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Acute and Long-Term Outcomes After Catheter Ablation of Atrial Tachycardia: Clinical and Electrophysiological Characteristics in the Era of High-Density Mapping

ABSTRACT

Background: Atrial tachycardia (AT) is a commonly encountered rhythm disorder and most patients require catheter ablation. In this study, the aim was to evaluate the outcomes of catheter ablation in patients with symptomatic AT, define acute and long-term outcomes, and determine the clinical and electrophysiological features that affect these outcomes.

Methods: A total of 666 (mean age: 55 ± 16, gender: 344 (51.7%) female) symptomatic patients with AT were enrolled. Activation mapping was performed using 3-dimensional electroanatomical mapping as well as entrainment mapping when needed. Atrial tachyarrhythmia (ATa) recurrence was defined as the presence of atrial fibrillation or AT (≥ 30 seconds) detected by electrocardiogram, Holter, or implantable device interrogation.

Results: Macroreentry was the primary mechanism in right and left atrium (70.2% and 52.8%, respectively). Cavotricuspid isthmus dependent macroreentry was the most frequent mechanism in right ATs, whereas perimitral reentry and roof-dependent macroreentry were the most common mechanisms in left ATs. Acute procedural success was 96.3% after catheter ablation. Freedom from ATa was 72.8% after index procedure and 84.5% after multiple procedures during a mean follow-up of 39 ± 23 months. In multivariable Cox regression analysis, history of atrial fibrillation [HR: 2.43, 95% confidence interval (CI): 1.78-3.30; $P < .001$], previous cardiac surgery (HR: 1.68, 95% CI: 1.22-2.30; $P = .001$) and moderate to severe tricuspid regurgitation (HR: 1.47, 95% CI: 1.08-2.01; $P = .014$) were significant predictors of ATa recurrence.

Conclusion: The findings demonstrated that catheter ablation of tachycardia has a high acute success rate and favorable long-term outcomes in patients with symptomatic AT.

Keywords: Atrial tachycardia, catheter ablation, macroreentry

ORIGINAL INVESTIGATION

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INTRODUCTION

Atrial tachycardia (AT) is a commonly encountered rhythm disorder, especially in patients with prior catheter ablation or cardiac surgery.[1,2] As anti-arrhythmic drugs (AADs) are generally ineffective in restoring sinus rhythm, radiofrequency (RF) ablation is the most commonly preferred therapeutic option in patients with symptomatic AT. The role of catheter ablation for maintaining sinus rhythm and relieving symptoms attributable to ATs has long been known; but mapping and ablation can be challenging as the underlying substrate may have complex characteristics.

Although procedural success is high in focal ATs due to its characteristic distribution arising from a single discrete site, reentrant ATs exhibit less favorable outcomes mostly related to the underlying atrial substrate.[3-5] Previous studies have provided detailed descriptions of the mechanisms and outcomes of catheter ablation, but studies evaluating the outcomes of AT mostly include specific types of tachycardia or patients with specific characteristics, such as a history of atrial fibrillation (AF) ablation or cardiac surgery.[6-10] In this study, the aim was to present a single-center experience regarding the acute and long-term success of catheter ablation of AT in a variety of patients with different atrial substrate characteristics using high-density mapping as well as clinical and electrophysiological characteristics predicting AT recurrence.

METHODS

Study Population

A total of 666 symptomatic patients with documented AT episodes who underwent catheter ablation between April 2014 and October 2022 were retrospectively enrolled. Atrial tachycardia was used to define organized atrial arrhythmias including focal AT, typical atrial flutter, atypical flutter, macroreentrant tachycardias, and localized reentrant tachycardias documented either by 12-lead ECG, 24-hour Holter monitoring, or intracardiac device interrogation. Baseline demographics and data about prior medical history were obtained from patients' files or electronic database of the hospital records. The study was approved by the Local Ethics Committee.

Preprocedural Management

Transthoracic echocardiography was performed in all patients prior to the ablation procedure. Transesophageal echocardiography was performed to rule out the presence of intracardiac thrombus when transseptal puncture for left AT or concomitant AF ablation was planned. Preprocedural computed tomography scan was performed, when clinically indicated, for the evaluation of left atrium (LA) and pulmonary vein (PV) anatomy and structural heart disease. Cardiac magnetic resonance imaging was also performed in selected cases.

All procedures were performed with uninterrupted oral anticoagulation with warfarin if international normalized ratio (INR) was <2.5, bridging with low molecular weight heparin (LMWH) was done when INR value was <2 on admission and LMWH was skipped on the day of the procedure. Direct oral anticoagulants were discontinued 24 hours before the procedure. All AADs were ceased 5 half-lives before the procedure except amiodarone.

Electrophysiological Study

All procedures were performed under either conscious sedation or general anesthesia. After femoral/subclavian vein punctures, a 6 Fr steerable diagnostic catheter was placed into the coronary sinus (Cs) as a reference.

All patients who were in sinus rhythm at the beginning of the procedure underwent a routine electrophysiology study. In patients who underwent catheter ablation with 3D mapping systems (CARTO, Biosense Webster or Ensite Precision/Ensite X; Abbott), voltage mapping and in some patients, isochronal late activation mapping was created. Multipolar mapping catheters [(Advisor Circular or Advisor HD Grid, Abbott), (Lasso or Pentaray, Biosense Webster)] were used for mapping, and an irrigated tip RF ablation catheter (SmartTouch, Thermocool, Biosense Webster or FlexAbility, TactiCath, Abbott) was used for ablation.

Activation Mapping

Activation mapping was done by using an atrial reference from Cs catheter and window of interest was set in order to identify critical isthmus (CI) / focus of AT, as described previously.[11] The right atrium (RA) was mapped initially when AT with a concentric Cs activation pattern was detected. Direct LA mapping was preferred in case of non-concentric Cs activation. After completion of the electroanatomical map the wavefront propagation, activation patterns, areas of slow conduction, anatomical and functional barriers and lines of the block were analyzed.[12] If left AT was detected, transseptal puncture was performed by modified Brockenbrough technique under fluoroscopic guidance. Afterwards transseptal sheath was replaced with steerable sheath (Agilis; Abbott). Unfractionated heparin boluses were administered to maintain the activated clotting time of 300-350 seconds, after LA access was obtained.

