Received: 6 August 2023 | Revised: 5 January 2024 | Accepted: 6 January 2024

DOI: 10.1002/joa3.12992

ORIGINAL ARTICLE

Journal of Arrhythmia Open Access WILEY

Impact of contact force on the lesion characteristics of very high-power short-duration ablation using a QDOT-MICRO catheter

Junji Yamaguchi MD[1,2] | **Masateru Takigawa MD[1]** | **Masahiko Goya MD[1]** | **Claire A. Martin MD[3]** | **Miho Negishi MD[1]** | **Tasuku Yamamoto MD[1]** | **Takashi Ikenouchi MD[1]** | **Kentaro Goto MD[1]** | **Takatoshi Shigeta MD[1]** | **Iwanari Kawamura MD[1]** | **Takuro Nishimura MD[1]** | **Tomomasa Takamiya MD[1]** | **Susumu Tao MD[1]** | **Shinsuke Miyazaki MD[1]** | **Tetsuo Sasano MD[1]**

[1]Department of Cardiovascular Medicine, Tokyo Medical and Dental University Hospital, Tokyo, Japan

[2]Department of Clinical and Diagnostic Laboratory Science, Tokyo Medical and Dental University, Tokyo, Japan

[3]Department of Cardiology, Royal Papworth Hospital, Cambridge, UK

Correspondence
Masateru Takigawa, Department of Cardiovascular Medicine, Tokyo Medical and Dental University Hospital, 1-5-45 Yushima, Bunkyo-ku, Tokyo 113-8510, Japan.
Email: teru.takigawa@gmail.com

Funding information
Japan Society for the Promotion of Science, Grant/Award Number: 22K16068

Abstract

Background: Lesion size is reported to become larger as contact force (CF) increases. However, this has not been systematically evaluated in temperature-guided very high-power short-duration (vHPSD) ablation, which was therefore the purpose of this study.

Methods: Radiofrequency applications (90 W/4 s, temperature-control mode) were performed in excised porcine myocardium with four different CFs of 5, 15, 25, and 35 g using QDOT-MICRO™ catheter. Ten lesions for each combination of settings were created, and lesion metrics and steam-pops were compared.

Results: A total of 320 lesions were analyzed. Lesion depth, surface area, and volume were smallest for CF of 5 g than for 15, 25, and 35 g (depth: 2.7 mm vs. 2.9 mm, 3.0 mm, 3.15 mm, $p<.01$; surface area: 38.4 mm^2 vs. 41.8 mm^2, 43.3 mm^2, 41.5 mm^2, $p<.05$; volume: 98.2 mm^3 vs. 133.3 mm^3, 129.4 mm^3, 126.8 mm^3, $p<.01$ for all pairs of groups compared to CF = 5 g). However, no significant differences were observed between CFs of 15–35 g. Average power was highest for CF of 5 g, followed by 15, 25, and 35 g (83.2 W vs. 82.1 W vs. 77.1 W vs. 66.1 W, $p<.01$ for all pairs), reflecting the higher incidence of temperature-guided power titration with greater CFs (5 g:8.8% vs. 15 g:52.5% vs. 25 g:77.5% vs. 35 g:91.2%, $p<.01$ for all pairs except for 25 g vs. 35 g). The incidence of steam-pops did not significantly differ between four groups (5 g:3.8% vs. 15 g:10% vs. 25 g:6.2% vs. 35 g:2.5%, not significant for all pairs).

Conclusions: For vHPSD ablation, lesion size does not become large once the CF reaches 15 g, and the risk of steam-pops may be mitigated through power titration even in high CFs.

Junji Yamaguchi and Masateru Takigawa contributed equally to this work as the first co-authors.

KEYWORDS
catheter ablation, contact force, lesion size, QDOT MICRO™, very high-power short-duration

1 | INTRODUCTION

Radiofrequency (RF) ablation with high-power and short duration (HPSD) has been widely used in the clinical setting with shortened procedure time and preserved efficacy.[1] Recently, a novel contact force (CF) sensing catheter, QDOT-MICRO™ (Biosense Webster, CA, USA) has been developed, which incorporates six thermocouples symmetrically embedded in the circumference of the tip electrode: three distal thermocouples positioned 75 μm from the tip and three proximal thermocouples positioned 3 mm proximally for precise temperature monitoring, allowing real-time temperature assessment at the catheter–tissue interface, which enables temperature-controlled ablation.[2] In the QMODE$^+$ ablation mode, this catheter enables very high-power short-duration (vHPSD) ablation with 90 W/4 s, which may shorten RF ablation time and reduce irrigation volume while maintaining safety.

Previous studies demonstrated that not only the lesion size but also the risk of steam-pops increases as the CF increases in a power-controlled irrigation catheter.[3] However, the impact of CF has not been evaluated in vHPSD ablation based on a temperature-controlled setting. This study aimed to clarify the effect of CF settings on lesion metrics and the incidence of steam-pops in vHPSD ablation in ex vivo conditions.

2 | METHODS

2.1 | Experimental model

A circulating saline bath (400 mL/min) and a deflectable sheath were assembled (Figure 1A). Freshly excised porcine hearts (<12 h), stored in the refrigerator, were utilized. The left ventricular myocardium was consistently sectioned to the same size and affixed to the ground plate under uniform tension, submerged in a 5.0 L saline bath at 37°C. RF applications were executed on the epicardial surface of the myocardium, carefully avoiding the presence of epicardial fat tissue. A 0.2 m/s flow pump was used for simulating the left atrial inflow velocity.[4] A 3.5 mm tip open-irrigated ablation catheter with three microelectrodes and six thermocouples at its tip (QDOT-MICRO™, Biosense Webster, Irvine, California) was positioned in both perpendicular and parallel orientations to the tissue (Figure 1B). To ensure a stable CF, the catheter was

