)	-0.1662	520 (49.24%)	546 (51.70%)	-0.0493
1	437 (31.01%)	596 (25.85%)	0.1148	315 (29.83%)	298 (28.22%)	0.0355
≥2	301 (21.36%)	421 (18.26%)	0.0780	221 (20.93%)	212 (20.08%)	0.0211
$CHADS_2$ score						
0	388 (27.54%)	627 (27.19%)	0.0078	281 (26.61%)	292 (27.65%)	-0.0234
1	663 (47.05%)	1061 (46.01%)	0.0209	495 (46.88%)	497 (47.06%)	-0.0038
≥2	358 (25.41%)	618 (26.80%)	-0.0317	280 (26.52%)	267 (25.28%)	0.0281
Comorbid conditions						
Sleep apnea	379 (26.90%)	477 (20.69%)	0.1463	267 (25.28%)	270 (25.57%)	-0.0065
Obesity	239 (16.96%)	213 (9.24%)	0.2305	146 (13.83%)	141 (13.35%)	0.0138
Diabetes	283 (20.09%)	431 (18.69%)	0.0353	223 (21.12%)	206 (19.51%)	0.0400
Hypertension	959 (68.06%)	1531 (66.39%)	0.0356	724 (68.56%)	708 (67.05%)	0.0324
CPD	228 (16.18%)	313 (13.57%)	0.0733	163 (15.44%)	158 (14.96%)	0.0132
Renal disease	86 (6.10%)	105 (4.55%)	0.0691	56 (5.30%)	49 (4.64%)	0.0305
CHF	280 (19.87%)	359 (15.57%)	0.1129	203 (19.22%)	193 (18.28%)	0.0243
Atrial flutter	460 (32.65%)	435 (18.86%)	0.3192	296 (28.03%)	294 (27.84%)	0.0042
Pacemaker/defibrillator	75 (5.32%)	94 (4.08%)	0.0589	59 (5.59%)	55 (5.21%)	0.0168
Valvular disease	260 (18.45%)	333 (14.44%)	0.1084	189 (17.90%)	195 (18.47%)	-0.0147
Cardiomyopathy	104 (7.38%)	113 (4.90%)	0.1035	71 (6.72%)	63 (5.97%)	0.0311
Cardiomegaly	75 (5.32%)	130 (5.64%)	-0.0138	66 (6.25%)	66 (6.25%)	0
Ischemic heart disease	311 (22.07%)	482 (20.90%)	0.0285	241 (22.82%)	224 (21.21%)	0.0389
PVD	83 (5.89%)	152 (6.59%)	-0.029	67 (6.34%)	58 (5.49%)	0.0361
PCD	43 (3.05%)	41 (1.78%)	0.0831	30 (2.84%)	25 (2.37%)	0.0297
Hospital bed size						
Under 300	129 (9.16%)	204 (8.85%)	0.0108	108 (10.23%)	110 (10.42%)	-0.0062
300–399	324 (23.00%)	389 (16.87%)	0.1538	237 (22.44%)	244 (23.11%)	-0.0158
400–499	420 (29.81%)	1012 (43.89%)	-0.2950	337 (31.91%)	342 (32.39%)	-0.0101
≥500	536 (38.04%)	701 (30.40%)	0.1616	374 (35.42%)	360 (34.09%)	0.0278
Hospital region						
Midwest	256 (18.17%)	977 (42.37%)	-0.546	256 (24.24%)	259 (24.53%)	-0.0066
Northeast	237 (16.82%)	52 (2.25%)	0.5119	59 (5.59%)	52 (4.92%)	0.0297
South	726 (51.53%)	1076 (46.66%)	0.0974	611 (57.86%)	598 (56.63%)	0.0249
West	190 (13.48%)	201 (8.72%)	0.1522	130 (12.31%)	147 (13.92%)	-0.0477
Surgeon CV specialty	658 (46.70%)	961 (41.67%)	0.1013	423 (40.06%)	415 (39.30%)	0.0155
Nonteaching hospital	510 (36.20%)	620 (26.89%)	0.2014	394 (37.31%)	397 (37.59%)	-0.0059
Inpatient setting	215 (15.26%)	304 (13.18%)	0.0595	148 (14.02%)	136 (12.88%)	0.0333

AF: Atrial fibrillation; CB: Cryoballoon; CCI: Charlson Comorbidity Index; CF: Contact force; $CHADS_2$: Congestive heart failure, hypertension, age >75 years, diabetes, stroke [doubled]; CHF: Congestive heart failure; CPD: Chronic pulmonary disease; CV: Cardiovascular; PCD: Pulmonary circulation disorder; PVD: Peripheral vascular disorder; SD: Standard deviation.

Table 3. Study characteristics before and after propensity score matching for the length-of-stay and room and board cost assessment among patients with index ablation procedure in an inpatient setting.

