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

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, SMARTOUCH) 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; 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 developed3,8 and is used clinically. The multicenter TOuCh+ for CATheter Ablation (TOCCATA) trial7 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.8,10 However, few studies have investigated the safety and effectiveness of the CF-sensing catheter when used for ablation of premature ventricular contractions (PVCs).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).
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 V1 and V2, and an R/S wave amplitude index ≥0.3 in leads V1 and V5; 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 Car
to® 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 Car
to 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 Car
to 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 χ² 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.
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...
needed no ablation or other intervention. Table II summarizes and compares the frequency of complications associated with the ablation procedure in the 2 groups.

**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

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**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.

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**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.
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 ($\geq 560$ g-s) (both $P < 0.001$).

**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 AF16 and found that high CFs may occur even during catheter manipulation.4

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 contact4,5; the CF between catheter tip and tissue correlates with procedure duration and ablation outcome5,4; and impedance drop during ablation, an

| 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. P < 0.05 was considered statistically significant.
established indicator of complete ablation\textsuperscript{17-19} and surrogate marker of lesion formation,\textsuperscript{20} closely correlates with CF and FTI.\textsuperscript{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.\textsuperscript{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.

References

1. Haines DE. Determinants of lesion size during radiofrequency catheter ablation: the role of electrode-tissue contact pressure and duration of energy delivery. J Cardiovasc Electrophysiol 1991;2(6):509-15.
2. Barnett AS, Bahnsen TD, Piccini JP. Recent advances in lesion formation for catheter ablation of atrial fibrillation. Circ Arrhythm Electrophysiol 2016;9(5):e003299.
3. Yokoyama K, Nakagawa H, Shah DC, Lambert H, Leo G, Aeby N, et al. Novel contact force sensor incorporated in irrigated radiofrequency ablation catheter predicts lesion size and incidence of steam pop and thrombus. Circ Arrhythm Electrophysiol 2008;1(5):354-62.
4. Shah DC, Lambert H, Nakagawa H, Langenkamp A, Aeby N, Leo G. Area under the real-time contact force curve (force-time integral) predicts radiofrequency lesion size in an in vitro contractile model. J Cardiovasc Electrophysiol 2010;21(9):1038-43.
5. Thiagalingam A, D’Avila A, Foley L, Guerrero JL, Lambert H, Leo G, et al. Importance of catheter contact force during irrigated radiofrequency ablation: evaluation in a porcine ex vivo model using a force-sensing catheter. J Cardiovasc Electrophysiol 2010;21(7):806-11.
6. Seiler J, Roberts-Thomson KC, Raymond JM, Vest J, Delacretaz E, Stevenson WG. Steam pops during irrigated radiofrequency ablation: feasibility of impedance monitoring for prevention. Heart Rhythm 2008;5(10):1411-6.
7. Reichlin T, Knecht S, Lane C, Kuhne M, Nof E, Chopra N, et al. Initial impedance decrease as an indicator of good catheter contact: insights from radiofrequency ablation with force sensing catheters. Heart Rhythm 2014;11(2):194-201.
8. Kuck KH, Reddy VY, Schmidt B, Natale A, Neuzig P, Saoudi N, et al. A novel radiofrequency ablation catheter using contact force sensing: Toccata study. Heart Rhythm 2012;9(1):18-23.
9. Sarkozy A, Shah D, Saenif J, Sieira J, Philips T, Boris W, et al. Contact force in atrial fibrillation: role of atrial rhythm and ventricular contractions: Co-Atrial Fibrillation Study. Circ Arrhythm Electrophysiol 2015;8(6):1342-50.
10. Lin H, Chen YH, Hou JW, Lu ZY, Xiang Y, Li YG. Role of contact force-guided radiofrequency catheter ablation for treatment of atrial fibrillation: a systematic review and meta-analysis. J Cardiovasc Electrophysiol 2017;28(9):994-1005.
11. Valk SD, de Groot NM, Jordans L. Catheter ablation of right ventricular outflow tract tachycardia using contact force guidance. Neth Heart J 2014;22(10):460-2.
12. Akca F, Janse P, Theuns DA, Szili-Torok T. A prospective study on safety of catheter ablation procedures: contact force guided ablation could reduce the risk of cardiac perforation. Int J Cardiol 2015;179:441-8.
13. Liang JJ, Santageli P. Contact force sensing during atrial fibrillation ablation: clinical experience and effects on outcomes. Expert Rev Cardiovasc Ther 2016;14(6):749-59.
14. Weiss JP, May HT, Bair TL, Crandall BG, Cutler MJ, Day JD, et al. A comparison of remote magnetic irrigated tip ablation versus manual catheter irrigated tip catheter ablation with and without force sensing feedback. J Cardiovasc Electrophysiol 2016;27 Suppl 1:S5-S10.
15. Stabile G, Di Donna P, Schillaci V, Di Monaco A, Iuliano A, Caponi D, et al. Safety and efficacy of pulmonary vein isolation using a surround flow catheter with contact force measurement capabilities: a multicenter registry. J Cardiovasc Electrophysiol 2017;28(7):762-7.
16. Reddy VY, Shah D, Kautzner J, Schmidt B, Saoudi N, Herrera C, et al. The relationship between contact force and clinical outcome during radiofrequency catheter ablation of atrial fibrillation in the TOCCATA study. Heart Rhythm 2012;9(1):1789-95.
17. Sanchez JE, Kay GN, Benser ME, Hall JA, Wallcott GP, Smith WM, Ideker RE. Identification of transmural necrosis along a linear catheter ablation lesion during atrial fibrillation and sinus rhythm. J Interv Card Electrophysiol 2003;8(1):9-17.
18. Reithmann C, Remp T, Hoffmann E, Matis T, Wakili R, Steinbeck G. Different patterns of the fall of impedance as the result of heating during ostial pulmonary vein ablation: implications for power titration. Pacing Clin Electrophysiol 2005;28(12):1282-91.
19. Otomo K, Uno K, Fujiwara H, Isobe M, Isakya Y. Local unipolar and bipolar electrogram criteria for evaluating the transmurality of atrial ablation lesions at different catheter orientations relative to the endocardial surface. Heart Rhythm 2010;7(9):1291-300.
20. Ullah W, Hunter RJ, Baker V, Dhojina MB, Sporton S, Earley MJ, Schilling RJ. Target indices for clinical ablation in atrial fibrillation: insights from contact force, electrogram, and biophysical parameter analysis. Circ Arrhythm Electrophysiol 2014;7(1):63-8.
21. Sulkin MS, Laughner JI, Hilbert S, Kapa S, Kosiuk J, Younaj P, et al. Novel measure of local impedance predicts catheter-tissue contact and lesion formation. Circ Arrhythm Electrophysiol 2018;11(4):e005831.
22. Wakili R, Clauss S, Schmidt V, Ulbrich M, Hahnefeld A, Schusler F, et al. Impact of real-time contact force and impedance measurement in pulmonary vein isolation procedures for treatment of atrial fibrillation. Clin Res Cardiol 2014;103(2):97-106.