Predictors and Incidence of Atrial Flutter After Catheter Ablation of Atrial Fibrillation

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Atrial flutter (AFL) is a common form of arrhythmia recurrence after atrial fibrillation (AF) ablation. We aimed to define (1) the incidence of AFL and (2) the clinical factors associated with cavo-tricuspid isthmus dependent (typical) and atypical AFL, after AF ablation. The retrospective cohort consisted of 1,029 patients that underwent initial radiofrequency AF ablation from May 2005 to December 2013 at a single academic center. Patients with missing follow-up data, history of AFL ablation, and those with undocumented AFL were excluded. Atrial volumes were measured using three-dimensional cardiac computed tomography or magnetic resonance imaging. A total of 607 patients were included in the final cohort (age 59.2 ± 10.6 years, 76.0% men, 58.7% paroxysmal AF). During a median follow-up of 845 days (interquartile range 389 to 1,597 days), 122 (20.1%) patients developed AFL. Of these, 17 had typical AFL, 98 had atypical AFL, and 7 patients had both circuits. In the multivariable Cox regression analysis, only right atrial volume index (hazard ratio [HR] 1.25 per 10 ml/m^2, confidence interval [CI] 95% 1.10 to 1.42) was associated with incident typical AFL; whereas persistent AF (HR 1.59, CI 95% 1.06 to 2.40), linear lesions (HR 1.58, CI 95% 1.02 to 2.46) and left atrial volume index (HR 1.17 per 10 ml/m^2, CI 95% 1.07 to 1.27) were associated with incident atypical AFL. In conclusion, noninvasive measures of right and left atrial remodeling are strongly associated with incident AFL after AF ablation. Strategies to prevent incident AFL using these measures after index ablation warrant further investigation. **(Am J Cardiol 2019;124:1690−1696)**

Catheter ablation of atrial fibrillation (AF) has become an established treatment modality in symptomatic patients.[1] However, atrial arrhythmias recur after AF ablation at a considerable rate, and atrial flutter (AFL) comprises an important proportion of these recurrences.[2,3] AFL is often persistent and more resistant to conservative management, and these patients usually present with severe symptoms requiring hospitalization, cardioversion or a repeat procedure.[4] Post-pulmonary vein isolation (PVI) AFL is most likely to originate from the LA. Procedure-related risk factors have been previously defined for left-sided (atypical) AFL, and include presence of linear lesions, gaps in the ablation lines, recovered conduction or longer ablation times.[5−7] However, less is known about pre-existing structural factors that may increase the risk of atypical AFL. Moreover, the incidence and predictors of cavo-tricuspid isthmus (CTI) dependent (typical) AFL after AF ablation remain undefined. The recent consensus statement on AF recommends the addition of a CTI ablation line in cases of spontaneous documented and/or induced typical AFL.[4] The role of empiric CTI ablation in the absence of documented or induced AFL is unknown. In this study, we sought to assess the incidence of AFL and clinical factors that associate with typical and atypical AFL, after AF ablation.

Methods

Consecutive patients that underwent catheter ablation for AF at the Johns Hopkins Hospital from May 2005 to December 2013 were retrospectively reviewed. The study cohort was selected from 1,029 patients in the source cohort that underwent initial PVI within the study period. The study flow chart is illustrated in Supplement 1. The cohort exclusion criteria were as follows: (1) Aborted PVI due to procedure-related complication or inability to cross the atrial septum, (2) Ablative energy source other than radiofrequency, (3) History of previous AFL ablation, (4) Concomitant AFL ablation at the time of PVI and/or empiric CTI lines, (5) History of AFL after PVI, but unavailable proof of the AFL, and (6) Absence of follow-up data beyond the 90 day blanking period.

Baseline demographics, clinical, echocardiographic, electrocardiographic, and procedural characteristics of the patients were assessed using the electronic database of the Johns Hopkins Hospital. For baseline electrocardiography,

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only the recordings available within the last month of catheter ablation were included, and the electrocardiography data of the patients with paced rhythm were not analyzed. Paroxysmal AF was defined as AF episodes that terminated spontaneously within 7 days; persistent AF was defined as AF sustained beyond 7 days or AF that required cardioversion. The Johns Hopkins University Institutional Review Board approved the study, and written informed consent was obtained from all participants.

