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ORIGINAL ARTICLE

Impacts of the body size on the left atrial wall thickness and atrial fibrillation recurrence after catheter ablation

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Abstract

The increased body size correlates with the occurrence of atrial fibrillation (AF); however, the impact of the body size on the AF recurrence after ablation remains unclear. We enrolled 283 AF patients (179 paroxysmal, 51 persistent, and 53 long-standing persistent) who received ablation and assessed the correlation between the body surface area (BSA) and the AF recurrence. Furthermore, we measured the left atrial wall thickness using computed tomography. During the 12-month follow-up period, the AF freedom rates for patients with paroxysmal AF, persistent AF, and long-standing persistent AF were 83%, 76%, and 77%, respectively. The left atrial dimension, BSA, and body mass index (BMI) were higher in the AF-recurrent group compared with the AF-free group (left atrial dimension: 44.1 ± 7.5 mm vs. 41.7 ± 6.5 mm, $P = 0.019$; BSA: 1.81 ± 0.20 m^2 vs. 1.72 ± 0.19 m^2, $P = 0.002$; BMI 25.0 ± 3.2 kg/m^2 vs. 24.0 ± 3.2 kg/m^2, $P = 0.035$). The multivariate analysis revealed that only the BSA was an independent predictor of the AF recurrence after ablation (hazard ratio 6.843; 95% confidence interval 1.523–30.759, $P = 0.012$). The BSA significantly correlated with the left atrial wall thickness ($R = 0.306$, $P < 0.001$), and the left atrial wall thickness was higher in the AF-recurrent group compared with the AF-free group (2.00 ± 0.20 mm vs. 1.87 ± 0.17 mm, $P < 0.001$). The large body size correlates with the AF recurrence after ablation, which could be attributed to an increase in the left atrial wall thickness.

Keywords Atrial fibrillation · Catheter ablation · Body mass index · Body surface area · Pulmonary vein isolation

Introduction

Recent technological advancements have enhanced the efficacy of catheter ablation for atrial fibrillation (AF), making it a first-line treatment option for AF. However, AF recurs in some patients who undergo catheter ablation. Some clinical characteristics, including AF perpetuation [1], comorbidities [2–4] and echocardiographic findings [5, 6], are associated with AF recurrence; however, predictors of the AF recurrence after catheter ablation remain unclear.

Obesity, which is indicated by the body mass index (BMI), occurs in association with diabetes mellitus, hypertension, sleep apnea syndrome, and cardiac diseases, which leads to the AF development [7, 8]. In addition, obesity itself contributes to the AF occurrence [9]. Thus, obesity has been implicated as a risk factor for new-onset AF [7–11]. Furthermore, the body size, which is indicated by the body surface area (BSA), is also associated with AF. Some long-term cohort studies have revealed that the high BSA predicted the subsequent development of AF [12, 13]. High BSA could provide the substrate for AF through left atrial dilatation because the BSA correlates with the left atrial volume [14].

Although some previous studies [15] revealed the contribution of obesity to the AF recurrence after catheter ablation, few studies have assessed the relationship between the body size and the AF recurrence. Hence, this study aimed to assess the effect of the BSA on the AF recurrence after catheter ablation. Furthermore, this study evaluated the left

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atrial volume and wall thickness using computed tomography (CT) to investigate the mechanisms of the effects of anthropometric measures on the AF recurrence.

Materials and methods

In this study, we enrolled consecutive patients with AF who underwent catheter ablation at the Toyama University Hospital (Toyama, Japan) between April 2010 and August 2016. We excluded patients with the previous ablation. Paroxysmal AF was defined as AF lasting <7 days, persistent AF was defined as AF lasting ≥ 7 days but <1 year, and long-standing persistent AF was defined as continuous AF lasting ≥ 1 year. Overall, we enrolled 283 patients (paroxysmal AF, 179; persistent AF, 51; long-standing persistent AF, 53). This study protocol was approved by the Institution Research and Ethics Committee of the University of Toyama (Toyama, Japan) and was conducted in accordance with the principles of the Declaration of Helsinki. Furthermore, we obtained written informed consent from patients before performing catheter ablation.

We obtained clinical characteristics, including comorbidities, echocardiographic data, and laboratory data, from the medical records. We evaluated the BSA by the formula of Du Bois [16] [body weight (kg)$^{0.425} \times$ height (cm)$^{0.725} \times 0.007184$] and BMI [body weight (kg)/height (m)^2], which were adopted as indicators of the body size and obesity, respectively.

