Clinical Investigation

Benefit of Contact Force–Guided Catheter Ablation for Treating Premature Ventricular Contractions

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We evaluated whether an irrigated contact force–sensing catheter would improve the safety and effectiveness of radiofrequency ablation of premature ventricular contractions originating from the right ventricular outflow tract.

We retrospectively reviewed the charts of patients with symptomatic premature ventricular contractions who underwent ablation with a contact force–sensing catheter (56 patients, SmartTouch) or conventional catheter (59 patients, ThermoCool) at our hospital from August 2013 through December 2015. During a mean follow-up of 16 ± 5 months, 3 patients in the conventional group had recurrences, compared with none in the contact force group. Complications occurred only in the conventional group (one steam pop; 2 ablations suspended because of significantly increasing impedance). In the contact force group, the median contact force during ablation was 10 g (interquartile range, 7–14 g). Times for overall procedure (36.9 ± 5 min), fluoroscopy (86.3 ± 22.7 s), and ablation (60.3 ± 21.4 s) were significantly shorter in the contact force group than in the conventional group (46.2 ± 6.2 min, 107.7 ± 30 s, and 88.7 ± 32.3 s, respectively; P *<0.001). In the contact force group, cases with a force-time integral <560 gram-seconds (g-s) had significantly longer procedure and fluoroscopy times (both* P *<0.001) than did those with a force-time integral ≥560 g-s.*

These findings suggest that ablation of premature ventricular contractions originating from the right ventricular outflow tract with an irrigated contact force–sensing catheter instead of a conventional catheter shortens overall procedure, fluoroscopy, and ablation times without increasing risk of recurrence or complications. ***(Tex Heart Inst J 2020;47(1):3-9)***

The creation of durable transmural lesions during radiofrequency catheter ablation (RFCA) of cardiac arrhythmias depends on several factors, including radiofrequency (RF) power, duration of energy application, electrode temperature, tip orientation, and tip size.[1,2] Lesion formation also depends greatly on the contact force (CF) between catheter tip and target tissue.[3-5] Insufficient CF may necessitate increased power and longer ablation times to create therapeutically effective lesions[5]; excessive CF may increase the risk of complications such as steam pop, heart wall perforation, and cardiac tamponade.[6] Therefore, in theory, more precise control of CF during ablation should help produce lesions that are more reliable and effective and less prone to complications.[7]

A novel open-irrigated RFCA catheter tipped with a sensor to enable real-time measurement of catheter tip-to-tissue CF has been developed[3-5] and is used clinically. The multicenter TOuCh+ for CATheter Ablation (Toccata) trial[8] in patients with supraventricular tachycardia and atrial fibrillation (AF) showed that ablation was safer with the CF-sensing catheter than with a conventional catheter. Other studies in patients with AF showed that ablation with the CF-sensing catheter improved lesion size and depth and thus improved outcomes.[9,10] However, few studies have investigated the safety and effectiveness of the CF-sensing catheter when used for ablation of premature ventricular contractions (PVCs).[9,11] Therefore, we evaluated whether an irrigated CF-sensing catheter would improve the safety and effectiveness of RFCA of idiopathic PVCs originating from the right ventricular outflow tract (RVOT).

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Patients and Methods

We retrospectively reviewed the records of patients at the First Affiliated Hospital of Dalian Medical University who underwent RFCA of PVCs originating from the RVOT from August 2013 through December 2015. Patients were characterized in terms of history; results of physical examination, conventional 12-lead electrocardiography (ECG), 24-hour 12-lead Holter monitoring, exercise stress test, transthoracic echocardiography, and chest radiography; and results of electrolyte, thyroid, hepatic, and renal function laboratory tests. Inclusion criteria included the following: frequent symptomatic PVCs originating from the RVOT documented by 12-lead ECG to have an inferior axis and a left bundle branch block QRS morphology; PVC burden >25%; and first-time ablation for PVC. Excluded were patients who had a non-RVOT origin for PVCs as indicated by an S wave in lead I, an R-wave duration index ≥0.5 in leads V_1 and V_2, and an R/S wave amplitude index ≥0.3 in leads V_1 and V_2; evidence of structural heart disease, including ischemic or valvular heart disease, hypertrophy and dilated cardiomyopathy, sarcoidosis, amyloidosis, arrhythmogenic right ventricular cardiomyopathy, and congenital defects; hyperthyroidism or electrolyte disturbances; drug toxicity; diabetes mellitus; blood pressure >160/100 mmHg; impaired renal function; a QT interval >450 ms without bundle branch block; atrioventricular block, bundle branch block, or both; a history of syncope; and decreased blood pressure at the onset of ventricular tachycardia (VT). The Ethics Committee at the First Affiliated Hospital approved the study protocol.

