CLINICAL STUDY

Role of Intracardiac Defibrillation During the Ablation Procedure as a Predictor of Atrial Fibrillation Recurrence After Catheter Ablation

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Summary

Intracardiac defibrillation (IDF) is performed to restore sinus rhythm (SR) during radiofrequency catheter ablation (RFCA) of atrial fibrillation (AF). This study aimed to investigate the change in the IDF threshold before and after RFCA during the ablation procedure and determine whether the IDF threshold after RFCA was associated with the AF substrate and AF recurrence. A total of 141 consecutive patients with drug-refractory persistent AF (age 62.5 ± 10.3 years, 84.4% male) were enrolled in this study. Before RFCA, we initially performed IDF with an output of 1 J. When IDF failed to restore SR, the output was gradually increased to 30 J. After RFCA, we attempted pacing-induced AF to provoke other focuses of AF. When AF was induced, we performed IDF again to terminate AF with outputs of 1 to 30 J. The change in the IDF threshold to restore SR before and after RFCA was evaluated. After RFCA, the IDF threshold for restoring SR significantly decreased (from 11.5 ± 8.6 J to 4.0 ± 3.8 J, $P < 0.001$). During the follow-up (24.3 ± 12.2 months), SR was maintained in 107 patients (75.9%). The multivariate analysis using a Cox proportional-hazards model revealed that an IDF threshold of > 5 J after RFCA was significantly associated with the AF recurrence (HR, 3.99; 95% confidence interval 1.93-8.22; $P = 0.0001$). RFCA decreased the IDF threshold for restoring SR in patients with persistent AF. The IDF output of > 5 J after RFCA could be a predictor of AF recurrence independent of the AF substrate.

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Key words: Substrate, Trigger and intracardiac threshold

Radiofrequency catheter ablation (RFCA) has been shown to be more effective than drug therapy in restoring sinus rhythm (SR) in patients with atrial fibrillation (AF). Compared with the other ablation strategies, pulmonary vein isolation (PVI) is a more basic strategy.[1)] Furthermore, trigger ablation is one of the strategies for AF ablation. It is effective in eliminating AF.[2)] Isoproterenol (ISP) is often used to induce AF triggers.[3)] In addition, defibrillation of induced AF is performed to identify the site of the trigger of spontaneously occurring AF. In those procedures, IDF is often performed to restore SR during RFCA of AF.[4)] The previous study has demonstrated the relationship between IDF output and complex fractionated atrial electrogram (CAFEA) or stepwise ablation.[4)] However, our RFCA protocol was trigger ablation. Furthermore, there are no reports on IDF output and trigger ablation.

There have been numerous studies on cardioversion of AF, such as those regarding the relationship between the defibrillation threshold and maintenance of SR in patients without RFCA.[5-11)] Conversely, many other studies have suggested the relationship between the AF recurrence after RFCA and the AF substrate, such as the left atrial (LA) size and low-voltage zones (LVZs). However, a few studies have demonstrated the relationship between the IDF threshold and AF recurrence after RFCA. Furthermore, no studies that evaluate the relationship between IDF and the LA substrate have been conducted. This study aimed to examine the change in the IDF threshold before and after RFCA to eliminate persistent AF during the procedure. In addition, we determined whether the IDF threshold after RFCA was associated with the recurrence of AF and the AF substrate after the ablation procedure in patients with persistent AF.

Methods

Study population and study design: A total of 141 consecutive patients with drug-refractory persistent AF (age 62.5 ± 10.3 years, 84.4% male) were enrolled in this study. The patients underwent RFCA between January 2013 and December 2015 in our institute. Persistent AF was defined by the guidelines as AF that continuously occurred beyond 7 days (including long-standing persistent

