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Atrial Arrhythmia Recurrence After Pulmonary Vein Isolation in Hypertrophic Cardiomyopathy: Insights from Repeat Ablations

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Abstract

Background

Patients with hypertrophic cardiomyopathy (HCM) are at high risk for atrial fibrillation (AF) and AF recurrence after catheter ablation remains frequent. Data on mechanisms underlying recurrence and on pulmonary vein isolation (PVI) durability in this setting remain scarce.

Methods

This retrospective multicenter study included HCM patients with atrial arrhythmia (AA) recurrence after an initial AF ablation, who underwent repeat ablation with left atrial 3D electroanatomic mapping (EAM). Procedural data, arrhythmia mechanisms, and outcomes during follow-up were analyzed.

Results

Among 23 patients (mean age 59 ± 12 years, 26% female), the type of arrhythmia at recurrence was AF in 16 patients (70%) and organized AAs in 7 patients (30%). In 5/16 patients with AF as the predominant clinical recurrence, mappable flutters were induced intra-procedurally. PV reconnection was observed in 74% of patients and 35% of all PVs were reconnected. Left atrial flutters were mapped in 48% of patients, including perimitral and roof-dependent circuits. Repeat ablation was performed with PFA in 48% and radiofrequency in 52%; PV re-isolation was performed in 74% of patients and extra-PV lesions in 61%. Median follow-up time was 12 months after redo ablation. Estimated AA-free survival at 3, 6, and 12 months was 82.6%, 69.6%, and 33.5%. 60% of the patients required a third ablation, and 56% remained on antiarrhythmic drugs.

Conclusions

In HCM patients undergoing repeat ablation, PV reconnection and left atrial flutters are common mechanisms of recurrence. Long-term rhythm control remains suboptimal with a frequent need for multiple procedures.

Introduction

Patients with hypertrophic cardiomyopathy (HCM) are at significantly higher risk of developing atrial fibrillation (AF) compared with the general population (1, 2). AF in HCM often occurs at a younger age (3) and carries a higher risk of stroke (4, 5). Individuals with HCM who develop AF experience greater rates of heart failure–related hospitalizations and mortality than those who remain in sinus rhythm (6, 7).

Management of AF in the HCM population mirrors that in the general population, namely antiarrhythmic drugs (AADs) and catheter ablation (8). Current guidelines recommend early catheter ablation, with a Class I indication for symptomatic patients refractory to AAD therapy and a Class IIa indication as first-line rhythm control in symptomatic patients (9). However, patients with HCM experience significantly higher rates of atrial arrhythmia (AA) recurrence after ablation and greater need for repeat ablations as compared to non-HCM patients (10, 11).

So far, few studies have examined the mechanisms of AA recurrence in HCM. The disease likely contributes to a higher rate of pulmonary vein (PV) reconnection, probably due to diffuse atrial fibrosis and increased atrial wall thickness (12). Also, a higher atypical atrial flutter incidence rate following a first ablation often triggers ablation strategies beyond standard PV isolation (PVI), which are in turn more prone to be arrhythmogenic considering the increased difficulty in achieving durable linear ablation in HCM patients (13).

Most studies on PVI durability in HCM have focused on patients treated with radiofrequency (RF) ablation (14–16). In a previous multicenter study, we showed that PFA was safer and more effective than thermal ablation (RF or CBA) in HCM patients (17). In particular, PFA was associated with significantly lower rates of sustained AA recurrence compared to thermal ablation and no increase in arrhythmic recurrence in patients who underwent extra-PV ablation, unlike thermal techniques. However, recurrence rates remained high with 57% freedom from AA recurrence at 12 months follow-up.

The aim of this study was to determine PVI durability, characterize AA recurrence mechanisms, and assess arrhythmic outcomes after repeat ablation.

Methods

Study population

In a previous study, consecutive patients with a diagnosis of HCM who underwent their first AF catheter ablation between 2016 and 2024 in three university centers in France and Switzerland were retrospectively enrolled 17. HCM was defined based on the 2023 guidelines from the European Society of Cardiology (ESC) on cardiomyopathy management (9). Patients whose left ventricular hypertrophy was due to hypertension were excluded.

Here, we included all patients from this cohort who had AA recurrence [defined as AF, atrial flutter (AFL - typical or atypical) and atrial tachycardia (AT) lasting ≥ 30s], and subsequently underwent at least one repeat ablation involving 3D electro-anatomical mapping (EAM) of the left atrium. Exclusion criteria included the use of hybrid (surgical ± transcatheter) ablation as the initial ablation procedure and the lack of left atrial 3D EAM data at repeat procedure.