Our retrospective review included patients who had undergone RFCA with either a CF-sensing catheter (CF group) or a conventional catheter (conventional group) at our hospital. Three operators (Drs. Xia, Yin, and Gao) had experience using both catheters and conducted the ablations independently. The CF-sensing catheter used for RFCA was a 3.5-mm Carto® ThermoCool SmartTouch® SF irrigated RF ablation catheter (Biosense Webster, a Johnson & Johnson company) equipped with a force sensor. The conventional catheter used for RFCA was a 3.5-mm ThermoCool® irrigated RF ablation catheter (Biosense Webster).

Radiofrequency Catheter Ablation

In each case, the PVC origin site, defined as the earliest site of local ventricular activation preceding onset of the QRS wave by at least 25 ms on the surface ECG, was localized as the ablation target point using the Carto 3 cardiac mapping system (Biosense Webster). During ablation, the maximum RF power setting was 40 W, and irrigated flow ranged between 2 and 17 mL/min. Termination of PVCs was confirmed by the isoproterenol infusion test.

Acute success was defined as the absence of PVCs morphologically similar to the original PVC during the first 30 min after RFCA. Recurrence was defined as the return of PVC-related symptoms and an electrocardiographic morphology similar to that seen before ablation as detected by ECG or 24-hour Holter monitoring, with a PVC burden >10% per day. For ablations done with the CF-sensing catheter, the Carto 3 mapping system was used to display the CF and 3-dimensional force vectors at 500-ms time intervals (Fig. 1). The CF value was zeroed at the inferior vena cava before mapping began. Mapping data were collected during the ablation procedure and analyzed offline to calculate the maximum, minimum, and mean CF values. The force-time integral (FTI), expressed in gram-seconds (g-s), was defined as the integral of the CF-time curve during the ablation period and was analyzed for its correlation with CF and procedure times.

Patient Follow-Up

All patients had a follow-up visit or telephone interview at 3, 6, 12, and 24 months after the initial ablation procedure. At each follow-up, the patient's history was updated, and 12-lead surface ECG and 24-hour Holter monitoring data were collected as applicable. At 24-month follow-up, patients were administered a standard questionnaire about symptoms and adverse events, including cardiovascular diseases, stroke, thrombosis, bleeding, hospitalization, and arrhythmia.

Statistical Analysis

Continuous variables were analyzed and presented as mean ± SD or as median and interquartile range and compared between the 2 study groups by using the Student *t* test. Categorical variables were expressed as number and percentage and were compared between the 2 groups by using the Fisher exact or χ^2 test. All tests were 2-tailed. *P* values <0.05 were considered statistically significant. All statistical analyses were performed with SPSS, version 13.0 (SPSS, an IBM company).

Results

From August 2013 through December 2015, a total of 115 patients underwent RFCA with either a CF-sensing catheter (56 patients) or a conventional catheter (59 patients). Table I shows their clinical characteristics at baseline. Both groups were comparable in terms of age; sex; hypertension history; left ventricular ejection fraction; left atrial diameter; and levels of B-type natriuretic peptide, creatinine, thyroid-stimulating hormone, and cardiac troponin I. Overall, the mean PVC frequency was 25,316 beats; the mean PVC burden, 26.4%; and the percentage of sustained VTs (>100 beats/min for at least 30 s), 7.8%. Most PVCs (82%) originated from the septal RVOT.

