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# Catheter ablation of atrial fibrillation in Korea: results from the Korean Heart Rhythm Society Ablation Registry for Atrial Fibrillation (KARA)

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## Abstract

**Background:** This study aims to investigate the current status of AF (atrial fibrillation) catheter ablation in Korea.

**Methods:** The patients who underwent AF catheter ablation from September 2017 to December 2019 were prospectively enrolled from 37 arrhythmia centers. Demographic data, procedural characteristics, the extent of catheter ablation, acute success of the ablation lesion set, rate and independent risk factor for recurrence of AF were analyzed.

**Results:** A total of 2402 AF patients [paroxysmal AF (PAF) 45.7%, persistent AF (PeAF) 43.1% and redo AF 11.2%] were included. Pulmonary vein isolation (PVI) was performed in 2378 patients (99%) and acute success rate was 97.9%. Additional non-PV ablation (NPVA) were performed in 1648 patients (68.6%). Post-procedural complication rate was 2.2%. One-year AF-free survival rate was 78.6% and the PeAF patients showed poorer survival rate than the ones with other types (PeAF 72.4%, PAF 84.2%, redo AF 80.0%). Additional NPVA did not influence the recurrence of AF in the PAF patients (PVI 17.0% vs. NPVA 14.6%, *P* value 0.302). However, it showed lower AF recurrence rate in the PeAF patients (PVI 34.9% vs. NPVA 24.4%, *P* value 0.001). Valvular heart disease, left atrial diameter, PeAF, PVI alone, need of NPVA for terminating AF, and failed ablation were independent predictors of AF recurrence.

**Conclusions:** Additional NPVA was associated better rhythm outcome in the patients with PeAF, not in the ones with PAF. The independent risk factors for AF recurrence in Korean population were similar to previous studies. Further research is needed to discover optimal AF ablation strategy.

**Keywords:** Atrial fibrillation, Catheter ablation, Outcomes, Risk factor

## Background

Atrial fibrillation (AF) is the most common sustained arrhythmia and causes serious cardiovascular diseases such as stroke and heart failure in the long term. In Korea, the incidence of AF in 2015 was 17.1 per 10,000 persons-year that was gradually increased from 2008, and its prevalence was 0.67% which was 1.7 times higher than that in 2008 [1]. AF-related hospitalization and outpatient clinic visits increased year by year, and consequent

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healthcare expenditure also continuously increased [2]. The main stems of AF treatment involve avoiding stroke, improving AF-related symptoms, controlling the heart rate or rhythm, and managing cardiovascular risk factors and concomitant diseases [3]. Catheter ablation of AF was effective in suppressing AF symptoms refractory to antiarrhythmic drug treatment, and recurrence of AF was smaller than medical therapy [4]. It has also been shown to improve quality of life and mortality and cardiovascular outcomes such as stroke, bleeding, and heart failure [5–7]. In Korea, AF catheter ablation has increased gradually and safely performed [8, 9]. However, there are little data on the current status of AF ablation in Korea. This study aims to establish a prospective AF ablation registry to investigate the current status of AF catheter ablation in Korea.

## Methods

### Study population

The Korean Heart Rhythm Society Ablation Registry for AF (KARA) is an investigator-initiated, multicenter, prospective registry of catheter ablation for AF. This study was approved by the Institutional Review Board of Seoul National University Hospital and each participating arrhythmia center. Written informed consent was obtained from study subjects. The study subjects were the patients who underwent AF catheter ablation for antiarrhythmic drug (AAD)-refractory symptoms from September 2017 to May 2020 in Korea. Young patients under the age of 19, the patients with cognitive impairments that could not understand informed consent, and the patients who did not consent to participate in the study were excluded from the registration.

### Data collection

All data were collected in each practicing center and sent to the core laboratory, Seoul National University Hospital. Baseline data included the patients' demographics (e.g., age, height, body weight, and sex), procedure date, type of AF, an indication of catheter ablation, cardiovascular comorbidities such as heart failure, hypertension, diabetes mellitus, cerebrovascular accident or arterial thromboembolic event, ischemic heart disease, valvular heart disease, peripheral arterial disease, presence of any cardiomyopathy, chronic kidney disease, obstructive sleep apnea, and history of any cardiac surgery, prescription of oral anticoagulants or antiplatelet agents, left ventricular (LV) ejection fraction (EF), and left atrial (LA) anteroposterior diameter. Procedural data included the number of previous AF ablation(s), an electrocardiographic (ECG) rhythm at the beginning of the procedure, mode of ablation energy, vendor name of three-dimensional mapping system, procedural time, ablation time,

fluoroscopic time, ablation lesion and acute result of each ablation lesion. Acute success of each ablation lesion was assessed by each operator and was defined as entrance and/or exit block for pulmonary vein (PV) or superior vena cava (SVC) isolation, bidirectional block by differential pacing for linear ablation, and disappearance of trigger beat from specific anatomical site for focal trigger ablation. If there was no record of confirmation, the lesion set was considered incomplete. Information for acute complications before discharge and their management were also collected.