Most participants (n = 690, 97%) underwent preprocedural 3D advanced cardiac imaging with cardiac tomography (73%) or cardiac magnetic resonance imaging (24%). OsiriX Software (Geneva, Switzerland) was used to measure LA and right atrium (RA) volumes by contouring axial slices of the atria, excluding PVs using the 3D volumetric method. Indexed volumes were calculated by dividing the volumes by body surface area and interpreted as LA volume index (LAVi) and RA volume index (RAVi). In 47 patients, 3D advanced cardiac imaging were lost in the PACS server; therefore atrial volumetric data could not be measured. The definition of the PV variant such as left common and right middle vein was made on the basis of previous studies.[8] For pulmonary variant, advanced cardiac imaging reports were used whenever available, if not available, angiographic evaluation at the time of ablation procedure was used.

The approach used for catheter ablation of AF and the temporal trends at our institution have been described previously.[9] After 2005, technique and tools remained relatively unchanged: all patients underwent radiofrequency catheter ablation to achieve electrical isolation using a wide antral circumferential ablation method. A 3.5 mm tip open irrigated catheter was used for mapping and ablation. Electroanatomic mapping of the LA endocardium was used in all cases, with guidance provided by registration of a preacquired 3D cardiac tomography or cardiac magnetic resonance imaging. After wide area circumferential ablation around the pulmonary venous antra, a circular multipolar electrode-mapping catheter was used to evaluate electrical isolation and additional ablations were applied in case of remaining potentials. Additional linear lesions and/or ablation of complex fractionated atrial electrograms were performed based on operator discretion. Patients with persistent AF underwent the procedure in AF. In these cases, the isolation of the PVs was confirmed with complete elimination of the intracardiac electrograms in AF. Some patients converted to sinus rhythm during isolation of the PVs or during the substrate modification. Toward the end of the procedure, patients who remained in AF underwent electrical cardioversion and complete isolation of the PVs was reconfirmed in sinus rhythm.

After the procedure, previously ineffective antiarrhythmic medications were continued in the majority of the patients. Patients were seen in an outpatient clinic 3 months after the ablation procedure. In general, antiarrhythmic medications were discontinued at 3 months in the absence of symptoms. The follow-up evaluation consisted of a detailed history, physical examination, and a 12-lead electrocardiogram. After 3 months, patients were followed by either clinic visits and/or phone contacts. In case of suggestive symptoms, patients underwent 24-hour Holter monitoring or 30-day event monitoring depending upon symptom frequency. All documents in the electronic database were reviewed to detect documented arrhythmia. These included all 12-lead electrocardiograms, Holter monitoring, event recorders, and pacemaker interrogations. In cases of outside hospital admissions, scanned recordings were tracked to evaluate the underlying rhythm. Patients without AFL were censored at the time of their last available follow-up.

Incident spontaneous AFL was defined as symptomatic or asymptomatic Electrocardiography (ECG)-documented AFL longer than 30 seconds in duration. A subset of the patients who developed AFL underwent a repeat procedure. During the repeat procedure, rapid atrial pacing from the coronary sinus was used to induce arrhythmia in patients presenting in sinus rhythm. The diagnosis and characterization of AFL was made based on activation and entrainment mapping and postpacing intervals. Ablation of AFL was performed after localization of the reentry circuit. In the absence of electrophysiology study for AFL, 2 expert reviewers who were masked to clinical information evaluated the ECG-documented arrhythmia, and the final diagnosis was made on the basis of agreement between the readers. The readers diagnosed typical AFL if the documented rhythm showed a saw tooth pattern in inferior leads, positive F waves in lead V1, and isoelectric or negative in leads V5 to V6. The diagnosis of atypical AFL was made if the F-wave morphology was not suggestive of typical AFL.

Statistical analyses were performed using SPSS software version 22.0 (IBM Corp., Armonk, New York). Continuous variables were presented as mean ± standard deviation or median and interquartile range (IQR), and categorical variables were presented as frequencies and percentages, where appropriate. Differences between groups were evaluated using the Student *t* test for continuous variables and the chi-square test for categorical variables. The receiver operating characteristic (ROC) curve was used to detect the optimal threshold for RAVi and LAVi to estimate AFL-free survival. Kaplan-Meier survival curves were utilized to visualize the AFL-free survivals in patient subgroups. Univariate and multivariable Cox regression analyses were performed to assess the association of the independent variables with time to incident AFL.