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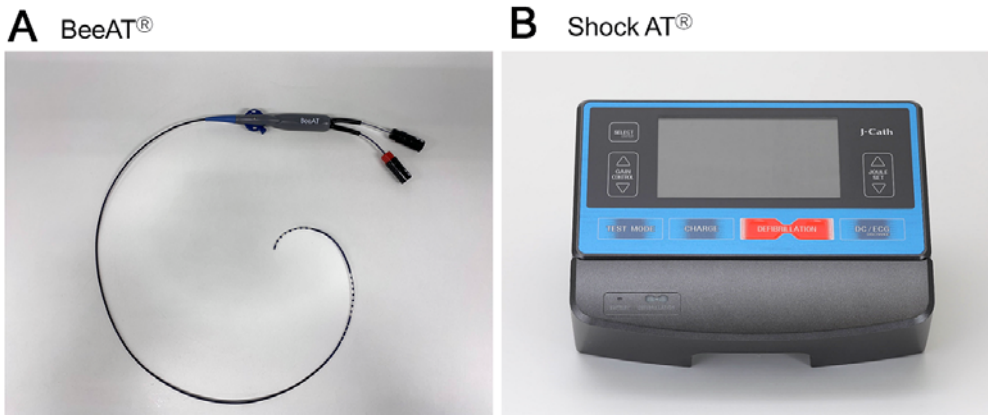

Figure 1. **A:** A 7Fr 20-pole 3-site mapping catheter (BeeAT®, Japan Lifeline, Tokyo, Japan). **B:** Dedicated defibrillator (Shock AT®, Japan Lifeline, Tokyo, Japan).

AF).[12] The study patients were followed up for at least 1 year after AF ablation.

If AF was terminated before RFCA, we artificially induced AF by high-rate burst pacing with a high-dose ISP infusion (starting at 5 μg and increasing up to 10 and 20 μg/minute). In addition, we initially performed IDF to identify the earliest site of the trigger premature atrial contraction (PAC) with spontaneously occurring AF. Defibrillation was performed with an output of 1 J. If defibrillation failed to restore SR with a low output, the output was gradually increased up to 30 J (1, 3, 5, 10, 15, 20, and 30 J). After RFCA, we attempted pacing-induced AF again to provoke other focuses of AF. When AF was artificially induced, we waited for 2 minutes and then performed IDF again to terminate AF with outputs of 1 to 30 J. The change in the IDF threshold to restore SR before and after RFCA was evaluated. Furthermore, we investigated the relationship between the IDF threshold and AF recurrence after RFCA.

This clinical study was a retrospective analysis of prospectively collected AF ablation data. The study protocol was approved by the ethics committee of Toho University Medical Center Omori Hospital (approval number: M20068). Moreover, this study was a retrospective observational study conducted using the opt-out method on our hospital website.

Ablation procedure: Antiarrhythmic drug (AAD) therapy was stopped at least five half-lives before the ablation. Patients on oral anticoagulants stopped their medications on the day the ablation procedure was performed. The study patients underwent transesophageal echocardiography to ensure that there was no thrombus in the atrium or LA appendage 24 hours before the ablation.

A 7 Fr 20-pole 3-site mapping catheter (BeeAT®, Japan Lifeline, Tokyo, Japan) was inserted into the coronary sinus (CS) *via* the right jugular vein. IDF could be performed using the BeeAT® catheter. Moreover, catheters were introduced percutaneously through the femoral vein, and a transseptal puncture was performed after confirming the absence of a patent foramen ovale to access the LA. After the transseptal access, a bolus of intravenous heparin (5,000 IU) was administered, with an additional bolus to maintain an activated clotting time of more than 350 seconds.[13] During ablation, we used propofol and dexmedetomidine to obtain deep sedation. In addition, high-dose ISP was continuously administered to investigate the trigger of AF before RFCA. If AF was not present, we effectively induced AF artificially by high-rate burst pacing during ISP infusion. After AF sustained for more than 2 minutes, IDF was performed to restore SR. Subsequently, we identified the earliest site of the trigger PAC with spontaneously occurring AF. If reproducible, the trigger was identified as an AF focus. We performed PVI on all patients. When we detected non-PV foci, we performed focal ablation again to that site. After RFCA, we used high-dose ISP and high-rate burst pacing to induce AF artificially. Then, we performed IDF again with outputs of 1 to 30 J to restore SR. The endpoint of our ablation was the absence of spontaneous AF occurring after ISP infusion.

All the patients underwent an enlarged PVI to achieve voltage abatement of the electrograms in the encircled areas. Radiofrequency current was delivered using an irrigated-tip ablation catheter (FlexAbility™; Abbott, Minneapolis, MN, or Thermocool®, Biosense Webster, Inc., Diamond Bar, CA, USA) through another long sheath under the guidance of a 3D cardiac mapping system (EnSite Precision™, Abbott or CARTO3, Biosense Webster).