Multi-detector enhanced CT

Within 3 days before ablation, contrast-enhanced multi-detector CT with a dual-source 128-slice multi-detector CT-scanner (Somatom Definition AS+; Siemens Medical Solutions, Forchheim, Germany; 0.30 s gantry rotation time, 120 kV) or 64-slice multi-detector CT-scanner (Somatom Sensation Cardiac 64; Siemens Medical Solutions; 0.33 s gantry rotation time, 120 kV) was performed in 212 patients. Among the paroxysmal AF patients, CT was performed during sinus rhythm in 120 (94%) patients and during AF in 7 (6%) patients, while among the persistent AF patients, it was during sinus rhythm in 6 (15%) patients and during AF in 33 (85%) patients. Moreover, among the long-standing persistent AF patients, CT was performed during AF in 46 (100%) patients. Contrast-enhanced scans were performed with an intravenous administration of 65–80 mL of a non-ionic contrast agent. All images were captured during a breath-hold at full expiration using cardiac gating from the caudal aspect of the aortic arch through the cranial aspect of the left hemidiaphragm. Of note, the slice was 0.6 mm thick, and we selected a reconstructed series in systole (20–40% of the *R*–*R* interval) for the analysis.

Analysis of CT images

The CT image analysis process has been detailed elsewhere [17]. Briefly, we manually assessed the left atrial volume and wall thickness using the visualization and analysis software (Synapse Vincent; Fujifilm, Tokyo, Japan). The wall thickness was measured at 35 areas of the left atrium—the roof area, high anterior area, mid-anterior area, low anterior area, high posterior area, mid-posterior area, low posterior area, the bottom area of the bilateral pulmonary vein antrum, all three areas (i.e., right, middle, and left) of the roof wall, anterior wall, high posterior wall, mid-posterior wall, low posterior wall, bottom wall of the left atrial body, and the mitral isthmus. The average value of the wall thicknesses measured at 35 areas was adopted as the left atrial wall thickness. In further analysis, the wall thicknesses of pulmonary vein antrum and the left atrial body were analyzed separately. In addition, both intraobserver and interobserver variabilities were tested in 10 randomly selected patients by 2 independent investigators. The intraobserver and interobserver correlation coefficients were $r=0.93$ and 0.89, respectively. The mean intraobserver and interobserver differences were 0.13 ± 0.34 mm and 0.05 ± 0.37 mm, respectively.

Ablation procedure

All antiarrhythmic drugs were discontinued for, at least, five half-lives, and no patients received oral amiodarone before catheter ablation. Catheter ablation was performed by two operators who have more than 5 years of experience in catheter ablation for AF (Y.N. and T.S.). The NavX system (St. Jude Medical Inc., St. Paul, MN, USA) or the CARTO system (Biosense-Webster, Inc., Diamond Bar, CA, USA) was used for ablation. Sheath introducers were inserted through the right femoral vein under sedation with propofol or dexmedetomidine. Furthermore, the trans-septal procedure was performed using fluoroscopic landmarks, and three 8-F SL0 sheaths (St. Jude Medical, Inc.) or two 8-F SL0 sheaths and a steerable sheath (Agilis, St. Jude Medical, Inc.) were advanced into the LA.

First, the pulmonary vein isolation was performed, which was guided by two 7-F decapolar circular catheters positioned at the ipsilateral pulmonary vein ostia. An irrigated tip radiofrequency catheter (St. Jude Medical Inc. or Biosense-Webster, Inc.) without a contact force sensor was used for the radiofrequency application. If AF did not terminate or was induced with atrial burst pacing after the pulmonary vein isolation, additional radiofrequency application targeting complex fractionated atrial electrogram (CFAE) or left atrial posterior wall isolation was performed.

For ablation targeting CFAE, fractionation analyses were performed on the NavX system. We defined the mapping parameter (CFAE-mean) as an interval-analysis algorithm that measured the average index of the fractionation. Recordings at each site were of 5 s. In addition, a continuous CFAE was determined by an average fractionated index of ≤ 50 ms, suggesting a high degree of temporal stability of the fractionated electrograms maintaining AF [18]. All continuous CFAE sites were targeted for ABL, starting at the shortest fractionated index point. Of note, ABL at a continuous CFAE site was continued for 40–60 s, until the local electrograms were eliminated.