The mechanism of tachycardia was primarily determined by activation mapping data, and entrainment mapping was performed at the operator's discretion to prevent a change in the baseline AT or degeneration into another rhythm (Figure 1). Macroreentry was defined as a continuous activation sequence covering >90% of the tachycardia cycle length (TCL) with a circular type of activation pattern around a central obstacle involving >2 separate atrial segments that can be entrained in the circuit, as described elsewhere.[13] Localized reentry was defined in the case of continuous or fragmented potentials spanning approximately 50% of the TCL around a diameter of <2 cm.[14] Centrifugal activation from a distinct focal source with presystolic potentials was considered as true focal AT.[3] Critical isthmus of the reentrant ATs was defined as the narrowest pathway between scars

HIGHLIGHTS

- Catheter ablation has a high acute success rate (96.3%) and favorable long-term outcomes in patients with symptomatic atrial tachycardias (ATs).
- Reentrant ATs are associated with less favorable outcomes compared to focal ATs.
- Macroreentry is the predominant mechanism of both right- and left-sided ATs, and tachycardia mechanisms do not differ significantly between patients with or without prior ablation history.
- Cavotricuspid isthmus—dependent atrial flutter is the most common type of ATs, followed by perimitral left atrial flutter.

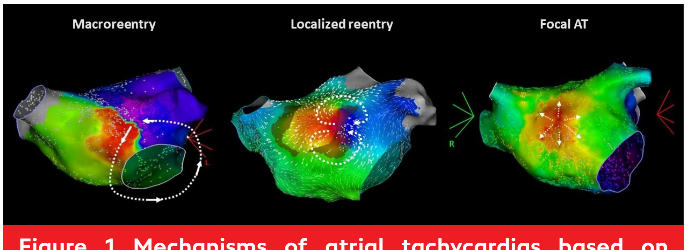

Figure 1. Mechanisms of atrial tachycardias based on activation mapping with 3D mapping systems.

and/or anatomical obstacles that had the slowest conduction based on propagation map analysis.

If the AT was not present in the beginning of the procedure, burst pacing or programmed stimulation was performed from the high right atrium, proximal and distal coronary sinus with/without intravenous isoproterenol infusion (at graded dosages from 1 to 4 µg/min, until AT developed).

Ablation Approach

Ablation strategy was primarily determined by the mechanism of AT. Radiofrequency ablation was performed using an irrigated tip contact force enabled ablation catheter with an energy setting of 25-40 W (contact force between 10 and 20 g, temperature limit <42°C, duration 20-60 seconds). These parameters were adjusted according to atrial wall thickness and the proximity to critical anatomical structures to optimize procedural safety and efficacy. A high-power short-duration ablation protocol was applied using power settings of 40-50 W delivered over short durations of 5-10 seconds in selected cases based on the operator's discretion. In focal ATs, ablation at the origin of AT was attempted. In the case of localized reentry, abnormal potentials at the isthmus of AT were completely ablated. Linear lesions aiming to connect the tachycardia isthmus with anatomical barriers or dense scar areas were attempted in the case of macroreentrant tachycardia. Phrenic nerve stimulation was performed using an ablation catheter and capture sites were tagged on the atrial wall if the ablation target is in the RA lateral wall in order to prevent phrenic nerve injury.

Procedural success was defined as termination of AT or change in reentrant circuit during RF ablation. Non-inducibility of tachycardia and abolition of abnormal electrograms were considered as procedural primary endpoints. Bidirectional block was confirmed after completion of linear lines using activation mapping and differential pacing from both sides of the ablation line, verifying absence of conduction across the ablation line in both directions. In focal or microreentrant tachycardias where linear lesions were not performed, arrhythmia termination and non-inducibility were considered procedural endpoints. Entrance and exit block in PVs were checked if concomitant or prior PV isolation was done. After ablation, non-inducibility was tested by programmed atrial stimulation with/without isoproterenol infusion in all cases. Additionally, in patients with failed endocardial ablation, epicardial mapping and ablation was performed via percutaneous subxiphoid puncture under fluoroscopic guidance.

Postprocedural Care and Follow-Up

All patients were monitored at the coronary care unit for at least 24 hours after ablation. Oral anticoagulation was started 6 hours after the procedure. Routine follow-up visits were scheduled at 1, 3, and 12 months, and every 12 months thereafter or earlier if patients had symptoms consistent with recurrence or procedure-related complications. Atrial tachyarrhythmia (ATa) was defined as the detection of AF or AT (≥30 seconds) detected by ECG, Holter, or implantable device interrogation. A 24-hour Holter monitoring was scheduled at the thirrd and 12th month after the procedure and yearly thereafter or if the patient has complaints compatible with AT. Patients remained on the AAD regimen that was prescribed before the ablation in the first 3 months after ablation, and continuation of AADs was at the discretion of the attending physician's decision.

Statistical Analysis

All statistical analysis was performed using SPSS Statistical software version 22.0. Descriptive and categorical variables were presented as counts and percentages. Normal distribution assumption was examined with detrended Q–Q plot and Kolmogorov–Smirnov test. The continuous data with normal distribution were expressed as mean ± SD and data without normal distribution were expressed as median and interquartile range. Comparisons between variables were performed by the Mann–Whitney *U*-test and independent Student's *t*-test where appropriate. To find significant predictors of ATa recurrence, Cox proportional hazard model was conducted. The Kaplan–Meier analysis was used to demonstrate freedom from ATa recurrence during the follow-up period, and the log-rank test was applied to compare recurrence-free survival across the groups. For pairwise comparisons between groups, post-hoc log-rank tests with Bonferroni correction were performed when appropriate. A 2-tailed *P* value <.05 was considered to indicate statistical significance.

RESULTS

Baseline Characteristics

A total of 666 patients [mean age: 55 ± 16; gender: 344 female (51.7%)] who underwent catheter ablation for AT were analyzed in this retrospective study. Among the study population, 478 patients [mean age: 56 ± 16; gender: 238 female (49.8%)] had no history of AF/AT ablation.