IDF: We used the BeeAT® catheter and a dedicated defibrillator (Shock AT®, Japan Lifeline, Tokyo, Japan), which together constituted the IDF system approved for use in Japan (Figure 1). The BeeAT® catheter has 20 poles consisting of a distal set of 8 poles, middle set of 8 poles, and proximal set of 4 poles. The distal 8 poles were positioned in the distal CS and the middle 8 poles along the lateral wall of the right atrium (RA). Conversely, the proximal four poles were positioned in the superior vena cava (SVC) and recorded the SVC activity during the procedure. We selected the catheter sizes (S, M, and L) that fit the LA and RA sizes of the patients. Cardioversion was effective with a current delivery between the distal and middle sets of electrodes; they were also able to record the local electrograms.

Table I. Patient Characteristics of Those with and Without Atrial Fibrillation Recurrence

	Total (n = 141)	No Recurrence (n = 107)	Recurrence (n = 34)	P value
Age (years)	62.5 ± 10.3	63.4 ± 10.3	59.8 ± 10.2	0.081
Male (%)	119 (84.4)	88 (82.2)	31 (91.2)	0.283
BMI (kg/m^2)	24.6 ± 3.3	24.6 ± 3.3	24.5 ± 3.6	0.253
Hypertension (%)	92 (65.2)	69 (64.5)	23 (67.6)	0.837
Dyslipidemia (%)	58 (41.1)	46 (43.0)	12 (35.3)	0.549
Diabetes (%)	28 (19.9)	21 (19.6)	7 (20.6)	0.999
Stroke (%)	11 (7.8)	9 (8.4)	2 (5.9)	0.999
Heart failure (%)	32 (22.7)	25 (23.4)	7 (20.6)	0.818
$CHADS_2$ score	1.3 ± 1.1	1.3 ± 1.1	1.2 ± 1.1	0.791
CHA_2DS_2-VASc score	2.1 ± 1.5	2.2 ± 1.5	1.7 ± 1.4	0.104
Creatinine (mg/dL)	0.9 ± 0.3	0.9 ± 0.3	1.0 ± 0.2	0.109
BNP (pg/dL)	154.6 ± 220.3	147.6 ± 135.7	176.5 ± 380.9	0.506
LAD (mm)	43.2 ± 6.3	42.8 ± 6.6	44.7 ± 5.1	0.120
LVEF (%)	64.6 ± 10.5	64.4 ± 11.1	65.2 ± 8.1	0.678
Duration of AF (months)	30.7 ± 42.3	23.7 ± 37.5	52.3 ± 49.2	< 0.001
Non-PV foci (%)	59 (41.8)	40 (37.4)	19 (55.9)	0.073
SVC isolation	15 (10.6)	13 (12.1)	2 (5.9)	0.523
Posterior wall isolation	25 (17.7)	17 (15.9)	8 (23.5)	0.312
Focal ablation	29 (20.6)	18 (16.8)	11 (32.4)	0.086
Use rate of AADs after RFCA (%)	101 (71.6)	70 (65.4)	31 (91.2)	0.004
IDF threshold before RFCA (J)	11.5 ± 8.6	10.9 ± 8.3	13.4 ± 9.5	0.158
IDF threshold after RFCA (J)	4.0 ± 3.8	3.4 ± 3.1	5.9 ± 4.9	< 0.001

BMI indicates body mass index; LAD, left atrial diameter; LVEF, left ventricular ejection fraction; AF, atrial fibrillation; PV, pulmonary vein; SVC, superior vena cava; AAD, anti-arrhythmic drug; RFCA, radiofrequency catheter ablation; and IDF, intracardiac defibrillation. Data are expressed as mean ± SD or number (%).

For cardioversion, a biphasic direct current was delivered between the distal set and middle set of electrodes synchronized to the R wave of the body-surface electrocardiogram. If cardioversion was not possible, we changed the lead of the body-surface electrocardiogram to detect and synchronize to any R wave. We started with the IDF output of 1 J and increased to 3, 5, 10, 15, 20, and 30 J. With this system, the maximum energy output was 30 J. We performed IDF under deep sedation with propofol and dexmedetomidine. When the blood pressure was low, we used phenylephrine.