Characteristic n (%)	Before propensity score matching			After propensity score matching		
	CF catheter n = 215	CB catheter n = 304	Standardized difference	CF catheter n = 117	CB catheter n = 117	Standardized difference
Age (mean [SD], yrs)	63.32 (9.63)	65.72 (10.77)	-0.2348	63.68 (9.43)	63.23 (9.96)	0.0458
Age group						
18–49 yrs	18 (8.37%)	21 (6.91%)	0.0551	8 (6.84%)	9 (7.69%)	-0.0329
50–59 yrs	48 (22.33%)	52 (17.11%)	0.1315	29 (24.79%)	26 (22.22%)	0.0605
60–69 yrs	91 (42.33%)	104 (34.21%)	0.1675	45 (38.46%)	49 (41.88%)	-0.0698
≥70 yrs	58 (26.98%)	127 (41.78%)	-0.3154	35 (29.91%)	33 (28.21%)	0.0377
Female gender	78 (36.28%)	125 (41.12%)	-0.0995	47 (40.17%)	46 (39.32%)	0.0175
White race	158 (73.49%)	287 (94.41%)	-0.5945	102 (87.18%)	103 (88.03%)	-0.0259
Marital status						
Married	131 (60.93%)	193 (63.49%)	-0.0527	75 (64.10%)	75 (64.10%)	0
Single	60 (27.91%)	107 (35.20%)	-0.1574	39 (33.33%)	38 (32.48%)	0.0182
Other	24 (11.16%)	4 (1.32%)	0.4158	3 (2.56%)	4 (3.42%)	-0.0502
Payer						
Commercial	86 (40.00%)	91 (29.93%)	0.2123	44 (37.61%)	42 (35.90%)	0.0355
Medicaid	12 (5.58%)	14 (4.61%)	0.0444	5 (4.27%)	5 (4.27%)	0
Medicare	104 (48.37%)	181 (59.54%)	-0.2255	60 (51.28%)	57 (48.72%)	0.0513
Other	13 (6.05%)	18 (5.92%)	0.0053	8 (6.84%)	13 (11.11%)	-0.1499
Year						
2014	47 (21.86%)	88 (28.95%)	-0.1633	27 (23.08%)	28 (23.93%)	-0.0201
2015	116 (53.95%)	98 (32.24%)	0.4495	53 (45.30%)	50 (42.74%)	0.0517
2016	35 (16.28%)	92 (30.26%)	-0.3356	28 (23.93%)	27 (23.08%)	0.0202
2017 (until end of June)	17 (7.91%)	26 (8.55%)	-0.0235	9 (7.69%)	12 (10.26%)	-0.0898
CCI score						
0	82 (38.14%)	110 (36.18%)	0.0405	46 (39.32%)	45 (38.46%)	0.0175
1	68 (31.63%)	96 (31.58%)	0.0011	37 (31.62%)	36 (30.77%)	0.0184
≥2	65 (30.23%)	98 (32.24%)	-0.0433	34 (29.06%)	36 (30.77%)	-0.0373
$CHADS_2$ score						
0	49 (22.79%)	50 (16.45%)	0.1602	31 (26.50%)	27 (23.08%)	0.0792
1	108 (50.23%)	157 (51.64%)	-0.0283	53 (45.30%)	58 (49.57%)	-0.0857
≥2	58 (26.98%)	97 (31.91%)	-0.1083	33 (28.21%)	32 (27.35%)	0.0191
Comorbid conditions						
Sleep apnea	50 (23.36%)	98 (32.24%)	-0.2016	32 (27.35%)	30 (25.64%)	0.0387
Obesity	37 (17.21%)	52 (17.11%)	0.0028	21 (17.95%)	19 (16.24%)	0.0454
Diabetes	45 (20.93%)	67 (22.04%)	-0.0270	23 (19.66%)	27 (23.08%)	-0.0835
Hypertension	160 (74.42%)	239 (78.62%)	-0.0992	84 (71.79%)	95 (72.65%)	-0.0191
CPD	42 (19.53%)	78 (25.66%)	-0.1468	30 (25.64%)	26 (22.22%)	0.0802
Renal disease	21 (9.77%)	30 (9.87%)	-0.0034	9 (7.69%)	8 (6.84%)	0.0329
CHF	77 (35.81%)	85 (27.96%)	0.1691	33 (28.21%)	42 (35.90%)	-0.1654
Atrial flutter	65 (20.23%)	53 (17.43%)	0.3038	33 (28.21%)	35 (29.91%)	-0.0377
Pacemaker/defibrillator	21 (9.77%)	21 (6.91%)	0.1036	8 (6.84%)	10 (8.55%)	-0.0642
Valvular disease	41 (19.07%)	40 (13.16%)	0.1613	23 (19.66%)	21 (17.95%)	0.0438
Cardiomyopathy	27 (12.56%)	22 (7.24%)	0.1789	8 (6.84%)	14 (11.97%)	-0.1764
Cardiomegaly	1 (0.47%)	7 (2.30%)	-0.1578	1 (0.85%)	1 (0.85%)	0
Ischemic heart disease	65 (30.23%)	96 (31.58%)	-0.0291	35 (29.91%)	32 (27.35%)	0.0567
PVD	12 (5.58%)	28 (9.21%)	-0.1390	6 (5.13%)	6 (5.13%)	0
PCD	10 (4.65%)	12 (3.95%)	0.0347	4 (3.42%)	4 (3.42%)	0
Hospital bed size						
Under 300	24 (11.16%)	14 (4.61%)	0.2452	9 (7.69%)	9 (7.69%)	0
300–399	36 (16.74%)	61 (20.07%)	-0.0858	20 (17.09%)	23 (19.66%)	-0.0662
400–499	67 (31.16%)	153 (50.33%)	-0.3977	48 (41.03%)	50 (42.74%)	-0.0347
≥500	88 (40.93%)	76 (25.00%)	0.3439	40 (34.19%)	35 (29.91%)	0.0917
Hospital region						
Midwest	36 (16.28%)	119 (39.14%)	-0.5284	28 (23.93%)	30 (25.64%)	-0.0396
Northeast	65 (30.23%)	27 (8.88%)	0.5589	26 (22.22%)	21 (17.95%)	0.1068
South	96 (44.65%)	153 (50.33%)	-0.1139	58 (49.57%)	63 (53.85%)	-0.0856
West	19 (8.84%)	5 (1.64%)	0.3270	5 (4.27%)	3 (2.56%)	0.0942
Surgeon CV specialty	113 (52.56%)	198 (65.13%)	-0.2576	70 (59.83%)	69 (58.97%)	0.0174
Nonteaching hospital	90 (41.86%)	80 (26.32%)	0.3324	49 (41.88%)	54 (46.15%)	-0.0862