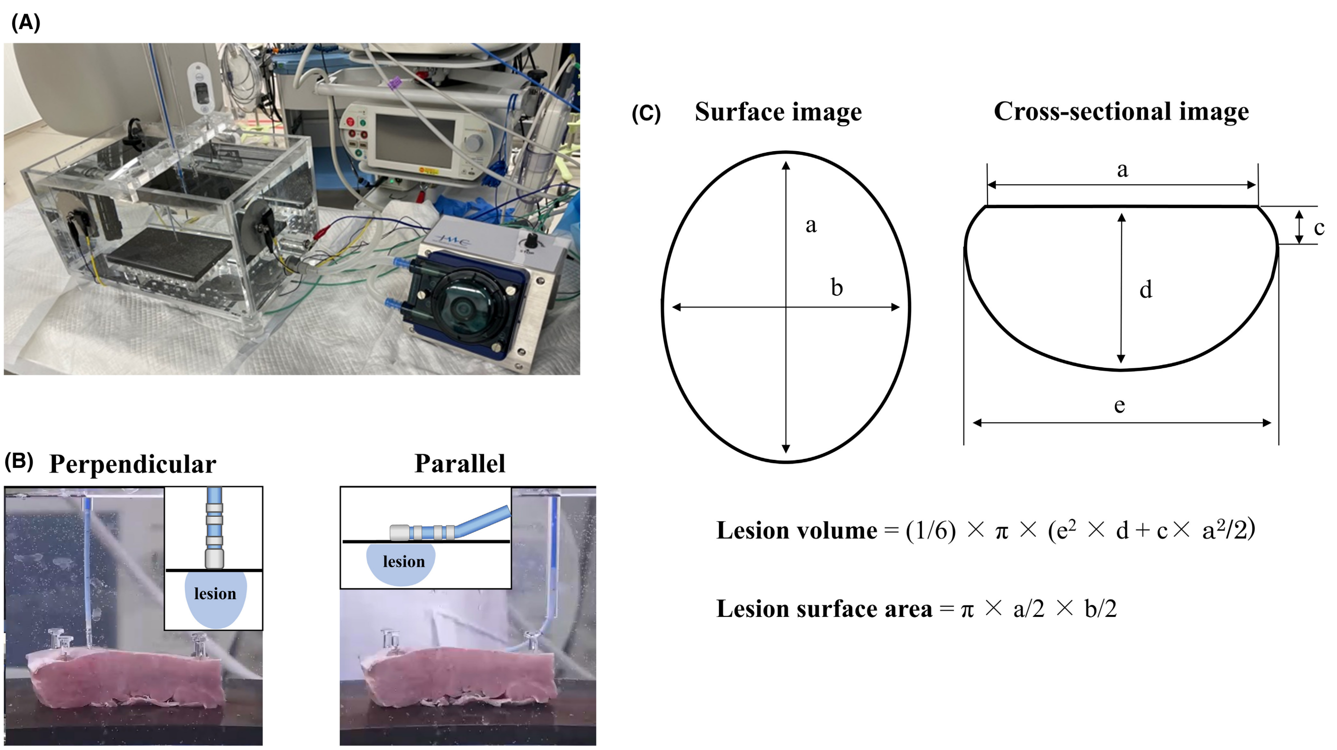

FIGURE 1 Ex vivo experimental model. (A) Experimental setup. Myocardial slab was placed on a ground plate in a circulating saline bath. (B) Ablation catheter orientations (perpendicular and parallel). (C) Scheme of the surface and cross-sectioned lesion.

securely fixed through a plastic pipe before initiating RF application. In instances of catheter movement during the application, another lesion was generated with the same setting. Salinity was controlled to maintain the impedance level of 95 ± 5 Ω, measured by the catheter above the myocardial slab, simulating the blood pool impedance of clinical studies.[5,6]

2.2 | RF applications

vHPSD ablation was performed using the QDOT-MICRO™ catheter at 90 W for 4 s (QMODE+ temperature control setting), with an irrigation rate of 8 mL/min. The nGEN™ RF generator (Biosense Webster, Inc., Diamond Bar, CA, USA) was used for vHPSD ablation. In this QMODE+ setting, ablation duration was fixed to 4 ss. Different CFs and catheter orientations were used during the experiment, as discussed in the following sections.

2.3 | Ablation protocol

To obtain a range of lesion sizes, myocardial lesions were created at separate sites with CF set at 5, 15, 25, and 35 g. The temperature limit was set at 55 or 60°C. The catheter was placed perpendicular or parallel to the tissue. For each CF and temperature limit, RF application was performed in two different arms: single application (SA) and double application (DA). DAs were performed with a "rest" interval of 1 min, and the second RF application was performed with the same setting as the first RF application.

2.4 | Lesion assessment

After RF delivery, the lesion surface was measured as shown in Figure 1C. The myocardium was cross-sectioned along the surface length at the level of each lesion. The cross-sectioned area was also measured as shown in Figure 1C. Each lesion was measured with a digital caliper with a resolution of 0.1 mm by one observer who was blinded to the lesion protocol. Surface area and lesion volume were calculated from the following formulae[7–9]:

$$\text{Lesion volume} = (1/6) \times \pi \times \left(e^2 \times d + c \times a^2 / 2\right)$$

$$\text{Lesion surface area} = \pi \times a/2 \times b/2$$

The incidence of steam-pops was noted and lesions with steam-pops were included into the analysis.

2.5 | Statistical analyses

Continuous variables were compared by Wilcoxon rank-sum test. Categorical variables were compared by an χ^2 test or Fisher's exact test. Significant differences were further evaluated by using Bonferroni's method for pairwise multiple comparisons. A p-value <.05 was considered statistically significant. All statistical analyses were performed with R software (The R Foundation for Statistical Computing, Vienna, Austria).