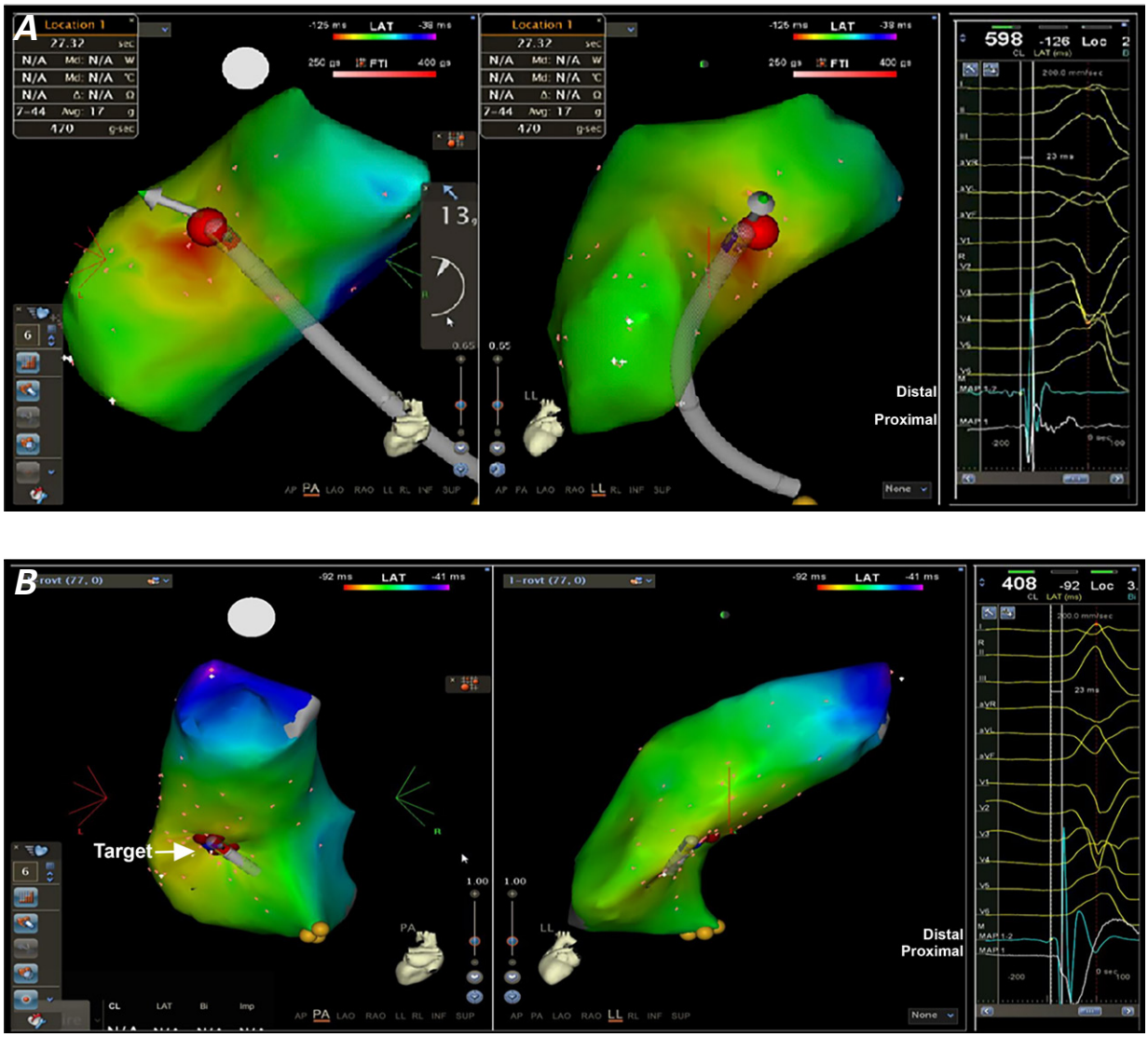

Fig. 1 *Shown are representative* CARTO *3 images captured using* ***A****) contact force (CF)–sensing* SMARTTOUCH *and* ***B****) conventional* THERMOCOOL *ablation catheters in posteroanterior (left panel) and left lateral (center panel) views, along with electrical signal maps recorded by each catheter's distal and proximal electrode pairs (right panel). In* ***A****), the CF-sensing* SMARTTOUCH *map in the left panel displays the target point of premature ventricular contractions (PVCs), CF value, and catheter direction (arrow). The target point is the earliest site of local ventricular activation preceding onset of the QRS wave by at least 25 ms on surface electrocardiogram. The map's display of CF value, catheter direction, and force-time integral enables the operator to know the exact position of the ablation catheter and predict lesion effectiveness. In* ***B****), the conventional* THERMOCOOL *map in the left panel displays the PVC target point; however, catheter direction must be inferred from the position of the coronary sinus catheter and other anatomic markers and, unless impedance is monitored, no information on any other parameter is available to predict lesion effectiveness.*

Contact Force Values during Ablation

In the CF group, the median CF value during ablation was 10 g (interquartile range [IQR], 7–14 g). Moreover, the median CF values recorded at the free wall (8.6 ± 2.7 g) and septal wall (11.1 ± 4.3 g) were comparable (P=0.109). The CF and conventional groups were similar in terms of impedance (135.7 ± 18.6 vs 136.7 ± 18.3 Ω; P=0.772), temperature (39.07 ± 2.9 vs 40.32 ± 4.45 °C; P=0.079), and RF power (32.9 ± 8.3 vs 30.9 ± 8.4 W; P=0.202).

Ablation Outcomes and Complications

Acute success was achieved in all patients in both study groups. No severe complications, including acute myocardial infarction, stroke, or significant bleeding, were recorded. No patient in either group had cardiac tamponade, embolization, pneumothorax, ventricular fibrillation, or arteriovenous fistula. Groin hematoma occurred in 2 patients in each group. During ablation, VT occurred in 3 patients in the CF group and 2 patients in the conventional group. All VTs were unsustained and