Results

The final cohort consisted of 607 patients. Mean age was 59.2 ± 10.6 years, 76.0% of the patients were men, and 58.7% of the patients had paroxysmal AF. A total of 122 (20.1%) patients had linear lesions at the initial PVI. The most common linear lesion was a roof-line followed by posterior box lesion and floor line. At baseline, 78.7% of the patients were on antiarrhythmic drugs, and discharged with these antiarrhythmics after PVI. Amiodarone was the most common antiarrhythmic drug, followed by flecainide. During a median follow-up of 845 days (IQR 389 to 1,597 days), 122 (20.1%) patients developed post-PVI AFL. Of those, 17 patients had typical AFL, 98 patients had atypical AFL, and 7 patients had both sided AFL. Median time to first documented incident AFL was 159.5 (IQR 64 to 637.5) days, (151.9 days in typical AFL, 199 days in atypical AFL). A total of 24 (19.6%) patients presented within 1 month after the PVI, 62 (50.8%) patients presented within

1 year but after 1 month after PVI, 36 (29.5%) patients presented after 1 year after PVI. Of 122 patients who developed AFL, 80 (65.6%) patients were on antiarrhythmic drug at the time of first documented AFL episode (58.6% of the typical AFL patients and 67.6% of the atypical AFL), most commonly amiodarone followed by propafenone and flecainide. Of the patients who developed AFL, 52 (42.6%) patients had a repeat procedure and had AFL ablation at the time of the repeat procedure. Of 52 patients, 41 (78.8%) were in AFL at the time of repeat ablation. In the rest, AFL was induced or empiric AFL ablation was performed. Among 52 patients that underwent AFL ablation, 32 had (61.5%) atypical AFL ablation, 11 (21.2%) had typical AFL ablation, and 9 (17.3%) had both of the circuits ablated. Atypical AFL was determined most commonly to be perimitral (51.6%), followed by macroreentry near the PV antra (29%), and involving the LA roof/posterior wall (19.4%). Mean cycle length was 240.7 ± 34 seconds in patients with typical AFL, and 243.4 ± 61.3 seconds in patients with atypical AFL.

The baseline characteristics of the patients with incident atypical AFL are summarized in Table 1. Persistent AF and linear lesions were more common in patients with atypical AFL. The right atrial and left atrial size as assessed using RAVi and LAVi were significantly higher in patients with atypical AFL. Although not statistically significant, congestive heart failure tended to be more common in the atypical AFL group. Similarly, radiofrequency time was slightly longer in the atypical AFL group compared with controls. The baseline characteristics of the patients with incident typical AFL are summarized in Table 2. Although not statistically significant, the prevalence of persistent AF was slightly higher in patients with typical AFL. LAVi and RAVi were significantly higher in patients with typical AFL compared with controls.

The Cox Proportional Hazards models for typical AFL incidence are listed in Table 3. After adjusting for age, gender, body mass index, and AF type; RAVi was the only variable that was associated with typical AFL. The Cox Proportional Hazards models for atypical AFL incidence are listed in Table 4. After adjusting for age, gender, body mass index, linear lesions, and AF type; persistent AF, linear lesions and LAVi were found to be associated with atypical AFL.

In the ROC analysis, baseline RAVi ≥71.5 (ml/m^2) predicted typical AFL with 67% sensitivity and 81% specificity (area under curve 0.77, p <0.001; Supplement 2, Panel 2a). Baseline LAVi ≥60.6 ml/m^2 predicted atypical AFL with 65% sensitivity and 60% specificity (area under curve 0.65, p <0.001; Supplement 2, Panel 2b). Patients were divided into subgroups on the basis of these thresholds. Figure 1 demonstrates Kaplan-Meier curves of typical AFL-free survival among patients with RAVi ≥71.5(ml/m^2) versus RAVi <71.5 (ml/m^2). Figure 1 demonstrates Kaplan-Meier curves of atypical AFL-free survival among patients with LAVi ≥60.6 (ml/m^2) versus LAVi <60.6 (ml/m^2). In patients with

Table 1
Baseline characteristics of the patients that presented with atypical atrial flutter after catheter ablation of atrial fibrillation and comparison with the controls