3 | RESULTS

3.1 | Lesion characteristics in different CFs

A summary of the total lesion count ($N = 320$, $N = 80$ in each CF group) is shown in Table 1. A representative lesion of each approach is shown in Figure 2. Lesion depth, surface area, and volume were smallest for a CF of 5 g compared to a CF of 15, 25, or 35 g (lesion depth: 2.7 mm vs. 2.9 mm, 3.0 mm, and 3.15 mm, $p < .01$; surface area: 38.4 mm^2 vs. 41.8 mm^2, 43.3 mm^2, 41.5 mm^2, $p < .05$; lesion volume: 98.2 mm^3 vs. 133.3 mm^3, 129.4 mm^3, 126.8 mm^3, $p < .01$ for all pairs of groups to CF of 5 g as a reference). No significant differences in lesion depth, surface area, and volume were observed between CF of 15, 25, and 35 g.

In subgroup analysis, similar tendencies were observed in both SA and DA groups except for surface area. In the SA group, surface area was smallest for a CF of 5 g compared to CF of 15, 25, and 35 g (34.5 mm^2 vs. 38.6 mm^2, 40.8 mm^2, and 40.7 mm^2, $p < .01$ for all pairs of groups to CF of 5 g as a reference), while in the DA group, surface area was similar between each CF setting (43.1 mm^2 vs. 45.1 mm^2, 45.4 mm^2, and 42.5 mm^2). The results were similar irrespective of inclusion/exclusion of steam-pop lesions.

To elucidate the potential influence of the target temperature on the association between CFs and lesion characteristics, we analyzed lesion features at two target temperatures, 55 and 60°C (refer to Table S1). Across both 55 and 60°C settings, lesions was generally smallest at a CF of 5 g compared to CFs of 15, 25, and 35 g.

3.2 | Steam-pops with different CFs

The incidence of steam-pops and parameters of RF delivery with different CFs are shown in Table 1. In total, average power was highest for a CF of 5 g, followed by 15, 25, and 35 g (83.2 W vs. 82.1 W vs. 77.1 W vs. 66.1 W, $p < .01$ for all pairs of groups), reflecting the higher incidence of temperature-guided power titration with higher CFs (5 g: 7 [8.8%] vs. 15 g: 42 [52.5%] vs. 25 g: 62 [77.5%] vs. 35 g: 73 [91.2%], $p < .01$ for all pairs of groups except for 25 g vs. 35 g). However, steam-pops were similarly observed between all four groups (5 g: 3 [3.8%] vs. 15 g: 8 [10%] vs. 25 g: 5 [6.2%] vs. 35 g: 2 [2.5%], $p = .99$ [5 g vs. 15 g], $p = .99$ [5 g vs. 25 g], $p = .99$ [5 g vs. 35 g], $p = .99$ [15 g vs. 25 g], $p = .59$ [15 g vs. 35 g], $p = .99$ [25 g vs. 35 g]). For both target temperatures of 55 and 60°C, the incidence of steam-pops was similarly observed across all four CF settings (see Table S1).

Similar tendencies were observed in both SA and DA groups. In the SA group, average power was highest for CF of 5 g, followed by 15, 25, and 35 g (83.2 W vs. 81.7 W vs. 78.8 W vs. 72.0 W, $p < .01$ for

TABLE 1 Lesion characteristics with different CFs and approaches.

	CF = 5 g	CF = 15 g	CF = 25 g	CF = 35 g	*p*-value 5 g vs. 15 g	*p*-value 5 g vs. 25 g	*p*-value 5 g vs. 35 g	*p*-value 15 g vs. 25 g	*p*-value 15 g vs. 35 g	*p*-value 25 g vs. 35 g
Total (SA + DA)	*N* = 80	*N* = 80	*N* = 80	*N* = 80						
Lesion depth	2.7 [2.2–2.9]	2.9 [2.5–3.3]	3.0 [2.8–3.3]	3.15 [2.8–3.6]	<.01	<.01	<.01	.99	.06	.99
Surface area	38.4 [33.8–43.8]	41.8 [37.8–46.5]	43.3 [37.4–47.0]	41.5 [37.5–46.0]	.02	<.01	.03	.99	.99	.99
Lesion volume	98.2 [80.0–128.4]	133.3 [100.7–157.1]	129.4 [113.5–157.8]	126.8 [102.6–152.7]	<.01	<.01	<.01	.99	.99	.99
Titration, *n* (%)	7 (8.8)	42 (52.5)	62 (77.5)	73 (91.2)	<.01	<.01	<.01	<.01	<.01	.16
Average power	83.2 [82.5–83.8]	82.1 [75.2–82.9]	77.1 [65.9–82.1]	66.1 [58.3–78.0]	<.01	<.01	<.01	<.01	<.01	<.01
Pop, *n* (%)	3 (3.8)	8 (10.0)	5 (6.2)	2 (2.5)	.99	.99	.99	.99	.59	.99
SA	*N* = 40	*N* = 40	*N* = 40	*N* = 40						
Lesion depth	2.3 [2.0–2.5]	2.6 [2.3–2.8]	2.75 [2.4–3.0]	2.8 [2.4–3.0]	.01	<.01	<.01	.64	.21	.99
Surface area	34.5 [31.9–39.4]	38.6 [37.0–41.8]	40.8 [35.4–45.1]	40.7 [36.6–43.2]	<.01	<.01	<.01	.99	.99	.99
Lesion volume	80.7 [70.0–89.9]	103.0 [85.0–132.3]	114.8 [93.0–128.3]	111.2 [91.3–122.7]	<.01	<.01	<.01	.99	.99	.99
Titration, *n* (%)	4 (10.0)	23 (57.5)	31 (77.5)	37 (92.5)	<.01	<.01	<.01	.56	<.01	.69
Average power	83.2 [82.7–83.8]	81.7 [73.4–82.7]	78.8 [67.7–82.2]	72.0 [64.1–79.7]	<.01	<.01	<.01	.31	<.01	.38
Pop, *n* (%)	1 (2.5)	2 (5.0)	3 (7.5)	1 (2.5)	.99	.99	1	.99	.99	.99
DA	*N* = 40	*N* = 40	*N* = 40	*N* = 40						
Lesion depth	2.9 [2.7–3.1]	3.3 [2.9–3.7]	3.35 [3.1–3.7]	3.6 [3.3–3.9]	<.01	<.01	<.01	.99	.06	.65
Surface area	43.1 [37.7–47.9]	45.1 [41.7–50.6]	45.4 [40.1–49.0]	42.5 [39.4–47.2]	.56	.99	.99	.99	.83	.99
Lesion volume	129.0 [107.8–143.0]	156.1 [136.4–185.7]	159.7 [132.4–187.9]	147.7 [134.2–175.5]	<.01	<.01	.02	.99	.99	.99
Titration, *n* (%)	3 (7.5)	19 (47.5)	31 (77.5)	36 (90.0)	<.01	<.01	<.01	.06	<.01	.99
Average power	83.0 [82.5–83.7]	82.3 [76.0–83.0]	73.6 [63.1–81.4]	59.4 [55.2–72.0]	<.01	<.01	<.01	<.01	<.01	.03
Pop, *n* (%)	2 (5.0)	6 (15.0)	2 (5.0)	1 (2.5)	.99	1	.99	.99	.65	.99

