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Right Atrial Anatomical Remodeling Affects Early Outcomes of Nonvalvular Atrial Fibrillation After Radiofrequency Ablation

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Background: The impact of the right atrial (RA) anatomical remodeling on outcomes of atrial fibrillation (AF) after radiofrequency ablation (RFA) is unclear.

Methods and Results: Sixty-three patients (50 men, 57±10 years, 23 persistent AF [PeAF]) who underwent RFA for AF were enrolled. Both RA and left atrial (LA) volumes, measured with multidetector computed tomography, as well as echocardiographic parameters were compared between subjects with early (<3 months, n=13) or 1-year (n=19) recurrence after RFA and without recurrence. The RA volume index (RAVI) was larger (98±21 vs. 77±22 ml/m^2) and PeAF was more common (62% vs. 30%) in the early recurrence group (P<0.05 for all), whereas the LA volume index (LAVI) was similar between the 2 groups (78±15 vs. 72±19 ml/m^2, P=0.23). Notably, RAVI was the only independent predictor of early recurrence (for each 10 ml/m^2 increase, OR: 1.650, 95%CI: 1.017–2.677, P=0.04). PeAF was the only independent predictor of 1-year recurrence after RFA (OR: 4.496, 95%CI: 1.110–18.211, P=0.04), whereas RAVI and LAVI were not.

Conclusions: RA anatomical remodeling might affect the early recurrence of AF after RFA. However, the chronicity of AF, rather than RA and LA anatomical remodeling, is a determinant of 1-year recurrence of AF after RFA. (*Circ J* 2012; **76:** 860–867)

Key Words: Ablation; Atrial fibrillation; Remodeling; Right atrium

Atrial fibrillation (AF) is the most common form of cardiac arrhythmia.[1] AF is not a benign disease and is associated with cardiovascular morbidity and mortality,[2,3] and as it persists, it often develops into a more chronic form and induces numerous pathologic changes to the heart.[4,5] In cases of persistent AF (PeAF), it has been revealed that the atria were enlarged and showed histological changes such as interstitial fibrosis in animal models.[6,7] AF causes electrical and structural remodeling of the atria, which promotes the continuation of AF itself.[6,8–10] However, the majority of those experimental observations were mainly focused on the left atrium (LA), which is generally thought to play a leading role in the pathophysiology of AF. In contrast, the role of right atrial (RA) electrical and structural remodeling in the pathophysiology of AF and prognosis after radiofrequency ablation (RFA) is relatively unclear. One conceivable reason for this is that information concerning the RA structure is technically limited when using conventional echocardiography, which is the most widely used imaging tool for evaluation of the cardiac chamber in the clinical field.[11] Meanwhile, the recently developed multidetector computed tomography (MDCT) can determine the volume of the cardiac chambers more accurately and relatively free from inter- and intra-observer variation than echocardiography. Furthermore, it provides more reliable 3-dimensional images of cardiac chambers. Thus, the volume and anatomical remodeling of the RA can be evaluated more reliably using MDCT. In this study, we sought to investigate the relationship between RA anatomical remodeling evaluated using MDCT and the outcomes of AF after RFA. The aim of this study was to determine the potential impact of the RA on prognosis of nonvalvular AF after RFA.