### Follow-up

Mandatory follow-up visits were performed at 3, 6, and 12 months after the procedure. Twelve-lead ECG was performed at each visit. Long-term ECG test, such as Holter or event recorder was not mandatory, and its use was at the operator's discretion. Additional clinic visits and ECG tests were allowed when the patient became symptomatic or the operator suspected recurrence. At each follow-up visit, cardiovascular outcomes (e.g., ischemic stroke/transient ischemic attack, systemic embolism, aggravation of heart failure, myocardial infarction, and all-cause death), ECG rhythm, and use of AAD were collected. Recurrence of AF was defined as the occurrence of any atrial tachyarrhythmia in 12-lead ECG or lasting more than 30 s in long-term ECG monitoring. The first 90 days from the procedure was regarded as a blanking period, and the recurrence of AF was ignored during this period.

### Statistical analysis

Categorical variables were expressed as frequency and percentage. Normally distributed continuous variables were expressed as mean  $\pm$  standard deviation. The variables that were not normally distributed were expressed as the median [lowest quartile, highest quartile]. The recurrence of AF was compared by the Kruskal–Wallis test and Mann–Whitney test with Bonferroni correction according to the type of AF (paroxysmal, persistent and redoAF). It was also evaluated by Kaplan–Meier survival analysis with the Log-rank test. Cox-proportional hazard model was used to elucidate independent predictors for recurrence of AF. A *P* value less than 0.05 was considered statistically significant in Kaplan–Meier survival analysis, Cox-proportional regression analysis, and Kruskal–Wallis test for recurrence of AF. In case of intergroup analysis by Mann–Whitney test, *P* value less than 0.017 was considered significant. All statistical analyses were performed using SPSS version 25.0 (IBM Corp., Armonk, NY, USA) & R software version 4.0.2 (R foundation for Statistical Computing, Vienna, Austria).

**Results**

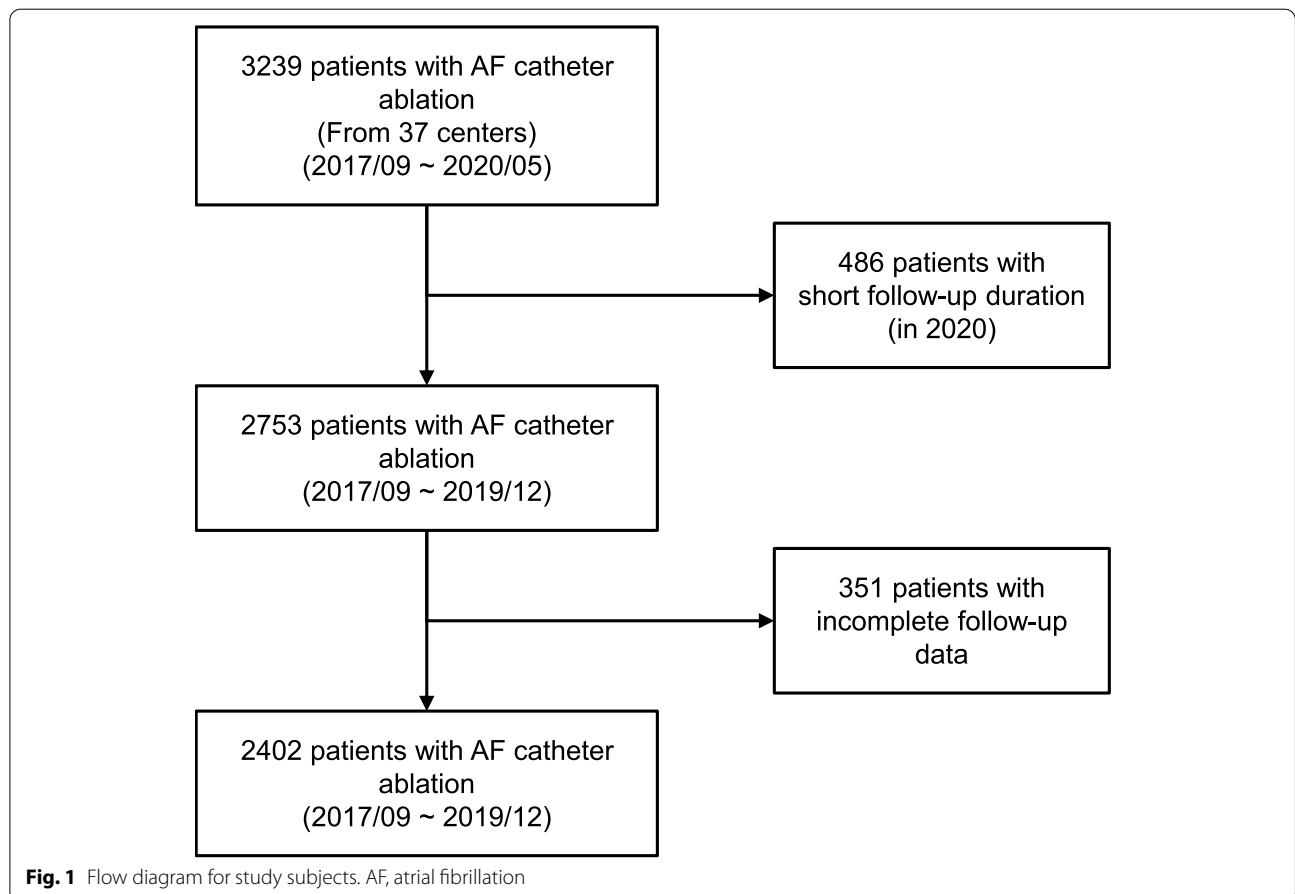
**Subject enrollment and baseline characteristics**

