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Original Article

Anteroposterior Diameter of The Left Atrium Determines The Occurrence of Left Atrial Tachycardia in Non–Paroxysmal Atrial Fibrillation Patients After Catheter Ablation

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Abstract

Objectives: The relationship between left atrial (LA) size and atrial fibrillation (AF) is well-established. However, the specifics of LA regional remodeling and its connection to left atrial tachycardia (LA-AT) post-ablation in patients with non-paroxysmal AF are less understood. This study aims to explore how LA dimensions are related to the development of LA-AT following AF ablation procedures in these patients.

Methods: This study focused on 73 patients with non-paroxysmal atrial fibrillation (average age 52, predominantly male, with a nearly even split between persistent and long-lasting persistent AF), all undergoing their first catheter ablation for AF. Prior to the ablation, left atrial dimensions were determined through computed tomography, measuring the maximal transverse, anteroposterior, and superoinferior diameters.

Results: Over an average follow-up period of 23 months, 31.5% of the patients (Group 1; comprising 23 patients with the occurrence of LA-AT during follow-up) experienced left atrial tachycardia (LA-AT) that required a second linear ablation procedure. This group had significantly larger left atrial (LA) dimensions in terms of transverse, anteroposterior, and superoinferior measurements compared to the other group (Group 2; comprising of 50 patients without the occurrence of LA-AT during follow-up). However, the recurrence of atrial fibrillation (AF) was not linked to any specific LA diameter. The anteroposterior diameter was identified as a significant predictor (p=0.002, HR 2.3, 95% CI 1.3-3.8) for LA-AT occurrence through multivariate analysis.

Conclusions: Eccentric dilatation involving the anteroposterior diameter is a significant predictor for the occurrence of LA-AT in patients with non-paroxysmal AF after catheter ablation.

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Keywords: *Atrial fibrillation; Atrial flutter; Atrial tachycardia; Left atrial diameter; Catheter ablation; Computed tomography*.

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Introduction

Atrial fibrillation (AF) is the most common clinical arrhythmia, leading to severe cardiovascular events such as ischemic stroke and acute heart failure[1]. Various treatments are recommended, including anti-arrhythmic drugs and catheter ablation. Catheter ablation is suggested as a rhythm control strategy for patients with symptomatic AF who do not respond to anti-arrhythmic drugs, with pulmonary vein isolation (PVI) being the standard approach for AF ablation[2]. A study revealed that 50% of patients who underwent initial PVI experienced AF recurrence three years after the blanking period follow-up[3]. Consequently, additional ablation strategies, such as Complex Fractionated Atrial Electrogram Ablation (CFEA), may be used to modify the AF substrate[4]. However, several randomized controlled trials have reported that integrating ablation targets beyond standard PV isolation does not reduce the recurrence or burden of AF.[3]

After AF ablation, atrial tachycardia frequently occurs, with the mechanism in most cases being reentry related to gaps in previous ablation lines[5]. Managing patients with reentrant left atrial tachycardia (LA-AT) can be challenging, and it remains unclear whether LA regional remodeling is associated with post-ablation LA-AT. This study aims to investigate the relationship between left atrial dimensions measured by computed tomography (CT) and LA-AT after AF ablation in patients with non-paroxysmal AF.

Methods

Study Patients

The study included seventy-three patients who had drug-refractory, symptomatic, non-paroxysmal AF and had already gone through their first catheter ablation operation. The mean duration of AF was 7±7 years. Prior to the catheter ablation procedure, the patients had shown resistance or an inability to tolerate 2±1 anti-arrhythmic medicines.

Echocardiography Studies

Before the catheter ablation procedure, patients underwent an echocardiographic examination. This included assessing the left atrium (LA) using the parasternal long-axis view and measuring the left ventricular ejection fraction via Simpson's method. The right atrium (RA) size was evaluated at the end-diastole phase using the apical four-chamber view, with size increases determined according to the standards set by the American Society of Echocardiography(6).

Computed Tomography Studies

Patients who undergo AF ablation use the technique that has been well implemented in this laboratory (7). A CT scan (Siemens Sensation 16, Siemens Medical Solutions, Forchheim, Germany) was done on all patients within 1-14 days prior to the ablation procedure. The LA diameter was acquired by manually measuring the maximal transverse diameters of the LA from the coronal section and the maximal anteroposterior and superoinferior diameters of the LA from the sagittal section. The volume of the left atrial was determined using the formula $4/3\pi$ (transverse dimension/2) (anteroposterior dimension/2) (superoinferior dimension/2).