TABLE I. Clinical Characteristics of the Study Population (N=115)

Variable	CF Group (n=56)	Conventional Group (n=59)	*P* Value
Age (yr)	52 ± 14	49 ± 16	0.375
Female	36 (64)	36 (61)	0.717
PVC burden (%)	27 (21–29)	26 (22–29)	0.613
PVC frequency (n/24 hr)	25,518 (19,682–27,510)	25,123 (19,987–28,198)	0.63
Sustained VT	4 (7)	5 (8)	0.999
Septal RVOT origin	47 (84)	47 (80)	0.554
Hypertension	25 (45)	27 (46)	0.904
Left atrial diameter (mm)	34 (32–37)	35 (32–38)	0.665
LVEF	0.59 (0.58–0.60)	0.58 (0.57–0.59)	0.088
Systolic BP (mmHg)	125 (120–139)	130 (120–140)	0.562
Diastolic BP (mmHg)	80 (70–90)	80 (70–90)	0.593
BNP (pg/mL)	64.86 ± 35.1	72.26 ± 55.54	0.836
Creatinine (μmol/L)	59.64 ± 11.79	61.39 ± 12.08	0.434
Failed AADs	1.07 ± 0.81	1.24 ± 0.9	0.334
TSH (μIU/mL)	2.20 ± 1.01	2.41 ± 1.14	0.36
Troponin I (μg/L)	0.03 ± 0.07	0.02 ± 0.01	0.319

AAD = antiarrhythmic drug; BNP = brain-type natriuretic peptide; BP = blood pressure; CF = contact force; LVEF = left ventricular ejection fraction; PVC = premature ventricular contraction; RVOT = right ventricular outflow tract; TSH = thyroid-stimulating hormone; VT = ventricular tachycardia

Data are presented as mean ± SD, number and percentage, or median and interquartile range. *P* <0.05 was considered statistically significant.

needed no ablation or other intervention. Table II summarizes and compares the frequency of complications associated with the ablation procedure in the 2 groups.

TABLE II. Complications Associated with Ablation Procedure

Complication	CF Group (n=56)	Conventional Group (n=59)	*P* Value
Ablation suspended due to increasing impedance	0	2 (3)	0.172
Fever	0	1 (2)	0.999
Groin hematoma	2 (4)	2 (3)	0.999
Steam pop	0	1 (2)	0.332
Ventricular tachycardia	3 (5)	2 (3)	0.952

CF = contact force

Data are presented as number and percentage. *P* <0.05 was considered statistically significant.