AF: Atrial fibrillation; CB: Cryoballoon; CCI: Charlson Comorbidity Index; CF: Contact force; $CHADS_2$: Congestive heart failure, hypertension, age >75 years, diabetes, stroke [doubled]; CHF: Congestive heart failure; CPD: Chronic pulmonary disease; CV: Cardiovascular; PCD: Pulmonary circulation disorder; PVD: Peripheral vascular disorder; SD: Standard deviation.

Table 4. Study characteristics before and after propensity score matching for the inpatient readmission assessment.

Characteristic n (%)	Before propensity score matching			After propensity score matching		
	CF catheter n = 637	CB catheter n = 1220	Standardized difference	CF catheter n = 358	CB catheter n = 358	Standardized difference
Age (mean [SD], yrs)	62.74 (10.13)	64.84 (10.62)	-0.2016	63.04 (10.38)	62.93 (10.35)	0.0113
Age group						
18–49 yrs	71 (11.15%)	92 (7.54%)	0.1241	41 (11.45%)	33 (9.22%)	0.0735
50–59 yrs	141 (22.14%)	239 (19.59%)	0.0627	73 (20.39%)	70 (19.55%)	0.0210
60–69 yrs	256 (40.19%)	457 (37.46%)	0.056	141 (39.39%)	169 (47.20%)	-0.1583
≥70 yrs	169 (26.53%)	432 (35.41%)	-0.1929	103 (28.77%)	86 (24.02%)	0.1079
Female gender	212 (33.28%)	457 (37.46%)	-0.0875	126 (35.20%)	114 (31.84%)	0.0711
White race	549 (86.19%)	1144 (93.77%)	-0.2546	324 (90.50%)	319 (89.11%)	0.0462
Marital status						
Married	456 (71.59%)	872 (71.48%)	0.0024	255 (71.23%)	259 (72.35%)	-0.0248
Single	173 (27.16%)	312 (25.57%)	0.0360	95 (26.54%)	90 (25.14%)	0.0319
Other	8 (1.26%)	36 (2.95%)	-0.1183	8 (2.23%)	9 (2.51%)	-0.0183
Payer						
Commercial	286 (44.90%)	491 (40.25%)	0.0942	154 (43.02%)	159 (44.41%)	-0.0282
Medicaid	23 (3.61%)	42 (3.44%)	0.0091	13 (3.63%)	10 (2.79%)	0.0475
Medicare	280 (43.96%)	641 (52.54%)	-0.1724	167 (46.65%)	165 (46.09%)	0.0112
Other	48 (7.54%)	46 (3.77%)	0.1636	24 (6.70%)	24 (6.70%)	0
Year						
2014	280 (43.96%)	585 (47.95%)	-0.0802	172 (48.04%)	156 (43.58%)	0.0898
2015	269 (42.23%)	469 (38.44%)	0.0772	131 (36.59%)	145 (40.50%)	-0.0804
2016	88 (13.81%)	166 (13.61%)	0.0061	55 (15.36%)	57 (15.92%)	-0.0154
CCI score						
0	301 (47.25%)	695 (56.97%)	-0.1954	179 (50.00%)	185 (51.68%)	-0.0335
1	191 (29.98%)	318 (26.07%)	0.0873	105 (29.33%)	107 (29.89%)	-0.0122
≥2	145 (22.76%)	207 (58.81%)	0.1456	74 (20.67%)	66 (18.44%)	0.0564
$CHADS_2$ score						
0	167 (26.22%)	342 (28.03%)	-0.0409	95 (26.54%)	92 (25.70%)	0.0191
1	313 (49.14%)	559 (45.82%)	0.0665	173 (48.32%)	180 (50.28%)	-0.0391
≥2	157 (24.65%)	319 (26.15%)	-0.0345	90 (25.14%)	86 (24.02%)	0.0260
Comorbid conditions						
Sleep apnea	167 (26.22%)	264 (21.64%)	0.1074	97 (27.09%)	97 (27.09%)	0
Obesity	113 (17.74%)	115 (9.43%)	0.2445	53 (14.80%)	57 (15.92%)	-0.031
Diabetes	129 (20.25%)	213 (17.46%)	0.0714	72 (20.11%)	79 (22.07%)	-0.0479
Hypertension	437 (68.60%)	798 (65.41%)	0.0679	242 (67.60%)	247 (68.99%)	-0.0300
CPD	113 (17.74%)	152 (12.46%)	0.1479	55 (15.36%)	41 (11.45%)	0.1150
Renal disease	43 (6.75%)	56 (4.59%)	0.0935	19 (5.31%)	18 (5.03%)	0.0126
CHF	137 (21.51%)	174 (14.26%)	0.1899	69 (19.27%)	62 (17.32%)	0.0506
Atrial flutter	184 (28.89%)	193 (15.82%)	0.3176	92 (25.70%)	99 (27.65%)	-0.0442
Pacemaker/defibrillator	41 (6.44%)	66 (5.41%)	0.0435	13 (3.63%)	18 (5.03%)	-0.0687
Valvular disease	109 (17.11%)	168 (13.77%)	0.0926	60 (16.76%)	55 (15.36%)	0.0380
Cardiomyopathy	64 (10.05%)	72 (5.90%)	0.1535	23 (6.42%)	23 (6.42%)	0
Cardiomegaly	36 (6.65%)	78 (6.39%)	-0.0312	18 (5.03%)	23 (6.42%)	-0.0601
Ischemic heart disease	120 (18.84%)	250 (20.49%)	-0.0416	65 (18.16%)	75 (20.95%)	-0.0705
PVD	31 (4.87%)	82 (6.72%)	-0.0795	19 (5.31%)	20 (5.59%)	-0.0123
PCD	20 (3.14%)	18 (0.097%)	0.1110	7 (1.96%)	6 (1.68%)	0.0209
Hospital bed size						
Under 300	76 (11.93%)	53 (4.34%)	0.2802	26 (7.26%)	26 (7.26%)	0
300–399	151 (23.70%)	131 (10.74%)	0.3486	75 (20.95%)	70 (19.55%)	0.0348
400–499	114 (17.90%)	654 (53.61%)	-0.8029	96 (26.82%)	90 (25.14%)	0.0382
≥500	296 (46.27%)	382 (31.31%)	0.3147	161 (48.35%)	172 (48.04%)	-0.0616
Hospital region						
Midwest	77 (12.09%)	634 (51.97%)	-0.9454	77 (21.51%)	74 (20.67%)	0.0205
Northeast	177 (27.79%)	22 (1.80%)	0.7864	35 (9.78%)	22 (6.15%)	0.1345
South	310 (48.67%)	544 (44.59%)	0.0818	227 (63.41%)	242 (67.60%)	-0.0882
West	73 (11.46%)	20 (1.64%)	0.4050	19 (5.31%)	20 (5.59%)	-0.0123
Surgeon CV specialty	363 (56.99%)	608 (49.84%)	0.1437	181 (50.56%)	168 (46.93%)	0.0727
Nonteaching hospital	187 (29.36%)	139 (11.39%)	0.4575	98 (27.37%)	102 (28.49%)	-0.0249
Inpatient setting	108 (16.95%)	158 (12.95%)	0.1124	57 (15.92%)	52 (14.53%)	0.0389

