A negative relationship between first-pass pulmonary vein isolation and body mass index in ablation index–guided pulmonary vein isolation

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BACKGROUND We previously reported the relationship between first-pass pulmonary vein isolation (FPI) and pulmonary vein isolation (PVI) durability in ablation index–guided atrial fibrillation ablation. Obesity is a worsening factor for atrial tachyarrhythmia (AT) recurrence. However, the impact of obesity on FPI has been scarcely reported. General anesthesia (GA) facilitates completing PVI by preventing airway obstruction caused by sedative drug use. However, the impact of GA on the relationship also has not been elucidated.

OBJECTIVE The study sought to evaluate the impact of obesity and its relationship with GA on FPI.

METHODS We retrospectively studied 2187 consecutive patients undergoing ablation index–guided first atrial fibrillation ablation (conscious sedation in 1969 and GA in 218). We divided them into 4 groups according to body mass index (BMI): underweight (BMI $<$ 18.5 kg/m2) (n = 80), normal (18.5 kg/m2 $\leq$ BMI $<$ 25 kg/m2) (n = 1,160), overweight (25 kg/m2 $\leq$ BMI $<$ 30 kg/m2) (n = 763), and obesity (BMI $\geq$30 kg/m2) (n = 184).

RESULTS FPI rate decreased as BMI increased in both conscious sedation (68.1% in underweight, 61.5% in normal, 48.7% in overweight, and 39.0% in obesity; $P < .001$) and GA (87.5%, 67.1%, 61.3%, and 44.7%, respectively; $P = .01$). Multivariate analysis revealed overweight (odds ratio 0.65, 95% confidence interval [CI] 0.53–0.79, $P < .001$, vs normal) and obesity (OR 0.44, 95% CI 0.31–0.62 $P < .001$, vs normal) as independent predictors for FPI and obesity as an AT recurrence predictor (hazard ratio 1.35, 95% CI 1.01–1.81, $P = .04$).

CONCLUSION BMI increase was negatively related to the FPI rate. Notably, the FPI rate in obese patients, even under GA, was low, which might be related to their high AT recurrence.

KEYWORDS Catheter ablation; Atrial fibrillation; First-pass pulmonary vein isolation; obesity; General anesthesia; Conscious sedation

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Introduction

Several previous studies reported obesity as a worsening factor for atrial tachyarrhythmia (AT) recurrence after catheter ablation for atrial fibrillation (AF).[1–5] However, the mechanism of poor outcomes after AF ablation in obese patients has not been fully elucidated. In catheter ablation for AF, creating durable pulmonary vein isolation (PVI) is essential to minimizing the AT recurrence. Although catheter ablation technology, including contact force–sensing catheters and lesion size markers, has advanced, pulmonary vein (PV) reconnection has been the primary mechanism of atrial fibrillation (AF) recurrence.[6–9] Exploring the durability of PVI in obese patients is needed to evaluate the mechanism of poor outcomes after AF ablation procedures but is rarely reported. In catheter ablation for obese patients with conscious sedation (CS), creating durable lesions by applying radiofrequency (RF) on the left atrial (LA) wall is frequently challenging due to airway obstruction and unstable breathing caused by sedative drug use during the procedure. General anesthesia (GA) seems to facilitate completing PVI in obese patients by preventing these problems during the procedure. However, the impact of GA on PVI durability in obese patients also has not been elucidated.

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KEY FINDINGS

- First-pass pulmonary vein isolation rate has a negative linear relationship with body mass index (BMI) increase in ablation index–guided radiofrequency catheter ablation for atrial fibrillation regardless of anesthesia type during the procedure.
- Overweight (BMI 25–30 kg/m^2) and obesity (BMI ≥30 kg/m^2) are negative independent predictors, and general anesthesia is a positive independent predictor of first-pass pulmonary vein isolation.
- Obesity (BMI ≥30 kg/m^2) is a negative independent predictor of atrial tachyarrhythmia recurrence after the procedure.

First-pass pulmonary vein isolation (FPI) was reported as a predictor of AT recurrence after the AF ablation procedure.[10,11] We previously reported that FPI is related to the durability of PVI in ablation index (AI)–guided RF catheter ablation by studying over 300 patients undergoing the second ablation procedure among over 2000 patients undergoing the first ablation procedure for AF.[12] Our previous study indicated that FPI was a marker for evaluating the durability of PVI. In the present study, we divided the patients into 4 groups from being lean to obese according to body mass index (BMI) and evaluated the relationship between the BMI level and FPI rate to estimate the impact of BMI on PVI durability and the effect of BMI on the outcome of AF ablation procedure. Furthermore, we assessed the impact of GA on the relationship between FPI and BMI to estimate the effect of GA on the PVI durability in obese patients.

Methods

The corresponding author (H.O.) can provide the data supporting this study's findings upon reasonable request. However, due to privacy or ethical restrictions, the data are not publicly available.

Study population

The study presented in this paper adhered to the Helsinki Declaration. The study was approved by the Institutional Review Board (approval number 1234). We respectively reviewed 2187 patients undergoing the first AI-guided RF catheter ablation for AF from January 2018 to October 2023 in Saiseikai Kumamoto Hospital. All patients provided written informed consent on the ablation procedure before performing the procedure. These patients were divided into 4 groups by their BMI: underweight (BMI <18.5 kg/m^2), normal (18.5 kg/m^2< BMI < 25 kg/m^2), overweight (25 kg/m^2≤ BMI < 30 kg/m^2), and obesity (BMI ≥30 kg/m^2).