Electrophysiological Study & Catheter Ablation

Earlier studies have detailed the electrophysiology study process[8,9]. Patients provided informed consent before the electrophysiology study and ablation, while they were fasting and not sedated. All anti-arrhythmic medications, except for amiodarone, were discontinued at least five half-lives before these procedures. Notably, 26% of the patients were on amiodarone before undergoing ablation.

The first step of the ablation procedure involved isolating the pulmonary veins (PVs). This was achieved by creating circumferential lesions around the ostia of both the left and right PVs, guided by the NavX system and using an irrigated-tip ablation catheter (Chilli II, Boston Scientific Corporation, MA, USA or Cool path, St. Jude Medical, MN, USA). The goal was to block PV entrance and exit. Successful isolation was indicated by the absence of electrical activity in the PVs or by dissociated activity during AF. If sinus rhythm did not attain post-PV isolation, additional complex fractionated electrogram (CFE) ablation was performed in the left atrium (LA), right atrium (RA), and coronary sinus until AF cessation. Electrical cardioversion was

employed if AF persisted after all ablation therapies. The procedure concluded with a check for PV isolation durability and elimination of AF triggered by non-PV sources. Linear ablation in the LA was not conducted in this initial procedure for any patient.

Bipolar atrial electrograms were obtained from over 300 points, approximately evenly distributed within both atria during sinus rhythm. This was done using a sequential point-by-point method guided by the NavX system. Measurement of the peak-to-peak bipolar voltage was taken, and the built-in software was used to calculate the mean voltage.

Follow-Up After Catheter Ablation and Repeated Procedures

Every 1 to 3 months, each of the patients received regular follow-up at our cardiovascular facility after being discharged. During this follow-up, all medical records including physical examinations and electrocardiogram results were collected. The administration of anti-arrhythmic medications was prescribed for 1-2 months to prevent early recurrence of AF. Following the ablation procedure, patients were scheduled every 3 months to undertake either a 24-hour Holter monitoring or a 1-week cardiac event monitoring for a year. By the time the patient experienced indicative tachycardia, patients would undergo electrocardiogram test, 24-hour Holter monitoring, or 1-week cardiac event monitoring; thus, these results were used to determine the cause of tachycardia.

Following ablation procedures, patients were in a blanking period (two months after receiving ablation therapies). After this period, given that the patients had atrial arrhythmia lasting for more than 30 seconds, they were referred as atrial arrhythmia recurrence. Thus, when the recurrence occurred more than one episode, individuals were advised to undergo an additional ablation procedure; anti-arrhythmic medications were administered to manage the recurrence.

The recurrence of AF and the presence of reentrant LA-AT were confirmed in the repeated procedures. The patients in this study were categorized into two groups: Group 1, comprising of 23 patients with the occurrence of LA-AT during follow-up (including 16 patients with both recurrent AF and LA-AT), and Group 2, comprising of 50 patients without LA-AT (including 13 patients with recurrent AF). If linear ablation is required, it was conducted in the second procedure.

Statistical Analysis

The study's results were presented as mean ± standard deviation or percentiles. Continuous data comparisons utilized the student's t-test, while categorical data comparisons used the Chi-square test, including Pearson or Fisher's exact test where applicable. Kaplan-Meier survival analysis depicted the timeline of atrial arrhythmia recurrence. LA-AT occurrence was examined through multivariate Cox stepwise forward regression to identify independent factors, considering variables with a univariate model P value <0.1. Statistical significance was set at P <0.05, with 95% confidence intervals. The Receiver Operating Characteristic (ROC) curve assessed the predictive power for LA-AT occurrence, using SPSS Statistics 17.0 for statistical analyses

Results

Baseline and Electrophysiological Characteristics

This study included 73 patients, mostly male, with a median age of 52, all of whom had non-paroxysmal atrial fibrillation and underwent their first catheter ablation due to resistance to medication and exhibiting symptoms. These participants were divided into two groups for analysis: Group 1, consisting of 23 patients who developed left atrial tachycardia (LA-AT) post-ablation, and Group 2, comprising 50 patients who did not experience LA-AT during the follow-up period.