Between September 2017 and May 2020, 3239 patients with AF who underwent catheter ablation from 37 centers were enrolled in this registry. Among them, 486 patients enrolled in 2020 were excluded in the present analysis because the follow-up duration was <1 year. Three hundred and fifty-one patients with incomplete follow-up data were also excluded from the analysis. Finally, 2402 patients were included in this analysis (Fig. 1). The mean age was 60.2 ± 9.6 years old, and the male was 73.6% (n = 1767). The proportion of paroxysmal AF was 45.7% (n = 1097) and that of persistent AF and redo ablation were 43.1% (n = 1035) and 11.2% (n = 270), respectively. Hypertension was the most common comorbidities (n = 1218, 50.7%), was followed by diabetes mellitus (n = 434, 18.1%), heart failure (n = 259, 10.8%), and cerebrovascular accident (n = 219, 9.1%). Proportion of the patients with structural heart diseases such as ischemic heart disease, cardiomyopathy, valvular heart disease, and history of cardiac operation were 7.4% (n = 178), 3.9% (n = 93), 3.8% (n = 92), and 2.1% (n = 51), respectively. A number of 2267 patients (94.4%) received

oral anticoagulant before the procedure and direct oral anticoagulants were used in most patients (n = 1996, 83.1%). The mean LV EF was 59%, and LA diameter was 43 mm (Table 1). About 90% of the cases were the first-time AF ablation (n = 2132, 88.8%). The proportion of cryoablation was 7.9% (n = 190). Mean procedure time, ablation time, and fluoroscopic time were 197.6 ± 90.2, 57.4 ± 42.0, and 33.8 ± 27.0 min (Table 2).

**Acute procedural success rates**

A number of 2378 patients received PVI (99.0%) and complete isolation was achieved in 97.9% of the patients. A dormant conduction test was performed on 36.5% of the patients. Additional non-PV ablation (NPVA) were performed in 1648 patients (68.6% of total), mostly atrial linear ablations (n = 1511, 62.9% of total). The most performed lesion was cavotricuspid isthmus (CTI) line (n = 1366, 56.9%), followed by LA roof line (n = 338, 14.1%), mitral isthmus line (n = 205, 8.5%), linear ablation between both inferior PVs (inferior line) (n = 142, 5.9%), superior vena cava (SVC)—interatrial septal (IAS) line (n = 149, 6.2%), and LA anterior line (n = 97, 4.0%). Non-PV trigger ablation was performed in 405



**Fig. 1** Flow diagram for study subjects. AF, atrial fibrillation

**Table 1** Baseline demographic characteristics of the study population

Variables	Total (N = 2402)
Age	60.2 ± 9.6
Male	1767 (73.6%)
Height (cm)	166.9 ± 8.6
Weight (kg)	71.7 ± 12.0
Paroxysmal AF	1097 (45.7%)
Persistent AF	1035 (43.1%)
Hypertension	1218 (50.7%)
Diabetes mellitus	434 (18.1%)
Heart failure	259 (10.8%)
Ischemic stroke/TIA/SE	219 (9.1%)
Ischemic heart disease	178 (7.4%)
Any cardiomyopathies <sup>1</sup>	93 (3.9%)
Valvular heart diseases	92 (3.8%)
History of cardiac operation	51 (2.1%)
Peripheral arterial disease	19 (0.8%)
Obstructive sleep apnea	112 (4.7%)
Oral anticoagulants	
No	135 (5.6%)
Warfarin	271 (11.3%)
DOAC	1996 (83.1%)
Antiplatelet agents	
No	2273 (94.6%)
Single	121 (5.0%)
Multiple	8 (0.3%)
LV ejection fraction (%)	59.0 ± 8.5
LA diameter (mm)	43.4 ± 6.7

Categorical data are expressed in frequency (percentage) and continuous data are expressed in mean ± standard deviation

<sup>1</sup> Any cardiomyopathies included ischemic cardiomyopathy, dilated cardiomyopathy, hypertrophic cardiomyopathy, amyloidosis, and sarcoidosis

AF, atrial fibrillation; LA, left atrium; LV, left ventricle; DOAC, direct oral anticoagulant; TIA, transient ischemic attack; SE, systemic embolism

patients (16.9%). SVC isolation ( $n=266$ , 11.1%), focal ablation on LA appendage ( $n=127$ , 5.3%), and coronary sinus ( $n=111$ , 4.6%) were performed. CTI ablation and SVC isolation showed high acute success rates (97.1% and 91.7%, respectively). Other linear ablations or focal ablations showed modest or low success rates (Table 3). Focal ablation based on complex fractionated atrial electrogram (CFAE) was performed in 254 patients (10.6%). About a half of the patients ( $n=1265$ , 52.7%) were sinus rhythm before the beginning of the procedure. Direct current (DC) cardioversion was performed in 439 patients (18.3%), and 193 patients (8.0%) showed sustained AF at the end of the procedure. After ablation, AF induction test was performed in about 70% of the patients.