For the left atrial posterior wall isolation, we created the left atrial roof line at the most cranial aspect of the left atrial roof and a floor line joining the most inferior margin of the pulmonary vein isolation line. If the left atrial posterior wall was not isolated, we performed additional radiofrequency applications targeting the earliest activation site on the isolation lines. While the entrance block was verified by the voltage mapping using a 3D mapping system, the exit block was verified by high-output pacing within the left atrial posterior wall isolation line. If AF continued despite performing the additional ablation procedure, we performed external cardioversion; the procedure was completed with cavotricuspid isthmus ablation. Each radiofrequency application was performed for 30–50 s. The temperature was limited to 42 °C and power to 30–35 W; the maximum power of 25 W was used while delivering energy to sites near the esophagus.

Post-procedure care and follow-up

We conducted a clinical interview and surface electrocardiogram on the day following catheter ablation and during monthly visits to the outpatient clinic after that. Patients were followed up until 12 months after ablation. Of note, 24-h Holter monitoring was performed on the day following ablation and as needed thereafter the follow-up period. In addition, the drugs were discontinued at the discretion of the treating physician. We defined AF recurrence as sustained AF lasting > 30 s, which occurred from 3–12 months after catheter ablation.

Statistical analysis

In this study, data are presented as mean ± standard deviation along with the 95% confidence interval (95% CI). We analyzed the significance of any between-group difference using the Student's *t* test for continuous variables, and the Fisher's exact probability test for categorical variables. Univariate and multivariate Cox proportional hazards regression analyses were performed to identify the predictors of AF recurrence. Moreover, univariate and multivariable linear regression analyses were conducted to identify the determinants of the left atrial wall thickness. Related factors with a *P* value < 0.200 in a univariate analysis were selected as independent variables for a multivariate analysis. If we observed a significant correlation between two variables, we excluded a variable with lower significance from the multivariate analysis to eliminate the multicollinearity. Furthermore, the correlations between parameters were analyzed using the Pearson's correlation coefficient. We considered $P < 0.050$ (two tailed) as statistically significant. All statistical analyses were performed using the SPSS statistical software for Windows version 16.0 (SPSS Inc., Chicago, IL, USA).

Results

Baseline patient characteristics and catheter ablation

The mean age was 63.6 ± 10.5 years, and 78% were males (Table 1). The mean height and body weight were 166 ± 10 cm and 66.9 ± 12.5 kg, respectively. We observed congestive heart failure in 14% of patients and hypertension in about half of the patients. Although the left atrium was mildly dilated, the left ventricular ejection fraction was in the normal range.

Among the paroxysmal AF patients, catheter ablation was performed during sinus rhythm in 170 (95%) patients and during AF in 9 (5%) patients, while among the persistent AF patients, it was during sinus rhythm in 6 (12%) patients and during AF in 45 (88%) patients. Moreover, among the long-standing persistent AF patients, catheter ablation was performed during AF in all patients. Radiofrequency application targeting CFAE was performed in 9 (5%), 19 (37%), and 25 (47%) patients with paroxysmal AF, persistent AF, and long-standing persistent AF, respectively. Moreover, left atrial posterior wall isolation was performed in 13 (7%), 21 (41%), and 20 (38%) patients with paroxysmal AF, persistent AF, and long-standing persistent AF, respectively. Total radiofrequency application time was 60.4 ± 16.7 min (Table 1). During the 12-month follow-up period, no patients were lost to follow-up. AF did not recur in 228 (81%) patients, including 148 (83%), 39 (76%), and 41 (77%) patients with paroxysmal AF, persistent AF, and long-standing persistent AF, respectively.

Clinical parameters and AF recurrence

The AF-recurrent group tended to be younger than the AF-free group (Table 1). In addition, the AF-recurrent group was markedly taller and more massive than the AF-free group. The prevalence of comorbidities was not different between the groups. Although the left atrial dimension was higher in the AF-recurrent group than that in the AF-free