AF: Atrial fibrillation; CB: Cryoballoon; CCI: Charlson Comorbidity Index; CF: Contact force; $CHADS_2$: Congestive heart failure, hypertension, age >75 years, diabetes, stroke [doubled]; CHF: Congestive heart failure; COPD: Chronic pulmonary disease; CV: Cardiovascular; PCD: Pulmonary circulation disorder; PVD: Peripheral vascular disorder; SD: Standard deviation.

Table 5. Study characteristics before and after propensity score matching in the secondary analysis.

Characteristic n (%)	Before propensity score matching			After propensity score matching		
	CF catheter n = 1409	CB catheter n = 3057	Standardized difference	CF catheter n = 1175	CB catheter n = 1175	Standardized difference
Age (mean [SD], yrs)	63.21 (10.21)	64.60 (10.61)	-0.1344	64.50 (10.29)	63.46 (10.61)	0.0037
Age group						
18–49 yrs	142 (10.08%)	246 (8.05%)	0.0708	115 (9.79%)	113 (9.62%)	0.0058
50–59 yrs	307 (21.79%)	598 (19.56%)	0.0550	250 (21.28%)	243 (20.68%)	0.0146
60–69 yrs	567 (40.24%)	1146 (37.49%)	0.0565	466 (39.66%)	475 (40.43%)	-0.0156
≥70 yrs	393 (27.89%)	1067 (34.90%)	-0.1515	344 (29.28%)	344 (29.28%)	0
Female gender	502 (35.63%)	1126 (36.83%)	-0.0251	424 (36.09%)	418 (35.57%)	0.0106
White race	1120 (86.59%)	2845 (63.70%)	-0.2156	1049 (89.28%)	1038 (88.34%)	0.0297
Marital status						
Married	993 (70.48%)	2152 (70.40%)	0.0017	826 (70.30%)	821 (69.87%)	0.0093
Single	352 (24.98%)	830 (27.15%)	-0.0494	302 (25.70%)	308 (26.21%)	-0.0116
Other	64 (4.54%)	75 (2.45%)	0.1139	47 (4.00%)	46 (3.91%)	0.0044
Payer						
Commercial	614 (43.58%)	1225 (40.07%)	0.0711	496 (42.21%)	511 (43.49%)	-0.0258
Medicaid	49 (3.48%)	100 (3.27%)	0.0114	41 (3.49%)	36 (3.06%)	0.0239
Medicare	628 (44.57%)	1599 (52.31%)	-0.1553	550 (46.81%)	546 (46.47%)	0.0068
Other	118 (8.37%)	133 (4.35%)	0.1654	88 (7.49%)	82 (6.98%)	0.0197
Year						
2014	310 (22.00%)	983 (32.16%)	-0.2300	268 (22.81%)	284 (24.17%)	-0.0321
2015	557 (39.53%)	1025 (33.53%)	0.1249	456 (38.81%)	444 (37.79%)	0.0210
2016	382 (27.11%)	611 (19.99%)	0.1685	305 (25.96%)	295 (25.11%)	0.0195
2017 (until the end of June)	160 (11.36%)	438 (14.33%)	-0.0889	146 (12.43%)	152 (12.94%)	-0.0153
CCI score						
0	671 (47.62%)	1660 (54.30%)	-0.1339	574 (48.85%)	569 (48.43%)	0.0085
1	437 (31.01%)	819 (26.79%)	0.0933	358 (30.47%)	366 (31.15%)	-0.0147
≥2	301 (21.36%)	578 (18.91%)	0.0613	243 (20.68%)	240 (20.43%)	0.0063
$CHADS_2$ score						
0	388 (27.54%)	816 (26.69%)	0.0190	317 (26.98%)	318 (27.06%)	-0.0019
1	663 (47.05%)	1413 (46.22%)	0.0167	551 (46.89%)	548 (46.64%)	0.0051
≥2	358 (25.41%)	828 (27.09%)	-0.0381	307 (26.13%)	309 (26.30%)	-0.0039
Comorbid conditions						
Sleep apnea	379 (26.90%)	655 (21.43%)	0.1281	300 (25.53%)	299 (25.45%)	0.0020