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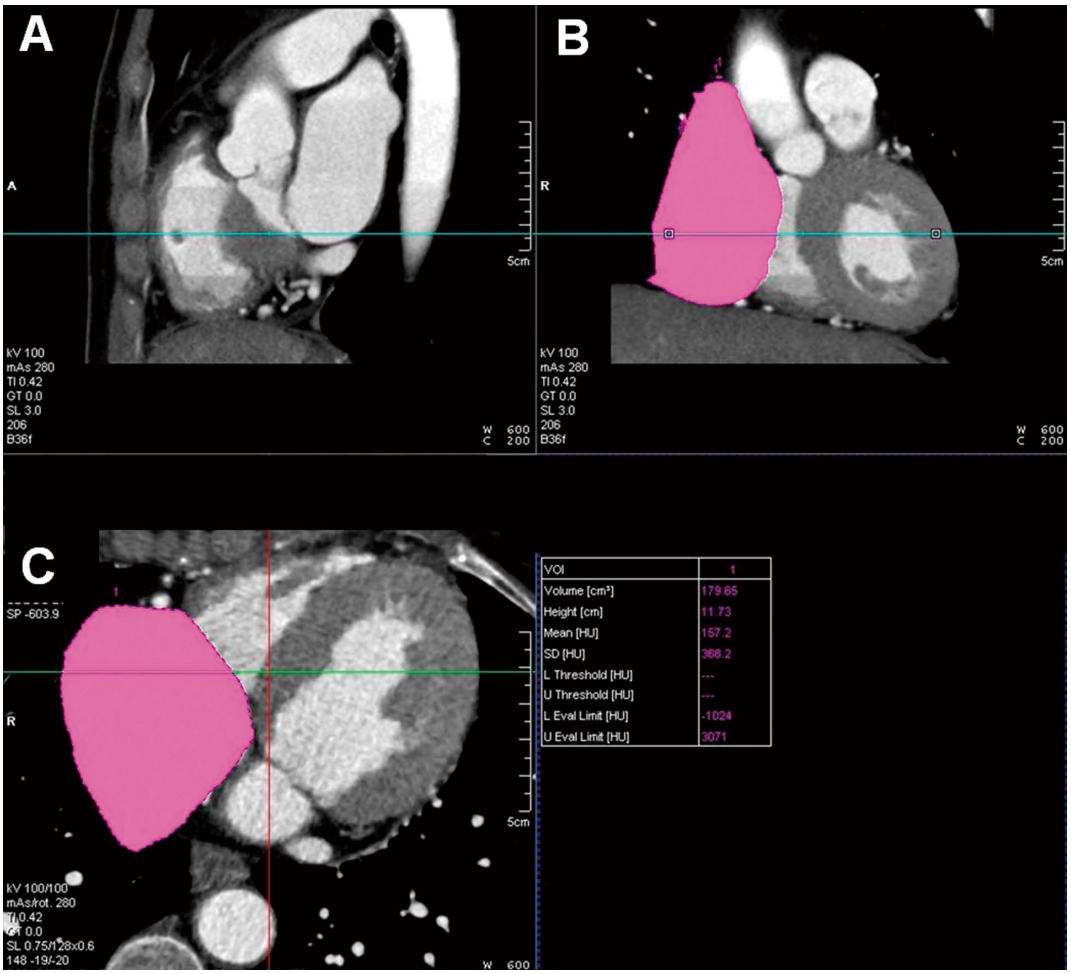

Figure 1. Three-dimensional measurement of the right atrial (RA) volume using multidetector computed tomographic images. (**A**) Coronal view of the heart showing the RA. (**B**) The margin of the RA was automatically traced using a commercially available workstation (Syngo, Siemens, Germany). (**C**) Sagital view of the heart showing the RA and the margin of the RA was automatically traced.

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Methods

Study Sample

The study protocol was approved by the Institutional Review Board of Severance Cardiovascular Hospital, in Seoul, Korea and it complied with the Declaration of Helsinki. All patients provided written informed consent. A total of 63 patients (50 men, 57±10 years) who underwent RFA of nonvalvular AF were consecutively enrolled at the Severance Cardiovascular Hospital. We divided the study patients into paroxysmal AF (PaAF) and PeAF groups. The PaAF group included the patients with a history of 1 or more episodes of self-terminating AF that lasted less than 7 days. The persistent AF (PeAF) group consisted of patients who had an AF episode that either lasted longer than 7 days or required termination by cardioversion, either with drugs or by direct current cardioversion. We also divided the enrolled subjects according to the presence of early recurrence (within 3 months) or 1-year recurrence of AF after successful RFA. No patient in this study had a medical history of lung disease including chronic obstructive pulmonary disease, which might cause right-heart dilation. In addition, we excluded the patients with organic heart disease, which might have contributed to RA enlargement such as significant tricuspid regurgitation, more than moderate pulmonary hypertension or cardiomyopathy involving right ventricle when assessed with clinical examination, electrocardiography, chest X-ray and echocardiography.