Prior catheter or surgical ablation history for AT/AF was present in 188 (28.2%) patients [mean age: 54 ± 14; gender: 106 female (56.4%)] and they underwent a redo ablation procedure in the hospital. The mean number of previous catheter ablation procedures was 0.6 ± 0.9. Among the whole study group, 219 (32.9%) patients had history of cardiac surgery [80 (12%) mitral valve replacement, 28 (4.2%) tricuspid valve surgery, 23 (3.5%) aortic valve replacement, 64 (9.6%) coronary artery bypass surgery, 44 (6.6%) atrial septal defect (ASD)/ventricular septal defect (VSD) closure, 15 (2.3%) other cardiac surgeries] and 40 (6%) of them had previous surgery for congenital heart disease. The mean LA diameter was 40.1 ± 7.2 mm and the median value of left ventricular ejection fraction (LVEF) was 60%. The baseline demographic and clinical characteristics of the study population are represented in Table 1.

Procedural Characteristics

A total of 780 procedures were performed in the whole study population. 750 (96.1%) of them were performed with 3D-electroanatomic mapping systems and in the remaining 30 procedures, AT was mapped conventionally. In 683 (87.6%) procedures, only 1 AT was recorded, whereas in the remaining 97 (12.4%) procedures, >1 ATs were documented.

Table 1. Baseline Characteristics of the Study Population (n = 666)

Age, years	55 ± 16
Gender, female, n (%)	344 (51.7)
Cardiovascular risk factors, n (%)	
Coronary artery disease	121 (18.2)
Hypertension	310 (46.5)
Diabetes mellitus	147 (22.1)
Chronic kidney disease	38 (5.7)
CHADS2-VASC2, 25th-75th percentile	2.00 (1.00-3.00)
AADs before ablation, n (%)	203 (30.4)
Echocardiographic parameters	
LA diameter, mm	40.1 ± 7.2
LVEDD, mm, 25th-75th percentile	47.0 (44-51)
Moderate to severe mitral regurgitation, n (%)	218 (32.7)
Moderate to severe tricuspid regurgitation, n (%)	284 (42.6)
LV EF, %, 25th-75th percentile	60 (50-61)
sPAP, mm Hg, 25th-75th percentile	35 (28-40)
BNP, pg/mL, 25th-75th percentile	119.5 (49.5-258.3)
History of AF, n (%)	269 (40.4)
Cardiac implantable electronic device, n (%)	45 (6.8)
ICD	23 (3.5)
PM	10 (1.5)
CRT-D	
Structural heart disease, n (%)	133 (19.9)
Previous AT/AF catheter ablation, n (%)	
Catheter ablation for AT/AF	199 (29.9)
AT Ablation	73 (11)
PVI	108 (16.2)
RF ablation	51 (7.6)
Cryoballoon	74 (11.1)
Surgical AF ablation	18 (2.7)
Cryoballoon	13 (1.9)
RF ablation	5 (0.7)
Cardiac surgery, n (%)	219 (32.9)

AADs, anti-arrhythmic drugs; AF, atrial fibrillation; AT, atrial tachycardia; BNP, B-type natriuretic peptide; CRT; cardiac resynchronization therapy; ICD, implantable cardiac defibrillator; LA, left atrium; LV EDD, left ventricular end-diastolic diameter; LV EF, left ventricular ejection fraction; PM, pacemaker; PVI, pulmonary vein isolation; RF, radiofrequency; sPAP, systolic pulmonary artery pressure.

Among all procedures, 241 (30.9%) were only left ATs and 503 (64.4%) were only right ATs; whereas in 34 (4.4%) procedures both right and left ATs were detected. In 2 (0.3%) procedures, biatrial AT was detected. Patients presented to the procedure with an initial rhythm of AT (43.5%), sinus rhythm (52.1%), AF (4%), junctional rhythm (0.3%) or pacemaker rhythm (0.1%). Mean total procedure time and fluoroscopy time were 146.1 ± 49.8 minutes and 26.8 ± 14.3 minutes, respectively.

In 751 (96.3%) procedures, AT was terminated during catheter ablation, whereas ATs could not be terminated despite the prolongation in TCL in 14 patients (1.8%). In 15 (1.9%) patients, AT was degenerated into AF. In 431/780 (55.3%) procedures, only RA mapping was performed; whereas in 154/780 (19.7%) procedures, only left-sided mapping was performed. In 195/780 (25%) procedures, both right and LA were mapped. Detailed procedural characteristics are shown in Table 2.

Table 2. Procedural Characteristics of the Study Population (n = 780)

Procedure Time, minutes	146.1 ± 49.8
Flouroscopy Time, minutes	26.8 ± 14.3
Radiation dose, mGy, median, 25th-75th percentile	647.3 (320-1099.5)
Total ablation time, min, 25th-75th percentile	19.7 (12-37.7)
Median number of mapped points	
RA	801 (338-1834)
LA	1701 (804-4608)
Mapping atrium, n (%)	
RA	431 (55.3)
LA	154 (19.7)
RA & LA	195 (25)
Type of anesthesia during catheter ablation, n (%)	
General anesthesia	268 (34.4)
Conscious sedation	512 (65.6)
Rhythm at the beginning of catheter ablation, n (%)	
AT	339 (43.5)
Sinus rhythm	407 (52.1)
AF	31 (4)
Junctional rhythm	2 (0.3)
Pacemaker stimulation	1 (0.1)
TCL of ATs, 25th-75th percentile	270 (230-335)
Acute procedural success, n (%)	96.3
Entrainment mapping, n (%)	87 (11.2)
Number of AT per procedure, n (%)	
1 AT	683 (87.6)
>1 AT	97 (12.4)

AF, atrial fibrillation; AT, atrial tachycardia; LA, left atrium; RA, right atrium; TCL, tachycardia cycle length.

Arrhythmia Mechanisms

The most common mechanism of AT was macroreentry in RA and LA (70.2% and 52.8%, respectively) (Figure 2). Among these, CTI-dependent macroreentry was the most frequent mechanism (58%) in right ATs, whereas perimitral reentry (29%) and roof-dependent macroreentry (16%) were the most common mechanisms in left ATs (Supplementary Figure 1).