Cardiac catheterization and ablation procedures

We previously described the procedural detail of our AI-guided AF ablation with the CARTO3 mapping system (Biosense Webster).[12,13] In the 1969 patients, we performed the ablation procedure under CS with intravenous dexmedetomidine, thiamylal, and fentanyl. Respiratory management devices, including nasal airway devices and adaptive servo-ventilation, were used at the operator's discretion. The remaining 218 patients underwent the ablation procedure under GA at the operator's discretion or the patient's preference. GA was performed by a trained cardiologist (H.O.) with total intravenous anesthesia using intravenous propofol and remifentanil and controlled ventilation via i-gel (Intersurgical), and the anesthesiologists were on standby. We did not use neuromuscular blocking drugs in GA. An 8.5-F deflectable sheath (Agilis [St. Jude Medical], VIZIGO [Biosense Webster]; Guidee Leftee [Japan Lifeline]) was used at the operator's discretion. To confirm the position of the esophagus, we asked the patients to swallow the contrast medium just before catheterization or performed intracardiac echocardiography from the left atrium (LA), as reported previously.[14] The AI target values we adopted were as follows: ≥400 at the anterior LA wall, ≥360 at the posterior LA wall, and ≥260 at the LA wall on the esophagus. We set RF power as follows: 30 to 40 W in the anterior LA wall, 20 to 25 W in the posterior LA wall, and 20 W LA wall on the esophagus until October 2018 and 50 W in the anterior LA wall, 40 W posterior LA wall, and 25 W on the esophagus since then (high-power RF application setting). In patients undergoing RF application with a high-power setting, we applied 5-second, 50 W RF applications with a contact force of <10 g on the esophagus at the operators' discretion. Almost all patients (n = 2122 of 2187 [97.0%]) underwent the RF application with an 8-F irrigation catheter (ThermoCool SmartTouch SurroundFlow; Biosense Webster). Since June 2021, we have used a recently available 8-F irrigation catheter (QDOT MICRO catheter; Biosense Webster) at the operator's discretion (n = 65 of 2187 [3.0%]) and applied RF with temperature control (Q MODE; irrigation 4–15 mL/min, target temperature 45–46 °C, low flow temperature 40 °C, cutoff temperature 50 °C) with the same power and AI target value. In 11 patients, very high-power, short-duration RF application (Q MODE+; 4 seconds, 90 W RF application, irrigation 8 mL/min, target temperature 52 °C, cutoff temperature 65 °C) was applied at the operator's discretion. After circular RF application around PV, we constructed the LA and PV voltage map in the CARTO3 system and confirmed the disappearance of the PV potential. FPI was defined as a bidirectional block after initial circumferential linear RF application around the PV. When the residual conduction gap was present, or reconnection between the LA and PV occurred, we eliminated the conduction gap during the procedure. The LA low-voltage zone was defined as the area with bipolar voltage <0.5 mV with an area >5 cm^2, and the non-PV AF triggers as ectopic beat initiating AF and frequent premature contractions from non-PV areas. After completing PVI, we performed a bolus infusion of 10 to 20 μg of isoproterenol in all patients and adenosine bolus infusion and cardioversion for the AF induced by burst atrial pacing at the operator's discretion to induce non-PV AF triggers.

We added RF applications for all origins of non-PV triggers. Superior vena cava isolation was performed for all patients with superior vena cava sleeve length >20 mm and cavotricuspid isthmus ablation for all patients with cavotricuspid isthmus–dependent atrial flutter. We performed another extra-PV RF application, including ablation for low-voltage zone ablation, ablation of LA roof linear ablation, posterior LA wall box isolation, anterior LA wall linear ablation, mitral isthmus linear ablation, and ablation for complex fractionated atrial electrogram, at the operator's discretion.

Follow-up

All patients were followed up at the outpatient clinic of Saiseikai Kumamoto Hospital. At 1, 3, 6, 9, and 12 months after ablation, we checked their symptoms and performed 12-lead electrocardiogram (ECG) and 24-hour Holter ECG monitoring in all patients and, at the physician's discretion, a mobile ECG recorder. We defined AT recurrence as any ATs lasting >30 seconds after a 3-month blanking period.

Statistical analysis

We expressed continuous variables with a normal distribution as mean ± SD and compared them using the Student's *t* test or 1-way analysis of variance. We expressed continuous variables with a non-normal distribution as the median and interquartile range and compared them using the Wilcoxon or Kruskal-Wallis test. We expressed categorical variables as numbers and percentages and compared them using Fisher's exact or chi-square test.

We used the Cochran-Armitage trend test to analyze the relationship between the FPI rate and BMI group. Additionally, we performed a propensity score (PS)–matched pairs analysis to adjust the patient and procedure characteristics of those undergoing the procedure with CS and GA to examine the relationship between the FPI rate and BMI group. In calculating the PS, we performed multivariate logistic analysis for undergoing GA, including age, sex, AF type, BMI, prior stroke or transient ischemic attack, comorbidities (hypertension, diabetes, heart failure, sick sinus syndrome, hypertrophic cardiomyopathy, dilated cardiomyopathy, ischemic cardiomyopathy, and dialysis), laboratory data (creatinine, brain natriuretic peptide [BNP]), and echocardiographic data (left ventricular ejection fraction and left atrial diameter [LAD]) as variables. We performed PS matching without a replacement in a 4:1 nearest-neighbor fashion with a caliper width of 20% of the estimated PS standard deviation. The performance of the matching was assessed by calculating standardized differences. To determine the predictor of the FPI in both the left and right PVs and each PV, we performed univariate and multivariate logistic regression analysis. All parameters with a P value <.1 in univariate analysis were included in multivariate analysis. Additionally, we analyzed 309 patients whose data on the location of residual conduction gap after linear RF application around PV and PV carina was available to elucidate the impact of BMI on the distribution of residual conduction gap. All 309 patients had AT recurrence after the procedure and performed a redo ablation procedure. We determined the location of the residual conduction gap as the site where an additional RF application resulted in a conduction block between the LA to PV or a change in the sequence of PV potential.