Variable	Atrial flutter		p
	Yes (n = 105)	No (n = 485)	
Age (years)	60.6 (±8.9)	58.8 (±10.9)	0.09
Men	82 (78.1%)	368 (75.9%)	0.63
Body mass index (kg/m^2)	30.4 (±6.2)	29.0 (±5.7)	0.03
Smoker	27 (30.3%)	133 (33.7%)	0.55
Hypertension	57 (54.3%)	259 (53.4%)	0.87
Diabetes mellitus	11 (10.5%)	36 (7.4%)	0.3
Coronary artery disease	14 (13.3%)	66 (13.6%)	0.94
Heart failure	15 (14.3%)	40 (8.2%)	0.05
Cerebrovascular event	9 (8.6%)	43 (8.9%)	0.92
Sleep apnea	20 (19%)	93 (19.2%)	0.98
On continuous positive airway pressure therapy	10 (9.6%)	49 (10.2%)	0.87
CHA_2DS_2VASc Score ≥2	47 (44.8%)	221 (45.6%)	0.88
Persistent atrial fibrillation	64 (61%)	196 (40.4%)	<0.001
Antiarrhythmic drug use	76 (72.4%)	390 (80.4%)	0.07
Cardiac surgery	8 (7.6%)	34 (7%)	0.83
Total radiofrequency ablation time (min)	52.2 (±16.7)	48.6 (±17.6)	0.06
Complex fractionated atrial electrograms ablation	7 (6.7%)	23 (4.7%)	0.42
Linear lesions	31 (29.5%)	88 (18.1%)	0.01
Complete pulmonary vein isolation	100 (95.2%)	468 (96.5%)	0.57
Left atrium size (cm)	4.75 (±0.75)	4.58 (±0.76)	0.05
Left ventricular ejection fraction (%)	55.7 (±10.8)	55.9 (±9.0)	0.81
Systolic pulmonary artery pressure (mm Hg)	32.1 (±5.78)	31.6 (±8.0)	0.78
Left atrium volume index (ml/m^2)	69.4 (±22.3)	59.1 (±21.1)	<0.001
Right atrium volume index (ml/m^2)	63.1 (±20.0)	57.2 (±21.5)	0.01
Pulmonary vein variation	34 (32.4%)	141 (29.2%)	0.52
PR interval (ms)	187.5 (±33.4)	182.1 (±45.6)	0.35
QRS duration (ms)	103 (±34.5)	99.6 (±18.7)	0.33
QTc interval (ms)	438.4 (±48.2)	439.9 (±40.7)	0.75

Table 2
Baseline characteristics of the patients that presented with typical atrial flutter after catheter ablation of atrial fibrillation and comparison with controls

Variable	Atrial flutter		p
	Yes (n = 24)	No (n = 485)	
Age (years)	60.4 (±9.4)	58.8 (±10.9)	0.5
Male gender	19 (79.2%)	368 (75.9%)	0.63
Body mass index (kg/m^2)	28.3 (±6.1)	29.0 (±5.7)	0.54
History of smoking	6 (26.1%)	133 (33.7%)	0.45
Hypertension	17 (70.8%)	259 (53.4%)	0.09
Diabetes mellitus	2 (8.3%)	36 (7.4%)	0.7
Coronary artery disease	2 (8.3%)	66 (13.6%)	0.76
Heart failure	2 (8.3%)	40 (8.2%)	1
Cerebrovascular event	1 (4.2%)	43 (8.9%)	0.71
Sleep apnea	4 (16.7%)	93 (19.2%)	1
On continuous positive airway pressure therapy	3 (13%)	49 (10.2%)	0.72
CHA_2DS_2VASc Score ≥2	11 (45.8%)	221 (45.6%)	0.98
Persistent atrial fibrillation	14 (58.3%)	196 (40.4%)	0.08
Antiarrhythmic drug use	18 (75%)	390 (80.4%)	0.6
Cardiac surgery	3 (12.5%)	34 (7%)	0.41
Total radiofrequency ablation time (min)	51.3 (±30)	48.6 (±17.6)	0.47
Complex fractionated atrial electrograms ablation	1 (4.2%)	23 (4.7%)	1
Linear lesions	0 (0%)	5 (1%)	1
Complete pulmonary vein isolation	24 (100%)	468 (96.5%)	1
Left atrium size (cm)	4.82 (±0.86)	4.58 (±0.76)	0.14
Left ventricular ejection fraction (%)	55.2 (±10.5)	55.9 (±9.0)	0.7
Systolic pulmonary artery pressure (mm Hg)	29.6 (±6.8)	31.6 (±8.0)	0.45
Left atrium volume index (ml/m^2)	70.8 (±20.8)	59.1 (±21.1)	0.02
Right atrium volume index (ml/m^2)	79.3 (±24.8)	57.2 (±21.5)	<0.001
Pulmonary vein variation	6 (25%)	141 (29.2%)	0.66
PR interval (ms)	178.7 (±27.0)	182.1 (±45.6)	0.78
QRS duration (ms)	102.8 (±21.6)	99.6 (±18.7)	0.44
QTc interval (ms)	454.4 (±69.3)	439.9 (±40.7)	0.12