Patient data (population characteristics, clinical data, genetic information and imaging) were collected from digital patient files.

Patients gave written consent for the pseudonymized use of routine clinical data for research purposes. Written consent for pseudonymized disclosure of genetic data for the purpose of research was included in signed consent forms for genetic analyses. This study complies with the reference methodology (MR004) of the French National Commission for Informatics and Liberties (CNIL) and the study was carried out in accordance with the principles of the Declaration of Helsinki. The specific aims and pre-specified analyses of the present study were reviewed and approved by the ethics committee/institutional review board of each participating center, in accordance with the applicable national regulations governing retrospective research. The authors had full access to the data and take full responsibility for their integrity.

Initial ablation procedure

Patients underwent AF catheter ablation either with thermal energy (RF or CBA) or PFA. Procedural details of the initial ablation procedure are reported in our previous study (17). After the procedure, AAD resumption and therapy duration was left at the discretion of the treating physician. Patients were then followed by the treating center through outpatient visits (every 3-6-12 months) with standard 12-lead ECG, 24 h Holter ECG and/or interrogation of cardiac implantable electronic devices.

AA recurrence was defined as evidence of sustained AA (lasting > 30 seconds), following a blanking period of 40 days. This 40-day blanking period was pre-specified to exclude early, potentially transient post-procedural arrhythmias while limiting the misclassification of clinically meaningful early recurrences; we acknowledge that it differs from the 8-week period used in our previous report and from the conventional 3-month blanking period, and this choice is addressed in the study limitations.

Repeat ablation procedure

Patients who experienced symptomatic AA recurrence following the blanking period were considered eligible for a repeat procedure. A three-dimensional EAM of the left and/or right atria was performed using either the CARTO (Biosense Webster, Irvine, CA) or ENSITE (Abbott Medical, IL) system to investigate the mechanism of arrhythmia recurrence. The choice of ablation system and energy source - including RFA, PFA with a pentaspline catheter, or alcohol ablation of the vein of Marshall - was left to the operator’s discretion.

After transseptal puncture, PV reconnection status was assessed using bipolar voltage mapping and determination of entrance/exit block. For left PVs, distal coronary sinus stimulation was performed to differentiate between local PV electrograms and far-field signals from the left atrial appendage. Extra-PV ablation lines or regions (e.g. roof line, posterior wall ablation with the pentaspline PFA catheter, mitral isthmus) were systematically checked for reconduction using activation mapping and bidirectional pacing. When patients presented with organized AAs at the start of the procedure, activation mapping was performed to determine the arrhythmia mechanism. Focal ATs were treated with ablation of the

point of origin, while ablation lines targeting the critical isthmus of the arrhythmia were performed in AFLs. Additional ablation lines - including roof, posterior wall and anterior mitral line - or vein of Marshall alcohol ablation were performed at the operator's discretion.

Follow-up

Follow-up included periodic outpatient visits at the center of reference at 3, 6, and 12 months, including 12-lead ECGs, mandatory 24-hour Holter monitoring at 6 months, and/or interrogation of implanted cardiac devices when applicable. Beyond the first 12 months, patients continued to be followed at the reference center according to the same schedule, and all arrhythmia recurrences, antiarrhythmic drug changes, and repeat procedures occurring throughout the entire available follow-up were captured. Decisions regarding AAD management were made according to the treating physicians' preferences. In case of AA recurrence, a third ablation procedure was performed based on the patient's clinical profile and on treating clinicians' discretion.

Sustained AA recurrence lasting ≥ 30 sec and need for a third repeat ablation procedure were assessed. Considering the small patient sample, the specificity of the population and the number of recurrences as organized arrhythmias, no blanking period was applied after repeat ablation. Procedural complications such as cardiac tamponade requiring drainage, stroke/transient ischemic attack, phrenic nerve palsy, atrio-esophageal fistula, major vascular complications requiring intervention or death were collected. Death at follow-up was evaluated as all-cause mortality, cardiovascular mortality and sudden cardiac death.