We analyzed the patients with ≥90 days of follow-up in the AT recurrence–free survival analysis. We treated the patients who died within 90 days after the procedure without AT recurrence as censored. The univariate and multivariate Cox proportional hazards model analysis was used to evaluate the impact of BMI and anesthesia on the outcome after AF ablation. In this analysis, we included BMI, anesthesia during the procedure, AF type, LAD, and FPI on at least 1 side of PV as parameters because AF type and LAD strongly impact the AT recurrence after AF ablation and FPI on at least 1 side of PV was reported to be a predictor of the AT recurrence.[10,11] We calculated the hazard ratio and 95% confidence interval (CI). We compared the AT recurrence among the 4 BMI groups by depicting the Kaplan-Meier curve with a log-rank test and the adjusted Cox mortality curve.

All tests were 2-tailed, and $P < .05$ was significant. We performed all statistical analyses with EZR (version 1.61; Saitama Medical Center, Jichi Medical University), a graphical user interface for R (version 4.2.2; R Foundation for Statistical Computing).[15] EZR is a modified version of R commander (version 2.8-0), which was designed to add statistical functions frequently used in biostatistics.

Results

Patient population

Table 1 shows the patient characteristics. Of the 2187 patients, 80 were underweight, 1160 were normal, 763 were overweight , and 184 were obesity. As the BMI increased, the age was younger, the percentages of female sex and paroxysmal AF were lower, those of diabetes and hypertension were higher and the LA dimension was larger. Table 2 shows the procedure characteristics. Among the 4 groups, several procedure characteristics were significantly different, including anesthesia during the procedure, ablation catheter, RF application method on the esophagus, the use of a steerable sheath, the existence of low-voltage zone, and the percentage of RF application on non-PV foci. As the BMI increased, the rate of performing the procedure under GA and steerable sheath use was higher. As an institutional limitation, patients undergoing the procedure under GA from November 2022 to September 2023 mainly performed the procedure with the QDOT MICRO catheter. The patients undergoing the procedure with GA underwent the procedure more frequently with QDOT MICRO catheter than those with CS (52 of 218 patients [23.9%] in GA vs 13 of 1969 patients [0.7%] in CS, $P < .001$).

BMI and FPI

Figure 1 shows the FPI rate of each BMI group in the patients undergoing the procedure in CS and GA. In CS, the FPI rate decreased in both PVs ($P < .001$) (Figure 1A), the left PV (P

Table 1 Patient characteristics

	Underweight (BMI <18.5 kg/m^2) (n = 80)	Normal (18.5 kg/m^2 ≤ BMI < 25 kg/m^2) (n = 1160)	Overweight (25 kg/m^2 ≤ BMI < 30 kg/m^2) (n = 763)	Obesity (BMI ≥30 kg/m^2) (n = 184)	*P* value
Female	50 (62.5)	379 (32.7)	188 (24.6)	51 (27.7)	<.001
Body mass index, kg/m^2	17.8 (16.9–18.2)	22.8 (21.3–23.9)	26.5 (25.7–27.9)	32.0 (30.9–34.5)	<.001
AF type					
Paroxysmal AF	48 (60.0)	680 (58.6)	381 (49.9)	75 (40.8)	<.001
Persistent AF	23 (28.7)	323 (27.8)	256 (33.6)	78 (42.4)	
Long-standing persistent AF	9 (11.2)	157 (13.5)	126 (16.5)	31 (16.8)	
Prior stroke or transient ischemic attack	8 (10.0)	114 (9.8)	55 (7.2)	11 (6.0)	.12
Congestive heart failure	16 (20.0)	192 (16.6)	125 (16.4)	35 (19.0)	.71
Diabetes mellitus	3 (3.8)	156 (13.4)	143 (18.7)	54 (29.3)	<.001
Hypertension	28 (35.0)	572 (49.3)	457 (59.9)	131 (71.2)	<.001
Dilated cardiomyopathy	1 (1.2)	13 (1.1)	6 (0.8)	3 (1.6)	.76
Hypertrophic cardiomyopathy	3 (3.8)	28 (2.4)	31 (4.1)	8 (4.3)	.17
Ischemic heart disease	2 (2.5)	59 (5.1)	45 (5.9)	11 (6.0)	.57
Sick sinus syndrome	5 (6.2)	35 (3.0)	14 (1.8)	5 (2.7)	.09
Dialysis	3 (3.8)	24 (2.1)	10 (1.3)	2 (1.1)	.29
$CHADS_2$ score	1 (0–2)	1 (0–2)	1 (1–2)	1 (1–2)	.009
CHA_2DS_2-VASc score	3 (2–3)	2 (1–3)	2 (1–3)	2 (1–3)	.06
Creatinine, mg/dL	0.98 ± 0.94	1.04 ± 0.97	1.06 ± 0.97	1.05 ± 1.01	.92
BNP, pg/mL	137.5 ± 181.5	109.3 ± 189.5	106.1 ± 170.5	84.5 ± 88.9	.13
Left ventricular ejection fraction, %	61.4 ± 10.2	60.5 ± 9.7	60.1 ± 9.8	60.4 ± 8.3	.63
LA diameter, mm	34.5 ± 6.6	40.0 ± 6.3	43.6 ± 6.2	45.7 ± 7.1	<.001

Values are n (%), median (interquartile range), or mean ± SD.

AF = atrial fibrillation; BNP = brain natriuretic peptide; CHA_2DS_2 = congestive heart failure, hypertension, age ≥75 years, diabetes mellitus, prior stroke or transient ischemic attack or thromboembolism; CHA_2DS_2-VASc = congestive heart failure, hypertension, age ≥75 years, diabetes mellitus, prior stroke or transient ischemic attack or thromboembolism, vascular disease, age 65–74 years, sex category; LA = left atrial.

< .001) (Figure 1B), and the right PV ($P < .001$) (Figure 1C) as the BMI increased. In GA, the FPI rate decreased in both PVs ($P = .01$) (Figure 1D) and the right PV ($P = .004$) (Figure 1F) as the BMI increased. The FPI rate of the left PV in GA numerically decreased as the BMI increased, but it did not reach statistical significance ($P = .08$) (Figure 1E).