Contact Force Value and Ablation Safety

The importance of CF in creating reliable lesions and improving safety during AF ablation is well documented.[7,10,12-15] In the CF group, VT was induced during the procedure in 3 patients (CF value >20 g). In contrast, in the conventional group (in which impedance and temperature—but not CF—were monitored), the ablation procedure had to be suspended because of increasing impedance in 2 patients. In one of these patients, the procedure was suspended because impedance rapidly increased from 120 to 200 Ω after a 10-s energy discharge. In another patient, the procedure was interrupted 36 s after the start of RF energy delivery because of a steam pop.

Contact Force and Procedure Times

Overall procedure time (36.9 ± 5 min), fluoroscopy time (86.3 ± 22.7 s), and ablation time (60.3 ± 21.4 s) were significantly shorter in the CF group than in the conventional group (46.2 ± 6.2 min, 107.7 ± 30 s, and 88.7 ± 32.3 s, respectively; all *P* <0.001) (Fig. 2). Post

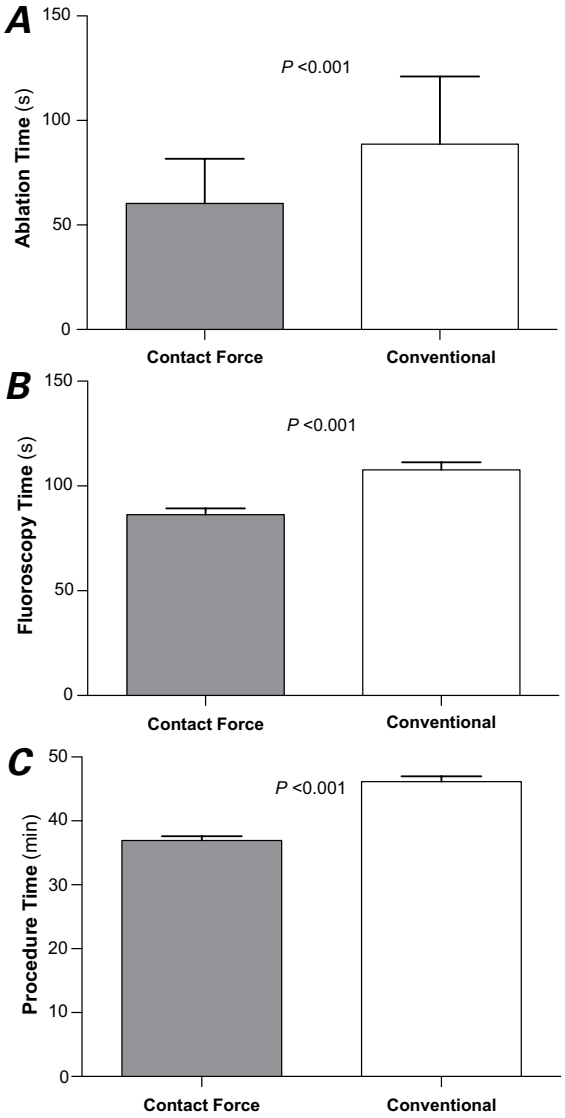

Fig. 2 *Graphs show that **A**) ablation, **B**) fluoroscopy, and **C**) procedure times were significantly shorter when a contact force–sensing catheter was used to ablate premature ventricular contractions (all* P *<0.001 vs conventional catheter).*

Data are presented as mean ± SD. P *<0.05 was considered statistically significant.*

hoc multivariate regression analysis adjusting for the effects of sex, age, PVC location, and operator showed that none of these variables had any significant effect on procedure times (Table III).

Correlation of Force-Time Integral with Contact Force and Procedure Time

In the CF group, FTI values ranged widely from 300 to 900 g-s with a median value of 560 g-s (Fig. 3A). Linear correlation analysis indicated that CF correlated well with FTI (r=0.388, P=0.003) (Fig. 3B). With the median FTI used as cutoff, correlation analysis also indicated that the cases with a lower FTI (<560 g-s) had significantly longer procedure times (Fig. 3C) and fluoroscopy times (Fig. 3D) than did those with a higher FTI (≥560 g-s) (both P <0.001).