Note: Values are given as median [25th–75th percentiles] or *n* (%). The same number of applications created with perpendicular and parallel is included in each group.

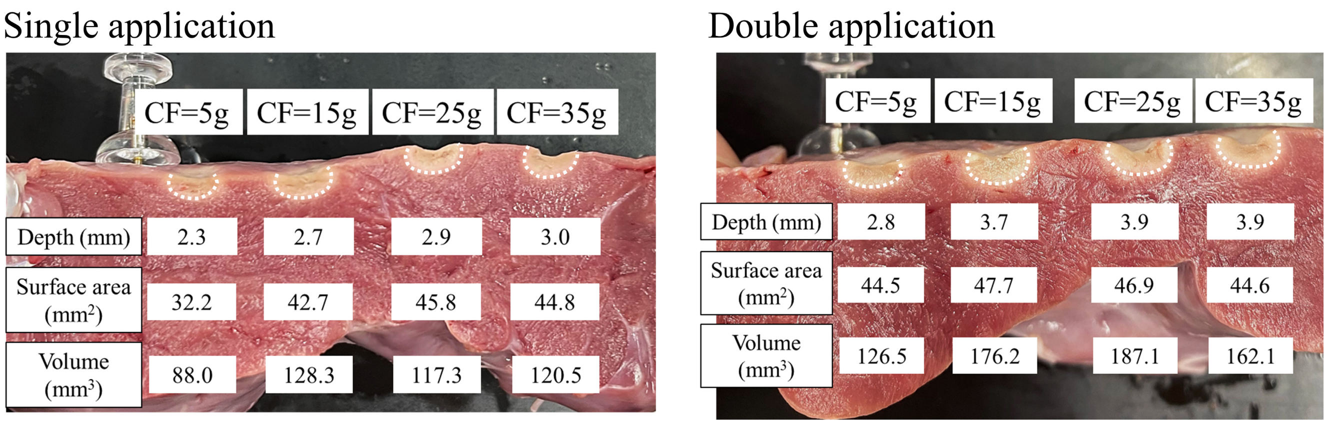

FIGURE 2 Representative lesions with perpendicular catheter contact to the tissue with CF of 5, 15, 25, and 35 g with a target temperature of 60°C. Left panel shows the lesions created by SA and right panel shows those created by DA.

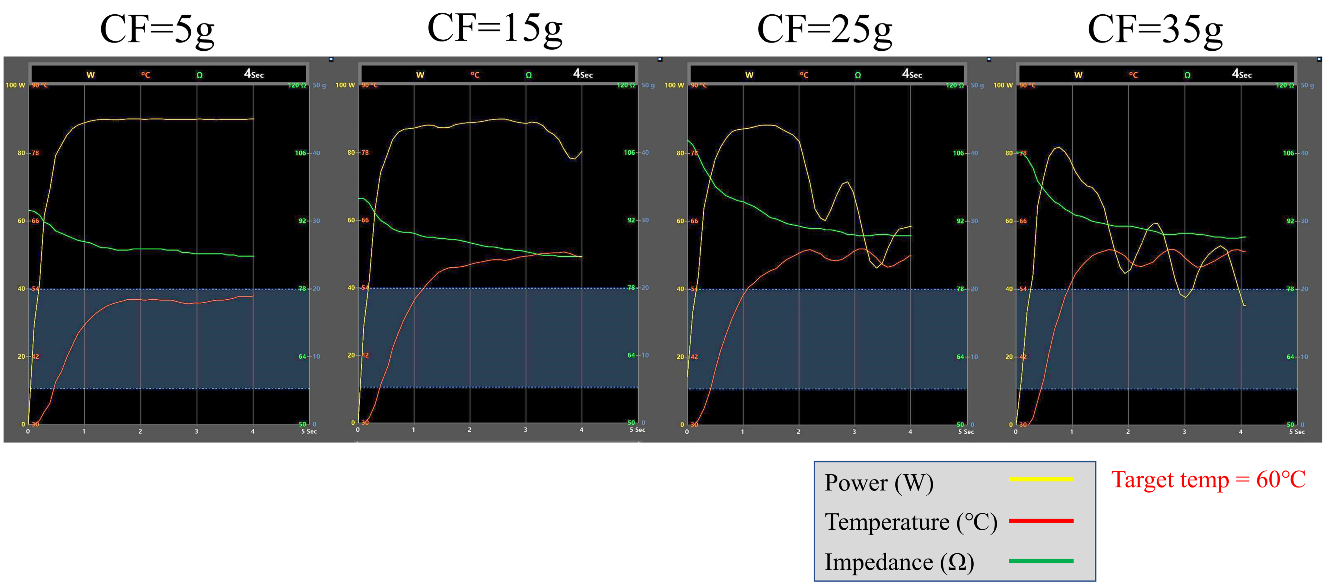

FIGURE 3 Ablation parameter graph examples created by single RF application with a target temperature of 60°C and different CFs (5, 15, 25, 35 g). At 35 g, power was titrated frequently, and temperature was controlled at around 50°C. At 5 g, power was not titrated and temperature did not even reach 40°C, resulting in only a small decrease of impedance during RF applications.