Table 1 displays the baseline characteristics and electrophysiological traits of both groups. The echocardiographic LA diameter (46±5mm vs. 44±6mm, p=0.049) and the computed tomographic LA dimensions (transverse, anteroposterior, superoinferior dimensions: 7.5±1.2cm vs. 7.0±1.1cm, p=0.045, 4.4±0.7cm vs. 3.8±0.7cm, p=0.004, 6.0±0.9cm vs. 5.6±0.7cm, p=0.049, respectively) were significantly larger in Group 1 than in Group 2 patients. Volume of LA (109±54 cm^3 vs. 82±34cm^3, p=0.011) demonstrated a marked increase in Group 1 compared to Group 2 patients. The other baseline and electrophysiological

Table 1. Baseline Characteristics of Patients with and without Left Atrial Tachycardia.

	With left atrial tachycardia, n=23	Without left atrial tachycardia, n=50	P value
General Characteristics			
Age (Year)	51±11	53±11	0.494
Male	18 (78%)	46 (92%)	0.129
Persistent atrial fibrillation	11 (48%)	27 (54%)	0.624
Long-lasting persistent atrial fibrillation	12 (52%)	23 (46%)	0.624
Hypertension	11 (48%)	24 (48%)	0.989
Diabetes mellitus	2 (9%)	6 (12%)	1.000
Hyperlipidemia	4 (17%)	16 (32%)	0.194
Serum creatinine (mg/dL)	1.0±0.2	1.0±0.2	0.719
Smoking	9 (39%)	16 (32%)	0.551
Coronary artery disease	5 (22%)	7 (14%)	0.500
Thyroid disease	3 (13%)	6 (12%)	1.000
Stroke / Transient ischemic attack	2 (9%)	4 (8%)	1.000
Anti-arrhythmic drugs (n)	2±1	2±1	0.724
Use of amiodarone	8 (35%)	11 (22%)	0.248
Duration of atrial fibrillation (years)	6±7	8±8	0.540
Body mass index (kg/m^2)	26±4	25±4	0.642
Echocardiographic Parameters			
Right atrial enlargement	16 (70%)	24 (48%)	0.085
Left atrial diameter (mm)	46±5	44±6	0.049
Left ventricular diameter (mm)	50±6	48±6	0.154
Left ventricular ejection fraction (%)	56±11	57±7	0.518
Computed Tomographic Parameters			
Transverse dimension (cm)	7.5±1.2	7.0±1.1	0.045
Anteroposterior dimension (cm)	4.4±0.7	3.8±0.7	0.004
Superoinferior dimension (cm)	6.0±0.9	5.6±0.7	0.049
Left atrial volume (cm^3)	109±54	82±34	0.011
Atrial Substrate and Ablation Procedures			
Mean left atrial substrate (mV)	1.2±0.3	1.3±0.4	0.484
Mean right atrial substrate (mV)	1.4±0.5	1.5±0.3	0.395
Procedure time (minutes)	221±47	225±60	0.826
Fluoroscopic time (minutes)	122±34	108±35	0.348