Patients with Index Procedure

In 478 patients without a history of AF/AT ablation, 87 (18.2%) were only left ATs and 377 (78.9%) were only right ATs; whereas in 14 (2.9%) procedures both right and left ATs were detected. Macroreentry was found to be the most common mechanism for right and left ATs (67.7% and 45.4%, respectively). Cavotricuspid isthmus–dependent macroreentry was the most frequent mechanism (229/252) in right atrial macroreentrant ATs, whereas perimitral reentry (29/49) and roof-dependent macroreentry (12/49) were the most common mechanisms in left atrial macroreentrant ATs.

A total of 51 localized reentrant ATs were detected, 39 (76.4%) of them were located in the LA and anterior wall (20/39) was the most common site of ATs. Among all, 12/51 of them were detected in the right atrium and lateral wall (11/12) was the most common site for localized reentries in the right atrium.

A total of 147 focal ATs were detected and 120 (81.6%) of them originated from right atrium. Crista terminalis (63/120) and PVs (16/27) were the most common origins for focal ATs in right and LA, respectively. Dual loop reentry was detected in 6.1% (25/409) and 4.9% (6/121) of the ATs in right and LA, respectively.

Patients with Previous Ablation

In 188 patients with history of AF/AT ablation, 93 (49.5%) were only left ATs and 83 (44.1%) were only right ATs; whereas in 12 (6.4%) procedures both right and left ATs were detected. The most common mechanism of AT was macroreentry in right and LA (62.2% and 48.8%, respectively). Cavotricuspid isthmus–dependent macroreentry was the most frequent mechanism (54/66) in right atrial macroreentrant ATs, and perimitral reentry (35/61) and roof-dependent macroreentry (20/61) were the most common mechanisms in left atrial macroreentrant ATs.

Localized reentrant ATs were detected in 49 patients and 42 (85.7%) of them were located in the LA and anterior wall (13/42) and posterior wall (12/42) were the most common sites.

Focal ATs were detected in 43 patients and 28 (65.1%) of them originated from right atrium. Crista terminalis (8/28), tricuspid anulus (6/28) and PVs (9/15) were the most common origins for focal ATs in right and LA, respectively. Dual loop reentry was detected in 4.7% (5/106) and 5.6% (7/125) of the ATs in right and LA, respectively.

Follow-Up and Predictors of Recurrence

During the mean follow-up duration of 39 ± 23 months, freedom from ATa after index procedure was 82.3%, 75.9%, and 71.7% at 12, 24, and 36 months, respectively, and after multiple procedures, 84.5% of patients were free from ATa recurrence on/off AADs (Supplementary Figure 2).

In patients with index procedure, freedom from ATa was 83.2%, 76.4%, and 72.7% at 12, 24, and 36 months, respectively. In patients with history of previous ablation, freedom

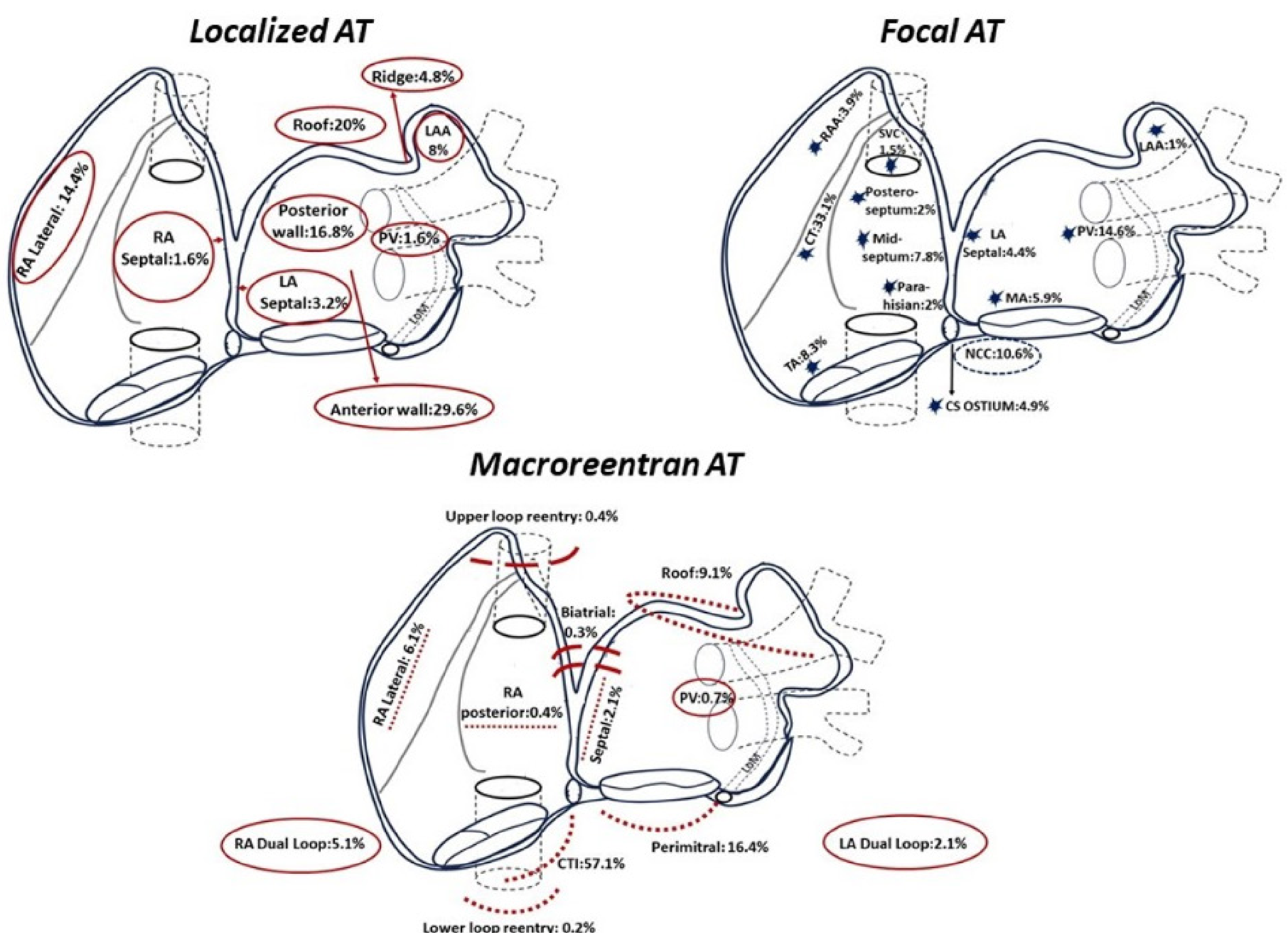

Figure 2. The distribution of atrial tachycardia types in both atria.

from ATa was 79.9%, 74.9%, and 69.3% at 12, 24, and 36 months, respectively ($P = .35$).