Statistical analyses

Descriptive statistics were used to describe baseline characteristics, initial ablation characteristics, recurrence mechanisms, repeat procedure characteristics and follow-up data. Categorical variables were presented as frequencies and percentages, while for continuous variables data are presented as mean ± standard deviation or median (interquartile range [IQR]) depending on the variable's distribution assessed by the Shapiro-Wilk test (non-normal distribution defined as $p < 0.05$). Survival analysis was performed with the Kaplan-Meier method to estimate overall event-free survival. Probability of freedom from AA recurrence at 3,6 and 12 months were reported along with 95% confidence intervals. Patients who were lost to follow-up or had not experienced the event at the time of analysis were censored. Statistical analyses were performed with *Jamovi v2.6.26.0* (The Jamovi project, Sydney, Australia).

Results

Population characteristics

In the initial study, we included 109 HCM patients from three centers undergoing AF ablation. Of these, 51 (47%) experienced AA recurrence during follow-up and of these 29 (57%) underwent repeat ablation. Two patients were excluded because they underwent a hybrid (surgical ± transcatheter) ablation procedure at the initial ablation; 4 patients were excluded due to missing EAM data (right atrium ablations only or hybrid ablations with no EAM data). Overall, a total of 23 patients were included in our study (PSL: 8, INSEL: 10, USB: 5) (Fig. 1).

Of these, 6 patients (26%) were female; mean age at repeat ablation was 59 ± 12 years and median BMI was 26 [IQR 24–32] kg/m2. Mean CHA2DS2-VA score was 1 ± 1. Five patients (21%) had a history of congestive heart failure and 11 patients (48%) had cardiac implantable electronic devices (CIEDs) (2 pacemakers and 9 implantable cardioverter-defibrillators). Two patients (8%) had already undergone surgical or percutaneous septal reduction and 7 patients (30%) had a history of significant LVOT obstruction (defined as maximal gradient > 30 mmHg). Average maximum septal thickness was 17 ± 5 mm, average LA volume indexed to body surface area was 52 ± 16 ml/m2 and mean LVEF was 57 ± 12%. Pathogenic genetic mutations were found in 6 (26%) patients (**Table 1**).

Initial ablation characteristics

14 (60%) patients underwent RFA, 6 (26%) CBA and 3 (13%) PFA during the first ablation (Table 2). Among them, 18 patients (78% – 11 in the RF group, 1 in the PFA group and all patients in the CBA group) underwent PV isolation only. Extra-PV ablation lines in the left atrium were performed in 5 patients (21% – 3 in the RFA group and 2 in the PFA group): all 5 patients had a posterior wall isolation and one of them a mitral isthmus line (with RF) together with ethanol infusion in the vein of Marshall. CTI ablation for typical atrial flutter was performed in 9 patients (39%).

Table 2
Initial AF ablation characteristics

Type of energy used	**All (n = 23)**
RFA	**14 (60)**
CBA	**6 (26)**
PFA	**3** (13)
PV isolation only	**18 (78)**
Extra-PV ablation in the left atrium	**5** (21)
Roof line/posterior wall ablation	**5** (21)
Mitral isthmus ablation	**1** (4)
Marshall vein alcoholisation	**1** (4)
Substrate ablation	**1** (4)
CTI ablation	**9 (39)**

Abbreviations: CBA: cryoballoon ablation; PFA: pulsed field ablation; PV: pulmonary veins; RFA: radiofrequency ablation

Arrhythmia recurrence after first procedure

The median time to recurrence following the initial procedure was 5 [IQR 3–19] months. Following the first ablation procedure, 13 patients (56%) were taking at least one AAD. During follow-up AADs were discontinued in two patients (8%) and antiarrhythmic treatment was changed to a different medication in 3 patients (13%). At the time of AA recurrence 11 patients (48%) were treated with AADs.

The type of arrhythmia at recurrence was AF in 16 patients (70%) and organized AAs (atypical macro-reentrant AFL or focal/micro-reentrant AT) in 7 patients (30%).

Repeat ablation procedure and arrhythmia recurrence mechanisms

All patients included in the study underwent 3D EAM of the left ± right atrium. Average procedure duration was 150 ± 68 min, median fluoroscopy duration was 13 [IQR 9–17] min and median fluoroscopy dose was 6 [IQR 3–9] Gy/cm2.

Ten patients were in sinus rhythm at the beginning of the procedure, 9 were in AF and 4 in AFL.

Ablation durability. PV reconnection was documented in 17 (74%) patients, with 33 reconnected PVs out of 92 (35%); 7 patients had 1 reconnected PV (30%), 6 had 2 reconnections (26%), 2 had 3 reconnections (9%) and 2 had all 4 PVs reconnected (9%). Thirteen (56%) patients had RIPV reconnection, 9 (39%) had RSPV reconnection, 5 (21%) had LSPV and 5 (21%) had LIPV reconnection. The most common sites of reconnection were the anterior portion of the LSPV (3 patients), left carina/common ostium (3 patients), right carina (3 patients) and the inferior/posterior portion of the RIPV (4 patients). The anatomical distribution of pulmonary vein reconnection is summarized in Fig. 2.