Long-term follow-up: Patient follow-up lasted for at least 12 months. The patients were followed up in the outpatient clinic after the procedure at every 0.5, 1, 2, 3, 4, and 6 months and then every 6 months thereafter; then, they were further followed up either in the outpatient clinic or by telephone every year. Anticoagulants were also used for at least 3 months and continued based on the patients' risk for thromboembolisms, as determined by the $CHADS_2$ or CHA_2DS_2-VASc score.[12] Each doctor decided whether or not to use AADs. Twelve-lead electrocardiogram (ECG) and clinical assessments were performed at each visit. Further, 24-hour Holter monitoring was performed at 3, 6, and 12 months after the initial ablation and every 6 months thereafter. The study patients were asked to record and report to us as soon as possible all episodes of any symptoms suggestive of arrhythmias, such as palpitations, dizziness, or shortness of breath. In such cases, an immediate ECG and 24-hour Holter monitoring at the nearest clinic during the symptomatic period were suggested. Recurrence was defined as episodes of atrial arrhythmia, including AF, atrial flutter, and other atrial tachycardias lasting more than 30 seconds after the first 3 months of blanking period.

Statistical analysis: All continuous data were expressed as means ± standard deviation, medians (quartile: 25%-75%), or numbers (expressed as percentage (%)). The comparison between groups was analyzed using unpaired Student's t-test and Fisher's exact test. The predictors of AF recurrence, including the IDF threshold, after RFCA were evaluated *via* univariate and multivariate analyses using a Cox proportional-hazards model. A P-value of < 0.05 was considered statistically significant. The cumulative non-recurrence rate of atrial arrhythmia after RFCA was plotted using the Kaplan-Meier method, and the difference between the groups was tested *via* the log-rank test. All statistical analyses were conducted using R commander, a graphical user interface for R (Saitama Medical Center, Jichi Medical University, Saitama, Japan).

Results

Baseline characteristics and AF recurrence after RFCA: The mean age of the patients was 62.5 ± 10.3 years, 119 (84.4%) were male, and the body mass index (BMI) was 24.6 ± 3.3 kg/m^2. The mean $CHADS_2$ and CHA_2DS_2-VASc scores were 1.3 ± 1.1 and 2.1 ± 1.5, respectively. The mean LA diameter (LAD) was 43.2 ± 6.3 mm, and the left ventricular ejection fraction (LVEF) was 64.6% ± 10.5%. These baseline characteristics are presented in Table I.

The mean follow-up period after the procedure was

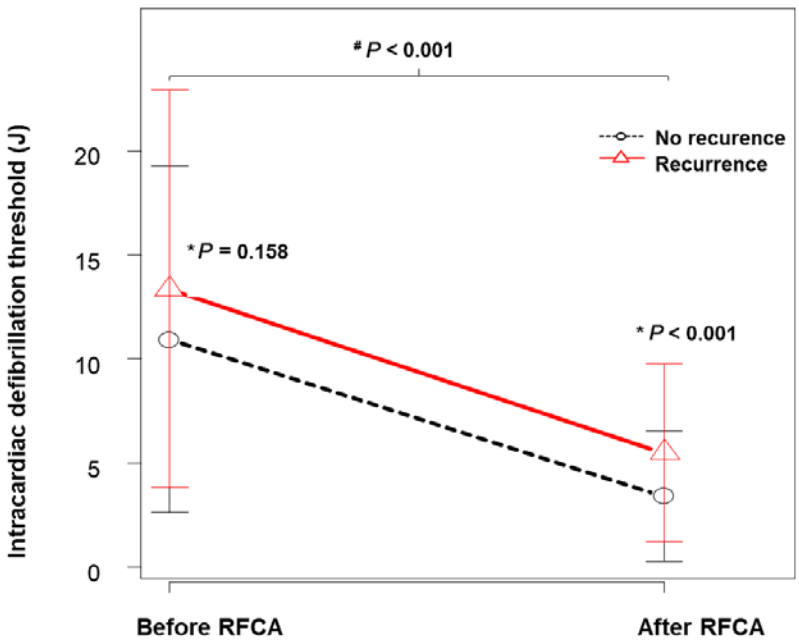

Figure 2. The change in the intracardiac defibrillation (ID) threshold before and after radiofrequency catheter ablation (RFCA). There was no difference in the IDF threshold between the no-recurrence group and recurrence group before RFCA. However, the threshold in the no-recurrence group was significantly lower than that in the recurrence group after RFCA. The red line and words indicate the recurrence group, and the black lines and words indicate the no-recurrence group. RFCA indicates radiofrequency catheter ablation.