Table 3
Cox regression models to predict typical atrial flutter after catheter ablation of atrial fibrillation

Variable	Unadjusted			Adjusted*		
	HR	95% CI	p	HR	95% CI	p
Age	1.01	0.97-1.05	0.53	1.01	0.97-1.05	0.62
Female gender	0.83	0.31-2.22	0.71	0.88	0.33-2.40	0.81
Body mass index	0.98	0.91-1.05	0.54	0.97	0.90-1.05	0.47
Persistent atrial fibrillation	1.95	0.87-4.38	0.11	1.99	0.87-4.54	0.10
Left atrial volume index†	1.19	1.02-1.38	0.03	1.16	0.98-1.37	0.08
Right atrial volume index†	1.27	1.13-1.42	<0.001	1.25	1.10-1.42	0.001

* Adjusted for age, gender, body mass index, atrial fibrillation type. The individual variables were not entered in the models multiple times.
† The calculations were done per 10 ml/m^2.
CI = confidence interval; HR = hazard ratio.

RAVi ≥71.5 (ml/m^2) and with LAVi ≥60.6 (ml/m^2), typical and atypical AFL-free survival rate was significantly decreased.

Discussion

In this study, we showed that AFL incidence exceeds 15% after AF ablation, and that patients with dilated atria; RAVi ≥71.5 (ml/m^2) and LAVi ≥60.6 (ml/m^2) are at higher risk for development of right and left AFL, respectively. The association of atrial volume with AFL incidence after PVI is a novel finding that suggests intrinsic structural factors are important determinants of fixed reentry. We also confirmed previously reported observations regarding the association of linear lesions and persistent AF with atypical AFL; however, RAVi was the only parameter that predicted typical AFL after PVI. As seen in the Kaplan-Meier curves, typical AFL mostly occurred within 2 years after PVI, but the time to first documented AFL varied in atypical AFL, ranging from a few days to several years after PVI.

Atypical AFL comprises a significant proportion of the recurrences after AF ablation and the management of these cases can be challenging due to severe symptoms and persistence of the arrhythmia.[4] The incidence of post-PVI atypical AFL has been reported as 4% to 20% across different series.[10–12] The variability of the incidence among different

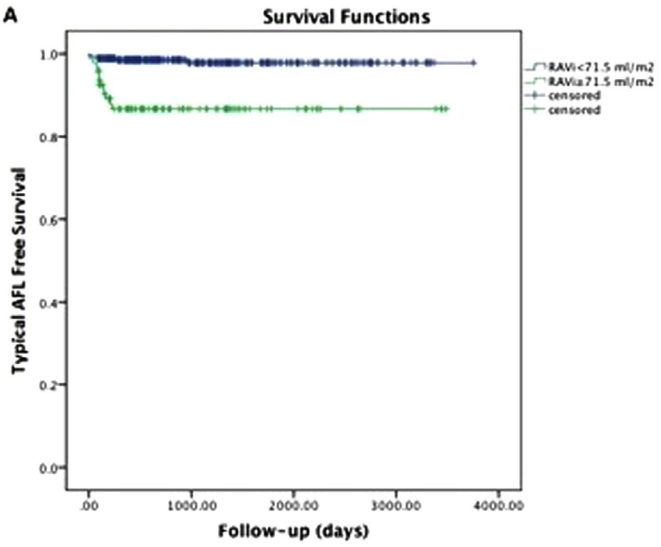
Table 4
Cox regression models to predict atypical atrial flutter after catheter ablation of atrial fibrillation