Among the 5 patients who underwent extra-PV roof line ablation with RFA or posterior wall isolation with PFA during the index procedure (3 with RF and 2 with PFA), no roof reconnection or roof-dependent AFL was observed. The single patient who underwent mitral isthmus ablation with RF exhibited reconnection thereof with recurring perimitral AFL.

Organized atrial arrhythmias. At least one atypical AFL was mapped in 11 (48%) patients: 4 (17%) patients had roof dependent flutters, 8 (34%) had perimitral flutters and 3 (13%) patients had a microreentry. CTI reconnection was documented in 6 (26%) patients. In one patient no clear recurrence mechanism was found, therefore empirical posterior wall isolation was performed.

Among 16 patients who experienced AF recurrence only, PV reconnection was identified in 13 patients (81%) and 45% of PVs (29/64). At least one left-sided atrial flutter was mapped and ablated in 5 of these patients (31%). In patients with AFL or AT (7 patients), PV reconnection was observed in 4 cases (57%) and 14% of PVs (4/28), and a left-sided atrial flutter was successfully mapped in all but one patient (85%).

PV re-isolation was performed in all 17 patients (74%) with reconnection, while extra-PV lines were performed in 14 patients (61%)– roof, floor, mitral isthmus line and anterior mitral line in 9 (39%), 6 (26%), 3 (13%) and 7 (30%) patients respectively. RF was the ablation energy in 12 (52%) patients while 11 (48%) patients were ablated with PFA. In patients ablated with RF, 9 (75%) had PV re-isolation and 7 (58%) had extra-PV linear lesions (roof, floor and/or mitral isthmus). Of the 11 patients ablated with PFA, PV re-isolation was performed in 8 patients (72%), a posterior wall isolation was performed in 6 patients (54%) and an anterior mitral line in 3 (27%). In one patient, ethanol infusion in the vein of Marshall was performed. No peri-procedural complications occurred (Table 3). A case-example of a redo AA ablation in a patient with HCM is shown in Fig. 3.

Table 3
Repeat ablation procedure characteristics

Procedure duration (min)	**All (n = 23)**
	150 ± 68
Fluoroscopy duration (min)	**13 [9–17]**
Fluoroscopy dose (Gy/cm^2)	**6 [3–9]**
At least one PV reconnection	**17 (74)**
Number of reconnected PVs per patient	
1	**7 (30)**
2	**6 (26)**
3	**2** (8)
4	**2** (8)
Reconnected PVs	
LSPV	**5** (21)
LIPV	**6 (26)**
RSPV	**9 (39)**
RIPV	**13 (56)**
Patients with at least one intraprocedural left atrial flutter	**11 (48)**
Roof dependent left atrial flutter	**4** (17)
Perimitral flutter	**8 (34)**
Microreentry	**3** (13)
CTI reconnection	**6 (26)**
Type of energy used	
RFA	**12 (52)**
PFA	**11 (48)**
PV re-isolation	**17 (74)**
Roof line	**9 (39)**

Abbreviations: CTI: cavo-tricuspid isthmus; LIPV: left inferior pulmonary vein; LSPV: left superior pulmonary vein; RIPV: right inferior pulmonary vein; RSPV: right superior pulmonary vein; PFA: pulsed field ablation; PV: pulmonary vein; RFA: radiofrequency ablation

Procedure duration (min)	All (n = 23)
	150 ± 68
Floor line	**6 (26)**
Mitral isthmus line	**3** (13)
Anterior mitral line	**7 (30)**
Marshall vein alcoholisation	**1** (4)

Abbreviations: CTI: cavo-tricuspid isthmus; LIPV: left inferior pulmonary vein; LSPV: left superior pulmonary vein; RIPV: right inferior pulmonary vein; RSPV: right superior pulmonary vein; PFA: pulsed field ablation; PV: pulmonary vein; RFA: radiofrequency ablation

Safety and efficacy outcomes

Follow-up data was available for all patients. Median follow-up time following repeat ablation was 12 [IQR 8–34] months. Overall, 18 (78%) patients experienced sustained AA recurrence after the procedure. The median time to AA was 8 [IQR 5–12] months. The estimated event-free rates at 3, 6, and 12 months were 82.6% (95%CI [68.5–99.6%]), 69.6% (95% CI [53.1–91.2%]), and 33.5% (95% CI [18.6–60.3%]) respectively (Fig. 4).