Obesity	239 (16.96%)	307 (10.04%)	0.2035	181 (15.40%)	191 (16.26%)	-0.0233
Diabetes	283 (20.09%)	583 (19.07%)	0.0256	239 (20.34%)	248 (21.11%)	-0.0189
Hypertension	959 (68.06%)	2055 (67.22%)	0.0179	802 (62.26%)	796 (67.74%)	0.0109
CPD	228 (16.18%)	433 (14.16%)	0.0563	187 (15.91%)	167 (14.21%)	0.0476
Renal disease	86 (6.10%)	143 (4.68%)	0.0632	62 (5.28%)	71 (6.04%)	-0.0332
CHF	280 (19.87%)	503 (16.45%)	0.0887	219 (18.64%)	220 (18.72%)	-0.0022
Atrial flutter	460 (32.65%)	773 (25.29%)	0.1628	370 (50.89%)	357 (30.38%)	0.0239
Pacemaker/defibrillator	75 (5.32%)	145 (4.74%)	0.0265	65 (5.53%)	71 (6.04%)	-0.0219
Valvular disease	260 (18.45%)	481 (15.73%)	0.0723	209 (17.79%)	204 (17.36%)	0.0112
Cardiomyopathy	104 (7.38%)	161 (5.27%)	0.087	79 (6.72%)	79 (6.72%)	0
Cardiomegaly	75 (5.32%)	178 (5.82%)	-0.0218	70 (5.96%)	70 (5.96%)	0
Ischemic heart disease	311 (22.07%)	658 (21.52%)	0.0133	265 (22.55%)	257 (21.87%)	0.0164
PVD	83 (5.89%)	193 (6.31%)	-0.0177	70 (5.96%)	68 (5.79%)	0.0072
PCD	43 (3.05%)	83 (2.72%)	0.0201	31 (2.64%)	28 (2.38%)	0.0072
Hospital bed size						
Under 300	129 (9.16%)	299 (9.78%)	-0.0214	116 (9.87%)	121 (10.30%)	-0.0141
300–399	324 (23.00%)	682 (22.31%)	0.0164	267 (22.72%)	292 (24.85%)	-0.0500
400–499	420 (29.81%)	1215 (39.74%)	-0.2098	386 (32.85%)	369 (31.40%)	0.0310
≥500	536 (38.04%)	861 (28.16%)	0.2110	406 (34.55%)	393 (33.45%)	0.0234
Hospital region						
Midwest	256 (18.17%)	1076 (35.20%)	-0.3923	255 (21.70%)	251 (21.36%)	0.0083
Northeast	237 (16.82%)	89 (2.91%)	0.4797	80 (6.81%)	86 (7.32%)	-0.0199
South	726 (51.53%)	1481 (48.45%)	0.0616	676 (57.23%)	668 (56.85%)	0.0138
West	190 (13.48%)	411 (13.44%)	0.0012	164 (13.96%)	170 (14.47%)	-0.0146
Surgeon CV specialty	658 (46.70%)	1270 (41.54%)	0.104	498 (42.38%)	484 (41.19%)	0.0242
Nonteaching hospital	510 (36.20%)	965 (31.57%)	0.0979	466 (49.66%)	458 (38.98%)	0.0139
Inpatient setting	215 (15.26%)	451 (14.75%)	0.0142	167 (14.21%)	176 (14.98%)	-0.0217

AF: Atrial fibrillation; CB: Cryoballoon; CCI: Charlson Comorbidity Index; CF: Contact force; $CHADS_2$: Congestive heart failure, hypertension, age >75 years, diabetes, stroke [doubled]; CHF: Congestive heart failure; COPD: Chronic pulmonary disease; CV: Cardiovascular; PCD: Pulmonary circulation disorder; PVD: Peripheral vascular disorder; SD: Standard deviation.

Table 6. Regression adjusted total index ablation costs and supply costs for inpatient and outpatient ablations and length of stay (days) and room and board costs for inpatient ablations only in patients with atrial fibrillation undergoing ablation in the (A) primary analysis and (B) secondary analysis.