Table 1 Baseline patient characteristics and catheter ablation

	All cases ($n=283$)	AF-recurrent group ($n=55$)	AF-free group ($n=228$)	P value
Age (years)	63.6 ± 10.5	61.2 ± 11.1	64.2 ± 10.3	0.061
Male gender	220 (78)	47 (85)	173 (76)	0.150
Height (cm)	166 ± 10	169 ± 10	165 ± 10	0.016
Body weight (kg)	66.9 ± 12.5	71.5 ± 12.7	65.8 ± 12.2	0.002
AF type (paroxysmal/persistent/long-standing)	179/51/53 (63/18/19)	31/12/12 (56/22/22)	148/39/41 (65/17/18)	0.193
Congestive heart failure	40 (14)	6 (11)	34 (15)	0.524
Hypertension	140 (49)	27 (49)	113 (50)	> 0.999
Diabetes mellitus	36 (13)	4 (7)	32 (14)	0.258
Cerebrovascular disease	28 (10)	5 (9)	23 (10)	> 0.999
Pulmonary disease	17 (6)	5 (9)	12 (5)	0.339
Thyroid dysfunction	18 (6)	2 (4)	16 (7)	0.541
Left atrial dimension (mm)	42.2 ± 6.7	44.1 ± 7.5	41.7 ± 6.5	0.019
Left ventricular ejection fraction (%)	62.6 ± 9.8	61.1 ± 11.2	62.9 ± 9.4	0.221
Left atrial appendage flow velocity (cm/s)	55.3 ± 29.3	55.1 ± 29.4	55.4 ± 29.3	0.960
B-type natriuretic peptide (pg/mL)	102 ± 128	109 ± 136	101 ± 126	0.664
Estimated glomerular filtration rate (mL/min/1.73m^2)	68.7 ± 16.9	69.6 ± 17.9	68.4 ± 16.6	0.653
CFAE ablation	53 (19)	10 (18)	43 (19)	> 0.999
Left atrial posterior wall isolation	54 (19)	7 (13)	47 (21)	0.251
Radiofrequency application time (min)	60.4 ± 16.7	61.0 ± 17.2	60.2 ± 16.5	0.735

Data are mean ± SD or number (%) of patients

AF atrial fibrillation, *CFAE* complex fractionated atrial electrogram

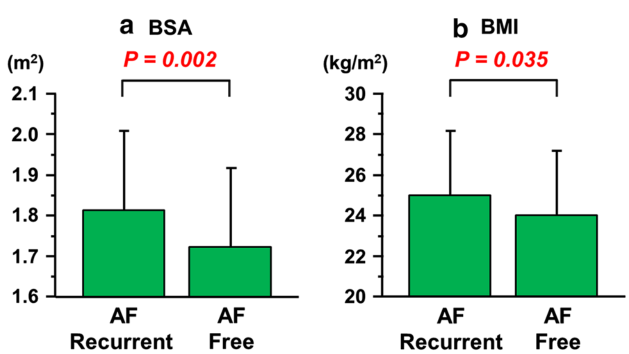

Fig. 1 Comparisons of anthropometric measures. The body surface area (BSA, **a**) and the body mass index (BMI, **b**) are compared between the AF-recurrent group and the AF-free group. *AF* atrial fibrillation

group, the left ventricular ejection fraction and the left atrial appendage flow velocity did not differ between the groups. The B-type natriuretic peptide level and the estimated glomerular filtration rate were not different between the groups. Moreover, the proportion of patients who underwent radiofrequency application targeting CFAE or left atrial posterior wall isolation did not differ between the groups. Total radiofrequency application time exhibited no between-group difference. Furthermore, the BSA was significantly higher in the AF-recurrent group compared with the AF-free group (1.81 ± 0.20 m^2 vs. 1.72 ± 0.19 kg/m^2, $P=0.002$; Fig. 1a). In addition, the BMI was significantly higher in the AF-recurrent group compared with the AF-free group (25.0 ± 3.2 kg/m^2 vs. 24.0 ± 3.2 kg/m^2, $P=0.035$; Fig. 1b).

According to the univariate Cox proportional hazards regression analysis, the age, BSA, BMI, left atrial dimension and left atrial posterior wall isolation were applicable to the multivariate analysis (Table 2); however, we observed a significant correlation between the BSA and the age ($R=0.523$, $P<0.001$) or BMI ($R=0.584$, $P<0.001$). Thus, we performed the multivariate analysis for the BSA, left atrial dimension, and left atrial posterior wall isolation. Consequently, only the BSA was the independent predictor of the AF recurrence after catheter ablation (hazard ratio 6.843; 95% CI 1.523–30.759, $P=0.012$).