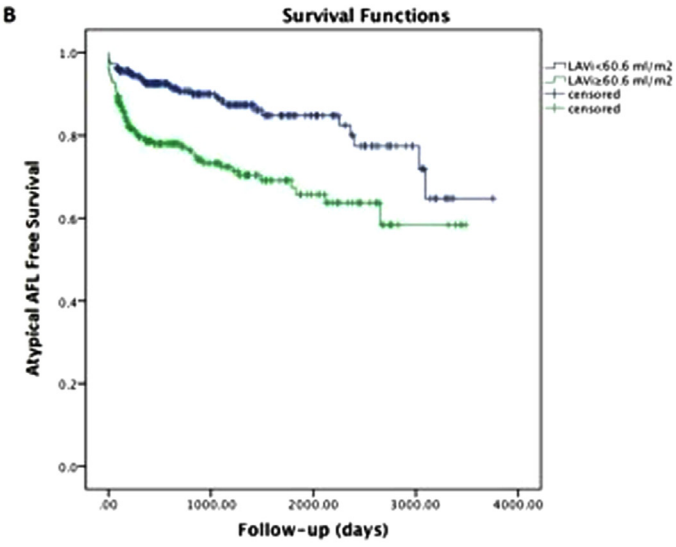
Variable	Unadjusted			Adjusted*		
	HR	95% CI	p	HR	95% CI	p
Age	1.01	0.99-1.03	0.14	1.01	0.99-1.03	0.19
Female gender	0.95	0.60-1.51	0.82	0.99	0.62-1.59	0.98
Body mass index	1.03	1.002-1.07	0.04	1.03	0.99-1.06	0.06
Persistent atrial fibrillation	1.87	1.26-2.77	0.002	1.59	1.06-2.40	0.03
Linear lesions	1.88	1.24-2.87	0.003	1.58	1.02-2.46	0.04
Heart failure	1.66	0.96-2.87	0.07	1.29	0.73-2.27	0.38
Antiarrhythmic drug	0.74	0.49-1.14	0.18	0.66	0.43-1.02	0.06
Left atrial volume index†	1.17	1.09-1.26	<0.001	1.17	1.07-1.27	<0.001
Right atrial volume index†	1.11	1.03-1.20	0.01	1.07	0.98-1.16	0.14

* Adjusted for age, gender, body mass index, atrial fibrillation type, linear lesions, and heart failure. The individual variables were not entered in the models multiple times.

† The calculations were done per 10 ml/m^2.

CI = confidence interval; HR = hazard ratio.





	Total N	N of Events	Censored N	Censored Percent
RAVi < 71.5 ml/m^2	355	6	349	98.3%
RAVi ≥ 71.5 ml/m^2	96	12	84	87.5%
Overall	451	18	433	96.0%

	Total N	N of Events	Censored N	Censored Percent
LAVi < 60.6 ml/m^2	293	34	259	88.4%
LAVi ≥ 60.6 ml/m^2	237	63	174	73.4%
Overall	530	97	433	81.7%

Figure 1. Kaplan-Meier curves display atrial flutter free survivals in patient subgroups that were grouped on the basis of receiver operating characteristic curve derived right atrium volume index and left atrium volume index thresholds. Panel A and Panel B indicate typical atrial flutter and atypical atrial flutter free survival, respectively. AFL = atrial flutter; LAVi = left atrium volume index; RAVi = right atrium volume index.

cohorts may be due to differences in patient characteristics, ablation techniques, follow-up duration or methods for AFL detection/definition. Previous studies evaluated patients with post-PVI AFL and defined procedural risk factors.[10,13] Those included linear lesions, gaps in the ablation lines, delayed recovery, and extensive ablation.[10,13–15] In the present study, patients with post-PVI AFL more likely to have had linear lesions performed at the time of initial PVI. In recent randomized trials, additional linear lesions did not improve outcomes; they prolonged the procedure duration and increased the radiation dose.[16,17]

The current study shows that LAVi, a readily available and generalizable measure of the LA size and extent of remodeling, is strongly associated with post-PVI AFL in a large cohort of AF patients referred for ablation, likely reflecting the underlying substrate and remodeling that serves as a suitable environment for fixed re-entry. Although there are several studies that examined the association of LA volume with outcome after AF ablation, no study to date has reported an association between LA size and post-PVI AFL. Most studies assessed LA size using diameter measurement, which is inferior to volume

assessment.[18] Another explanation may be the longer follow-up duration of our study cohort. Procedural factors tend to be associated with AFL incidence during short-term follow-up, whereas intrinsic factors may be associated with long-term outcome.