The patient characteristics significantly differed between the patients undergoing the procedure under CS and GA

TABLE 2 Procedure characteristics

	Underweight (BMI <18.5 kg/m^2) (n = 80)	Normal (18.5 kg/m^2 ≤ BMI < 25 kg/m^2) (n = 1160)	Overweight (25 kg/m^2 ≤ BMI < 30 kg/m^2) (n = 763)	Obesity (BMI ≥30 kg/m^2) (n = 184)	*P* value
GA	8 (10.0)	79 (6.8)	93 (12.2)	38 (20.7)	<.001
Ablation catheter					<.001
ThermoCool SmartTouch SF	78 (97.5)	1142 (98.4)	735 (96.3)	167 (90.8)	
QDOT MICRO catheter	2 (2.5)	18 (1.6)	28 (3.7)	17 (9.2)	
High-power RF application	70 (87.5)	985 (84.9)	661 (86.6)	162 (88.0)	.55
RF application on esophagus					<.001
25 W with AI target value 260	57 (71.2)	934 (80.5)	591 (77.5)	140 (76.1)	
5 s, 50 W	23 (28.7)	222 (19.1)	168 (22.0)	37 (20.1)	
90 W with QDOT MICRO catheter	0 (0.0)	4 (0.3)	4 (0.5)	7 (3.8)	
Steerable sheath	38 (47.5)	539 (46.5)	441 (57.8)	123 (66.8)	<.001
Low-voltage zone	9 (11.2)	132 (11.4)	53 (6.9)	12 (6.5)	.005
Low-voltage zone ablation	3 (3.8)	57 (4.9)	25 (3.3)	9 (4.9)	.36
Cavotricuspid isthmus ablation	13 (16.2)	202 (17.4)	132 (17.3)	19 (10.3)	.112
LA roof linear ablation	15 (18.8)	266 (22.9)	179 (23.5)	45 (24.5)	.77
Posterior LA wall box isolation	9 (11.2)	210 (18.1)	156 (20.4)	40 (21.7)	.13
LA anterior linear ablation	2 (2.5)	27 (2.3)	9 (1.2)	1 (0.5)	.15
Mitral isthmus linear ablation	0 (0.0)	6 (0.5)	5 (0.7)	0 (0.0)	.64
SVC isolation	38 (47.5)	677 (58.4)	460 (60.3)	105 (57.1)	.16
Non-PV foci ablation	14 (17.5)	139 (12.0)	63 (8.3)	12 (6.5)	.003
Ablation for CFAE	1 (1.2)	58 (5.0)	54 (7.1)	9 (4.9)	.07

Values are n (%).

AI = ablation index; BMI = body mass index; CFAE = complex fractionated atrial electrogram; GA = general anesthesia; LA = left atrial; PV = pulmonary vein; RF = radiofrequency; SVC = superior vena cava.

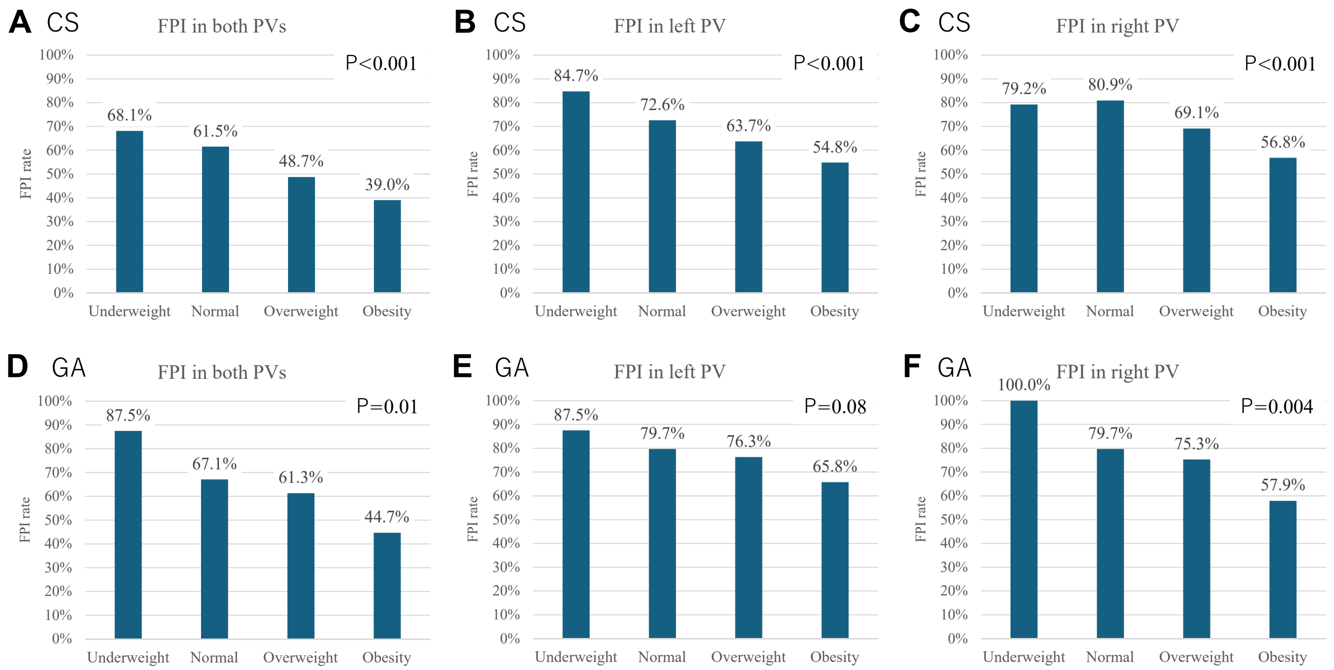

Figure 1 The relationship between the body mass index (BMI) group and first-pass pulmonary vein isolation (FPI) rate. The relationship in patients undergoing the procedure with conscious sedation (CS) (A–C) and those patients with general anesthesia (GA) (D–F). The FPI in both pulmonary veins (PVs) (A, D), the left PV (B, E), and the right PV (C, F).