Correlation between anthropometric measures and CT parameters

Although the BSA did not significantly correlate with the left atrial volume ($R=0.154$, $P=0.079$; Fig. 2a), it significantly correlated with the left atrial wall thickness ($R=0.306$, $P<0.001$; Fig. 2b). Conversely, we did not observe a significant correlation between the BMI and the left atrial volume ($R=0.147$, $P=0.099$; Fig. 2c) or the left atrial wall thickness ($R=0.149$, $P=0.093$; Fig. 2d). According to the

Table 2 Univariate and multivariate Cox proportional hazards regression analyses for recurrence of atrial fibrillation (AF) after ablation

	Univariate		Multivariate	
	Hazard ratio (95% CI)	*P* value	Hazard ratio (95% CI)	*P* value
Age (years)	0.973 (0.952–0.994)	0.014		
Male gender	0.639 (0.313–1.303)	0.218		
Body surface area (m^2)	6.110 (1.605–23.261)	0.008	6.843 (1.523–30.759)	0.012
Body mass index (kg/m^2)	1.074 (0.995–1.159)	0.066		
AF type (paroxysmal/persistent/long-standing)	1.046 (0.470–2.329)	0.912		
Congestive heart failure	1.386 (0.594–3.234)	0.449		
Hypertension	1.060 (0.628–1.790)	0.828		
Diabetes mellitus	1.934 (0.699–5.346)	0.204		
Cerebrovascular disease	1.110 (0.443–2.782)	0.824		
Pulmonary disease	0.643 (0.257–1.612)	0.347		
Thyroid dysfunction	1.877 (0.260–13.565)	0.533		
Left atrial dimension (mm)	1.043 (1.003–1.085)	0.036	1.040 (0.997–1.084)	0.072
Left ventricular ejection fraction (%)	0.986 (0.960–1.012)	0.291		
Left atrial appendage flow velocity (cm/s)	1.000 (0.991–1.009)	0.936		
B-type natriuretic peptide (pg/mL)	1.000 (0.999–1.002)	0.670		
CFAE ablation	1.072 (0.541–2.125)	0.842		
Left atrial posterior wall isolation	1.678 (0.760–3.705)	0.199	0.911 (0.790–1.051)	0.200
Radiofrequency application time (min)	1.004 (0.987–1.022)	0.634		

The age and body mass index were excluded from the multivariate analysis because of a significant correlation with the body surface area

CFAE complex fractionated atrial electrogram

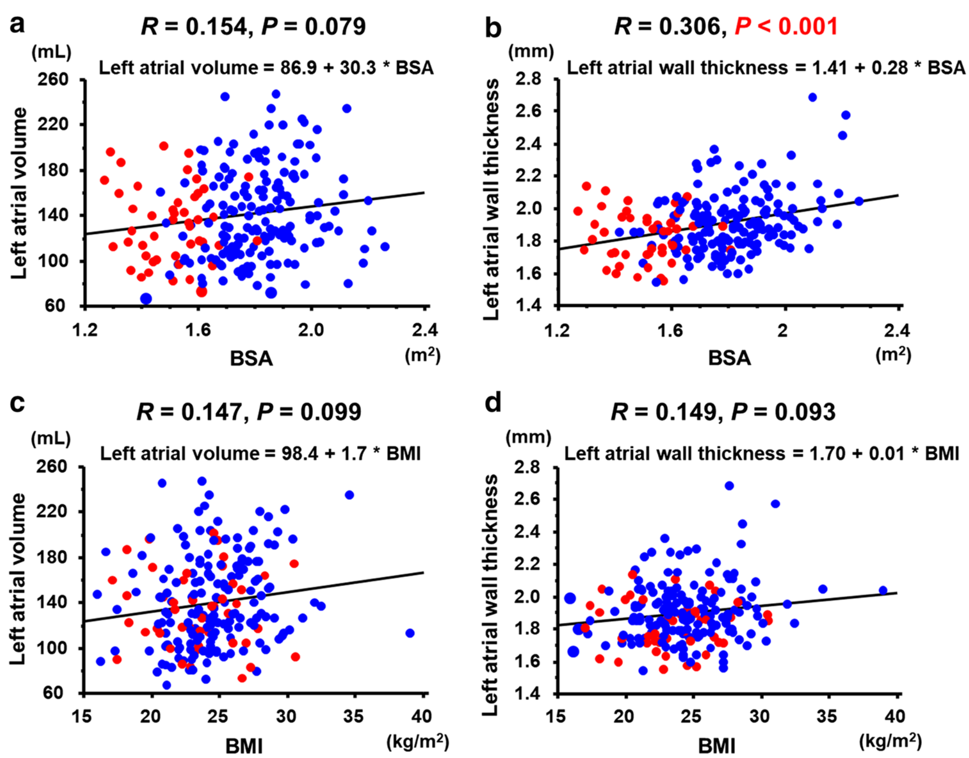

Fig. 2 Correlations between anthropometric measures and computed tomographic parameters. Correlations between the body surface area (BSA) and the left atrial volume (**a**) or the left atrial wall thickness (**b**), and those between the body mass index (BMI) and the left atrial volume (**c**) or the left atrial wall thickness (**d**) are shown. Blue and red circles, males and females, respectively