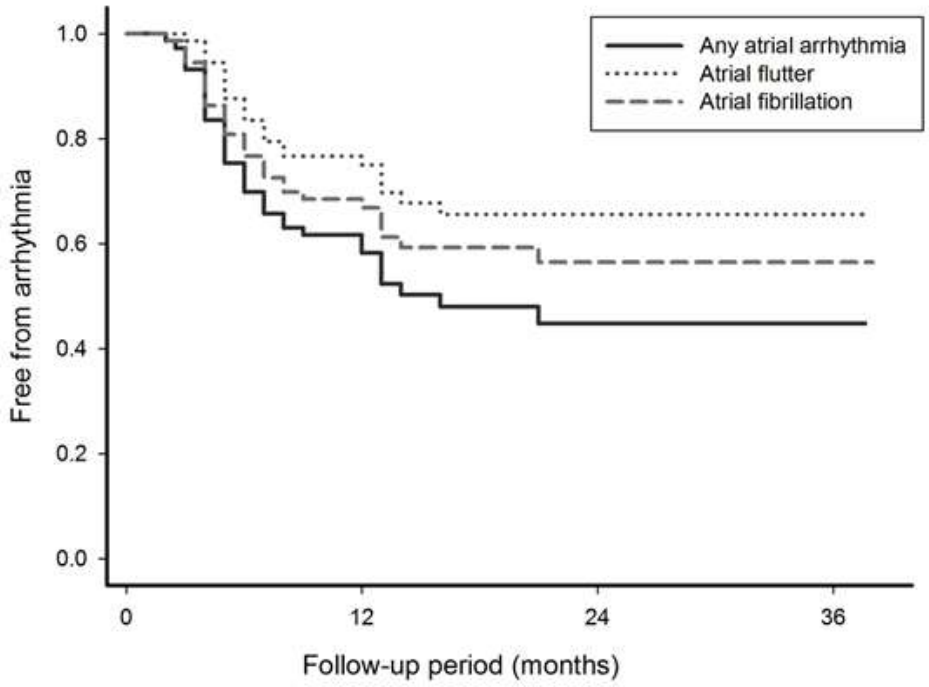

Figure 1. Kaplan-Meier survival curves show the freedom from any atrial arrhythmias, atrial fibrillation, and atypical atrial. flutter rates after a single catheter ablation procedure.

Table 2. Electrophysiological Characteristics of Patients with Left Atrial Tachycardia in the Second Procedures.

	Overall (n=23)
Duration from first catheter ablation (months)	7±4
Cardioversion for sustained organized atrial tachycardia	3 (13%)
Characteristics	
Incessant left atrial tachycardia	6 (26%)
Inducible sustained left atrial tachycardia	17 (74%)
Inducible sustained right atrial flutter	3 (13%)
Mechanism	
Mitral annulus dependent flutter	10 (44%)
Roof dependent flutter	9 (39%)
Sepal flutter	2 (9%)
Right pulmonary vein gap reentrant flutter	3 (13%)
Left pulmonary vein gap reentrant flutter	4 (17%)
Linear ablation in the second procedure	
Mitral line ablation	11 (48%)
Roofline ablation	15 (65%)
Septal line ablation	3 (13%)