(Supplemental Table 1 in supplementary material). The patients undergoing the procedure under GA had significantly higher BMI (24.6 ± 3.7 kg/m^2 in CS vs 26.2 ± 4.4 kg/m^2 in GA, $P < .001$) and had a lower percentage of paroxysmal AF than those under CS (1085 [55.1%] vs 99 [45.4%], $P = .02$). We calculated PS and extracted the PS-matched pairs (812 patients in CS and 203 in GA). The patient characteristics were balanced between the 2 groups (Supplemental Table 1). The negative relationship between FPI rate and BMI was similarly detected in the PS-matched pairs except for left PV in GA (both sides of PV in CS [Figure 2A], $P < .001$; left PV in CS [Figure 2B], $P < .001$; Figure 2B, right

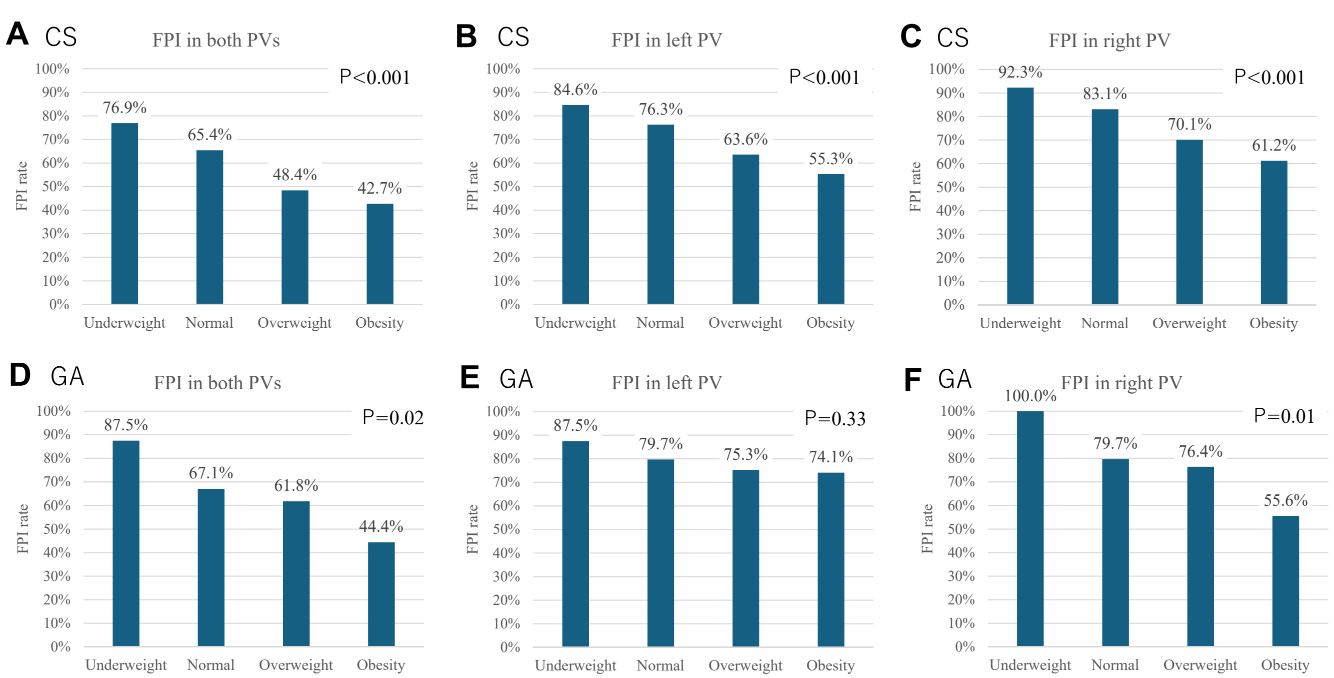

Figure 2 The relationship between the body mass index (BMI) group and first-pass pulmonary vein isolation (FPI) rate in propensity score–matched pair analysis. The relationship in patients undergoing the procedure with conscious sedation (CS) (A–C) and those with general anesthesia (GA) (D–F). The FPI in both pulmonary veins (PVs) (A, D), the left PV (B, E), and the right PV (C, F).

Table 3 Predictors of FPI in both of left and right PVs

	Univariate analysis		Multivariate analysis	
	OR (95% CI)	*P* value	OR (95% CI)	*P* value
BMI				
Underweight (BMI <18.5 kg/m^2)	1.44 (0.88–2.35)	.15	1.26 (0.76–2.10)	.37
Normal (18.5 kg/m^2 ≤ BMI < 25 kg/m^2)	Reference		Reference	
Overweight (25 kg/m^2 ≤ BMI < 30 kg/m	0.62 (0.52–0.75)	<.001	0.65 (0.53–0.79)	<.001
Obesity (BMI ≥30 kg/m^2)	0.41 (0.30–0.57)	<.001	0.44 (0.31–0.62)	<.001
Anesthesia				
CS	Reference		Reference	
GA	1.27 (0.95–1.69)	.10	1.61 (1.18–2.19)	.003
AF type				
Paroxysmal AF	Reference		Reference	
Persistent AF	1.14 (0.94–1.38)	.18	1.27 (1.02–1.58)	.03
Long-standing persistent AF	0.77 (0.60–0.99)	.04	0.92 (0.69–1.22)	.56
Age	1.02 (1.01–1.03)	<.001	1.01 (1.00–1.02)	.04
Female	1.45 (1.21–1.75)	<.001	1.23 (1.00–1.50)	.047
Prior stroke or transient ischemic attack	1.05 (0.78–1.42)	.74		
Congestive heart failure	1.17 (0.93–1.47)	.17		
Diabetes	0.82 (0.66–1.03)	.09	0.91 (0.71–1.15)	.41
Hypertension	0.94 (0.79–1.11)	.45		
Dilated cardiomyopathy	1.01 (0.44–2.31)	.98		
Hypertrophic cardiomyopathy	0.65 (0.40–1.04)	.07	0.66 (0.40–1.08)	.10
Ischemic heart disease	1.04 (0.72–1.52)	.83		
Sick sinus syndrome	1.06 (0.63–1.79)	.83		
Dialysis	0.53 (0.28–1.02)	.06	0.37 (0.18–0.75)	.01
LAD	0.98 (0.97–0.99)	.003	1.00 (0.98–1.01)	.72
Creatinine	0.93 (0.86–1.02)	.12		
BNP	1.0006 (1.0001–1.0012)	.03	1.0008 (1.0000–1.0015)	.04
Low-voltage zone	1.50 (1.11–2.02)	.01	1.23 (0.89–1.70)	.21
Ablation catheter				
ThermoCool SmartTouch SF	Reference			
QDOT MICRO catheter	0.80 (0.49–1.30)	.36		
RF application power				
Conventional power	Reference			
High power	1.06 (0.83–1.35)	.63		
RF application on esophagus				
25 W with AI target value 260	Reference			
5 s, 50 W	1.12 (0.91–1.39)	.28		
90 W with QDOT MICRO catheter	0.53 (0.19–1.49)	.23		
Steerable sheath	0.82 (0.69–0.97)	.02	0.77 (0.63–0.94)	.01