univariate linear regression analysis, the age, sex, BSA, BMI, AF type, left ventricular ejection fraction and left atrial appendage flow velocity were applicable to the multivariate analysis (Table 3). However, we performed the multivariate analysis for the sex, BSA, AF type, left ventricular ejection fraction and left atrial appendage flow velocity because of

Table 3 Univariate and multivariate linear regression analyses for the determinants of the left atrial wall thickness

	Univariate		Multivariate	
	Standardized β (95% CI)	P value	Standardized β (95% CI)	P value
Age (years)	– 0.140 (– 0.005 to 0.000)	0.042		
Male gender	0.206 (0.032 to 0.147)	0.003	– 0.035 (– 0.089 to 0.058)	0.682
Body surface area (m^2)	0.313 (0.167 to 0.401)	< 0.001	0.374 (0.181 to 0.494)	< 0.001
Body mass index (kg/m^2)	0.154 (0.001 to 0.016)	0.024		
AF type (paroxysmal/persistent/long-standing)	– 0.177 (– 0.068 to – 0.010)	0.010	– 0.216 (– 0.082 to – 0.013)	0.007
Congestive heart failure	– 0.037 (– 0.087 to 0.050)	0.587		
Hypertension	0.022 (– 0.041 to 0.057)	0.754		
Diabetes mellitus	0.003 (– 0.077 to 0.081)	0.964		
Cerebrovascular disease	– 0.028 (– 0.093 to 0.061)	0.680		
Pulmonary disease	0.044 (– 0.072 to 0.140)	0.526		
Thyroid dysfunction	– 0.026 (– 0.079 to 0.053)	0.707		
Left atrial dimension (mm)	– 0.012 (– 0.004 to 0.003)	0.865		
Left ventricular ejection fraction (%)	– 0.105 (– 0.004 to 0.001)	0.128	– 0.123 (– 0.005 to 0.000)	0.066
Left atrial appendage flow velocity (cm/s)	0.184 (0.000 to 0.002)	0.008	0.071 (0.000 to 0.001)	0.381
B-type natriuretic peptide (pg/mL)	– 0.074 (0.000 to 0.000)	0.282		

The age and body mass index were excluded from the multivariate analysis because of a significant correlation with the body surface area

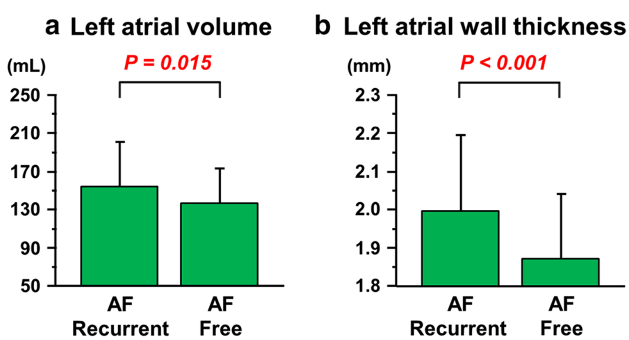

Fig. 3 Comparisons of computed tomographic parameters. The left atrial volume (**a**) and the left atrial wall thickness (**b**) are compared between the AF-recurrent group and the AF-free group. *AF* atrial fibrillation

a significant correlation between the BSA and the age or BMI. Consequently, the BSA (standardized β, 0.374; 95% CI 0.181–0.494, $P < 0.001$) and AF type (standardized β, 0.216; 95% CI 0.082 to 0.013, $P = 0.007$) were the independent determinants of the left atrial wall thickness.