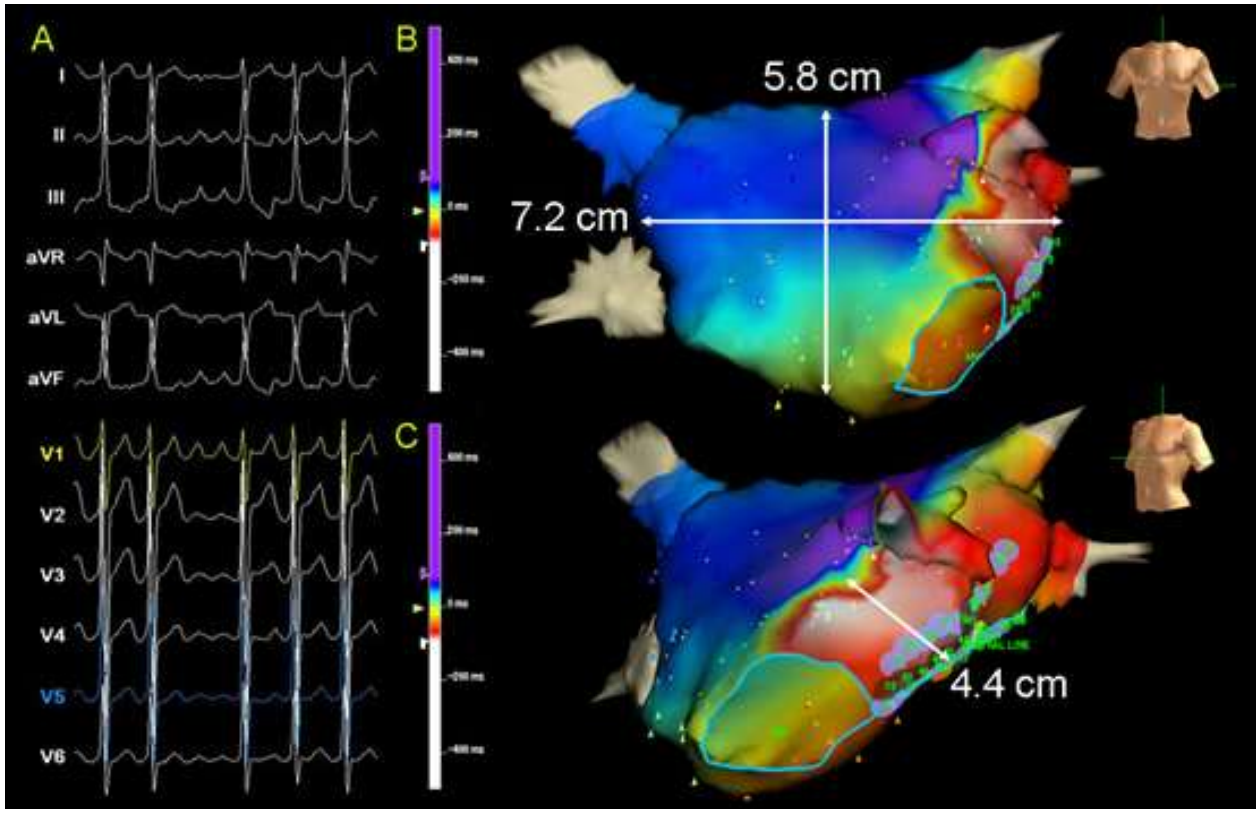

Figure 2. Panel A: Incessant left atrial tachycardia happened 13 months after the first catheter ablation procedure of atrial fibrillation. Panel B and Panel C show the activation map of this mitral annulus dependent atrial flutter and the diameters of the left atrium. The anteroposterior diameter is 4.4 centimeters in length. flutter rates after a single catheter ablation procedure.

characteristics were comparable in both groups.

The Recurrence of Atrial Arrhythmia

Throughout a mean follow-up duration of 23±9 months, following a single ablation procedure, the atrial arrhythmia recurrence was noted in 36 (49%) patients. Clinically documented organized ATs were noted in 14 (19%) patients and three of them underwent external cardioversion. The second procedure were performed in all (n=36) patients with the recurrence of atrial arrhythmia, and there were 13 (18%) patients with recurrent AF only, 7 (10%) patients with LA-AT and 16 (22%) patients with both LA-AT and recurrent AF. Kaplan-Meier survival curves illustrated the freedom from atrial arrhythmias following a single catheter ablation procedure in **Figure 1**.

Regarding the patients with post-ablation LA-AT, there were 3 (13%) patients with right pulmonary vein gap reentrant LA flutter, 4 (17%) patients with left pulmonary vein gap reentrant LA flutter, 9 (39%) patients with roof dependent flutter, 10 (43%) patients with mitral flutter and 2 (9%) patients with LA septal flutter. The detailed electrophysiological findings in the second procedure are shown in **Table 2. Figure 2** demonstrates an example of mitral annulus dependent atrial flutter.

Predictors of Occurrence of Post-ablation Left Atrial Tachycardia

The outcomes of both univariate and multivariate analyses for the occurrence of post-ablation LA-AT are shown in **Table 3**. The independent predictor of the LA-AT was a larger anteroposterior dimension (p=0.002, HR 2.3, 95% CI 1.3-3.8 per increase in 1 centimeter). **Figure 3** shows CT reconstruction images of the patients with and without post-ablation LA-AT.

Same variables were used to perform multivariate

Table 3. Univariate and Multivariate Analysis for the Occurrence of Left Atrial Tachycardia.

Variables	Univariate	Multivariate		
	P value	With left	Hazard Ratio	95% confidence interval
Age	0.561			
Gender	0.178	-	-	-
Persistent atrial fibrillation	0.621			
Hypertension	0.856	-	-	-
Diabetes mellitus	0.572	-	-	-
Hyperlipidemia	0.317	-	-	-
Serum creatinine	0.669	-	-	-
Smoking	0.585	-	-	-
Coronary artery disease	0.307	-	-	-
Thyroid disease	0.518	-	-	-
Stroke/Transient ischemic attack	0.811	-	-	-
Numbers of anti-arrhythmic drugs	0.756	-	-	-
Use of amiodarone	0.270			
Duration of atrial fibrillation	0.618	-	-	-
Body mass index	0.530	-	-	-
Right atrial enlargement	0.099	NS	-	-
Left atrial diameter	0.024	NS	-	-
Left ventricular diameter	0.221	-	-	-
Left ventricular ejection fraction	0.604	-	-	-
Transverse dimension	0.032	NS	-	-
Anteroposterior dimension (per increase in 1cm)	0.002	0.002	2.3	1.34-3.83
Superoinferior dimension	0.041	NS	-	-
Mean left atrial substrate	0.806	-	-	-
Mean right atrial substrate	0.438	-	-	-
Procedure time	0.850	-	-	-
Fluoroscopic time	0.260	-	-	-

analysis for AF recurrence. The recurrence of AF did not correlate to any diameter of the LA.