Low-voltage zone, LA bipolar voltage <0.5.

AF = atrial fibrillation; AI = ablation index; BMI = body mass index; BNP = brain natriuretic peptide; CI = confidence interval; CS = conscious sedation; FPI = first-pass pulmonary vein isolation; GA = general anesthesia; LA = left atrial; LAD = left atrial diameter; OR = odds ratio; RF = radiofrequency.

PV in CS [Figure 2C], P < .001; both sides of PV in GA [Figure 2D], P = .02; left PV in GA [Figure 2E], P = .33; right PV in GA [Figure 2F], P = .01).

Supplemental Table 2 compares FPI rates between the patient groups undergoing CS and GA. For all patients, the rates of FPI in both PVs and right PV were similar between CS and GA, but those in the left PV was significantly higher in GA than in CS. The comparison of the FPI rate in each BMI group showed that in the overweight group the FPI rate was significantly higher in GA than CS in both PVs and the left PV but was similar in the right PV. The analysis in PS-matched pairs showed similar results.

Supplemental Table 3 shows the distribution of the residual conduction gap after linear RF application around PV and PV carina. The distribution was similar among the BMI groups except for the right PV carina. The percentage of the residual conduction gap in the right PV carina was significantly higher in patients with obesity.

Predictors of FPI in both the left and right PVs

Table 3 shows the univariate and multivariate analyses for predicting FPI in both PVs. Univariate analysis indicates that overweight (odds ratio [OR] 0.62, 95% CI 0.52–0.75, P < .001) and obesity (OR 0.41, 95% CI 0.30–0.5, P < .001) were negative predictors of FPI in both PVs. In multivariate analysis, in addition to overweight (OR 0.65, 95% CI 0.53–0.79, P < .001) and obesity (OR 0.44, 95% CI 0.31–0.62, P < .001), GA was the independent positive predictor of FPI (OR 1.61, 95% CI 1.18–2.19, P = .003). Furthermore, persistent AF (OR 1.27, 95% CI 1.02–1.58, P = .03), age (OR 1.01, 95% CI 1.00–1.02, P = .04), female sex (OR

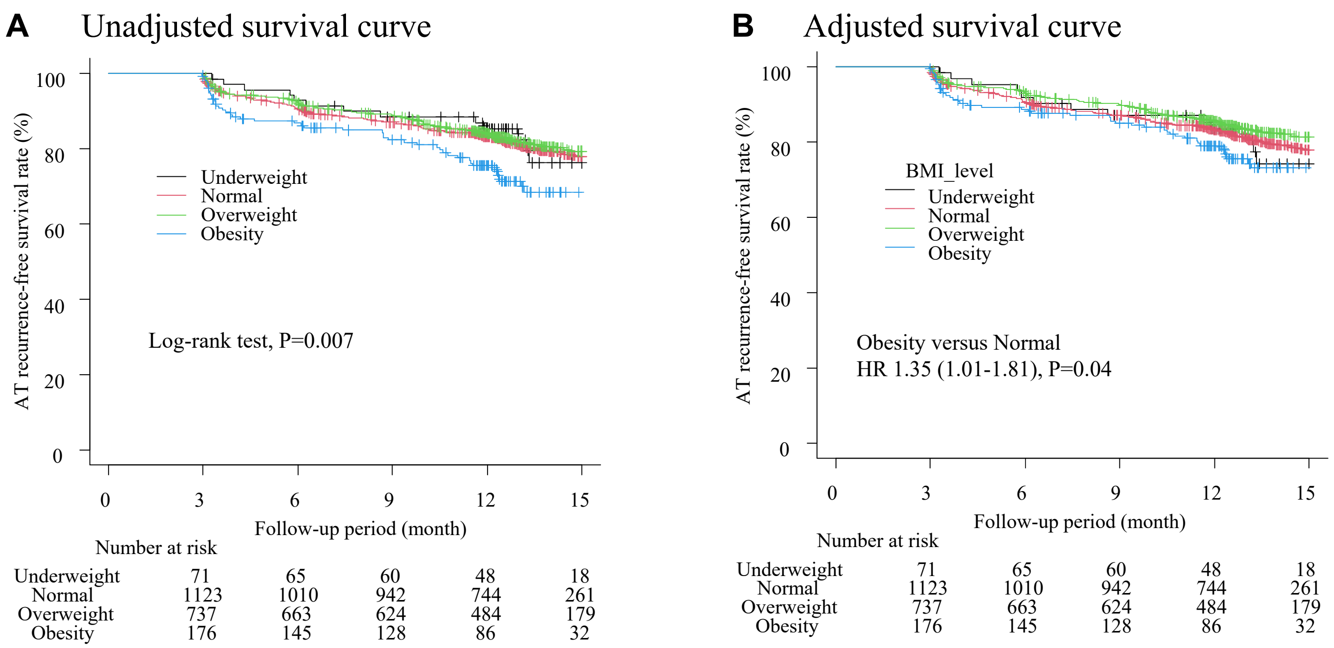

Figure 3 The comparison of unadjusted (A) and adjusted (B) atrial tachyarrhythmia (AT) recurrence–free survival curves among the body mass index (BMI) group.