**Table 2** Baseline procedural characteristics of the study population

Variables	Total (N = 2402)
First-time ablation	2132 (88.8%)
Redo ablation	270 (11.2%)
Energy source	
Radiofrequency	2212 (92.1%)
Cryoenergy	190 (7.9%)
Mode of sedation	
No sedation	74 (3.1%)
Deep sedation	1939 (80.7%)
General anesthesia	389 (16.2%)
Start rhythm <sup>1</sup>	
SR	1265 (52.7%)
AF/AT	1137 (47.3%)
Procedure time (min)	197.6 ± 90.2
Ablation time (min)	57.4 ± 42.0
Fluoroscopic time (min)	33.8 ± 27.0

Categorical data are expressed in frequency (percentage) and continuous data are expressed in mean ± standard deviation

<sup>1</sup> Starting rhythm is the ECG rhythm at the beginning of the first energy application

AF, atrial fibrillation; AT, atrial tachycardia; SR, sinus rhythm

### Post-procedural complications

Post-procedural complication rate was 2.2% ( $n=54$ ). The most common complication was cardiac tamponade ( $n=15$ , 0.6%). Access site complications ( $n=11$ , 0.5%) and pericardial effusion ( $n=6$ , 0.2%) were followed. There was no procedure-related death in this registry (Table 4).

### Rhythm control outcome and independent predictors for recurrence of atrial fibrillation

Sixty percent of the patients received any AAD after the blanking period ( $n=1442$ , 60.2%). The patients with persistent AF were prescribed the AADs more frequently compared to the patients with paroxysmal AF and redo AF (68.0%, 54.1%, and 53.7%, respectively;  $P$  value < 0.001) (Fig. 2A). Among 2397 patients, freedom from AF at one year was achieved in 1888 patients (78.6%). Those of the patients with paroxysmal, persistent and redo AF were 84.6%, 72.4%, and 80%, respectively ( $P$  value < 0.001). In intergroup analysis, the patients with persistent AF showed statistically higher recurrence rate compared to the patients with paroxysmal and redo AF [ $P$  value (persistent AF vs. paroxysmal AF) < 0.001; (persistent AF vs. redo AF) 0.012]. The recurrence rates of the patients with paroxysmal AF and redo AF were not statistically different ( $P$  value 0.066) (Fig. 2B).

**Table 3** Acute procedural acute success rate in various types of ablation

Type of ablation	Number (N=2402)	Success <sup>1</sup>
PVI	2378 (99.0%)	2352 (97.9%)
Dormant conduction		
None	780 (32.5%)	–
Presence	96 (4.0%)	–
Not assessed	1526 (63.5%)	–
Any non-PV ablation	1648 (68.6%)	–
Linear ablation	1511 (62.9%)	–
LA roof	338 (14.1%)	201 (59.5%)
LA inferior	142 (5.9%)	79 (55.6%)
LA anterior	97 (4.0%)	54 (55.7%)
LA mitral isthmus	205 (8.5%)	126 (61.5%)
Cavotricuspid isthmus	1366 (56.9%)	1326 (97.1%)
SVC-IAS	149 (6.2%)	21 (14.1%)
Non-PV trigger ablation	405 (16.9%)	
LA appendage	127 (5.3%)	14 (11.0%)
SVC	266 (11.1%)	244 (91.7%)
Coronary sinus	111 (4.6%)	87 (78.4%)
Ligament of Marshall	23 (1.0%)	8 (34.8%)
Crista terminalis	16 (0.7%)	10 (62.5%)
Other focal ablations <sup>2</sup>	80 (3.3%)	–
CFAE ablation	254 (10.6%)	–
GP ablation	16 (0.7%)	–
FIRM ablation	1 (0.0%)	–

Data are expressed in frequency (percentage)

<sup>1</sup> The percentage was calculated as the number of each type of ablation as denominator and the number of success as numerator

<sup>2</sup> It included any focal atrial ablation not mentioned in this table (e.g. LA or RA free wall, interatrial septum, slow pathway, or bypass tract)

AF, atrial fibrillation; AT, atrial tachycardia; CFAE, complex fractionated atrial electrogram; DC, direct current; FIRM, focal impulse and rotor modulated; GP, ganglionated plexus; IAS, interatrial septum; LA, left atrium; PVI, pulmonary vein isolation; RA, right atrium; SVC, superior vena cava

Kaplan–Meier survival analysis showed that the patients with persistent AF showed worse rhythm outcome compared to other types of AF [Log-rank *P* value (persistent AF vs. paroxysmal AF) < 0.001; (persistent AF vs. redo AF) 0.010]. There was no statistical difference between the patients with paroxysmal AF and redo AF (*P* value 0.070) (Fig. 3). There was no statistical difference in recurrence of AF according to ablation strategy (PVI alone vs. PVI and additional NPVA) in the patients with paroxysmal AF (17.0% vs. 14.6%, Log rank *P* value 0.284). However, the patients with persistent AF who received PVI and additional NPVA showed lower recurrence rate than ones received PVI alone (34.9% vs. 24.4%, Log rank *P* value 0.001) (Fig. 4).