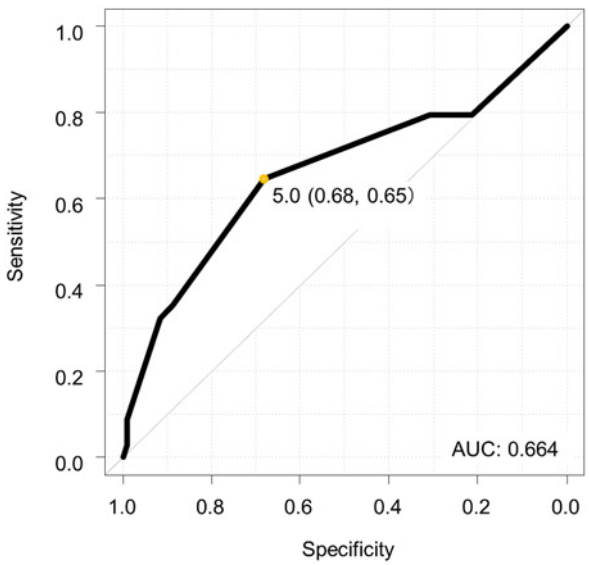

Figure 3. Receiver operating characteristic curve of the recurrence of atrial arrhythmia and the ID threshold after RFCA. The cutoff point analysis revealed that an ID threshold of > 5 J after RFCA was the optimal point that discriminated those with AF recurrence from the rest of the participants (sensitivity, 68.0%; specificity, 65.2%).

24.3 ± 12.2 months. Among the patients, nine were censored cases, but we contacted patients by outpatient clinic or telephone to confirm that there was no recurrence. A total of 107 patients (75.9%) had SR, and 34 (24.1%) developed AF recurrence. As presented in Table I, the AF recurrence group had a longer duration of AF, higher use rate of AADs after RFCA, and higher IDF threshold after RFCA compared with the no-recurrence group ($P < 0.05$). However, no significant differences were observed between the two groups in terms of the age, sex distribution, BMI, $CHADS_2$ score, creatinine, brain natriuretic peptide (BNP), LAD, LVEF, non-PV foci, and IDF threshold before RFCA.

RFCA and IDF: Before RFCA, AF did not terminate spontaneously in all patients, including the artificially induced AF. After RFCA was successfully performed, AF was induced artificially in all patients to induce AF triggers. However, there were 30 patients with inducible AF lasting less than 2 minutes who demonstrated spontaneously restored SR. The IDF threshold to restore SR was significantly decreased after RFCA (from 11.5 ± 8.6 J to 4.0 ± 3.8 J, $P < 0.001$). No difference in the IDF threshold was observed between the recurrence and no-recurrence groups before the RFCA (Table I); however, the threshold in the no-recurrence group was significantly lower than that in the recurrence group after RFCA, as presented in Figure 2. A cutoff point analysis revealed that the IDF threshold after RFCA of > 5 J was the optimal point that discriminated those with AF recurrence from the rest of the participants, as presented in Figure 3 (sensitivity, 68.0%; specificity, 65.2%). We divided the patients into two groups according to the IDF outputs of ≤ 5 J or > 5 J. Among the patients, 117 demonstrated restored SR with an IDF output of ≤ 5 J. Table II shows that the IDF threshold before RFCA, the LAD, and the BNP in the patients with an output of ≤ 5 J were significantly

Table II. Patient Characteristics Between Intracardiac Defibrillation Output Groups of ≤ 5 J and > 5 J