1.23 [1.00–1.50, P = .047), and BNP (OR 1.0008, 95% CI 1.0000–1.0015, P = .04) were positive predictors of FPI, and dialysis (OR 0.37, 95% CI 0.18–0.75, P = .006) and steerable sheath use (OR 0.77, 95% CI 0.63–0.94, P = .01) were negative predictors. Supplemental Table 4 shows the univariate and multivariate analyses for predictors of FPI in the left and right PVs. Multivariate analysis showed that overweight and obesity were independent worsening predictors of FPI in the left and right PVs. GA was a positive predictor of FPI in the left PV but not in the right PV. Additionally, persistent AF, dialysis, and steerable sheath use were predictors of FPI in the left PV, and age was a predictor of FPI in the right PV.

Factors affecting AT recurrence

We performed a Kaplan-Meier survival curve analysis in 2119 patients with a follow-up period ≥90 days (Figure 3A). AT recurrence–free survival rate was significantly lower in obesity (1-year AT recurrence–free survival rate: 85.4% in underweight, 83.3% in normal, 84.2% in overweight, and 75.5% in obesity; log-rank test, P = .007). The adjusted AT recurrence–free survival curve is shown in Figure 3B. A total of 1870 (88.2%) of 2119 patients achieved FPI on at least 1 side of PV. We analyzed the independent predictors for AT recurrence by using a multivariate Cox proportional hazards model (Table 4). Model 1, including AF type and FPI on at least 1 side of PV as parameters, showed that persistent AF, long-standing persistent AF, and FPI on at least 1 side of PV were predictors of AT recurrence. Model 2, including BMI, anesthesia, AF type, LAD, and FPI on at least 1 side of PV, revealed that obesity, long-standing persistent AF, and LAD were independent predictors.

Discussion

Main findings

Our study's main findings were as follows: (1) BMI was negatively related to the rate of FPI in both PVs regardless of the procedure undergone in CS or GA; (2) GA, persistent AF, female sex, age, and BNP were positive predictors and overweight, obesity, dialysis, and steerable sheath use were negative predictors of FPI in both PVs; and (3) obesity was an independent negative predictor of AT recurrence after AF ablation.

FPI and obesity

An analysis of 2671 patients from the Real-world Experience of Catheter Ablation for the Treatment of Symptomatic Paroxysmal and Persistent Atrial Fibrillation (REAL-AF) registry undergoing radiofrequency catheter ablation for AF showed that BMI >30 kg/m^2 was an independent negative predictor of FPI.[16] In this registry, all patients underwent RF catheter ablation procedure with ThermoCool SmartTouch Catheter or ThermoCool SmartTouch SF Catheter (Biosense Webster). However, procedure characteristics were heterogeneous because all data were collected from multiple high-volume centers, and all procedures were conducted according to clinician preference. Almost 90% of patients underwent the procedure using AI-guided RF applications. However, no AI target value was set for this analysis. We analyzed 2187 patients undergoing the RF application with the same AI target value. We showed a significant negative relationship between the FPI rate in both PVs and BMI regardless of the sedation/anesthesia used during the procedure.

TABLE 4 Predictor of AT recurrence

	Univariate analysis		Multivariate analysis: Model 1		Multivariate analysis: Model 2	
	HR (95% CI)	*P* value	HR (95% CI)	*P* value	HR (95% CI)	*P* value
BMI (kg/m^2)						
Underweight (BMI $<$18.5 kg/m^2)	0.94 (0.60–1.47)	.78			1.00 (0.62–1.62)	.996
Normal (18.5 kg/m^2 $\leq$ BMI $<$ 25 kg/m^2)	Reference				Reference	
Overweight (25 kg/m^2 $\leq$ BMI $<$ 30 kg/m^2)	1.02 (0.85–1.22)	.87			0.90 (0.74–1.08)	.26
Obesity (BMI $\geq$30 kg/m^2)	1.54 (1.17–2.02)	.002			1.35 (1.01–1.81)	.04
Anesthesia						
CS	Reference				Reference	
GA	0.83 (0.57–1.19)	.30			0.78 (0.54–1.12)	.18
AF type						
Paroxysmal AF	Reference		Reference		Reference	
Persistent AF	1.22 (1.00–1.48)	.047	1.25 (1.04–1.52)	.02	1.11 (0.90–1.36)	.33
Long-standing persistent AF	2.58 (2.09–3.17)	$<$.001	2.59 (2.11–3.18)	$<$.001	2.31 (1.84–2.90)	$<$.001
LAD	1.04 (1.02–1.05)	$<$.001			1.02 (1.00–1.03)	.01
FPI on at least 1 side of PV	0.78 (0.62–0.998)	.048	0.77 (0.61–0.98)	.03	0.82 (0.64–1.05)	.12

AF = atrial fibrillation; BMI = body mass index; CI = confidence interval; CS = conscious sedation; FPI = first-pass pulmonary vein isolation; GA = general anesthesia; HR = hazard ratio; LAD = left atrial diameter.

The rate of FPI in our study in the group with BMI $\geq$30 kg/m^2 (39.0% in CS and 44.7% in GA) was lower than that of the REAL-AF registry (about 60%–70%). Our AI target values were $\geq$400 at the anterior LA wall and $\geq$360 at the posterior LA wall. These values were lower than those adopted in the CLOSE protocol, which adopted 550 and 400, respectively.[17] The rate of FPI was excellent in the CLOSE protocol (256 of 260 PVs [98%]). Our lower AI target value might negatively impact the FPI rate in obese patients. The mean BMI in our study (24.7 $\pm$ 3.8 kg/m^2) was lower than that in the REAL-AF registry (30.8 $\pm$ 6.6 kg/m^2) and the CLOSE protocol (26.5 $\pm$ 4.1 kg/m^2). These results indicated that a lower AI target value might be appropriate for Asian patients with smaller BMI. In the Japan Multicenter Registry of AF Ablation with Ablation Index, we suggested that the target AI value 550 at the anterior LA wall might not be needed for Asian patients.[9] We speculated that adjusting the AI target value according to the patient's BMI might achieve a higher FPI rate without excessive RF application.