In the general population, typical AFL is encountered with an incidence of 88 of 100,000 person-years, and the clinical risk factors are age, male gender, heart failure, and chronic obstructive lung disease.[19] In the course of AF, AFL is common, and patients with AFL also have higher risk of developing AF.[20,21] AF can organize to typical AFL, but typical AFL may occur in the absence of an AF trigger as well.[22] It is also possible for AFL to degenerate into AF.[21] Moreover, the underlying atrial substrate may provoke both arrhythmias and may explain why both arrhythmias often coexist in an individual.[23] In a previous study, Scharf et al evaluated the inducibility of typical AFL in patients who underwent AF ablation.[24] One third of the patients had an inducible typical AFL, and presented with AFL when CTI ablation was not performed at the time of PVI. The incidence of the post-PVI typical AFL was much higher than that of our cohort (23% vs 4%). Notably, we have excluded patients with a previous history of CTI ablation, and all of our patients with inducible typical AFL at the time of initial PVI underwent a CTI ablation. In a study by Moreira et al, new-onset typical AFL was observed in 8.1% of the patients after AF ablation.[21] The results of this study were in line with our findings and may support the hypothesis that elimination of the AF triggers may reduce the incidence of the typical AFL. In that study, the authors concluded that co-existence of typical AFL and AF may indicate more severe disease and electrical remodeling in the both atria. In our study cohort, patients with incident typical AFL had higher RAVi and LAVi. It appears that atrial dilation is associated with the substrate that promotes both AF and typical AFL.

AF is associated with structural remodeling which often manifests as enlargement of the LA. It is now well established that increased LA size is a clinical risk factor for AF recurrence following ablation.[25] Data regarding RA remodeling and associations with outcome, however, have been limited. One study evaluated RA and LA atrial size to predict outcome in patients who underwent cardioversion.[26] In this study, RAVi was found to be superior to LAVi in predicting AF recurrences after cardioversion in 95 patients. Similarly, in a study with 63 patients, RAVi predicted short-term outcomes after AF ablation better than LAVi.[27] The authors reported that patient with persistent AF had larger RAVi, and the RAVi was closely associated with LAVi. Atrial remodeling indicates more advanced disease, and such patients are more prone to atrial arrhythmias. In our cohort, atrial enlargement was the only predictor of typical AFL, likely because it directly reflects the arrhythmogenic substrate for fixed circuit reentry.

Our findings suggest that noninvasive assessment of the atria may be useful in the clinical setting to estimate the likelihood of post-PVI AFL. Patients with RAVi $\geq$71.5 (ml/m^2) may benefit from empiric CTI lines, even in the absence of history of documented AFL. The clinical utility of the LAVi is less clear, due to lack of evidence to prevent atypical AFL, and the role of an induction study to examine their propensity for AFL at the time of initial PVI is controversial. We may create more arrhythmogenic substrate by adding a mitral isthmus line in case of an induced atypical AFL. Avoiding excessive ablation and limiting the use of linear lesions in patients with LAVi $\geq$60.6 (ml/m^2) seems to be a prudent strategy to prevent future atypical AFL episodes.

Our single-center cohort may not reflect the characteristics of the general population and has the limitations of a retrospective and observational study. Although we have applied strict inclusion criteria to make the data more homogeneous, there may be some changes in catheters, imaging, and techniques used for AF ablation throughout the study period. Only a subset of the patients with AFL underwent an electrophysiology study and had the arrhythmia circuits localized. In others, 2 readers blinded to other clinical parameters, reviewed and diagnosed the ECG-documented AFL. However, due to multiple other factors, such as existence of scar tissue may have caused atypical morphology on ECGs. We cannot exclude the possibility that the surface electrocardiogram may have been misleading in some of the cases. Finally, routine continuous monitoring was not performed, and some patients had shorter follow-up data. Some of the asymptomatic AFL recurrences might have been overlooked. Therefore, we may have underestimated the incidence of AFL.

In conclusion, incident AFL was common after AF ablation. RA size and LA size were associated with typical AFL and atypical AFL, respectively. Strategies to investigate and suppress AFL in patients with dilated atria warrant prospective investigation.

Disclosures

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Supplementary materials

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