Patients with ATa recurrence had higher prevalence of a history of AF (55.8% vs. 34.6%, $P < .001$) or cardiac surgery (44.2% vs. 28.7%, $P < .001$) and had a significantly larger LA diameter (41.0 vs. 39.6 mm, $P = .039$) and greater baseline BNP level (150.2 vs. 105.2 pg/mL, $P < .001$) than those without recurrence (Supplementary Table 1).

Among the whole study group, 231 (34.6%) patients were on AADs for the first 3 months after ablation. In 165 (24.7%) of them, AADs were given beyond 3 months and in 58/165 of them, AADs were either escalated or switched to another AAD because of the side effects or ATa recurrence during the follow-up.

During long-term follow-up of 39 ± 23 months, 68.5%, 74.6%, and 83.6% patients were free from ATa recurrence after index procedure for macroreentrant, localized reentrant and focal ATs, respectively ($P = .001$) (Figure 3).

Univariate Cox regression analysis showed that history of cardiac surgery [HR 1.75, 95% confidence interval (CI) 1.30-2.35; $P < .001$], LA diameter (HR 1.02, 95% CI 1.00-1.04; $P = .009$), systolic pulmonary artery pressure (HR 1.02, 95% CI 1.01-1.03; $P < .001$), severity of mitral regurgitation (HR 1.20, 95% CI 0.88-1.63; $P = .24$), tricuspid regurgitation (HR 1.74, 95% CI 1.29-2.35; $P < .001$), history of previous LA ablation (HR 1.42, 95% CI 1.05-1.91; $P = .020$) and history of AF (HR 2.26, 95% CI 1. 68-3.04; $P < .001$) were associated with ATa recurrence. In multivariable Cox regression analysis, history of AF (HR 2.43, 95% CI 1.78-3.30; $P < .001$), previous cardiac surgery (HR 1.68, 95% CI 1.22-2.30; $P = .001$) and moderate to severe tricuspid regurgitation (HR 1.47, 95% CI 1.08-2.01; $P = .014$) were significant predictors of ATa recurrence; history of AF (HR 2.43, 95% CI 1.78-3.30; $P < .001$), history of cardiac surgery (HR 1.68, 95% CI 1.22-2.30; $P = .001$) and moderate to severe tricuspid regurgitation (HR 1.47, 95% CI 1.08-2.01; $P = .014$) were significant predictors of ATa recurrence.

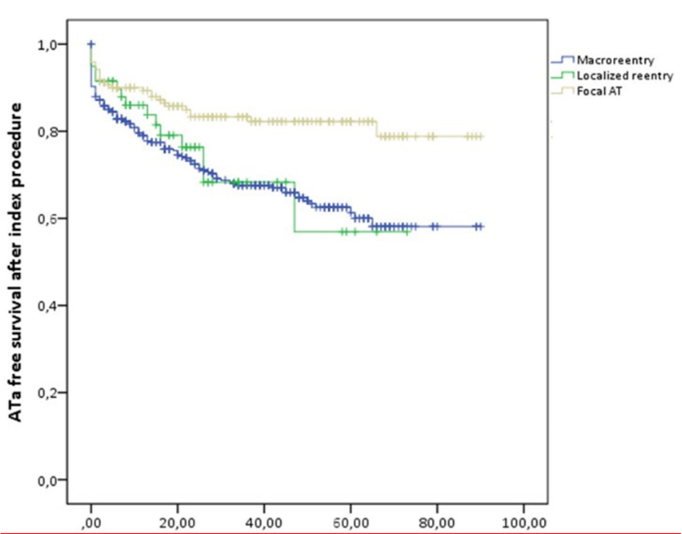

Figure 3. Freedom from atrial tachyarrhythmia after index procedure for macroreentrant, localized reentrant and focal atrial tachycardias during the mean follow-up of 39 ± 23 months.

In patients with index procedure, history of AF (HR 2.69, 95% CI 1.86-3.88; $P < .001$), history of cardiac surgery (HR 1.56, 95% CI 1.06-2.29; $P = .022$) and moderate to severe tricuspid regurgitation (HR 1.73, 95% CI 1.17-2.54; $P = .005$) were significant predictors of ATa recurrence. In patients with previous ablation, history of AF (HR 2.21, 95% CI 1.11-4.40; $P = .024$) and history of cardiac surgery (HR 1.78, 95% CI 1.02-3.10; $P = .040$) were found to be significant predictors of ATa recurrence in multivariable Cox regression analysis, history of AF (HR 2.43, 95% CI 1.78-3.30; $P < .001$), previous cardiac surgery (HR 1.68, 95% CI 1.22-2.30; $P = .001$) and moderate to severe tricuspid regurgitation (HR 1.47, 95% CI 1.08-2.01; $P = .014$) were significant predictors of ATa recurrence.

Complications

A total of 59 (7.5%) complications were observed in 780 procedures. Vascular access complications (femoral pseudoaneurysm/fistula) were the most common complications seen in 20 procedures and endovascular/surgical treatment was required in 3/20 patients. In 18 procedures, pericardial effusion was observed; only 4/18 of them necessitated pericardiocentesis. In 4 procedures, splines of the PentaRay mapping catheter were entrapped in the mechanical mitral valve prosthesis, which were freed by sheath and catheter maneuvers. Periprocedural prosthetic valve dysfunction was not observed in these patients. The details of procedural complications are given in Supplementary Table 2.