all pairs of groups except for 15 g vs. 25 g and 25 g vs. 35 g), the incidence of temperature-guided power titration was higher with higher CFs (5 g: 4 [10%] vs. 15 g: 23 [57.5%] vs. 25 g: 31 [77.5%] vs. 35 g: 37 [92.5%], $p < .01$ for all pairs of groups except for 15 g vs. 25 g and 25 g vs. 35 g), but the incidence of steam-pop was similar between all four groups (5 g: 1 [2.5%] vs. 15 g: 2 [5.0%] vs. 25 g: 3 [7.5%] vs. 35 g: 1 [2.5%], $p = .99$ or 1 for all pairs of groups). In the DA group, average power was highest for CF of 5 g, followed by 15, 25, and 35 g (83.0 W vs. 82.3 W vs. 73.6 W vs. 59.4 W, $p < .05$ for all pairs of groups). The incidence of temperature-guided power titration was higher with higher CFs (5 g: 3 [7.5%] vs. 15 g: 19 [47.5%] vs. 25 g: 31 [77.5%] vs. 35 g: 36 [90.0%], $p < .01$ for all pairs of groups except for 15 g vs. 25 g and 25 g vs. 35 g), but the incidence of steam-pops was similar between all four groups (5 g: 2 [5.0%] vs. 15 g: 6 [15.0%] vs. 25 g: 2 [5.0%] vs. 35 g: 1 [2.5%], $p = .99$ [5 g vs. 15 g], $p = 1$ [5 g vs. 25 g], $p = .99$ [5 g vs. 35 g], $p = .99$ [5 g vs. 25 g], $p = .65$ [15 g vs. 35 g], $p = .99$ [25 g vs. 35 g]). Examples of ablation parameter graphs with different CFs are shown in Figure 3. For 15–35 g settings, the temperature was controlled at around 50°C with effective power titration, while for 5 g settings, the temperature did not even reach 40°C without power titration.

3.3 | Lesion characteristics with different contact angles

Lesion characteristics with different contact angles are shown in Table 2. In total, lesion depth and volume were significantly larger with perpendicular rather than parallel contact to the tissue (lesion depth: 3.0 mm vs. 2.8 mm, $p < .01$; lesion volume: 128.4 mm^3

TABLE 2 Lesion characteristics with or without steam-pops.

	Perpendicular	Parallel	*p*-value
Total	*N* = 160	*N* = 160	
Lesion depth	3.0 [2.7–3.5]	2.8 [2.3–3.2]	<.01
Surface area	41.3 [36.8–46.2]	40.7 [36.6–45.8]	.72
Lesion volume	128.4 [108.5–155.5]	120.5 [88.2–143.3]	<.01
Titration	86 (53.8)	98 (61.3)	.21
Average power	82.1 [69.7–83.0]	80.0 [66.6–82.9]	.19
Pop	8 (5.0)	10 (6.2)	.81
CF = 5 g	*N* = 40	*N* = 40	
Lesion depth	2.75 [2.3–3.0]	2.55 [2.1–2.8]	.13
Surface area	37.2 [33.5–44.0]	39.5 [35.0–42.8]	.53
Lesion volume	99.4 [82.2–126.5]	95.7 [75.4–131.1]	.32
Titration	3 (7.5)	4 (10.0)	.99
Average power	83.1 [82.5–83.9]	83.2 [82.6–83.7]	.70
Pop	2 (5.0)	1 (2.5)	.99
CF = 15 g	*N* = 60	*N* = 60	
Lesion depth	2.95 [2.7–3.6]	2.8 [2.3–3.2]	<.01
Surface area	42.6 [38.1–47.9]	40.1 [37.2–45.1]	.18
Lesion volume	134.6 [113.6–164.6]	131.4 [88.7–151.5]	.11
Titration	18 (45.0)	24 (60.0)	.26
Average power	82.4 [74.5–82.9]	81.7 [75.6–82.8]	.50
Pop	3 (7.5)	5 (12.5)	.71
CF = 25 g	*N* = 60	*N* = 60	
Lesion depth	3.15 [2.9–3.6]	2.95 [2.5–3.3]	.01
Surface area	43.0 [36.8–46.4]	43.99 [37.8–47.5]	.79
Lesion volume	136.1 [118.3–174.4]	128.6 [96.4–155.0]	.08
Titration	29 (72.5)	33 (82.5)	.42
Average power	78.8 [67.7–82.4]	73.5 [64.2–80.4]	.14
Pop	3 (7.5)	2 (5.0)	.99
CF = 35 g	*N* = 60	*N* = 60	
Lesion depth	3.35 [2.9–3.8]	3.0 [2.6–3.5]	.05
Surface area	42.0 [38.2–45.5]	41.1 [37.2–46.0]	.72
Lesion volume	137.1 [114.0–168.3]	122.0 [95.7–140.9]	.04
Titration	36 (90.0)	37 (92.5)	.99
Average power	70.5 [58.4–79.5]	64.0 [57.8–74.4]	.24
Pop	0 (0.0)	2 (5.0)	.49

Note: Values are given as the median [25th–75th percentiles] or *n* (%).