**Table 4** Acute post-procedural complications

Variables	Total (N=2402)
No complication	2348 (97.8%)
Any complication	54 (2.2%)
Cardiac tamponade <sup>1</sup>	15 (0.6%)
Pericardial effusion	6 (0.2%)
Pericarditis	3 (0.1%)
Access site complications <sup>2</sup>	11 (0.5%)
Phrenic nerve palsy	5 (0.2%)
Cerebrovascular accidents <sup>3</sup>	5 (0.2%)
Others <sup>4</sup>	9 (0.4%)
Mode of treatment	54
Conservative management	32 (59.3%)
Interventional management	22 (40.7%)

Data are expressed in frequency (percentage)

<sup>1</sup> Cardiac tamponade defined as pericardial effusion that required pericardiocentesis or surgical intervention

<sup>2</sup> Access site complications included hemorrhage requiring intervention, pseudoaneurysm, and arteriovenous fistula

<sup>3</sup> Cerebrovascular accidents included overt cerebral infarction and transient ischemic attack

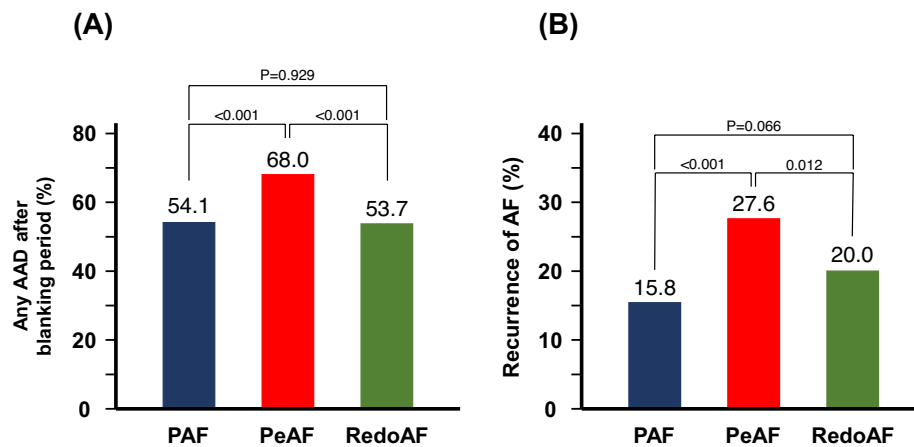
<sup>4</sup> Others included pleural effusion, pneumothorax, coronary spasm, chest pain, bradycardia, sinus node dysfunction, fever, cellulitis, and pulmonary vein stenosis

In univariable Cox-proportional analysis, presence of valvular heart disease (HR 2.46, 95% CI 1.780–3.396), LV EF (by 1%) (HR 0.99, 95% CI 0.976–0.995), LA diameter (by 1 mm) (HR 1.06, 95% CI 1.042–1.069), persistent AF (vs. paroxysmal AF) (HR 1.92, 95% CI 1.589–2.324), PVI alone (vs. PVI and additional NPVA) (HR 1.27, 95% CI 1.064–1.526), mode of AF termination (need of NPVA, need of DC cardioversion, and not terminated by any ablation vs. sinus rhythm before the first energy application), [HR 1.83, 95% CI 1.363–2.453; HR 1.77, 95% CI 1.411–2.215; HR 2.82, 95% CI 2.166–3.678] and not performing AF induction test (vs. no AF inducibility) (HR 1.22, 95% CI 1.003–1.486) were associated with the recurrence of AF. In multivariable Cox proportional hazard model, valvular heart disease (HR 1.60, 95% CI 1.139–2.253), LA diameter (HR 1.04, 95% CI 1.024–1.053), persistent AF (HR 1.43, 95% CI 1.152–1.764), PVI alone (HR 1.34, 95% CI 1.104–1.619), need of NPVA for terminating AF (HR 1.56, 95% CI 1.153–2.152) and not terminated by any ablation (HR 1.94, 95% CI 1.460–2.578) were independent predictors of AF recurrence (Table 5).

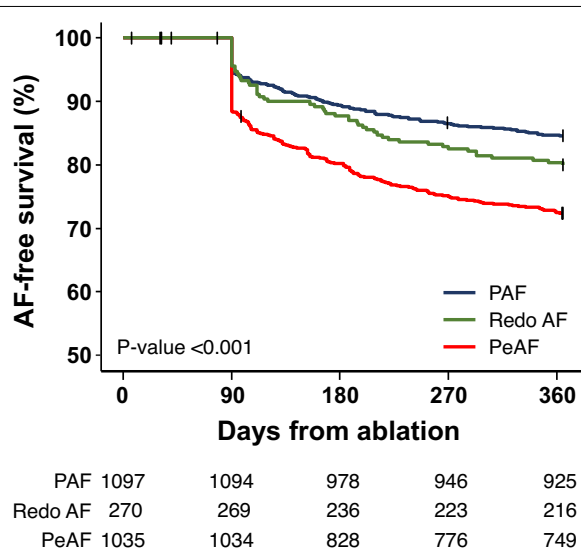
## Discussion

### Demographic profiles

This study is a multicenter, prospective registry that enrolled 37 arrhythmia centers in Korea. The demographic profiles of the study population, such as age,