Redo Procedures

Patients with Index Procedure

In the group of 127 (26.6%) patients with recurrence, presenting rhythm was AT in 81 (63.7%) of them, whereas 45 (35.4%) patients had AF and 1 (0.9%) patient had supraventricular tachycardia (SVT). In patients with ATa recurrence, index procedure was performed in RA and LA in 6/14 (42.9%) patients, RA in 93/376 (24.8%) patients and LA in 28/87 patients (32.3%) ($P = .07$).

Repeat ablation was performed in 66 patients (58 for AT and 8 for AF). Recurrences were from previous ablation site in 33% of patients with focal AT, 41.3% of patients with macroreentrant AT, and 50% of patients with localized reentrant AT.

In 87 patients who underwent catheter ablation for left ATs in the index procedure, 28 patients (24.7%) had ATa recurrence (8 of them AF, 20 of them AT). One patient was referred for redo ablation in patients with AF recurrence. In 20 patients with AT recurrence, 14/20 patients underwent a redo ablation procedure. In 10/14 patients, recurrences were left AT, and right and left AT in 3/17 patients. In 1 patient, the recurrence AT was biatrial AT.

For patients who underwent catheter ablation for right AT in the index procedure, 93/376 patients (24.7%) had ATa recurrence (37 of them AF, 55 of them AT, 1 of them SVT). In patients with AF recurrence, 7/37 patients underwent AF ablation and 1 patient, atrioventricular (AV) node ablation was performed. Among patients with AT recurrence, 40/55 of them underwent redo ablation procedures. In 10/40 patients, recurrences were left AT and in 30/40 patients, right AT was detected in the subsequent ablation procedure.

In 14 patients who underwent catheter ablation for right and left AT in the index procedure, 6 patients (42.9%) had AT recurrence. In 5/6 patients, left AT ablation and in 1 patient, DCCV was performed.

Patients with Previous Ablation

A total of 54 (28.7%) patients had ATa recurrence and presenting rhythm was AT in 44 (81.5%) of them, whereas 9 (16.7%) patients had AF and 1 (1.8%) patient had SVT. In patients with ATa recurrence, index procedure was performed in RA and LA in 4/12 (33.3%) patients, RA in 27/83 (32.5%) patients and LA in 23/93 patients (24.7%) ($P = .65$).

Repeat ablation was performed in 37 patients (33 for AT and 4 for AF). Recurrences were from previous ablation site in 50% of patients with focal AT, 40.9% of patients with macroreentrant AT, and 40% of patients with localized reentrant AT.

Of the 93 patients who underwent catheter ablation for left ATs in the index procedure, 23 (24.7%) had ATa recurrence (3 of them AF, 20 of them AT). Atrial fibrillation ablation procedure was performed in 1 patient with AF recurrence and AV node ablation in 1 patient. Redo ablation procedure was performed in 17/20 of patients with AT recurrence and AV node ablation was performed in 2 patients. Recurrences were left AT in 16/17 patients and right AT in 1/17 patient.

Among 83 patients who underwent catheter ablation for right AT in the index procedure, 27 patients (32.5%) had ATa recurrence (6 of them AF, 20 of them AT, 1 of them SVT). In patients with AF recurrence, AF ablation was performed in 3/6 patients. A redo ablation procedure was performed in 14/20 patients with AT recurrence. Recurrence was left AT in 5/14 patients, whereas in 9/14 patients, right AT was detected in the subsequent ablation procedure.

Four patients (4/12) had ATa recurrence after catheter ablation for right and left AT in the index procedure and, in 3/4 patients, left AT ablation and in 1 patient, AV node ablation was performed.

DISCUSSION

The main findings of this study were as follows: i) Catheter ablation has a high acute success rate (96.3%) and favorable long-term outcomes in patients with symptomatic ATs, ii) Reentrant ATs had less favorable outcomes compared to the patients with focal ATs, iii) Macroreentry is the major mechanism for right- and left-sided ATs. Tachycardia mechanisms did not differ between patients with or without a history of prior ablation. Cavotricuspid isthmus–dependent atrial flutter is the most common type of tachycardia followed by perimitral and roof-dependent left atrial flutter and localized reentrant ATs were predominantly determined in the left atrial anterior wall in both groups.

These findings revealed that the right atrium was the predominant origin for focal ATs with an acute procedural success rate of 99% and a low recurrence rate (16.6%) during the long-term follow-up. Moreover, anatomical sites hosting focal ATs were consistent with previous studies, where 74.1% of ATs originated from right atrium and right-sided focal ATs predominantly originated from the crista terminalis (33.1%), parahisian region-noncoronary cusp (12.6%), tricuspid annulus (8.3%), and coronary sinus ostium (4.9%). On the other hand, left-sided focal ATs mainly originated from the PVs (14.6%) and mitral annulus (5.9%). In the era of conventional mapping, the right atrium origin was found to be the only significant predictor of successful radiofrequency catheter ablation.[15] However, these findings revealed an acute procedural success of 99% for focal ATs, which did not differ between both atria. Overall freedom from ATs was 81.1% and 84.3% for left and right focal ATs during the long-term follow-up, respectively. These findings were also in line with a previous study by Whitaker and colleagues,[16] which demonstrated no statistically significant difference in recurrence rates according to the location of origin for focal ATs.

The number of studies evaluating the outcomes of catheter ablation for localized reentrant ATs in the literature is limited and data were derived from small-scale studies or subgroup analyses of patients with left/right atrial reentrant tachycardias. Almost all of the studies evaluating electrophysiological characteristics and follow-up results of catheter ablation of left atrial localized reentries included patients with history of AF ablation. In a previous study including 70 patients undergoing catheter ablation of long-lasting persistent AF, in 9 of them localized reentry was demonstrated in a repeat ablation and at 11 ± 7 months after the procedure, 8 of 9 patients (89%) were free from any arrhythmias.[17] Previously, Ju et al[18] reported that freedom from ATa was 90.9% for 11 patients with localized reentrant AT recurrence after AF ablation. An important limitation of the above-mentioned studies was having a very small sample size. On the other hand, this study includes one of the highest number of patients in the literature with an ATa freedom rate of 86% at 12 months and 76.3% at 24 months after the index procedure. Although most of the patients with localized reentry had a previous history of ATa ablation or surgery, in 18 patients de novo localized reentrant ATs were observed. Characteristics of de novo localized reentries have not yet been well defined, but recent studies provided some data about underlying pathogenesis, distribution, and ablation outcomes.[19-21] Yet, Zaidi et al[22] reported a study with 62 patients and among 85 de novo atypical flutters, contrary to previous studies, most of the tachycardias (50% of left ATs and 70% of right ATs) were localized reentries. One of the notable findings of this study is that despite high recurrence rates (66%), recurrent ATs predominantly originated from discrete sites of the atrium compared to the index ablation procedure. Therefore, high ATa/AF recurrence is attributed mainly to the progression of already existing atrial myopathy. These functional properties of the atrial substrate may play a role in the development of atrial tachyarrhythmias as well as future recurrences.