Echocardiography

Comprehensive transthoracic echocardiography was performed using commercially available equipment (Vivid 7, GE Vingmed ultrasound, Horten, Norway or Sonos 5500, Philips Medical System, Andover, MA, USA) in each patient before the RFA of AF. Standard M-mode, 2-dimensional, and color Doppler imaging were performed in the parasternal and apical views. The measurements were averaged over 5 cardiac cycles. The left ventricular (LV) end diastole was defined as the frame with the largest cavity area immediately before the onset of the QRS complex and the end systole as the frame with the smallest LV cavity area. LV end-diastolic dimension (LVEDD) and LV end-systolic dimension (LVESD) were determined, and

the LV ejection fraction (LVEF) was calculated from 2-dimensional recordings using the previously described modified using Quinones method.[12] The LA volume was assessed with the prolate ellipsoid formula and was indexed to the body surface area (LA volume index [LAVI]).[13] The echocardiographic data were analyzed by 2 experienced echocardiographers who were unaware of patients' clinical data.

Measuring Atrial Volume With MDCT

Because the atrial volume is largest and smallest in systolic and diastolic periods, respectively, the 3-dimensional end-systolic RA and LA volumes were measured using electrocardiogram (ECG)-gated MDCT images before the onset of the T wave. We injected 50 ml of contrast agent via the arm vein before acquiring the images. After acquisition, the images were reconstructed and transferred to a commercially available workstation (Syngo, Siemens, Germany) that uses Hounsfield unit-based endocardial border detection technology with appropriate manual correction. A semi-automated 3-dimensional reconstruction technique was applied to calculate the atrial volume (**Figure 1**). RA volumes excluded appendages, and the inferior and superior vena cava were manually eliminated. LA volumes also excluded appendages and the pulmonary veins were manually eliminated. Atrial volume was indexed to each patient's body surface area (RAVI and LAVI, respectively). Post-processing and image analysis were performed by 2 independent radiologists who were unaware of the patients' clinical and electrophysiological data.

Electrophysiologic Study and Radiofrequency Ablation

An electrophysiologic study was performed in patients in a postabsorptive state who had been sedated with midazolam and fentanyl. Multipolar catheters were positioned as follows: (1) a 20-pole catheter with 2-5-2 mm interelectrode spacing in the coronary sinus (CS) with the proximal electrode pair positioned at the lateral RA; and (2) a 10-pole catheter with 2-7-2 mm interelectrode spacing along the lateral RA, positioned to ensure that the first 10 electrodes were linearly arranged along the lateral RA border. Surface ECGs and bipolar endocardial electrograms were continuously monitored and stored on a computer-based digital amplifier/recorder system with optical disk storage for offline analysis. Intracardiac electrograms were filtered from 30 to 500 Hz and measured with computer-assisted calipers at a sweep speed of 400 mm/s.

A 3-dimensional geometry of the LA was reconstructed with a CARTO or NavX electroanatomic mapping system. Before ablation, triggers were evaluated after direct current cardioversion of AF. Circumferential pulmonary vein isolation was performed in all patients using a 3.5-mm irrigated-tip catheter (ThermoCool). We used a circular mapping catheter (Lasso, Biosense Webster) to confirm isolation of pulmonary veins. Successful ablation was defined by the elimination of all of the pulmonary vein potentials along the antrum or inside the veins (entry block). If AF was not terminated after the elimination of all of the pulmonary vein potentials, linear ablation and complex fragmented atrial electrogram ablation were performed. Cavotricuspid isthmus ablation was performed in all patients.

Sinus Node Function Sinus node function was evaluated as follows: (1) baseline sinus cycle length (CL) was determined over 10 consecutive sinus cycles; (2) sinoatrial conduction time (SACT) was determined after an 8-beat pacing train using the formula (SACT = [return − basic CL]/2) three times and averaged; and (3) corrected sinus node recovery time (CSNRT) was determined after a 30-s drive train at CL of 600, 500 and 400 ms, correcting for the baseline CL. At each CL, CSNRT was determined 3 times and averaged.

Effective Refractory Period (ERP) Atrial ERPs were evaluated twice at the diastolic threshold (for a pacing threshold of <2 mA) at CL of 600, 500, and 400 ms. An incremental technique was used, starting with an S2 coupling interval of 150 ms, and increased at increments of 5 ms. The ERP was defined as the longest coupling interval failing to propagate to the atrium. ERP was measured from the distal and proximal CS, while low and high lateral RA was measured 3 times during each CL at each site. If the maximum and minimum measurements differed by >10 ms, 2 more measurements were taken, and the total was averaged. The heterogeneity of the ERP was determined by the coefficient of variation of ERP at each CL (SD/mean×100%). The dispersion of ERP was determined by the difference between the highest and lowest ERPs.