vs. 120.5 mm^3, $p < .01$). However, surface area did not differ between perpendicular and parallel contact to the tissue (41.3 mm^2 vs. 40.7 mm^2, $p = .72$). The same tendencies were observed at each CF setting (lesion depth: CF = 5 g: 2.75 mm vs. 2.55 mm, $p = .13$; CF = 15 g: 2.95 mm vs. 2.8 mm, $p < .01$; CF = 25 g: 3.15 mm vs. 2.95 mm, $p = .01$; CF = 35 g: 3.35 mm vs. 3.0 mm, $p = .05$, lesion volume: CF = 5 g: 99.4 mm^3 vs. 146.5 mm^3, $p = .02$; CF = 15 g: 134.6 mm^3 vs. 131.4 mm^3, $p = .11$; CF = 25 g: 136.1 mm^3 vs. 128.6 mm^3, $p = .08$; CF = 35 g: 137.1 mm^3 vs. 122.0 mm^3, $p = .04$).

4 | DISCUSSION

In this study, we demonstrated the effect of CF on lesion characteristics in vHPSD (90 W/4 s) RF applications. This study demonstrates the followings:

1. Although a CF of 5 g is significantly associated with decreased lesion size, once the CF reaches 15 g, CF-dependent lesion increase is not observed.
2. At higher CF settings, average power is lower owing to temperature-guided power titration. As a result, steam-pops are not frequently observed even though the CF increases.
3. Regardless of CF settings, perpendicular catheter contact to the tissue generally produces deeper lesions.

4.1 | Effect of CF on lesion metrics in vHPSD ablation

We compared four different CFs (5, 15, 25, and 35 g) and demonstrated that CFs of 15, 25, and 35 g produced similarly larger lesions than those at 5 g, and surface area did not differ significantly between the four different CFs.

With normal to moderate ablation power with a power-control mode, it is well known that lesion sizes become larger with higher CF, because greater CF may increase the catheter tip area covered by the tissue, allowing larger current to flow into the tissue without power regulation.[3] In our study, higher CFs were associated with lower average power, attributed to more frequent power titration specific to the temperature-control mode. The QDOT-MICRO™ catheter, equipped with three distal and three proximal thermocouples symmetrically embedded in the tip electrode, allows sensitive tissue temperature monitoring and dynamic power titration within the 4-s ablation duration. Consequently, this catheter achieves lesions with comparable depth and volume by balancing CF and RF power effects. In essence, very high power, such as 90 W, may be unnecessary for moderate to high CFs in which a larger part of the electrode is likely to covered by the tissue, to achieve similar lesion characteristics. This conclusion is supported by the observation that the average power was 77.1 W at CF = 25 g and 66.1 W at CF = 35 g in our study. However, at a CF of 5 g, RF power delivery to the tissue was insufficient, likely due to a smaller tissue–catheter tip interface. This configuration allows the electric current to more easily distribute to the blood pool, resulting in a lower tissue temperature (as shown in Figure 3) and smaller lesion creation compared to a CF of 15 g or higher. However, with a CF of 5 g, RF power was not sufficiently delivered to the tissue, likely due to a smaller tissue–catheter tip interface, which allows the electric current to more easily distribute to the blood pool, resulting in a lower tissue temperature (as shown in Figure 3) and smaller lesion creation than with a CF of 15 g or higher.[10] Based on our results, vHPSD ablation using the QDOT-MICRO™ catheter has the advantage of producing a stable lesion size with preserved safety using a CF of 15 g or higher. However, we have to emphasize that extremely high CFs are not recommended because of the risk of mechanical injury or traumatic damage to the atrium.[11,12] Further studies are needed to clarify the optimal CF of 90W/4s ablation using QDOT-MICRO catheter.

Additionally, even in the low CF of 5g, DA produced significantly larger lesion depth, surface area, and volume than SA (depth: 2.9mm vs. 2.3mm, $p<.01$; surface area: 43.1mm^2 vs. 34.5mm^2, $p<.001$; 129.0mm^3 vs. 80.7mm^3, $p<.01$). In the clinical settings, it is sometimes difficult to place the catheter stably and securely, especially at pulmonary vein (PV) carina area, where the gap formation is frequently observed.[13] Since RF duration is fixed to 4 seconds in this vHPSD ablation, DA may be of help to create transmural lesions when it is difficult to increase the CF due to the unstable catheter fixation.

4.2 | Steam-pops did not increase with higher CFs

In our study, steam-pop rates were similar with different CF settings. It is well known that steam-pops are more frequent with higher CFs in a power control setting, because greater CF increases RF energy delivery to the tissue without regulating the power.[3] As mentioned in the previous section, a lower average power with higher CFs owing to the accurate tissue temperature monitoring and feedback behavior may be the main reason for low steam-pop rates with high CFs in this study. Temperature-controlled ablation enables deeper lesion formation by safely prolonging the RF duration while minimizing the complication of excessive heating including steam-pops.[14] On the other hand, power-controlled ablation can output stable RF energy but may increase steam-pops due to overheating. Leshem et al reported that temperature- and irrigation flow-controlled RF ablation using the QDOT-MICRO™ catheter produced similar lesion depth with fewer steam-pops than power-controlled ablation at 40–50W settings.[15] vHPSD ablation using a QDOT-MICRO™ catheter may safely produce more homogenous lesions in both the atrium and ventricle.[16]

The safety of vHPSD ablation using the QDOT-MICRO™ catheter has also been reported in clinical studies. Halbfass et al reported a two-center trial where none of the 90 patients who underwent pulmonary vein isolation (PVI) with vHPSD ablation using QDOT-MICRO™ demonstrated steam-pops, cardiac tamponades, fistulas, esophageal ulcerations, or strokes.[17] Richard et al reported from their single center experience that no steam-pops, cardiac tamponades, pericardial effusion, or strokes were observed in 28 vHPSD-PVI-treated patients.[18] Our results may provide additional insights into the safety mechanisms of vHPSD ablation using the QDOT-MICRO™ catheter, where even the CF rises, the risk of steam-pops may be reduced by effective power titration.