Cavotricuspid isthmus–dependent macroreentry is the primary mechanism of right-sided macroreentry; however, non-CTI-dependent ATs are also frequent and catheter ablation had high success rates in previous studies.[23-25] In a meta-analysis including 10 719 patients, Perez et al[26] reported that freedom from ATa was 89% after CTI-dependent AT ablation during a mean follow-up of 13.8 ± 0.3 months. These findings also revealed favorable outcomes after CTI-dependent AT ablation as well as non-CTI-dependent macroreentry in the right atrium. Studies evaluating the outcomes of left atrial reentrant tachycardias mostly include patients with AT recurrence after AF ablation and perimitral and roof-dependent macroreentry are the most commonly reported mechanisms with the ratio of 4%-20%.[27] Previous studies reported that catheter ablation had an 85%-91% acute success rate and freedom from ATa was 73%-97% in long-term follow-up.[28-30] Similar to these studies, the current study's findings demonstrated freedom from ATa of 79.6% and 73.2% after the index procedure at 12th and 24th months for macroreentrant tachycardias, respectively. Recurrences were reported to be predominantly from the reconnections from prior lesions for reentrant tachycardias in previous studies.[31] Similar to these findings, in 57 patients that underwent redo ablation procedure, ATs originated from the previous ablation sites in half of the patients, whereas different tachycardia circuits were documented in the other half. These findings underscore the importance of contiguous and durable linear lesion formation to prevent future recurrences. Furthermore, new ATs originating different from index sites were not uncommon, highlighting the role of substrate progression in such patient groups despite high acute procedural success.

The large-scale single-center experience regarding AT ablation outcomes has several strengths. To the authors' knowledge, this is one of the highest volume studies presenting clinical and electrophysiological findings and overall long-term outcomes for all types of AT. These results demonstrated that focal ATs had better long-term results compared to reentrant tachycardias, and there was no statistically significant difference between recurrence rates for right- and left-sided ATs. In addition, the findings demonstrated the long-term success rate even in the case of extensive atrial remodeling or after multiple ablation procedures, which may be due to more extensive ablation. Moreover, the study findings revealed no difference in terms of AT mechanisms and outcomes in patients with or without prior ablation history. Furthermore, extensive use of high-resolution multipolar mapping catheters and contact-forced RF ablation catheters enabled accurate identification of the origin of focal ATs or CI sites of reentrant circuits, as well as areas of low voltage and slow conduction.

Study Limitations

Our study had several limitations. Firstly, this was a retrospective analysis of a single-center experience. Secondly, this center is a referral center which may limit the generalizability of these findings in routine clinical practice in terms of patient sample. Thirdly, at least one-third of the patients had history of catheter/surgical ablation or cardiac surgery, which may mitigate the generalizability of these findings to the entire patient population. Finally, the tachycardia mechanism was primarily determined based on activation mapping, and entrainment mapping was not systematically performed to confirm critical sites for reentry in all patients to prevent degeneration into another AT or AF or termination of tachycardia.

CONCLUSION

This study characterized the clinical and electrophysiological features and long-term ablation outcomes of different types and mechanisms of AT. These findings indicated that catheter ablation is an effective therapeutic option with a high acute procedural success rate and favorable long-term results, especially in focal AT patients, whereas there are moderate long-term outcomes in reentrant ATs.

Ethics Committee Approval: Hacettepe University Noninterventional Clinical Research Ethics Committee (Date: November 29, 2022; No.: 2022/20-05).

Informed Consent: Due to the retrospective nature of the study, written informed consent from patients was unattainable.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept – H.Y., K.A.; Design – G.S.K., H.Y.; Supervision – H.Y., K.A.; Resources – G.S.K., C.Ç.; Materials – G.S.K., C.Ç.; Data Collection and/or Processing – G.S.K.; Analysis and/or Interpretation – G.S.K. C.Ç.; Literature Search – G.S.K., H.Y.; Writing –G.S.K.; Critical Review – K.A., H.Y.