Discussion

Major Findings

The key finding of this research was that LA eccentric dilatation involving the anteroposterior diameter is a significant predictor for LA-AT occurrence in patients with non-paroxysmal AF after catheter ablation.

Catheter Ablation for Non-paroxysmal Atrial Fibrillation

Many studies have reported the long-term outcome following catheter ablation for AF. Following RF ablation, recurrent AF is prevalent; in as many as 50% of cases, a recurrence occurs within three months[10]. Research

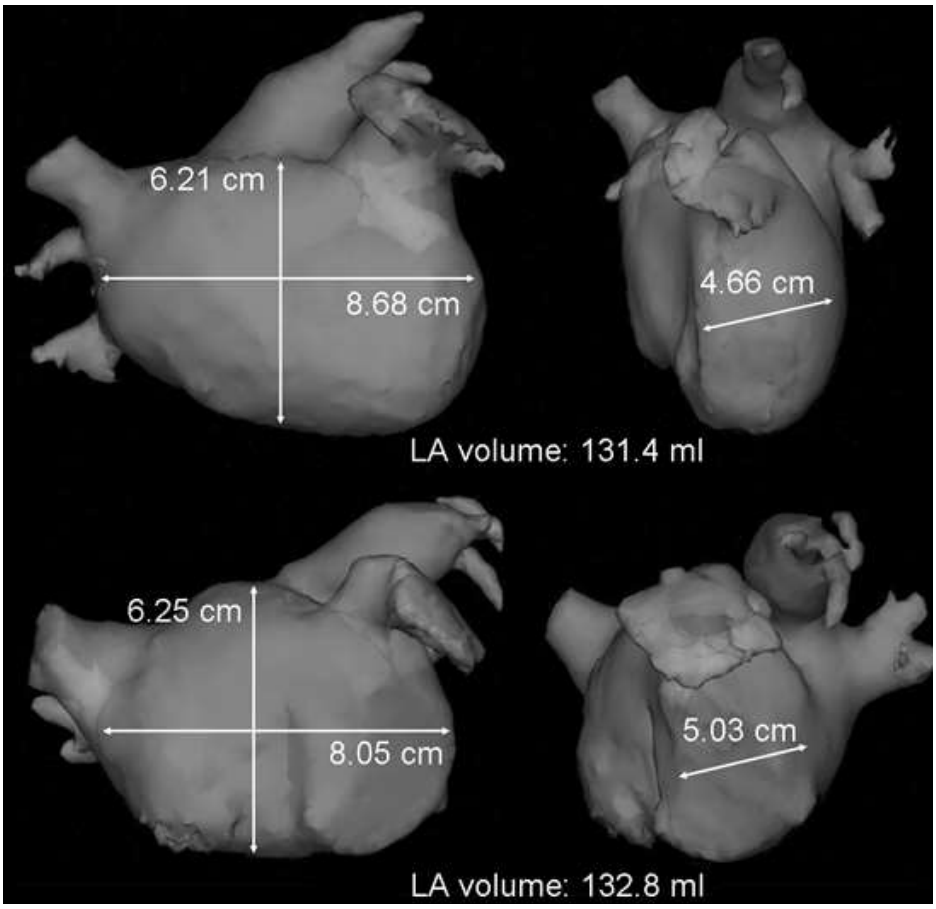

Figure 3. Panel A and Panel B show two reconstructed computed tomographic images of the left atrium with similar volume. Panel A shows a horizontal, flat left atrium with a long transverse diameter. Panel B shows a relatively round left atrium. The patient in Panel B had recurrent atypical left atrial flutter.

by Efremidis et al. informed that 81% of participants with non-paroxysmal AF had recurrence in the initial year following catheter ablation[11]. Among individuals experiencing non-paroxysmal atrial AF, a previous study showed that within ten years, 84% of patients suffered from recurrence following the first ablation procedure, and 53% remained in sinus rhythm after multiple procedures[12]. The study conducted by Weerasooriya et al., concluded that a strategy of repetition with catheter ablation is necessary to provide long-term relief from the recurrence of symptoms in selected AF patients[13]. In the current study, the recurrence of atrial arrhythmias was identified in 49% of patients within a follow-up period of 23±9 months. These studies indicated the need for multiple procedures to increase the recurrence-free rate among patients experiencing non-paroxysmal AF.