Atrial Conduction Conduction time was assessed along the CS via pacing from the distal bipole (1–2) of the CS catheter and by measuring the time to activate the proximal bipole (9–10), and along the lateral RA by pacing from the distal bipole (1–2) of the lateral RA catheter and measuring the time to activate bipole 9–10. At both sites, conduction was measured at pacing CLs of 600, 500, and 400 ms during stable capture. Conduction time was determined 10 times at each CL and averaged. We evaluated conduction velocity by dividing interelectrode distance by conduction time.

Follow up

During hospitalization, all the patients were monitored by continuous ECG recordings. In the case of early AF recurrence, antiarrhythmic drug treatment (class Ic or amiodarone) followed by electrical cardioversion was instituted. According to the study protocol, antiarrhythmic drug treatment was withdrawn 3 months after ablation. After discharge, the patients were followed up with clinical examination, ECG, and Holter monitoring at 3, 6, 9, and 12 months. In the case of symptom recurrence between follow-up visits, patients were evaluated with clinical examination, ECG and Holter monitoring. AF recurrences within the first 3 months after ablation were defined as early recurrence. A successful outcome was defined as the absence of all documented arrhythmia (AF or atrial tachycardia) beyond the third month after ablation. Oral anticoagulation therapy was prescribed for at least 3 months.

Statistical Analysis

Continuous data are expressed as mean ± SD and normality tests were performed for each variable to determine whether a data set was well-modeled by normal distribution or not. The baseline characteristics of the 2 groups were compared using the 2-sample t-test for continuous variables, and the Chi-square test and Fisher's exact test for categorical variables. Univariate and multivariate logistic regression analysis was performed for evaluation of factors associated with early recurrence or 1-year recurrence. Pearson's bivariate correlation analysis was used to determine the correlation between variables. To assess multicollinearity, we determined the variance inflation factors. The receiver operating characteristics curve was used to determine the accuracy of a variable in predicting the recurrence. Statistical significance was established at a value of $P<0.05$.

Results

Patient Characteristics

Patient characteristics are provided in **Table 1**. The PeAF patients had a mean age of 55±12 years and consisted of 23

Table 1. Comparison of Baseline and Electrophysiologic Characteristics Between Patients With PeAF and PaAF

	PeAF (n=23)	PaAF (n=40)	P value
Clinical characteristics			
Male, n (%)	20 (87)	30 (75)	0.34
Age, years	55±12	58±9	0.28
Underlying diseases			
Congestive heart failure, n (%)	0 (0)	1 (3)	1.00
Hypertension, n (%)	14 (61)	17 (43)	0.20
Age >75 years, n (%)	2 (9)	1 (3)	0.55
Diabetes mellitus, n (%)	1 (4)	1 (3)	1.00
Stroke, n (%)	1 (4)	4 (10)	0.64
Dyslipidemia, n (%)	4 (17)	3 (8)	0.25
CHADS2 score	0.61±0.66	0.60±0.74	0.96
Electrophysiologic study parameters			
RA conduction velocity, m/s	0.86±0.21	0.99±0.26	0.06
LA conduction velocity, m/s	1.03±0.21	1.11±0.21	0.23
SA node conduction time, ms			
Pacing CL, 600 ms	189±150	167±152	0.62
Pacing CL, 500 ms	173±65	148±69	0.21
Pacing CL, 400 ms	139±66	143±85	0.87
CSNRT, ms			
Pacing CL, 600 ms	373±237	420±249	0.50
Pacing CL, 500 ms	424±232	388±307	0.66
Pacing CL, 400 ms	562±508	405±362	0.23
ERP, ms			
High lateral RA	223±41	229±28	0.73
Low lateral RA	234±35	239±21	0.53
Proximal CS	251±34	243±33	0.50
Distal CS	272±66	245±34	0.08

PeAF, persistent atrial fibrillation (AF); PaAF, paroxysmal AF; SA, sinoatrial; CL, cycle length; CSNRT, corrected sinus node recovery time; ERP, effective refractory period.