**Fig. 2** Use of antiarrhythmic drug after blanking period and recurrence rate of AF at 1 year. Use of antiarrhythmic drugs after blanking period (A) and AF recurrence rate at 1 year (B) were more frequent in the patients with persistent AF compared to the ones with paroxysmal AF and redo AF. AAD, antiarrhythmic drug; AF, atrial fibrillation; PAF, paroxysmal AF; PeAF, persistent AF



**Fig. 3** Kaplan–Meier survival curve for recurrence of atrial tachyarrhythmia after AF catheter ablation. The patients with persistent AF showed the lowest AF free survival compared to the patients with paroxysmal AF and redo AF. There was no statistical difference between the patients with paroxysmal AF and redo AF. AF, atrial fibrillation; PAF, paroxysmal atrial fibrillation; PeAF, persistent atrial fibrillation

gender distribution, and type of AF were comparable to other Korean or foreign studies [8, 10, 11]. Of note, the proportion of heart failure patients is relatively low compared to other studies using the Korean claim database [1, 8]. However, the rate was similar compared to other cohort studies in Korea [12, 13]. NHIS claim data might be over-claimed the heart failure diagnosis related

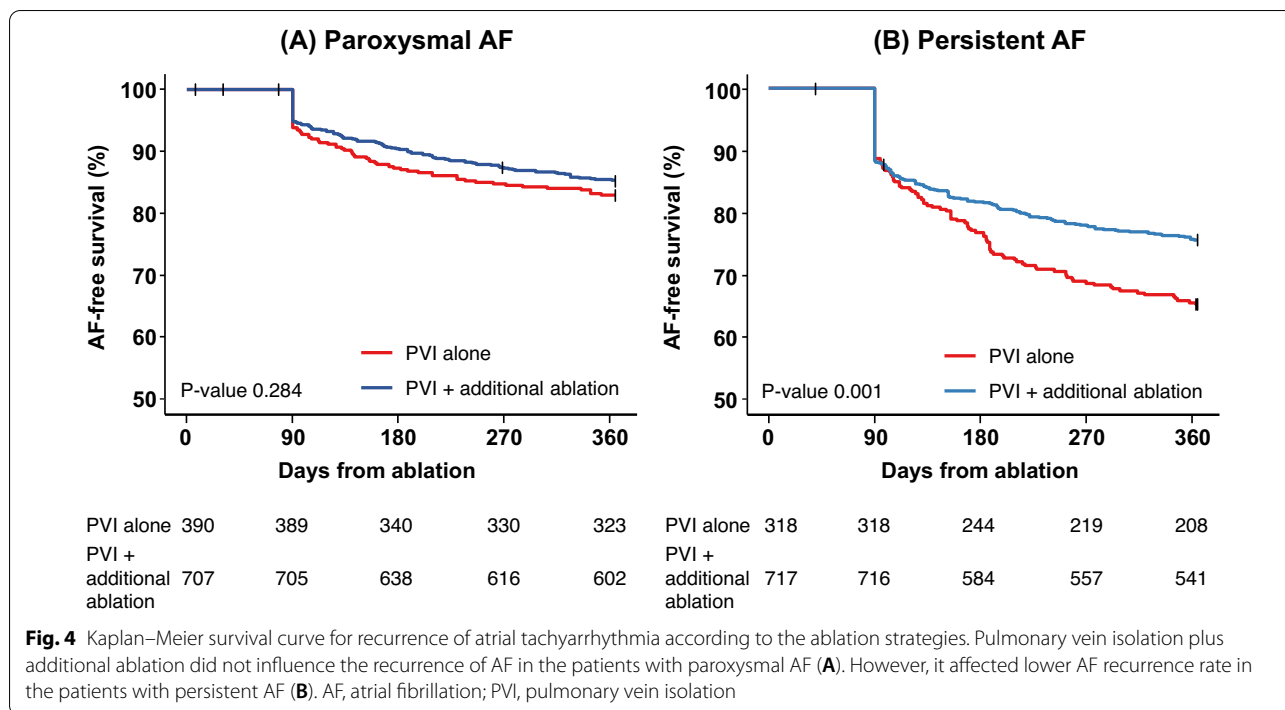
to some drug use and did not have echocardiographic parameters in it. On the other hand, our study had echocardiographic data that could identify the LV dysfunction more correctly.

Sleep apnea is known as a risk factor for AF [3]. The prevalence of sleep apnea in patients with AF was variable in previous studies, ranging from 18 to 49% [14, 15]. However, an awareness of sleep apnea is not widespread in clinical practice, and a diagnostic test is cumbersome. Therefore, the prevalence of sleep apnea might be underestimated in this study.

The proportion of cryoablation was small because the cryoablation system has been available since late 2018 in Korea, which was very late compared to other countries.