4.3 | Lesion characteristics with different contact angles

Our study demonstrated that regardless of CF settings, perpendicular catheter placement produces deeper and larger lesions with a similar incidence of steam-pops. This tendency was more remarkable in larger CF settings.

Our previous study demonstrated that lesion size does not significantly differ between perpendicular and parallel catheter placement in 3.5-mm tip irrigation catheter (TactiCath), whereas it is significantly larger with parallel catheter placement in 4-mm tip catheter (FlexAbility).[9] This may be explained by the fact that the area of catheter–tissue interface is larger with parallel contact than perpendicular contact in the 4.0mm tip catheter, but equivalent in in the 3.5-mm tip catheter. Theoretically, the larger the contacted area is, the larger current flows into the tissue and the smaller current dissipates to the blood pool, resulting in the enlargement of the lesion size.[19] The tendency that perpendicular contact produces larger lesion is more significant in the larger CFs in our study. This is probably because that the catheter is further buried into the tissue and enlarge the catheter–tissue contacted area in perpendicular placement. Although no significant differences in average power were observed between perpendicular and parallel contact to the tissue, relatively higher average power was observed with perpendicular than with parallel in the higher CFs (CF=25g: 78.5W vs. 73.5W, $p=.14$; CF=35g: 70.5W vs. 64.0W, $p=.24$), and this may partially explain the lesion size differences between contact angles. However, difference in lesion size between two angles in our current study is relatively small, showing that the power-regulation may play an important role to produce clinically stable and homogenous lesions in any angles with this catheter.

5 | CLINICAL IMPLICATIONS

In the present study, we established that neither the lesion size nor the incidence of steam-pops increased beyond a CF of 15g, indicating that the impact of CF becomes minimal beyond this threshold with the novel catheter. It is, however, noteworthy that while power titration may mitigate the risk of steam-pops at higher CFs, excessively high CFs are not advisable to avoid the potential for mechanical injury or traumatic damage.

6 | LIMITATIONS

This study was performed on an ex vivo model and the results cannot be translated directly into clinical practice. Impedance decrease was not recorded and myocardial thickness at each ablation site was not measured. Lesion characteristics were analyzed using a nonperfused myocardial slab; therefore, the effect of convective cooling may be underestimated. Additionally, we utilized the left ventricular epicardial myocardium in this study; therefore, the results may differ for atrial myocardium. Despite the use of unperfused ex vivo porcine myocardium without cardiac and respiratory movement in the present study, several technical measures were implemented to align the results with clinical conditions. These included adjusting impedance, employing freshly excised hearts (<12h), simulating the left atrial inflow velocity by the pump, and prewarming the section just before RF application. However, we must acknowledge the potential overestimation of the risk of steam-pops in this ex vivo study, as steam-pops were observed in 5.6% of cases in the present study; a frequency was higher than that reported in clinical studies.[17,18,20,21] However, we still believe that we can compare the tendencies in lesion formation between different groups even with the ex vivo studies as previously published reports.[22,23]

7 | CONCLUSIONS

vHPSD ablation using the QDOT-MICRO™ catheter produced similar lesion size once the CF reached 15 g without increasing the risk of steam-pops. Although the risk of steam-pops may be appropriately mitigated by the power titration, high CF may not be recommended to avoid mechanical complications.

FUNDING INFORMATION

This work was partially supported by JSPS KAKENHI Grant Number 22K16068.

CONFLICT OF INTEREST STATEMENT

Drs. Goto, Takigawa, and Miyazaki received endowments from Medtronic Japan, Boston Scientific, Japan Lifeline, and WIN international. Dr. Martin has received honoraria and speaker fees from Medtronic, Boston Scientific, and Biosense Webster. No other authors have conflict of interest to declare.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ETHICS STATEMENT

The ethical committee of Tokyo Medical and Dental University granted an exemption from requiring ethics approval because this research was neither a clinical study nor an animal experiment.

PATIENT CONSENT

Not applicable.

CLINICAL TRIAL REGISTRATION

Not applicable.

ORCID

Junji Yamaguchi https://orcid.org/0000-0001-9324-9603
Masahiko Goya https://orcid.org/0000-0002-7210-0671
Takatoshi Shigeta https://orcid.org/0000-0003-1781-9218
Tetsuo Sasano https://orcid.org/0000-0003-3582-6104