	Output ≤ 5 J (n = 117)	Output > 5 J (n = 24)	P value
Age (years)	62.3 ± 10.3	63.7 ± 10.5	0.551
Male (%)	99 (84.6)	20 (83.3)	0.999
Hypertension (%)	75 (64.1)	17 (70.8)	0.641
Dyslipidemia (%)	50 (42.7)	8 (33.3)	0.497
Diabetes (%)	25 (21.4)	3 (12.5)	0.409
BMI (kg/m^2)	24.5 ± 3.3	24.8 ± 3.4	0.72
Prior stroke (%)	9 (7.7)	2 (8.3)	0.999
Chronic heart failure (%)	28 (23.9)	4 (16.7)	0.595
CAD (%)	10 (8.5)	1 (4.2)	0.69
CHA_2DS_2-VASc score	2.1 ± 1.5	2.0 ± 1.5	0.917
Creatinine (mg/dL)	0.9 ± 0.3	0.9 ± 0.2	0.803
BNP (pg/dL)	134.7 ± 118.8	250.9 ± 459.3	0.018
LAD (mm)	42.7 ± 6.3	45.6 ± 6.2	0.04
LVEF (%)	64.9 ± 10.1	62.8 ± 12.1	0.356
Duration of AF (months)	30.9 ± 42.7	29.7 ± 41.0	0.899
Non-PV foci (%)	48 (41)	11 (45.8)	0.658
SVC isolation	13 (11.1)	2 (8.3)	0.999
Posterior wall isolation	21 (17.9)	4 (16.7)	0.999
Focal ablation	23 (19.7)	6 (25.0)	0.583
Low-voltage zone (%)	17 (14.5)	8 (33.3)	0.039
Use rate of AADs after RFCA (%)	81 (69.2)	20 (83.3)	0.216
IDF threshold before RFCA (J)	10.4 ± 7.8	17.2 ± 10.6	< 0.001
IDF threshold after RFCA (J)	2.6 ± 1.9	10.8 ± 3.4	< 0.001
Recurrence (%)	22 (18.8)	12 (50)	0.003

BMI indicates body mass index; CAD, coronary artery disease; LAD, left atrial diameter; LVEF, left ventricular ejection fraction; AF, atrial fibrillation; PV, pulmonary vein; SVC, superior vena cava; AAD, anti-arrhythmic drug; RFCA, radiofrequency catheter ablation; and IDF, intracardiac defibrillation. Data are expressed as mean ± SD or number (%).

lower than those in the patients with an output of > 5 J. Conversely, no significant differences in the LVEF, AF duration, and non-PV foci were observed between the two groups. The presence of an LVZ in the LA significantly differed between the two groups (17 patients, 14.5% versus 8 patients, 33.3%, P = 0.039).

IDF threshold and recurrence of atrial arrhythmia: The recurrence ratio of AF was significantly higher in the patients with an output of > 5 J than in those with an output of ≤ 5 J (22 patients, 18.8% versus 12 patients, 50%). Further, the cumulative non-recurrence rate using the Kaplan-Meier method was significantly lower in the patients with an output of > 5 J than in those with an output of ≤ 5 J (P < 0.001, Figure 4).

The multivariate analysis using Cox proportional-hazards models (models 1 and 2) after adjusting for the patient background, LAD, AF duration, and use rate of AADs after RFCA revealed that an IDF threshold of > 5 J after RFCA (HR, 3.99; 95% confidence interval (CI) 1.93-8.22; P = 0.0001) was significantly associated with the AF recurrence (Table III, model 1). Additionally, the type of 3D cardiac mapping system (CARTO or EnSite) was not associated with the recurrence. Model 2, which included the 3D system in model 1, also demonstrated that an IDF threshold of > 5 J after RFCA was the higher risk factor of AF recurrence than an IDF threshold of ≤ 5 J after RFCA (HR, 2.84; 95% CI 1.34-6.03; P = 0.007).

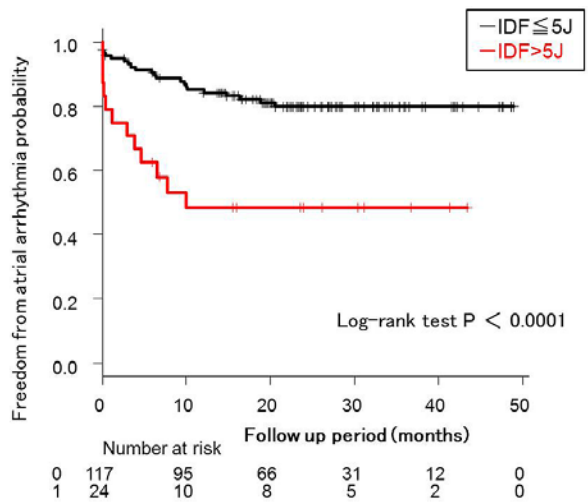

Figure 4. Kaplan–Meier curve for the non-recurrence of atrial arrhythmia. Kaplan–Meier survival analysis for long-term sinus rhythm maintenance after RFCA. Patients with an ID threshold of > 5 J after RFCA had a higher risk of recurrence than those with an ID threshold of ≤ 5 J after RFCA.