	(A)		
Inpatient and outpatient†	**CF catheter n = 1056**	**CB catheter n = 1056**	**p-value**
Total index ablation cost	\$23,281	\$24,934	0.0121
Supply cost	\$9947.58	\$11,338	< 0.0001
Inpatient only‡	CF catheter n = 117	CB catheter n = 117	p-value
LOS (days)	3.16	2.86	0.5067
Room and board cost	\$4148.43	\$3650.10	0.4352
	(B)		
Inpatient and outpatient§	**CF catheter n = 1175**	**CB catheter + point-by-point catheter use n = 1175**	**p-value**
Total index ablation cost	\$23,271	\$25,766	< 0.0001
Supply cost	\$9949.71	\$12,077	< 0.0001
Inpatient only¶	CF catheter n = 145	CB catheter + point-by-point catheter use n = 145	p-value
LOS (days)	3.10	3.05	0.9064
Room and board cost	\$4142.42	\$3870.55	0.6529

†Propensity score-matched analysis; results based on GEE model with log link and γ-distribution.
‡Propensity score-matched analysis with model adjusted for significant standardized differences postmatching in provider region, payer, CHF and cardiomyopathy; results based on GEE model with log link and negative binomial distribution.
§Propensity score-matched analysis; results based on GEE model with log link and γ-distribution.
¶Propensity score-matched analysis with model adjusted for significant standardized differences postmatching in year, age and PVD; results based on GEE model with log link and negative binomial distribution.
CB: Cryoballoon; CF: Contact force; CHF: Congestive heart failure; GEE: Generalized Estimating Equation; LOS: Length of stay; PVD: Peripheral vascular disorder.

As with earlier samples, assessment of the sample for sensitivity analysis revealed a higher comorbidity burden for the CF catheter group (n = 1269) as compared with the CB catheter group (n = 2083; table available on request). The CCI score was significantly higher in the CF catheter group as compared with the CB catheter group (0.91 ± 1.18 vs 0.77 ± 1.13; p = 0.0006).

Study outcome measurements

Hospital costs

CF-sensing catheter use was associated with approximately 7% lower total index ablation costs (\$23,281 vs \$24,934; p = 0.0121) and approximately 13% lower supply costs (\$9,947.58 vs \$11,338; $p < 0.0001$) compared with the CB catheter use (Table 6A). In the secondary analysis including point-by-point catheter use, the CF catheter was associated with approximately 10% lower total index ablation costs (\$23,271 vs \$25,766; $p < 0.0001$) and approximately 18% lower supply costs (\$9,949.71 vs \$12,077; $p < 0.0001$) versus the CB catheter plus point-by-point catheter use (Table 6B). In the postmatch sensitivity analysis sample, the CF catheter group (n = 961) had approximately 8% lower total index ablation costs (\$23,404 vs \$25,308; p = 0.0051) and approximately lower supply costs (\$9944.37 vs \$11,420; $p < 0.0001$) as compared with the CB catheter group (n = 961).

LOS & room & board cost

No significant difference in LOS (3.16 vs 2.86 days; p = 0.5067) and room and board costs (\$4148.43 vs \$3650.10; p = 0.4352) emerged between the CF catheter group versus the CB catheter group (Table 6A). These outcomes were also not significantly different in the secondary analysis of the CF catheter group versus the CB catheter plus point-by-point catheter use group (LOS: 3.10 vs 3.05 days; p = 0.9064 and room and board cost: \$4142.42 vs \$3870.55; p = 0.6529; Table 6B). Results from sensitivity analysis did not reveal any significant difference in LOS (3.47 vs 3.05 days; p = 0.4735) and room and board costs (\$4,598.44 vs \$3,891.40; p = 0.4255) between the CF catheter group (n = 81) and CB catheter group (n = 81).

Table 7. Likelihood of inpatient readmissions during the 4 to 12-months postindex period in patients with atrial fibrillation undergoing ablation using contact force catheter versus cryoballoon catheter or cryoballoon catheter plus point-by-point catheter use in the bivariate analyses.

Inpatient readmission n (%)	CF catheter n = 358	CB catheter n = 358	p-value	CF catheter n = 445	CB catheter + point-by-point catheter use n = 445	p-value
All-cause	22 (6.15)	43 (12.01%)	0.0063	31 (6.57%)	41 (9.21%)	0.2190
CV-related	16 (4.47%)	24 (6.70%)	0.1930	21 (4.72%)	26 (5.84%)	0.4536
AF-related	9 (2.51%)	16 (4.47%)	0.1541	11 (2.47%)	16 (3.60%)	0.3285

AF: Atrial fibrillation; CB: Cryoballoon; CF: Contact force; CV: Cardiovascular.

Table 8. Likelihood of inpatient readmissions during the 4 to 12-months postindex period in patients with atrial fibrillation undergoing ablation using contact force catheter versus cryoballoon catheter or cryoballoon catheter plus point-by-point catheter use in the regression analyses.

Inpatient readmission odds ratio (CI)	CF catheter (n = 358) versus CB catheter (n = 358)†	CF catheter (n = 445) versus CB catheter + point-by-point catheter use (n = 445)‡
All-cause	0.456 (0.323–0.644)	0.751 (0.508–1.111)
CV-related	0.615 (0.389–0.972)	0.821 (0.519–1.298)
AF-related	0.546 (0.260–1.144)	0.673 (0.308–1.470)

†Results based on survey logistic regression analysis; model adjusted for significant standardized differences in postmatching in age, provider region and CPD.
‡Results based on survey logistic regression analysis; model adjusted for significant standardized differences postmatching in provider region.
AF: Atrial fibrillation; CB: Cryoballoon; CF: Contact force; CPD: Chronic pulmonary disease; CV: Cardiovascular.