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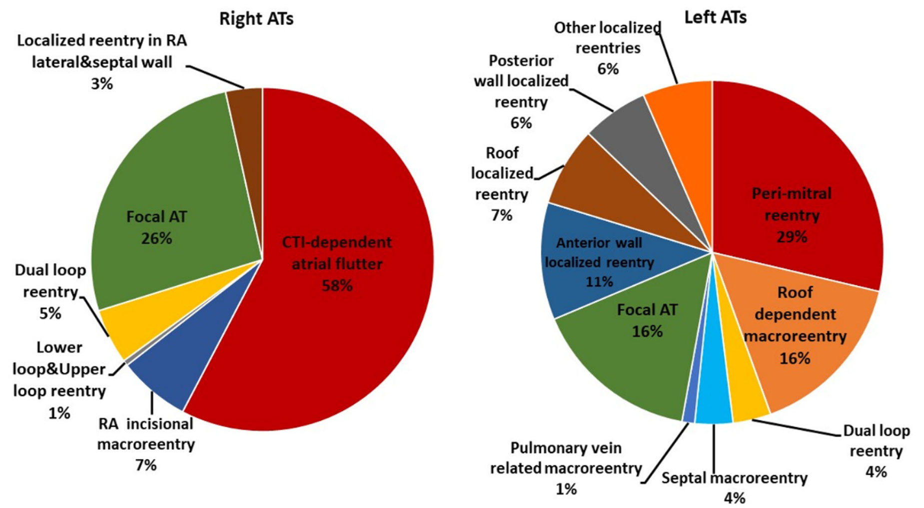
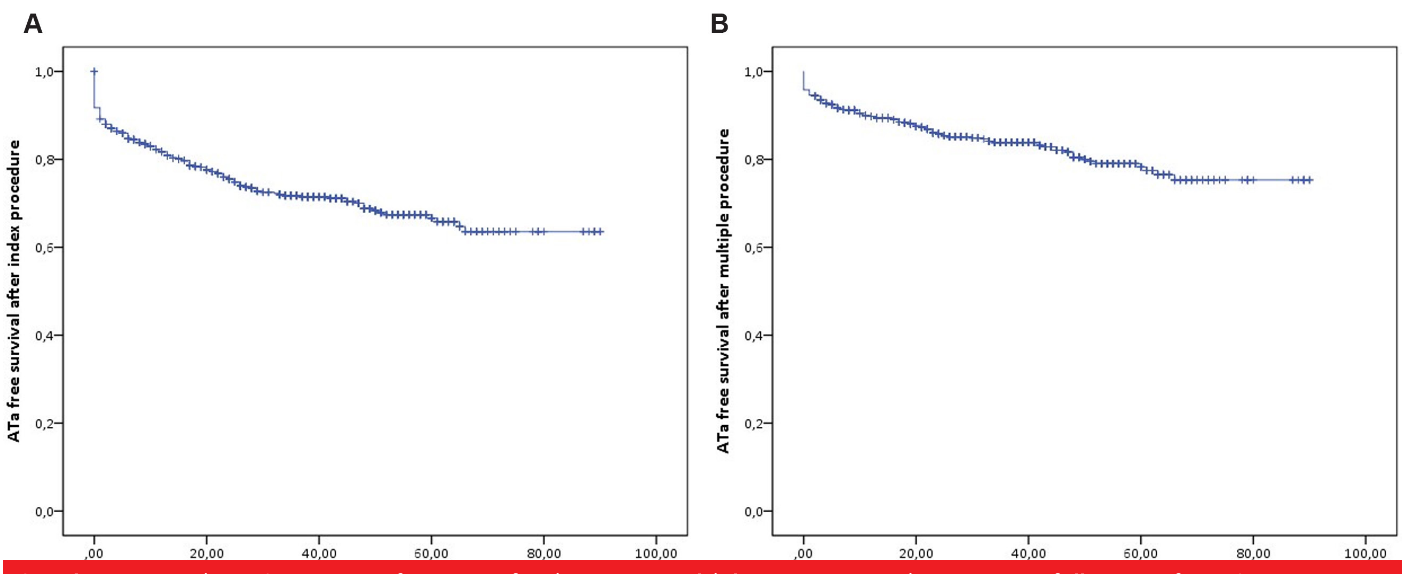


Supplementary Figure 1. The characteristics of AT mechanisms for right & left ATs.



Supplementary Figure 2. Freedom from ATa after index and multiple procedure during the mean follow-up of 39 ± 23 months.

Supplementary Table 1. Baseline characteristics of patients with or without ATa recurrence			
	Patients with ATa recurrence (n=181)	**Patients without ATa recurrence (n=485)**	***P***
Age, years	54 ± 16	55 ± 15	0.147
Gender, female, n (%)	99 (54.7%)	245 (50.5%)	0.33
Cardiovascular Risk Factors, n (%);			
Coronary artery disease	32 (17.7%)	89 (18.4%)	0.84
Hypertension	79 (43.6%)	231 (47.6%)	0.35
Diabetes mellitus	31(17.1%)	116 (23.9%)	0.06
Chronic kidney disease	12 (6.6%)	26 (5.4%)	0.53
CHADS2-VASC2, 25^{th}-75^{th} percentile	2.00 (1.00-3.00)	2.00 (1.00-3.00)	0.95
Echocardiographic parameters;			
LA diameter, mm	41 ± 7.7	39.6 ± 7.04	0.039***
LVEDD, mm	48.2± 6.6	47.9 ± 6.05	0.702
LV EF, %	54.4%±11.2%	55.0% ± 11.4%	0.51
sPAP, mm Hg, 25^{th}-75^{th} percentile	38.8±13.6	34.9 ± 10.2	<0.001***
Mitral regurgitation			
Mild	65%	67.1%	0.61
Moderate to severe	35%	31.9%	
Tricuspid regurgitation			
Mild	46%	59.4%	0.002***
Moderate to severe	54%	40.6%	
AF, n (%)	101 (55.8%)	168 (34.6%)	<0.001***
BNP, pg/ml, 25^{th}-75^{th} percentile	150.2 (82.4-357.3)	105.2 (45.5-222.1)	<0.001***
Index procedure, n	127 (70.2%)	351 (72.4%)	
Redo procedure, n	54 (29.8%)	134 (27.6%)	
History of cardiac surgery, n	80 (44.2%)	139 (28.7%)	<0.001***
History of catheter ablation, n	51 (28.2%)	148 (30.5%)	0.55
History of surgical ablation, n	8 (4.4%)	10 (2.1%)	0.09***

AF, atrial fibrillation; ATa, atrial tachyarrhythmia; LA, left atrium; LV EDD, left ventricular end-diastolic diameter; LV EF, left ventricular ejection fraction; sPAP, systolic pulmonary artery pressure.

Supplementary Table 2. Major and minor complications after AT ablation	
Major Complications	14 (1.8%)
Tamponade	4 (0.5%)
Major vascular injury	2 (0.2%)
Hemorragic/thromboembolic cerebrovascular event	3 (0.3%)
PTE/DVT	3 (0.3%)
High grade AV block	2 (0.2%)
Minor Complications	45 (5.7%)
Vascular access complications	20 (2.5%)
Minor Pericardial effusion	13 (1.6%)
Diaphragm paralysis	2 (0.2%)
Pneumotorax	1 (0.1%)
Acute pulmonary edema	1 (0.1%)
Coronary spasm	2 (0.2%)
GI bleeding	2 (0.2%)
Mapping catheter entrapping in mechanical mitral valve prosthesis	4 (0.5%)

AV, atrioventricular; DVT, deep vein thrombosis; GI, gastrointestinal; PTE, pulmonary thromboembolism.