Discussion

Main findings: The main findings were as follows. First, the IDF threshold to restore SR in patients with persistent

Table III. Clinical Factors for Atrial Fibrillation Recurrence Determined by Univariate and Multivariate Analyses

	Univariate analysis	Multivariate analysis	
		Model 1	Model 2
	HR, 95% CI	HR, 95% CI	HR, 95% CI
Age (years)	0.96 (0.94–0.99) *	0.95 (0.92–0.98) *	
Male (%)	2.14 (0.65–6.99)	1.63 (0.46–5.80)	
BMI (kg/m^2)	1.07 (0.96–1.19)		
Hypertension (%)	1.08 (0.53–2.21)		
Dyslipidemia (%)	0.69 (0.34–1.40)		
Diabetes (%)	1.12 (0.49–2.57)		
Prior stroke (%)	0.65 (0.16–2.73)		
Chronic heart failure (%)	0.82 (0.36–1.90)		
CAD (%)	0.33 (0.05–2.44)		
CHA_2DS_2-VASc score	0.79 (0.61–1.02)		0.76 (0.57–1.01)
Creatinine (mg/dL)	2.06 (0.71–6.03)		
BNP (pg/dL)	1.00 (0.99–1.00)		
LAD (mm)	1.04 (0.98–1.09)	1.02 (0.96–1.08)	
LVEF (%)	1.01 (0.97–1.04)		
Duration of AF (months)	1.01 (1.00–1.02) *	1.01 (1.00–1.02) *	1.01 (1.00–1.01)
Non-PV foci (%)	1.89 (0.95–3.71)	1.86 (0.93–3.72)	1.95 (0.97–3.93)
Low-voltage zone (%)	3.43 (1.70–6.95) **	2.18 (1.00–4.79)	2.76 (1.28–5.98) *
AADs after RFCA (%)	4.99 (1.52–16.37) *	4.32 (1.29–14.65) *	3.80 (1.14–12.64) *
IDF output > 5 J after RFCA	3.61 (1.78–7.32) **	3.99 (1.93–8.22) **	2.84 (1.34–6.03) *
3D mapping system (CARTO)	0.92 (0.40–2.11)		0.98 (0.42–2.27)

BMI indicates body mass index; CAD, coronary artery disease; LAD, left atrial diameter; LVEF, left ventricular ejection fraction; AF, atrial fibrillation; PV, pulmonary vein; AAD, anti-arrhythmic drug; RFCA, radiofrequency catheter ablation; IDF, intracardiac defibrillation; and 3D, three-dimensional.*$P < 0.05$, **$P < 0.001$.

AF was significantly decreased after RFCA. Second, the IDF threshold in the no-recurrence group was significantly lower than that in the AF recurrence group. However, before RFCA, no difference in the IDF threshold between the recurrence and no-recurrence groups was observed. Third, the IDF outputs (threshold > 5 J) after RFCA were an independent predictor of AF recurrence.

IDF and AF: Some reports have evaluated the efficacy and safety of transvenous internal atrial cardioversion performed in patients with persistent AF.[14,15] IDF is an effective procedure for restoring SR in patients with AF,[6] and it has few complications. Boriani, *et al*. reported myocardial injury following repeated internal atrial defibrillations.[16] Although minor elevations in the troponin I level were detected, minor asymptomatic myocardial injury was suggested. Moreover, there was no relationship between an elevated troponin I level and the number of shocks or amount of energy delivered. Therefore, the BeeAT® catheter and dedicated defibrillator could be used multiple times for IDF; thus, they are useful for checking triggers. The maximum energy output of this system was 30 J. Although the mean number of IDFs was 9.1 ± 7.5 times (max 28 times) per RFCA procedure, no complications associated with IDF were observed in our study. All patients demonstrated restored SR by IDF with an output of less than 30 J.

The electrode position for the outcome of IDF was very important. Thus, low-energy biphasic shocks positioned between the RA and CS were effective for AF cardioversion. The distal eight poles of the BeeAT® catheter were positioned in the distal CS, whereas the middle eight poles were positioned along the lateral wall of the RA. We selected different catheter sizes (S, M, and L) to fit the LA and RA sizes of the patients. Therefore, an appropriate IDF could be performed in this study.