**Procedure patterns**

Pulmonary vein isolation is a standard procedure in AF ablation. All patients who underwent de novo AF ablation and the patients with AF recurrence were received PVI in this study. Some patients who did not receive PVI were the redo AF patients without PV reconnection. More than 60% of the procedure did not confirm the presence of the dormant conduction in the present registry. It is thought that controversial results for the effectiveness of elimination of the dormant conduction could affect the current practice pattern [16, 17]. Interestingly, the incidence of dormant conduction was 11% (n=96/876) that was lower than in other studies [18, 19]. Further evaluations would be needed to clarify it. Additional NPVA were widely performed in this study. The most common lesion set was a CTI linear ablation (n=1366, 56.9%). Typical atrial flutter often accompanied with AF and the CTI ablation is easy to achieve



**Fig. 4** Kaplan–Meier survival curve for recurrence of atrial tachyarrhythmia according to the ablation strategies. Pulmonary vein isolation plus additional ablation did not influence the recurrence of AF in the patients with paroxysmal AF (A). However, it affected lower AF recurrence rate in the patients with persistent AF (B). AF, atrial fibrillation; PVI, pulmonary vein isolation

bidirectional block [20]. The success rate of the CTI ablation was 97.1% that was consistent with other studies [20, 21]. Other LA linear ablations were performed in about 20% of the patients and it was similar to other studies [10, 22]. However, the success rates of LA linear ablations were lower than in a previous paper [23]. We considered the linear ablation was not successful when there was no confirmation of the linear lesion set. Probably, it could make underestimation of the success rate of linear lesion sets in this study. Additional NPVA are often performed in patients with persistent AF and macro-reentrant atrial tachycardia. Still, there is no consensus for the effective ablation strategy for persistent or long-standing persistent AF because previous studies showed controversial results [24, 25]. It is thought that they influenced the utilization of LA linear ablations although the rate of the patients with persistent AF was 43.1% in this study. Non-PV trigger is an important source of AF development but non-PV trigger ablation was not widely performed in this study. In addition, it was 30% that did not perform AF induction test. In STAR-AF II trial, the authors reported that additional linear ablation or ablation for complex fractionated electrogram (CFAE) did not show the benefit for AF recurrence in the patients with persistent AF [25]. This result is thought to influence the PVI as the initial ablation strategy for persistent AF. Another possible explanation is that it is often difficult to localize the focal trigger source despite support by a 3D mapping system. Also, there is no clear endpoint for focal trigger ablation.

The SVC isolation was more frequently performed than other non-PV trigger source ablation, and the success rate was high (91.7%). It is thought that there was a definite anatomical structure and a clear endpoint such as an entrance or exit block. Substrate modifications for CFAE, ganglionated plexus, and focal impulse and rotor mapping were performed in limited numbers. The complexity of the procedures, unclear endpoints, and little evidence for better prognosis could hinder the wide adoption of these technologies.

**Rhythm outcome**

The rate of AF-free survival at one year was 78.6% that was higher than other studies, although about half of the patients were persistent AF [11, 26]. Long-term ECG monitoring was not mandatory during the follow-up period and it could make less detection of atrial tachyarrhythmias. In addition, the use of AAD after blanking period was at the physician’s discretion in this study. It was different from other clinical trials that strongly discourage the use of AAD after blanking period. Previous studies also reported that the patients with persistent AF showed worse AF-free survival after catheter ablation than the ones with paroxysmal AF and it is consistent with our results [27, 28]. In present study, AF-free survival rate of the patients with redo AF was similar to that of the patients with paroxysmal AF. The rate of maintaining sinus rhythm after multiple procedures was higher than that of de novo ablation [29, 30]. It is thought that

**Table 5** Cox proportional hazard model for rhythm outcome (recurrence at 1 year)

Variable	Unadjusted hazard ratio			Adjusted hazard ratio		
	HR	95% CI	P value	HR	95% CI	P value
Age						
< 60	1.000	Reference	–	1.000	Reference	–
60–69	0.889	0.735–1.076	0.227	0.846	0.697–1.026	0.089
> 70	0.939	0.731–1.206	0.621	0.854	0.661–1.105	0.230
Female (vs. male)	0.940	0.769–1.147	0.541	1.095	0.865–1.310	0.555
Valvular heart disease <sup>1</sup>	2.459	1.780–3.396	<0.001	1.602	1.139–2.253	0.007
LV EF (by 1%)	0.985	0.976–0.995	0.002	0.999	0.989–1.009	0.794
LAD (by 1 mm)	1.055	1.042–1.069	<0.001	1.039	1.024–1.053	<0.001
Ablation indication						
Paroxysmal AF	1.000	Reference	–	1.000	Reference	–
Persistent AF	1.921	1.589–2.324	<0.001	1.426	1.152–1.764	0.001
Redo ablation	1.321	0.972–1.794	0.075	1.220	0.890–1.600	0.216
PVI only (vs. additional NPV ablation) <sup>2</sup>	1.274	1.064–1.526	0.009	1.337	1.104–1.619	0.003
Mode of AF termination						
Initial SR <sup>3</sup>	1.000	Reference	–	1.000	Reference	–
By PVI	1.106	0.817–1.496	0.515	0.973	0.716–1.324	0.863
By NPV ablation	1.829	1.363–2.453	<0.001	1.581	1.157–2.160	0.004
By DCC <sup>4</sup>	1.768	1.411–2.215	<0.001	1.243	0.966–1.600	0.090
Not terminated	2.822	2.166–3.678	<0.001	1.940	1.459–2.579	<0.001
AF induction test <sup>5</sup>						
No induction	1.000	Reference	–	1.000	Reference	–
AF/AT	0.920	0.727–1.165	0.489	0.954	0.751–1.213	0.702
Not done	1.221	1.003–1.486	0.046	1.106	0.898–1.362	0.342