TABLE III. Adjusted Comparison of Procedure Time with and without Contact Force Sensing

Variable	Coefficient	95% CI	*P* Value
Group	9.384 ± 1.066	7.271 to 11.496	0.001
Sex	–1.204 ± 1.093	–3.371 to 0.962	0.273
Age	–0.002 ± 0.036	–0.073 to 0.069	0.96
PVC location	0.861 ± 1.378	–1.870 to 3.592	0.533
Operator	–0.282 ± 0.673	–1.616 to 1.051	0.676

PVC = premature ventricular contraction

Data are presented as mean ± SD and 95% CI. P <0.05 was considered statistically significant.

Patient Follow-Up

All patients were followed for 24 months. During a mean follow-up of 16 ± 5 months, 3 in the conventional group had recurrences, compared with none in the CF group. No patient reported procedure-related adverse events during telephone interviews or clinic visits.

Discussion

The results of our study suggest that using a CF-sensing catheter instead of a conventional catheter reduces ablation time during RFCA therapy for PVCs of the RVOT. They also suggest that FTI, which is known to predict RF-induced lesion size in AF ablation, correlates with procedure and fluoroscopy times during PVC ablation.

Our study supplements previous investigations into the benefits of CF sensing and measurement during cardiac ablation. Studies in bovine and porcine ex vivo models of arrhythmia have suggested that CF measurement can help predict lesion size and prevent thrombus formation, steam pops, and ablation-related complications.[4,5] Emerging studies in patients with AF, supraventricular tachycardia, and ventricular arrhythmia have suggested that measuring CF during catheter ablation may reduce procedure time and risk of complications and enable more effective lesion creation.[6,9,11-15] The multicenter Toccata study evaluated the real-time measurement of CF during RFCA of supraventricular tachycardia and AF[8,16] and found that high CFs may occur even during catheter manipulation.[8]

In agreement with a recent meta-analysis of CF-guided AF ablation,[10] our study suggests that CF-guided RFCA of PVCs is as safe and effective as non-CF-guided ablation. Also, as already known from studies with CF-sensing catheters, lesion size is markedly affected by catheter contact[4,5]; the CF between catheter tip and tissue correlates with procedure duration and ablation outcome[3,4]; and impedance drop during ablation, an