IDF and AF substrate: The factors for the persistence of AF are regarded as trigger factors and arrhythmogenic substrate factors, which act as AF perpetuators.[17,18] The triggers generally induce AF, and the substrate plays a critical role in AF persistence. Therefore, with a prolonged AF, LA remodeling proceeds, and the AF substrates increase. Thus, the success rate of AF cardioversion is inversely correlated with the LA size, because fibrosis accompanying atrial dilatation increases the AF substrate.[19] There are many reports on the predictors of AF recurrence after electrical cardioversion, such as the LA size, age, and BNP.[20-22] However, reports on cardioversion after AF ablation are scarce.

In the present study, RFCA significantly decreased the IDF threshold for restoring SR (Figure 2). The conditions for IDF were the same before and after RFCA; we induced AF artificially with high-rate burst pacing and ISP. After AF sustained for more than 2 minutes, IDF was performed to detect any AF triggers. Although the main strategy for RFCA in our institute is an AF trigger ablation, an extensive encircling PVI or posterior wall isolation may decrease the AF substrate. This suggests that RFCA could eliminate or decrease both AF triggers and the AF substrate as well as decrease the cardioversion threshold. Thus, the difference in the cardioversion threshold before and after RFCA may reflect the elimination of the AF substrate and AF triggers. In our study, there were

some cases with LA enlargement but without a low-voltage area. In those cases, the IDF threshold could reflect the AF substrate, which could not be evaluated *via* electrophysiology. Additionally, our study revealed that the group with lower IDF output (≤ 5 J) after RFCA was associated with lower AF recurrence. In fact, in patients with an output of > 5 J, the LAD was larger, and there was a greater presence of an LVZ in the LA. Thus, LA remodeling proceeded in those patients. An IDF threshold of > 5 J was a strong predictor of AF recurrence in the multivariate analysis after adjusting for the patient background, LAD, LVZ, AF duration, and AAD administration after RFCA. Furthermore, the LVZ disappeared in multivariate analysis model 1. Additionally, the ablation strategies (such as SVC isolation, posterior wall isolation, and focal ablation) did not have any significant value for detecting AF recurrence or the IDF threshold (Tables I, II). The IDF method was useful for determining whether RFCA could decrease the AF substrate during the RFCA procedure.

AF recurrence and other factors: AADs after RFCA were a strong confounding factor for AF recurrence. In our study, the LA size of the patients with an output of > 5 J was larger than that in the patients with an output of ≤ 5 J. However, the IDF threshold remained as an independent predictor of AF recurrence. These findings suggested that a greater AF substrate remained in the patients with an output > 5 J after the RFCA. However, no significant difference was observed in the presence of non-PV foci between the patients with an output of ≤ 5 J and those with an output > 5 J. Moreover, the LA size was not associated with AF recurrence, but the LA size was larger in the patients with an output of > 5 J. These findings suggested that it is important to not only eliminate AF triggers but also approach the LA substrate, because the patients with an output of > 5 J had a higher rate of AF recurrence and greater AF substrate. Recent studies have demonstrated that the effectiveness of substrate ablation is questionable.[23,24] In our study, AADs after RFCA could not prevent AF recurrence, especially in patients with an output of > 5 J. Therefore, further studies are required to study such patients.

Limitations: This study had some potential limitations. First, it was a retrospective and observational study conducted in a single institute. We did not have many patients with persistent AF, which may have caused a statistical bias. Second, we did not perform substrate ablations, such as a line ablation, CAFEA ablation, rotor ablation, and LVZ ablation. However, recent studies have revealed that only the effectiveness of PVI has been proven.[25-28] In this study, no significant difference was observed in the non-PV foci between the two groups. Third, we also considered the effects of the confounding predictors of AF recurrence. However, the IDF threshold was a useful predictor of AF recurrence because the IDF remained after the multivariate analysis following the adjustment for the patient factors.

Conclusion

Radiofrequency catheter ablation (RFCA) decreased the intracardiac defibrillation (IDF) threshold for restoring SR in patients with persistent atrial fibrillation (AF). IDF outputs of > 5 J after RFCA could be a predictor of the recurrence of persistent AF independent of an AF substrate. Moreover, it is useful for determining whether RFCA could decrease the AF substrate during the procedure.

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Disclosure

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