Table 2. Comparison of MDCT and Echocardiographic Parameters Between Patients With PeAF and PaAF

	PeAF (n=23)	PaAF (n=40)	P value
MDCT			
LA volume index, ml/m^2, [range]	94±25 [41–115]	73±18 [29–99]	<0.001
RA volume index, ml/m^2, [range]	84±19 [46–119]	67±15 [41–124]	0.001
Echocardiographic parameters			
LV EF, %	63±5	65±8	0.21
LA anterior-posterior diameter, mm	41±5	41±6	0.97
LA volume index, ml/m^2, [range]	39±11 [20–61]	31±8 [16–50]	0.001
LVEDD, mm	49±4	50±4	0.57
LVESD, mm	34±4	33±4	0.67

MDCT, multidetector computed tomography; LA, left atrium/atrial; RA, right atrium/atrial; LV, left ventricle; EF, ejection fraction; LVEDD, LV end-diastolic dimension; LVESD, LV end-systolic dimension. Other abbreviations as per Table 1.

patients including 20 men (87%). The PaAF patients (n=40) had a mean age of 58±9 years and included 30 men (75%). There was no significant difference in demographic findings between the 2 groups. The proportions of underlying conditions, including congestive heart failure, hypertension, age >75 years, diabetes mellitus and stroke were also grossly similar between the 2 groups. At the same time, electrophysiologic study parameters were not different between the 2 groups.

Anatomical Remodeling of RA and LA in AF

Table 2 demonstrates the comparison of MDCT and echocardiographic parameters between patients with PeAF and PaAF. Compared to PaAF patients, PeAF patients had larger LAVI (94±25 vs. 73±18 ml/m^2, P<0.001) and RAVI (84±19 vs. 67±15 ml/m^2, P=0.001). On echocardiographic evaluation, LAVI was also larger in PeAF patients than in PaAF patients (39±11 vs. 31±8 ml/m^2, P=0.001). Echocardiography considerably underestimated LAVI than MDCT (34±10 vs. 72±19 ml/m^2, P<0.001). Figure 2A shows the interrelationship between RAVI and LAVI determined with MDCT. The enlargement of the RA showed a significant strong positive correlation with the enlargement of LA (R=0.64, P<0.001) in AF patients