This negative relationship was similarly observed in patients undergoing CS and GA in the right PV and those undergoing CS in the left PV. This negative relationship remained in the PS-matched pair analysis. The negative relationship between FPI and BMI group did not reach statistical significance in the left PV (P = .08). In the PS-matched pair analysis, in the GA group, the percentage of patients in obesity achieving FPI in the left PV was similar to that in overweight (75.3% in overweight and 74.1% in obesity), and a negative relationship between FPI and BMI was not observed in the left PV in GA (P = .33). Multivariate analysis revealed that overweight and obesity were negative predictors of FPI in both the left and right PVs, and GA was the positive predictor of FPI in the left PV. However, GA was not related to FPI in the right PV. We speculated that unstable respiration was the mechanism of low FPI rate in the left PV in obese patients in CS, and GA improved it. We applied RF energy on the ridge between the left PV and left appendage. Stable positioning during RF application is frequently difficult in patients with unstable respiration. We speculated that GA mainly improved the stability of the catheter in this area. On the contrary, GA did not impact the negative relationship between BMI and FPI rate in the right PV. The mechanism of this negative relationship was unclear. A study showed fat acting as thermal insulation during the RF application.[18] Our data on the distribution of the residual conduction gap showed that the distribution of the residual conduction gap was similar among the BMI group except for the right PV carina, in which the percentage of the residual conduction gap was significantly higher in patients with obesity. We speculated that fat precluded transmural lesion creation and resulted in epicardial residual conduction to the right PV carina in obese patients. Further studies were needed to evaluate our speculation.

As mentioned previously, obesity has been reported as a worsening predictor of AT recurrence after the AF ablation procedure.[1–5] The present study also showed a lower AT recurrence–free survival rate in obese patients. We previously reported that FPI was related to PVI durability in the AI-guided PVI.[12] Several studies showed that FPI was related to AT recurrence after PVI.[10,11] In our study, multivariate analysis (model 1) showed that FPI was the positive predictor of AT recurrence. We speculated that the AT recurrence rate was higher in obese patients due to lower PVI durability related to lower FPI rates in obese patients. However, further studies are needed to verify the relationship between obesity and PVI durability.

Predictors of FPI

The present study showed that persistent AF, female sex, age, and BNP were positive predictors and dialysis and steerable sheath use were negative predictors of FPI in both PVs. Furthermore, we evaluated the predictor of FPI in the left and right PVs. Female sex was related to FPI in both PVs, and age was associated with FPI in both PVs and in right PV. We speculated that the small BMI pertaining to sex and aging might be related to FPI. Persistent AF and dialysis were positive predictors, and steerable sheath use was a negative predictor of FPI in the left PV, but they were not in the right PV. BNP positively predicted FPI in both PVs but not in the left and right PVs. The mechanism of these parameters impacting the FPI was unclear. Steerable sheath use was generally thought to impact FPI positively. The steerable sheath was reported to reduce the procedure and fluoroscopy time, but its impact on the procedure outcome was conflicting.[19–22] However, the effect of the steerable sheath on FPI was scarcely reported. In our study, the steerable sheath was used at the operator's discretion. We speculated that the LA morphology, which the operator thought to be difficult to manipulate the catheter without the steerable sheath, might impact on achieving FPI. A randomized study is needed to estimate the impact of the steerable sheath on FPI.

Limitations

The present study had some limitations. First, it is a single-center retrospective study. Second, the number of patients who underwent the procedure under GA was small (n = 218). The patient characteristics were significantly different between CS and GA. We performed PS-matched pair analysis to adjust the patient characteristics. However, the unmeasured parameters might be the bias elucidating the impact of GA on the FPI. To elucidate the impact of GA on FPI, a randomized study comparing the FPI rate between CS and GA is needed. Third, the percentage of QDOT MICRO catheter use in patients undergoing the procedure under GA was significantly higher than those under CS. However, the efficiency in completing PVI was reported to be similar between the QDOT MICRO catheter and ThermoCool SmartTouch SurroundFlow. We think this difference might have a limited impact on our study results. Fourth, the numbers of underweight (n = 80) and obesity (n = 184) were small. A study with a significantly large number of patients is needed to confirm the impact of underweight and obesity on FPI. Fifth, our follow-up of patients after the procedure was not strict. Asymptomatic recurrence might be missed because we assessed AT recurrence based on symptoms and periodically repeated electrograms and Holter electrograms, and we did not use an implantable loop recorder. The AT recurrence rate might be underestimated. Sixth, the number of patients we used to evaluate the distribution of the residual conduction gap was small, and all patients had AT recurrence after the procedure and underwent a redo procedure. Seventh, although model 1, including AF type and FPI on at least 1 side of PV as parameters of Cox proportional hazards model analysis, showed FPI as the positive predictor of AT recurrence, in model 2, including BMI, anesthesia, AF type, LAD, and FPI on at least 1 side of PV as the parameter, FPI did not reach statistical significance as a predictor for AT recurrence. Further studies with a larger number of obese patients are needed to elucidate the impact of FPI on AT recurrence in obese patients.

Conclusion

The increase in BMI is negatively related to the FPI rate and GA positively related to the FPI rate. Notably, the rate of FPI in both PV in obese patients, even under GA, is low, which is similar to those under CS. This low FPI rate in obese patients might be related to the high AT recurrence after AF ablation.

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Patient Consent: All patients provided written informed consent on the ablation procedure before performing the procedure.

Ethics Statement: Our study presented in this paper adhered to the Helsinki Declaration and was approved by the Institutional Review Board (Approval number 1234).

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