4 to 12 month inpatient readmissions

Bivariate analyses (Table 7A) revealed a significantly lower rate of 4–12 month all-cause inpatient readmission in the CF catheter group as compared with the CB catheter group (6.15 vs 12.01%; p = 0.0063). No significant difference in 4–12 month CV-related and AF-related inpatient readmission rate emerged between the two groups. Results from regression modeling (adjusting for age, provider region and chronic pulmonary disease that emerged significant postmatching; Table 8) in the matched cohort revealed that patients with AF who had ablation using CF catheter had approximately 55% lower odds of all-cause readmissions (odds ratio [OR]: 0.456; CI = 0.323–0.644) and approximately 39% lower odds of CV-related readmissions (OR: 615; CI = 0.389–0.972) compared with those patients who had ablation using CB catheter. Bivariate and regression analysis (adjusting for provider region that emerged significantly different in the matched cohorts) revealed no significant difference in inpatient readmissions between the CF catheter and CB catheter plus point-by-point catheter-use group. Sensitivity analysis results revealed significant difference in 4–12 month all-cause inpatient readmission, with CF catheter group (n = 287) having 37% lower odds of having a readmission (OR: 0.631; CI = 0.446–0.892) as compared with the CB catheter group (n = 287). No significant differences in 4–12 month CV-related inpatient readmission (OR: 0.888; CI = 0.557–1.414) and AF-related inpatient readmission (OR: 0.652; CI = 0.250–1.702) emerged among the two groups.

Discussion

A few studies have compared the CF catheter and CB catheter, [13,14] and have reported similar effectiveness for the two technologies. However, these studies were restricted to very few centers, and may not be fully reflective of differences in the two technologies among AF patients in a real-world setting. Using a multihospital US database, our study highlights the differential in health utilization outcomes among AF patients undergoing ablation using a CF catheter as compared with the CB catheter. Lower total index ablation costs and supply costs, and lower all-cause and CV-related inpatient readmissions were demonstrated with the CF catheter compared with the CB catheter (without additional point-by-point catheter use). When compared with the CB catheter cohort including additional point-by-point catheter use, significantly lower total cost and supply cost emerged in the CF catheter group.

When comparing the characteristics of AF patients undergoing ablation using the CF catheter as compared with the CB catheter in this multihospital study, an interesting pattern emerged. Patients with AF undergoing ablation with CF catheter had higher comorbidity burden, when assessed in terms of a higher CCI score, and higher occurrence of sleep apnea, obesity, CHF, atrial flutter, valvular disease and cardiomyopathy as compared with those who had ablation using the CB catheter. Whether this is an artifact of the database studied or represent more typical practice pattern remains to be confirmed. Future center-based or large database studies like ours could explore this differential in patient comorbidity status among the two technologies of catheter ablation.

The current study indicates CB technology to be associated with higher costs than CF technology, and the cost differential increases when comparing with CB catheter including additional point-by-point catheter use. In an earlier study using nationally representative multihospital US database, CB catheter use was shown to be considerably more costly than RF catheter technology [19]. In that study, CB catheter use was associated with 30% higher costs for inpatient ablations and approximately 20% higher costs for outpatient ablations as compared with RF catheter. Our results similarly reflect the cost savings associated with the CF catheter use as compared with CB catheter, indicating that newer RF catheter with CF-sensing technology continue to provide economic savings as with earlier generations of RF catheters when compared with the CB catheter.

Postblanking odds of all-cause readmission were more than 50% lower among the CF catheter group as compared with the CB catheter group. Results from sensitivity analyses mirrored these results, with the CF catheter group having significantly lower odds of readmission as compared with the CB catheter group. When ablation using the CB catheter included point-by-point catheter use, there were no significant differences in likelihood of readmissions (all-cause, CV-related and AF-related) between the CF catheter and the CB catheter. The likelihood that all-cause and CV-related readmissions were lower with the CF catheter versus the CB catheter alone (without point-by-point catheter use) and that comparable readmission rates emerged when point-by-point catheter use was included suggests that in order for similar clinical outcomes to be achieved with the CB catheter versus CF catheter, point-by-point catheter use is required. It also reflects the variation in patient population within the CB arm, which may influence the providers' decision on the use of point-to-point catheter. To better understand this, we compared characteristics among CB patients with (n = 751) versus without (n = 2306) additional point-to-point catheter use, and observed significant differences in the two sets of patients within the CB sample. Patients who had CB catheter use with additional point-to-point catheter use had significantly higher CCI scores (CCI score 1: 29.69 vs 25.85%) and higher prevalence of obesity (12.52 vs 9.24%), CHF (19.17 vs 15.57%), atrial flutter (45.01 vs 18.86%), valvular disease (19.71 vs 14.44%) and PCD (5.59 vs 1.78%) as compared with patients who had CB catheter use without additional point-to-point catheter use (all values; $p < 0.05$). Further real-world research is needed to better understand the use of additional point-to-point catheter use with the CB catheter, as well as the potential implications on outcomes among such patients.

Comparable clinical outcomes among patients with paroxysmal AF undergoing ablation with a CF catheter versus a CB catheter has been demonstrated across some prior studies. In one such study that examined economic outcomes from the FIRE and ICE trial, CB ablation was associated with a reduction in resource use and costs among national healthcare systems in Germany, the UK and the US [16]. However, this economic analysis was generated with clinical trial data, using clinical outcomes from a highly restricted study sample with very limited generalizability. Further, the RF technology group in the original trial primarily included older RF catheters without CF-sensing technology. The advent of CF-sensing has led to significant improvements in outcomes associated with RF ablation among AF patients. In their review of CF technology, Afzal *et al.* [20] found 37% reduction in AF recurrence with 12-month median follow-up associated with CF technology as compared with RF technology without CF-sensing. In a prospective trial among symptomatic paroxysmal AF patients comparing ablation with the CF THERMOCOOL SMARTTOUCH catheter with standard technology EZ Steer THERMOCOOL catheter, Marijon *et al.* [21] found the CF group to have 82% lower odds (OR: 0.18; 95% CI: 0.04–0.94; p = 0.04) of AF recurrence at 12-month as compared with the standard RF group. Together, these studies suggest that patient outcomes are likely to improve with the use of CF catheter as compared with standard RF catheters and reflect that any comparison of CB catheter with RF technology should consider inclusion of a CF-sensing RF catheter. The current study, using real-world evidence from a nationally representative multihospital US database, shows that CF catheter use is associated with significantly lower rate of readmissions than CB catheter use among AF patients.