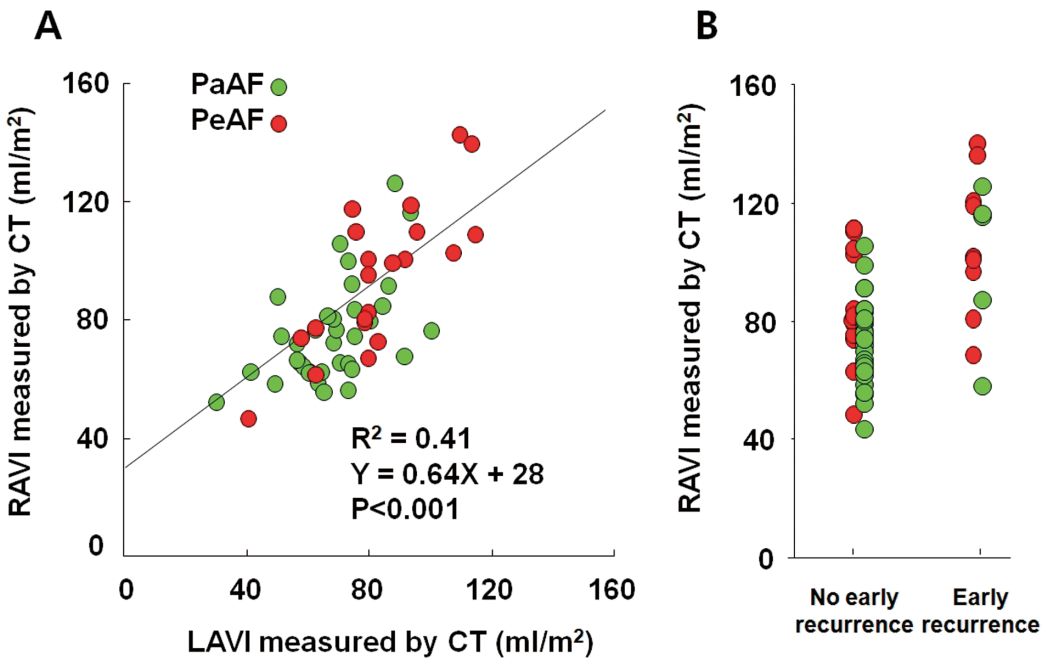

Figure 2. (**A**) The correlation between the right atrial volume index (RAVI) and left atrial volume index (LAVI) measured with multi-detector computed tomography (CT), showing a significant strong linear correlation (R=0.64, Y=0.64X+28.4, P<0.001) in the study sample. Paroxysmal atrial fibrillation (PaAF) and persistent atrial fibrillation (PeAF) patients were marked with green and red circles, respectively. (**B**) The comparison of RAVI between patients with early recurrence and the subjects without early recurrence.

Table 3. Comparison of Clinical Characteristics, Echocardiographic Parameters and MDCT Findings Between Patients With Early Recurrence of AF After Successful Ablation

	Early recurrence (n=13)	No early recurrence (n=50)	P value
Clinical characteristics			
Male, n (%)	12	38	0.19
Age, years	53±10	58±10	0.16
PeAF, n (%)	8 (62)	15 (30)	0.04
Underlying diseases			
Congestive heart failure, n (%)	1 (8)	0 (0)	0.21
Hypertension, n (%)	8 (62)	23 (46)	0.37
Age >75 years, n (%)	0 (0)	3 (6)	1.00
Diabetes mellitus, n (%)	0 (0)	2 (4)	1.00
Stroke, n (%)	1 (8)	4 (8)	1.00
Dyslipidemia, n (%)	1 (8)	6 (12)	1.00
CHADS2 score	0.85±0.56	0.54±0.73	0.17
Echocardiographic parameters			
LV EF, %	62±6	65±7	0.99
LA anterior-posterior diameter, mm	42±5	41±6	0.81
LA volume index, ml/m²	37±10	33±10	0.24
LVEDD, mm	51±3	50±4	0.43
LVESD, mm	35±4	33±4	0.18
MDCT			
LA volume index, ml/m²	78±15	72±19	0.23
RA volume index, ml/m²	98±21	77±22	0.003

Abbreviations as per Tables 1,2.

Table 4. Predictor of Early Recurrence of AF After Successful Ablation

	OR	CI	P value
Univariate			
PeAF	3.733	1.048–13.301	0.04
RA volume index (for each 10 ml/m² increase)	1.479	1.109–1.973	0.008
LA volume index (for each 10 ml/m² increase)	1.247	0.870–1.786	0.23
Multivariate			
PeAF	1.035	0.796–20.442	0.09
RA volume index (for each 10 ml/m² increase)	1.650	1.017–2.677	0.04
LA volume index (for each 10 ml/m² increase)	0.633	0.331–1.211	0.17

OR, odds ratio; CI, confidence interval. Other abbreviations as per Tables 1,2.

Table 5. Comparison of Clinical Characteristics, Echocardiographic Parameters and MDCT Findings Between Patients With 1-Year Recurrence Without Anti-Arrhythmic Drug Treatment After Successful Ablation of AF

	1-year recurrence (n=19)	No 1-year recurrence (n=44)	P value
Clinical characteristics			
Male, n (%)	16 (84)	34 (77)	0.53
Age, years	58±13	57±9	0.71
PeAF, n (%)	12 (63)	11 (25)	0.004
Underlying diseases			
Congestive heart failure, n (%)	1 (1)	0 (0)	0.13
Hypertension, n (%)	11 (58)	20 (45)	0.37
Age >75 years, n (%)	2 (1)	1 (0)	0.16
Diabetes mellitus, n (%)	0 (0)	2 (1)	0.35
Stroke, n (%)	2 (1)	3 (1)	0.62
Dyslipidemia, n (%)	4 (2)	3 (1)	0.10
CHADS2 score	0.63±0.60	0.59±0.76	0.84
Echocardiographic parameters			
LV EF, %	65±7	64±7	0.59
LA anterior-posterior diameter, mm	42±5	41±5	0.66
LA volume index, ml/m²	37±11	33±9	0.18
LVEDD, mm	50±4	50±4	0.89
LVESD, mm	33±4	34±4	0.71
MDCT			
LA volume index, ml/m²	80±18	70±17	0.04
RA volume index, ml/m²	91±27	77±20	0.02

Abbreviations as per Tables 1,2.