CT parameters and AF recurrence

Representative CT images of patients with or without the AF recurrence are shown in Supplementary Figure 1. Compared with the AF-free group, the left atrial volume (Fig. 3a) and wall thickness (Fig. 3b) were significantly higher in the AF-recurrent group (left atrial volume 154 ± 48 mL vs. 137 ± 36 mL, $P = 0.015$; left atrial wall thickness 2.00 ± 0.20 mm vs. 1.87 ± 0.17 mm, $P < 0.001$). Furthermore, when the wall thicknesses of pulmonary vein antrum and the left atrial body were analyzed separately, both were higher in the AF-recurrent group compared to the AF-free group (pulmonary vein antrum 1.56 ± 0.12 mm vs. 1.48 ± 0.15 mL, $P = 0.002$; left atrial body 2.36 ± 0.36 mm vs. 2.20 ± 0.24 mm, $P < 0.001$). The effect of the BSA on the AF recurrence remained unchanged upon the inclusion of the left atrial volume as a variable exchange for the left atrial dimension (Supplementary Table 1); however, it disappeared when the left atrial wall thickness was included as a variable (Supplementary Table 2).

Differences in the effects of anthropometric measures and CT parameters on the AF recurrence between males and females

AF did not recur in 173 (79%) males and 55 (87%) females. The BSA and the BMI were higher in males than females (BSA 1.81 ± 0.16 m^2 vs. 1.51 ± 0.13 mm, $P < 0.001$; BMI 24.5 ± 3.2 kg/m^2 vs. 23.3 ± 3.2 kg/m^2, $P = 0.009$). Among CT parameters, the left atrial volume was not different between males and females; however, the left atrial wall thickness was higher in males than that in females (left atrial volume 142 ± 40 mL vs. 133 ± 33 mL, $P = 0.184$; left atrial wall thickness: 1.91 ± 0.18 mm vs. 1.83 ± 0.15 mm, $P = 0.004$). In males, although the BMI did not differ between the AF-recurrent and AF-free groups, the BSA, left atrial volume, and wall thickness were higher in the AF-recurrent group compared with the AF-free group (Table 4). Conversely, we did not observe significant differences in anthropometric

Table 4 Comparison of anthropometric measures and computed tomographic parameters in males

	All cases ($n=220$)	AF-recurrent group ($n=47$)	AF-free group ($n=173$)	*P* value
Body surface area (m^2)	1.81 ± 0.16	1.86 ± 0.17	1.79 ± 0.15	0.014
Body mass index (kg/m^2)	24.5 ± 3.2	25.1 ± 3.3	24.3 ± 3.1	0.140
Left atrial volume (mL)	142 ± 40	161 ± 48	137 ± 37	0.002
Left atrial wall thickness (mm)	1.91 ± 0.18	2.02 ± 0.21	1.89 ± 0.17	< 0.001

Data are mean ± SD

AF atrial fibrillation

Table 5 Comparison of anthropometric measures and computed tomographic parameters in females

	All cases ($n=63$)	AF-recurrent group ($n=8$)	AF-free group ($n=55$)	*P* value
Body surface area (m^2)	1.51 ± 0.13	1.55 ± 0.06	1.50 ± 0.13	0.323
Body mass index (kg/m^2)	23.3 ± 3.2	24.7 ± 2.1	23.0 ± 3.3	0.178
Left atrial volume (mL)	133 ± 33	120 ± 29	136 ± 34	0.251
Left atrial wall thickness (mm)	1.83 ± 0.15	1.88 ± 0.11	1.82 ± 0.16	0.290

Data are mean ± SD

AF atrial fibrillation

measures and CT parameters between the groups in females (Table 5).

Discussion

This study revealed that the large body size, which was indicated by the high BSA, contributed to the AF recurrence after catheter ablation independent from the left atrial size. In addition, the body size was the independent determinant of the left atrial wall thickness, and the left atrial wall thickness was higher in patients with the AF recurrence than in those without the AF recurrence. Hence, the large body size contributed to the AF recurrence, at least partly, through an increase in the left atrial wall thickness.

Mechanisms of the AF recurrence in patients with large body size

Some previous studies support the finding of this study that the large body size correlates with the AF recurrence. The high BSA in youth correlated with the AF occurrence risk [12–14]. In addition, the correlation between the height, which is also an indicator of the body size, and AF has been reported in several studies [19, 20]. However, the mechanisms of the effects of the large body size on the risk of AF remain unclear.