Left Atrial Tachycardia After Catheter Ablation for Atrial Fibrillation

Reentrant LA-AT occurs commonly after catheter ablation of AF. In the modern era, LA macroreentrant tachycardias are most commonly associated with substrate ablation techniques, particularly lesions during the index ablation[10]. Recurrent tachycardia after AF ablation is caused by the involvement of focal micro-reentrant tachycardia that appeared from reconnection of pulmonary vein ostia or macro-reentrant tachycardia surrounding anatomical obstacles or scar tissue following intrinsic LA disease or past ablation procedure[13].

In a study conducted by Gerstenfeld et al., following PV isolation for paroxysmal or persistent AF in 341 patients, persistent organized left atrial tachycardia

was developed in 10 patients (2,9%)[15]. Demarchi et al. informed that following catheter ablation, LA tachycardia or flutter was found in 22 of 439 cases (5%) [12]. Both previous studies showed a low incidence of LA-AT while in this study, 31.5% of patients experiencing non-paroxysmal AF had LA-AT in the second procedure after the initial AF catheter ablation. Of note, 26% of these patients presented as an incessant AT, which was highly symptomatic and usually drug-refractory.

Chugh et al. stated that the occurrence of macro-reentrant AT during the first procedure was the only independent indicator to predict the development of macro-reentrant AT during follow-up[17]. Vlachos et al. examined the electrophysiological traits of termination sites, where 70% of overall atrial tachycardia macro-reentries were associated with anatomical obstacles, and 29.9% of overall atrial tachycardia localized re-entries were identified near scar regions resulting from prior ablation or structural atrial cardiomyopathy[18]. As for atrial flutter immediately after AF ablation, a study by Daoud et al. documented the occurrence of LA flutter in 38% of patients who had undergone circumferential ablation[19]. Ipek et al. found that 20% of patients developed post-PV isolation; 17 patients experienced typical atrial flutter, 98 patients experienced atypical atrial flutter, and 7 patients had both-sided atrial flutter[19]. Some authors considered new-onset LA-AT as a manifestation of the proarrhythmic effect after AF ablation, and they suggested that catheter ablation of LA-AT need to be taken into consideration for individuals who exhibit clinical symptoms during follow-up[16,18]. In our study, clinically documented organized AT was seen in 19% of patients throughout follow-up, and our study found that the LA anteroposterior diameter is a significant predictor for the occurrence of LA-AT in patients after catheter ablation.

Regional LA Remodeling and Post-ablation LA Flutter

A few meta-analyses analyzed by Garvanski et al. reveal that LA enlargement caused by AF can alter its shape from ellipsoidal to trapezoidal, primarily due to the atrialization of the PVs[20]. As a result, key measurements like the echocardiography-based anteroposterior diameter may not accurately represent actual LA size. Mujovic et al.'s research also indicate that early AF recurrence often correlates with pulmonary vein reconnection and gaps in the roof line observed in repeat electrophysiology studies[21].

Although LA was more dilated and all transverse, anteroposterior and superoinferior dimensions of LA were more expanded in patients with recurrent post-ablation LA-AT; we demonstrated the presence of a longer anteroposterior diameter of LA was particularly associated with the occurrence of LA-AT Regional LA anteroposterior remodeling might play an essential role in the formation of reentrant circuits. Another possibility is that the elongation of anteroposterior length might cause unstable catheter contact and poor lesion formation, which subsequently result in a "gap" and facilitate the occurrence of reentrant LA-AT.

Conclusion

In non-paroxysmal AF patients who received catheter ablation without linear ablation during the index procedure, clinically documented organized AT was observed in 19% of patients. Eccentric dilatation involving the anteroposterior diameter is a significant predictor of LA-AT occurrence.

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