(Figure 2A).

RA Volume as a Predictor of Early Recurrence After Successful RFA of AF

Table 3 demonstrates comparison of clinical characteristics, echocardiographic parameters and MDCT findings between the patients with early recurrence and the subjects without early recurrence. The proportion of PeAF was higher in the early recurrence group. LAVI measured with echocardiography and MDCT were grossly similar between the patients with early recurrence and without early recurrence. However, RAVI determined with MDCT was significantly larger in the early recurrence group (Table 3). Interestingly, RAVI was the only significant predictor of early recurrence after successful RFA of AF, whereas PeAF and LAVI were not (Table 4). Variance inflation factors in the regression model among the variables used in multivariate regression model were as follows: the presence of PeAF (1.312), RAVI (2.277) and LAVI (2.254). In addition, RAVI ≥78 ml/m² were able to predict the early recurrence with fair sensitivity (0.737) and specificity (0.682) (AUC: 0.676, P=0.03). Figure 2B illustrates the comparison of RAVI between the early recurrence group and the patients without early recurrence.

Predictor of 1-Year Recurrence After Successful RFA of AF

The comparison of clinical characteristics, echocardiographic parameters and MDCT findings between the patients with 1-year recurrence and without recurrence are summarized in Table 5. Twelve (63%) and 11 (25%) patients had PeAF in the 1-year recurrence and no recurrence groups, respectively. PeAF was more common in the 1-year recurrence group (P=0.004). Echocardiography failed to find any difference in LAVI between the recurrence group and the no recurrence group. In contrast, LAVI and RAVI measured with MDCT were significantly larger in the recurrence group (P<0.05 for all). However, PeAF was the only independent predictor of 1-year recurrence of AF after RFA, while LAVI and RAVI were not (Table 6).

Table 6. Predictor of 1-Year Recurrence Without Anti-Arrhythmic Drug Treatment After Successful Ablation of AF

	OR	CI	P value
Univariate			
PeAF	5.143	1.620–16.327	0.005
RA volume index (for each 10 ml/m² increase)	1.319	1.029–1.691	0.03
LA volume index (for each 10 ml/m² increase)	1.415	1.004–1.994	0.047
Multivariate			
PeAF	4.496	1.110–18.211	0.04
RA volume index (for each 10 ml/m² increase)	1.388	0.908–2.121	0.13
LA volume index (for each 10 ml/m² increase)	0.865	0.500–1.497	0.61

Abbreviations are same as in Tables 1,2,4.

Discussion

The principal findings of the present study are: (1) RA anatomical remodeling is more severe in PeAF than PaAF, and the degree of remodeling was correlated with the severity of LA enlargement; (2) RA enlargement was closely related to the early recurrence after successful RFA of nonvalvular AF; (3) the 1-year recurrence of AF after RFA is associated with the chronicity of the disease, rather than both atrial volumes measured at the time of RFA. Our study suggests that even though LA is known to have a key role in the pathophysiology of AF, RA also has an impact on the early recurrence of AF after RFA. However, the independent prognostic meaning of RA anatomical remodeling is somewhat limited regarding the 1-year recurrence of AF after RFA.

Atrial Anatomical Remodeling in AF

It is believed that atrial structural remodeling, such as atrial enlargement, cellular hypertrophy,[6] dedifferentiation,[14] fibrosis,[15] apoptosis[16,17] and myolysis[17] is a main contributor to the initiation and persistence of AF.[18] The relationship between atrial enlargement and AF has been established by numerous research studies.[19–21] However, these studies mainly focused on LA, and data regarding the structure and remodeling of RA is rare. Until recently, even a reference value had not been established for RA size.[22] As revealed in the current investigation, RA volume and LA size were more increased in patients with PeAF than in subjects with PaAF. Thus, it can be said that the severity of RA anatomical remodeling, along with LA enlargement, is correlated with the chronicity of AF. To the best of our knowledge, this is the first study to investigate the RA anatomic remodeling assessed with MDCT in AF patients.