With a lower index ablation cost and a lower rate of readmission, the total cost of care is likely to be significantly lower among patients who undergo ablation using the CF catheter versus the CB catheter. The improved outcomes associated with the CF catheter signify benefits to patients, providers and payers. In addition to reducing the cost burden, lower rates of readmission associated with CF catheter as compared with CB catheter use demonstrates a reduced disease burden among AF patients. For providers, the use of CF catheter as compared with CB catheter is likely to translate into economic savings and at the same time improve patient outcomes.

Limitations

There are a few limitations to this study, but most are inherent to those associated with observational database analyses. Unlike randomized control trials where selection bias can be controlled through randomization, observational research using retrospective database analysis do not offer such flexibility. One approach to alleviate selection bias in observational research is through propensity matching. In the context of our study, we used the doubly robust approach, wherein we not only used propensity matching to match the two groups, but any significant differences postmatching were also adjusted in regression analysis (with the exception of LOS and room and board cost comparison conducted as part of sensitivity analysis, as we had a small sample [n = 81 for each group] postmatching for that comparison). Though the Premier Healthcare database contains information from more than 700 hospitals and includes information on 1 in 5 discharges in the US, study results may have limited generalizability to hospitals not included in the database. We could not adjust for physician level differences in our study, as the data was not available; however, we did perform sensitivity analysis wherein we restricted our sample to include providers that had at least 100 ablation procedures. In our study, the use of relevant devices was ascertained based on text search strategy relying on combination of device name, model number or catalog identification numbers. Such approach is likely to be associated with high positive predictive value; however, we may have missed on including patients where relevant devices were used if the combination approach used for device identification did not appear in charge descriptor file. The recent implementation of unique device identifiers (UDIs) could make it easier for device identification in future, but for us, such an option was not available. We did not have clinical or procedural level data including AF severity, fluoroscopy time and ablation time available in the database. As our data was from both ICD-9 and ICD-10 diagnosis era, we were unable to adjust for AF type in our analysis. Considering that AF type is available in ICD-10 diagnosis codes, future studies could focus exclusively on patients with paroxysmal AF. In our study, we did adjust for comorbidity burden along with several common comorbidities typically associated with AF severity (such as sleep apnea, obesity, heart failure, etc.). Further, procedural elements like fluoroscopy time and ablation time, though important, are unlikely to influence long-terms outcomes (readmissions) that were studied. In our study, we excluded patients who had ablation in the 12-month pre-index period. It is possible that some patients may have had an ablation earlier than the 12-month pre-index period. For such patients, the index ablation classified in our study may not be the first procedure. Last, the occurrence of billing and coding errors could influence study results. Study results should therefore be interpreted in light of these limitations.

Conclusion

This real-world study is the first to compare economic and clinical outcomes among patients with AF undergoing ablation with a CF catheter versus a CB catheter in a nationally representative sample. Key differences emerged,

Summary points

- Catheter ablation is an effective treatment approach for patients with atrial fibrillation (AF).
- The objectives of this study were to compare outcomes including cost, length of stay (LOS) and readmissions among AF patients undergoing ablation using a contact force (CF) catheter (THERMOCOOL SMARTTOUCH® catheter) as compared with a cryoballoon catheter (Arctic Front™/Arctic Front Advance™).
- Using a nationally representative hospital database (Premier Healthcare), AF patients undergoing ablation using either of the two catheters were identified.
- Propensity matching was used to match the two groups of patients on study characteristics.
- The CF catheter group had significantly lower total index ablation cost ($23,281 vs $24,934; $p = 0.0121$) and supply cost ($9948 vs $11,338; $p < 0.0001$) as compared with the cryoballoon (CB) catheter group.
- No significant difference in length of stay and room and board cost was observed among the two groups.
- The CF catheter group had significantly lower odds of all-cause inpatient readmission (odds ratio [OR]: 0.456; CI: 0.323–0.644) and cardiovascular-related inpatient readmission (odds ratio [OR]: 0.615; CI: 0.389–0.972) in the 4–12 month period postablation as compared with the CB catheter group.
- Results from this real-world study suggest lower cost and improved outcomes associated with CF catheter ablation as compared with CB catheter ablation.

with lower total costs and supply costs, and a lower likelihood of all-cause and CV-related inpatient readmissions with a CF catheter versus a CB catheter.

Financial & competing interests disclosure

S Pollak is consultant to Biosense Webster. L Goldstein, M Daskiran, I Kalsekar and R Khanna are employees of Johnson and Johnson. The authors have no other relevant affiliations or financial involvement with any organization or entity with a financial interest in or financial conflict with the subject matter or materials discussed in the manuscript apart from those disclosed.

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Ethical conduct of research

The authors state that they have obtained appropriate institutional review board approval or have followed the principles outlined in the Declaration of Helsinki for all human or animal experimental investigations. In addition, for investigations involving human subjects, informed consent has been obtained from the participants involved.

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