<sup>1</sup> Valvular heart disease is defined as stenosis or regurgitation of any valve which severity was moderate or severe

<sup>2</sup> NPV ablation is defined as any ablation other than pulmonary vein isolation

<sup>3</sup> It is defined as the rhythm state before the first energy delivery of the procedure

<sup>4</sup> It is categorized when cardioversion was performed after the first energy delivery of the procedure

<sup>5</sup> Induction of AF was usually performed by atrial burst pacing with isoproterenol infusion. Pacing protocol and isoproterenol dose were left to the operator's discretion

AF, atrial fibrillation; AT, atrial tachycardia; CI, confidence interval; DCC, direct current cardioversion; EF, ejection fraction; HR, hazard ratio; LAD, left atrial diameter; LV, left ventricle; NPV, non-pulmonary vein; PVI, pulmonary vein isolation; SR, sinus rhythm

recurrence of AF was reduced by performing PV re-isolation, atrial substrate modification or non-PV trigger elimination during redo-ablation. However, it could not be concluded that the aggressive approach to the patients with redo AF is warranted and further randomized trials should be needed to investigate this issue.

Valvular heart disease, LA diameter, persistent AF, PVI alone, and AF termination by non-PV ablation or failed ablation were independent predictors of AF recurrence in this study. Moderate or severe valvular heart diseases and persistent AF are well-known risk factors for AF recurrence after catheter ablation [11]. They cause long-term hemodynamic deterioration, which leads to structural remodeling, and fibrosis of the atrium. Consequently, LA enlargement was developed and it is also a risk factor for

AF recurrence after catheter ablation [31]. Our results were consistent with the previous evidence. Interestingly, PVI alone (vs. PVI and additional NPVA) is associated with the increased risk of AF recurrence. There were possible explanations. Impact of additional NPVA on maintaining sinus rhythm after catheter ablation is controversial [25, 32]. However, macro-reentrant AT or non-PV trigger related AF were found in 20–30% of the procedure [33, 34]. In this situation, additional NPVA is needed to restore sinus rhythm. Our result could be thought as a necessity to find and resolve atrial tachyarrhythmias that were not related to PVs. Second, use of the AADs during the follow-up period was more than 60% and that probably affected to the result. Third, the success rate of the linear ablation might be underestimated



because we considered the lesion set was incomplete when there was no confirmation of the linear lesion set. Mode of termination was also showed an interesting finding. Termination of AF by PVI had similar prognostic effect compared to sinus rhythm before the first ablation. It could be considered that the PVs were significant AF substrate and other atrial substrates were insufficient to perpetuating AF in both conditions. On the other hand, the fact that AF was terminated by NPVA or failed by any ablation implies that there might be an AF trigger or significant atrial substrates. Meanwhile, there was no difference between the initial sinus rhythm and the termination by cardioversion. It is thought that the timing of DC cardioversion was different for each operator or case.

### Limitation

There are several limitations in this study. There was no mandatory recommendation of ablation and follow-up strategy. The definition of acute success may be different depending on the operators. Nonuniform follow-up methodology also influenced collecting recurrence data as asymptomatic or short, intermittent atrial tachyarrhythmia episodes may have been ignored. Second, there was limited data on AF cryoablation. It has been available in Korea since 2018, and it was not widely adopted when the study enrollment was active.

### Conclusions

Catheter ablation for AF is an effective and safe treatment modality in Korean real-world practice. Additional NPVA was associated with better rhythm outcome in the patients with persistent AF, not in the ones with paroxysmal AF. Valvular heart disease, persistent AF, PVI alone, need of NPVA for terminating AF, and failed ablation are independent risk factors for AF recurrence after catheter ablation. Those were consistent in the previous studies. Further investigations are needed to discover optimal strategy of catheter ablation for AF.

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### Authors' contributions

SO contributed to the conception, design, acquisition and analysis of data and critical revision of the manuscript. EL and HSP contributed to the interpretation of data for the work and drafting of the manuscript. HSP, SH, GBN, JIC, HNP, IYO, DGS, YKO, SWP, YHK, and SO contributed to the design, acquisition and analysis of data for the work. All authors approved the final version to be published and agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. All authors read and approved the final manuscript.

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### Availability of data and materials

The data that support the findings of this study are available from Korean Heart Rhythm Society but restrictions apply to the availability of these data, which were used under license for the current study, and so are not publicly available. Data are however available from the authors upon reasonable request and with permission of Korean Heart Rhythm Society.

### Declarations

#### Ethical approval and consent to participate

This study protocol was approved by the Institutional Review Board of the Seoul National University and each participating center.

#### Consent for publication

Not applicable.

#### Competing interests

There are no competing interests for this study in all authors.

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