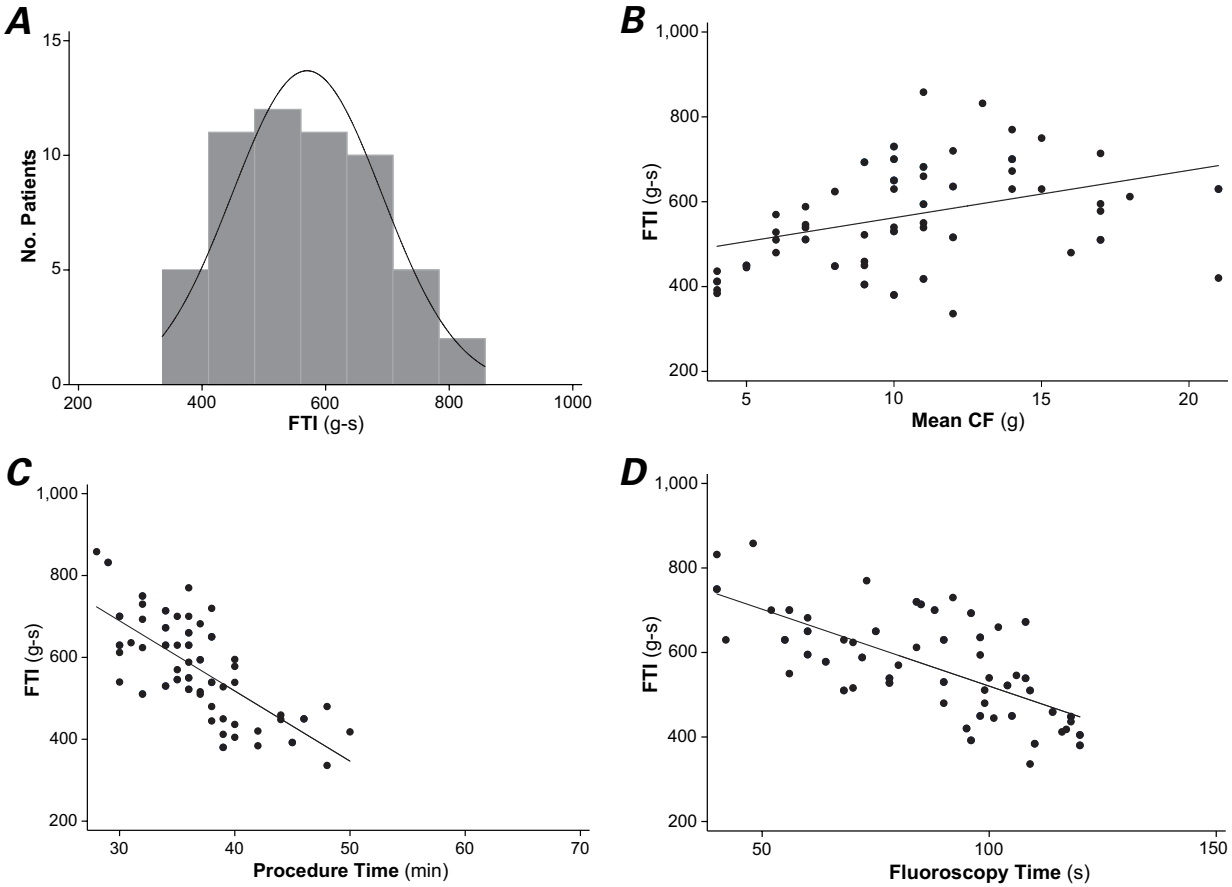

Fig. 3 ***A****) Histogram shows the standard distribution of force-time integral (FTI) in the contact force (CF) group. Scatter plots show that FTI correlated linearly with* ***B****) the mean CF value,* ***C****) procedure time, and* ***D****) fluoroscopy time.*

established indicator of complete ablation[17-19] and surrogate marker of lesion formation,[20] closely correlates with CF and FTI.[20-22] Thus, monitoring CF during ablation would safely provide experienced operators with feedback for delivering RF energy more effectively and creating lesions more completely.

In addition, CF measurement could be useful for training purposes. Operators could learn to use the immediate feedback on catheter manipulation to reduce variability in CF application. For instance, because the catheter forms an angled curve inside the RVOT to accommodate the RVOT's peculiar anatomy, the operator could use measurements by a CF-sensing catheter to gauge whether tip-to-tissue contact is adequate and whether therapeutically effective lesions are being created. High CF values may occur even while the catheter is being manipulated for mapping or ablation, so CF monitoring could help to avoid complications during the procedure.[6]

Study Limitations

Our study had several important limitations. First, it only included patients with PVCs originating from the RVOT, thus limiting any conclusions to that particular population. Second, this retrospective study of patients who underwent RFCA with 2 types of catheters (CF vs conventional) was neither randomized nor controlled and involved no matching between the 2 groups. A large-scale, prospective, randomized, controlled study to confirm our present results is warranted. Third, our study was designed as a pilot study to investigate the influence of CF measurement on acute procedural parameters in patients undergoing RFCA of PVCs initially. Monitoring of the long-term clinical outcomes in these patients is warranted. Finally, despite the involvement of experienced electrophysiologists, procedure, fluoroscopy, and ablation times might have been affected by other operator-related factors such as length of experience in ventricular ablation, familiarity with the novel CF-sensing catheter, and variation in anatomic access.

Conclusion

Ablation of PVCs originating from the RVOT with an irrigated CF-sensing catheter that enables measurement of CF and calculation of FTI in real time can shorten overall procedure, fluoroscopy, and ablation times without increasing the risk of recurrence or complications.

Prospective, randomized studies in larger populations are warranted.

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