Our knowledge of the influence of RA anatomical remodeling is scanty, not only in AF but in many other cardiac diseases as well. At the same time, the influential factors in RA enlargement remain to be determined. In this study, we excluded the patients with chronic lung disease, pulmonary hypertension or organic heart disease, including significant tricuspid regurgitation or myocardial disease involving the RV, all of which might contribute to the RA enlargement. Therefore, we think the determinant of RA enlargement of our study patients was AF itself. Currently, the most frequently used diagnostic imaging tool to measure cardiac chamber sizes is the transthoracic echocardiography. However, echocardiographic windows for evaluating RA size are technically challenging and the information regarding the structural remodeling and size of the RA is also limited.[13] In contrast, the recently developed MDCT provides reliable 3-dimensional reconstruction images of the RA acquired with high spatial resolutions. In this study, we were able to determine effectively and reliably both atrial sizes with MDCT.

RA Enlargement Is an Independent Predictor of Early Recurrence of AF After RFA

Significant RA remodeling including decreases in sarcomere content, and myolysis has been reported in RA appendages from PeAF patients, but not from PaAF patients.[23,24] In chronic AF, stepwise ablation of LA, including the pulmonary vein, roof line, CS, complex LA activities, and mitral isthmus, failed to terminate AF in 21% patients, suggesting that RA contributes, at least partially, to the maintenance of AF.[25] Meanwhile, Elayi et al reported that the bi-atrial ablation of a complex fragmented atrial electrogram has a minimal impact on AF termination during ablation.[26] However, the impact of the RA on the outcomes of AF after RFA is still controversial. As revealed in this study, the RA volume affects the early recurrence after RFA and it might be more important than LA size, at least in that aspect. Although LA anatomical remodeling is a key determinant of AF prognosis after RFA, our study patients were highly selected for RFA, so the patients with severe LA enlargement were excluded before RFA. In our opinion, in this patient group, RA volume had additional prognostic information for early recurrence.

Determinants of 1-Year Outcome of AF After RFA

Both atrial volumes were larger in patients with 1-year recurrence. However, RA volume and LA volume were not able to predict independently the 1-year recurrence in our study group. Rather, the chronicity of AF was an independent predictor of 1-year outcome. It is well known that LA volume is an independent predictor of AF recurrence after catheter ablation.[27] Interestingly, as shown in the results, both atrial volumes have a close interrelationship with each other and the severity of atrial anatomical remodeling also correlated with the chronicity of AF. The close relationship between both atrial volume and chronicity of AF might be the reason why atrial volumes are not able to predict independently 1-year recurrence after RFA.

Study Limitations

Limitations of this study should be addressed. First, this was a single tertiary center study and our patients were carefully selected for RFA of AF. Therefore, the study subjects might not be representative of the overall patient population with AF. Second, the method for atrial volume measuring with MDCT used in this study is not widely validated. Third, in this study, we used the prolate ellipsoid formula to measure the LA volume with echocardiography. Although the biplane area-length methods[13] are recommended for measuring the LA volume by

the American Society of Echocardiography, it was difficult to trace the exact border of LA in AF patients with severe LA remodeling. The prolate ellipsoid formula is known to underestimate the LA volume more than the other method.[28] Interestingly, LA size measured by MDCT is approximately 2-fold larger than that measured by echocardiography. In our opinion, echocardiographic measurement of LA volume has its inborn limitation in patients with severely abnormal LA and thus it is not suitable for application to patients with AF who have extreme LA. Fourth, because electrophysiological parameters were measured after sedation, these cannot be considered to be baseline measurements. However, comparing electrophysiological parameters between PaAF and PeAF patients has no crucial problem, because both groups were in an identical sedation status. Finally, pulmonary vein antrum isolation in patients with AF resulted in a significant decrease of LA size,[29] and LA volume decrease was related to the recurrence pattern after AF ablation.[30] The evaluation of the change in RA volume after AF ablation will be important to reveal the precise role of RA in AF. Unfortunately, however, we do not have the 1- or 2-year follow-up MDCT data in our cohort and thus the probable reverse remodeling of RA after AF ablation has not been revealed in our study. Despite those limitations, our results provide important new insights into better understanding the prognostic impact of the RA in AF patients who undergo RFA, which is mainly performed in the LA.

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