As the BSA correlates with the stroke volume and cardiac output [21], the increased risk of the AF recurrence could be mediated by the high cardiac load in patients with the large BSA; this corresponds to the increased risk of AF in endurance-trained athletes [22], who are characterized by a high cardiac load because of excessive training. Among other potential mechanisms for the contribution of the body size to the AF recurrence, possibilities might lie in the genome-wide association studies. Reportedly, genes near loci associated with the increased AF risk, *PITX2* [23] and *ZFHX3* [24], also related to growth pathways. In addition, one of the most likely mechanisms of the AF recurrence is the divergence of the left atrial size accompanying body size differences. A study reported a marked correlation between the body size and the left atrial size [25], and several studies have reported a positive correlation between the increased atrial size and new-onset AF [26] or the AF recurrence after catheter ablation [27]. This study corroborates previous studies in that the left atrial size was higher in patients with the AF recurrence than those without (Fig. 3b); however, it does not agree in that the BSA did not correlate with the left atrial volume (Fig. 2c). As subjects of this study already had AF, structural remodeling because of the persistence of AF might have caused the left atrial dilation. Consequently, the correlation between the BSA and the left atrial size might have lost after the AF occurrence. Furthermore, it is assumed that the effects of the large body size on the AF recurrence are mediated by the mechanisms other than left atrial dilatation because the BSA correlated with the AF recurrence independent of the left atrial size (Table 2).

This study suggests that the effects of the large body size on the AF recurrence are demonstrated by an increase in the left atrial wall thickness. In this study, the BSA markedly correlated with the left atrial wall thickness. Moreover, we previously demonstrated that a thick left atrial wall correlated with the AF recurrence after catheter ablation [17]. Notably, such a correlation was observed in both patients with paroxysmal and persistent AF [17]. In addition, the effects of the BSA on the prediction of the AF recurrence disappeared when the left atrial wall thickness was included as a variable for the multivariate analysis. The higher wall thickness of pulmonary vein antrum in the AF-recurrent group suggests that a thick left atrial wall could have hindered the creation of the transmural and durable lesion and increased the reconnection of the pulmonary vein isolation. Moreover, the "critical mass theory" might elucidate the correlation between the higher wall thickness of the left atrial body and the AF recurrence. Reportedly, electrical patterns required to sustain AF depend on a critical mass of atrial tissue [28, 29]. Hence, the thick left atrial wall in patients with large body size might have contributed to the AF recurrence by providing the myocardial mass needed for the AF perpetuation.

In females, we did not observe the impact of the body size on the AF recurrence (Table 5); however, this finding may not mean that the body size is not associated with the AF recurrence in females. In this study, the BSA correlated with the left atrial wall thickness regardless of sex (Fig. 2b). Thus, as the body size is smaller in females than in males, the left atrial wall thickness is lower in females than in males. Consequently, the left wall thickness might not have been sufficiently high to cause the AF recurrence, even in females with relatively large body size. This hypothesis is supported by the finding that the left atrial wall thickness of the AF-free group in males was higher than that of females (1.89 ± 0.17 mm vs. 1.83 ± 0.15 mm, $P = 0.032$).

Clinical implication

As patients with large body size have a large left atrial wall thickness, increasing the radiofrequency application time and/or power in patients with a large body size might be effective for decreasing the AF recurrence. A study [30] reported that the correlation between the left atrial wall thickness and the force–time integral correlated with the reconnection and dormant conduction of the pulmonary vein isolation. Furthermore, it may be useful to determine the end-point of the radiofrequency application at each site by monitoring a decrease in impedance and loss of pace capture, because we end up performing more extended radiofrequency application on the thicker tissues.

Limitations

This study has several limitations. First, owing to the retrospective study design, the causal relationship remains unclear. Second, the limited number of subjects, especially for the AF-recurrent group in females, might have affected the findings of this study. Third, the subjects of this study had a relatively small and uniform body size compared to those of other studies [12, 13]. This finding may be the result of the small body size and racial homogeneity of the Japanese population. Therefore, careful consideration is needed to apply the results of this study to the population of other countries. Fourth, the AF recurrence was diagnosed by a clinical interview and clinical examinations, including surface ECG and 24-h Holter monitoring, a method that is well known for underestimating the prevalence of AF because it neglects asymptomatic AF. Lastly, both intraobserver and interobserver variabilities are inevitable in the manual measurement of the left atrial wall thickness. However, we observed high intraobserver and interobserver correlation coefficients in this study. Hence, further studies using the automated measurement system are warranted for a definite conclusion.

Conclusion

This study establishes a correlation between the large body size and the AF recurrence after catheter ablation. Perhaps, an increase in the left atrial wall thickness along with an increase in the body size could contribute to the AF recurrence.

Compliance with ethical standards

Conflict of interest None for all authors.

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