REFERENCES

1. Yavin HD, Leshem E, Shapira-Daniels A, Sroubek J, Barkagan M, Haffajee CI, et al. Impact of high-power short-duration radiofrequency ablation on long-term lesion durability for atrial fibrillation ablation. JACC Clin Electrophysiol. 2020;6:973–85.
2. Reddy VY, Grimaldi M, de Potter T, Vijgen JM, Bulava A, Duytschaever MF, et al. Pulmonary vein isolation with very high power, short duration, temperature-controlled lesions: the QDOT-FAST trial. JACC Clin Electrophysiol. 2019;5:778–86.
3. Ikeda A, Nakagawa H, Lambert H, Shah DC, Fonck E, Yulzari A, et al. Relationship between catheter contact force and radiofrequency lesion size and incidence of steam pop in the beating canine heart: electrogram amplitude, impedance, and electrode temperature are poor predictors of electrode-tissue contact force and lesion size. Circ Arrhythm Electrophysiol. 2014;7:1174–80.
4. Fluckiger JU, Goldberger JJ, Lee DC, Ng J, Lee R, Goyal A, et al. Left atrial flow velocity distribution and FLOW coherence using four-dimensional FLOW MRI: a pilot study investigating the impact of age and pre- and postintervention atrial fibrillation on atrial hemodynamics. J Magn Reson Imaging. 2013;38:580–7.
5. Pesch E, Riesinger L, Vonderlin N, Kupusovic J, Koehler M, Bruns F, et al. Role of catheter location on local impedance measurements and clinical outcome with the new direct sense technology in cardiac ablation procedures. Int J Cardiol Heart Vasc. 2022;8(42):101109. https://doi.org/10.1016/j.ijcha.2022.101109
6. Masuda M, Kanda T, Kurata N, Asai M, Iida O, Okamoto S, et al. Clinical utility of local impedance monitoring during pulmonary vein isolation. J Cardiovasc Electrophysiol. 2020;31(10):2584–91. https://doi.org/10.1111/jce.14678
7. Nakagawa H, Ikeda A, Sharma T, Govari A, Ashton J, Maffre J, et al. Comparison of in vivo tissue temperature profile and lesion geometry for radiofrequency ablation with high power-short duration and moderate power-moderate duration: effects of thermal latency and contact force on lesion formation. Circ Arrhythm Electrophysiol. 2021;14:e009899.
8. Takigawa M, Goya M, Iwakawa H, Martin CA, Anzai T, Takahashi K, et al. Impact of a formula combining local impedance and conventional parameters on lesion size prediction. J Interv Card Electrophysiol. 2022;63:389–98.
9. Yamaguchi J, Takigawa M, Goya M, Martin C, Amemiya M, Yamamoto T, et al. Impact of tip design and thermocouple location on the efficacy and safety of radiofrequency application. J Interv Card Electrophysiol. 2022;66:885–96. https://doi.org/10.1007/s10840-022-01219-8
10. Amemiya M, Takigawa M, Goya M, Martin CA, Anzai T, Takahashi K, et al. Comparison of two catheters measuring local impedance: local impedance variation vs lesion characteristics and steam pops. J Interv Card Electrophysiol. 2022;65:419–28.
11. Shah D, Lambert H, Langenkamp A, Vanenkov Y, Leo G, Gentil-Baron P, et al. Catheter tip force required for mechanical perforation of porcine cardiac chambers. Europace. 2011;13:277–83.
12. Kuck KH, Reddy VY, Schmidt B, Natale A, Neuzil P, Saoudi N, et al. A novel radiofrequency ablation catheter using contact force sensing: toccata study. Heart Rhythm. 2012;9:18–23.
13. Sørensen SK, Johannessen A, Worck R, Hansen ML, Ruwald MH, Hansen J. Differential gap location after radiofrequency versus cryoballoon pulmonary vein isolation: insights from a randomized trial with protocol-mandated repeat procedure. J Cardiovasc Electrophysiol. 2023;34:519–26.
14. Iwasawa J, Koruth JS, Petru J, Dujka L, Kralovec S, Mzourkova K, et al. Temperature-controlled radiofrequency ablation for pulmonary vein isolation in patients with atrial fibrillation. J Am Coll Cardiol. 2017;70:542–53.
15. Leshem E, Zilberman I, Barkagan M, Shapira-Daniels A, Sroubek J, Govari A, et al. Temperature-controlled radiofrequency ablation using irrigated catheters: maximizing ventricular lesion dimensions while reducing steam-pop formation. JACC Clin Electrophysiol. 2020;6:83–93.

16. Ikenouchi T, Takigawa M, Goya M, Martin CA, Yamamoto T, Yamaguchi J, et al. Comparison of lesion characteristics using temperature-flow-controlled versus conventional power-controlled ablation with fixed ablation index. J Cardiovasc Electrophysiol. 2023;34:908–17. https://doi.org/10.1111/jce.15883
17. Halbfass P, Wielandts JY, Knecht S, le Polain de Waroux JB, Tavernier R, de Wilde V, et al. Safety of very high-power short-duration radiofrequency ablation for pulmonary vein isolation: a two-centre report with emphasis on silent oesophageal injury. Europace. 2022;24:400–5.
18. Richard Tilz R, Sano M, Vogler J, Fink T, Saraei R, Sciacca V, et al. Very high-power short-duration temperature-controlled ablation versus conventional power-controlled ablation for pulmonary vein isolation: the fast and furious–AF study. Int J Cardiol Heart Vasc. 2021;35:100847.
19. Masnok K, Watanabe N. Catheter contact area strongly correlates with lesion area in radiofrequency cardiac ablation: an ex vivo porcine heart study. J Interv Card Electrophysiol. 2022;63:561–72.
20. Bortone A, Albenque JP, Ramirez FD, Haïssaguerre M, Combes S, Constantin M, et al. 90 vs 50-watt radiofrequency applications for pulmonary vein isolation: experimental and clinical findings. Circ Arrhythm Electrophysiol. 2022;15:e010663.
21. Orbán G, Salló Z, Perge P, Ábrahám P, Piros K, Nagy KV, et al. Characteristics of very high-power, short-duration radiofrequency applications. Front Cardiovasc Med. 2022;9:941434.
22. Bourier F, Popa M, Kottmaier M, Maurer S, Bahlke F, Telishevska M, et al. RF electrode-tissue coverage significantly influences steam pop incidence and lesion size. J Cardiovasc Electrophysiol. 2021;32:1594–9.
23. Tsutsui K, Mori H, Kawano D, Tanaka N, Ikeda Y, Sumitomo N, et al. Ablation characteristics and incidence of steam pops with a novel, surface temperature-controlled ablation system in an ex vivo experimental model. Pacing Clin Electrophysiol. 2022;45:1390–400.

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Yamaguchi J, Takigawa M, Goya M, Martin CA, Negishi M, Yamamoto T, et al. Impact of contact force on the lesion characteristics of very high-power short-duration ablation using a QDOT-MICRO catheter. J Arrhythmia. 2024;40:247–255. https://doi.org/10.1002/joa3.12992