At discharge, 11 patients (48%) were prescribed AADs. During follow-up, 6 patients (26%) required an escalation of AAD therapy due to AA recurrence, while AAD de-escalation was achieved in only one patient. At last evaluation, 13 (56%) patients were under antiarrhythmic therapy.

Fourteen patients (60%) underwent a third ablation procedure during follow-up. No patients died during follow-up. Two patients underwent atrioventricular node ablation following arrhythmia recurrence and one patient awaits cardiac transplant and is on mechanical circulatory support (LVAD) for end-stage heart failure.

Discussion

Limited data are available regarding AA recurrence in HCM patients who underwent a first AF ablation (11). We analyzed mechanisms of recurrence and ablation durability during repeat procedures after AF ablation in HCM using various ablation energies including PFA. Prior larger studies and meta-analyses have already established that patients with HCM experience high AA recurrence rates, frequently require repeat ablation, often remain on antiarrhythmic drugs, and display complex non-PV arrhythmia mechanisms (8, 10, 11). The incremental contribution of the present work is therefore not the confirmation that rhythm control remains difficult in HCM, but rather the detailed characterization of redo-procedure electroanatomic mapping findings, including PV reconnection patterns and organized atrial flutters, in a contemporary multicenter cohort that also includes patients treated with PFA.

Accordingly, our findings should be regarded as descriptive and hypothesis-generating. The main findings are:

1. PV reconnection was observed in 74% of patients and involved 35% of pulmonary veins (33/92; i.e., 65% of pulmonary veins remained durably isolated), most frequently the right inferior PV.
2. Atypical atrial flutters were mapped in 48% of patients, often coexisting with PV reconnection.
3. Despite repeat ablation, 78% of patients experienced arrhythmia recurrence during follow-up, with an estimated 12-month arrhythmia-free survival of 34%.
4. Over half of the patients (60%) required a third ablation procedure, and 56% remained on antiarrhythmic drugs at last follow-up.

Previously, we showed that PFA has a better safety and efficacy profile when compared to thermal energies (17). PFA was associated with lower rates of sustained AA recurrence and less post-procedural heart failure. Despite this, arrhythmic outcomes (57% repeat ablation rate vs 16% in the general population (18)) were in line with previous publications of AF ablation in HCM (10). Whether this translates into increased PV durability remains unclear. Although only a minority of patients in our cohort initially underwent PFA (n = 3), these cases did not show roof line reconnection or roof-dependent flutters. Given the very small number of PFA-treated patients, this cohort is not powered to compare lesion durability or homogeneity across energy sources; any suggestion that PFA offers superior transmurality or homogeneity in specific atrial regions is therefore speculative and rests primarily on prior studies rather than on the present dataset.

PV reconnection in patients with AA recurrence was observed in nearly three-quarters of patients, predominantly involving the right inferior PV and carinal regions. This number is not markedly higher than those of patients without HCM. The recently published MANIFEST-REDO (19) study showed that only 45% of patients and 70% of PVs exhibited durable isolation following PFA-based AF ablation with a pentaspline PFA catheter. In our population, 65% of PVs were durably isolated, with similar durability rates between the types of energy used during the index procedure. This finding is consistent with prior literature (10, 15) and reinforces the notion that PV isolation durability remains suboptimal in patients with HCM, often necessitating multiple ablation procedures throughout the disease course.

Organized AAs, including perimitral and roof-dependent flutters, were mapped in nearly half of our cohort, despite representing a minority of clinical recurrences. Of note, in our population induction of AA was not performed systematically if the patient didn’t present organized AAs during follow-up. Among patients who recurred exclusively as AF during follow-up, 31% were found to have inducible or spontaneous organized flutters intra-procedurally. This emphasizes the complex arrhythmogenic substrate in HCM and the pro-arrhythmogenic potential of linear ablation. These results diverge from previous reports (14, 16), which have described markedly higher rates (62–89%) of organized AAs in HCM patients. In our previous study (17), we demonstrated that patients undergoing additional extra-PV linear ablations with RFA experienced higher rates of AA recurrence compared to ablation lines performed with PFA. This finding was likely attributed to the potentially increased homogeneity of linear

lesions achievable with the pentaspline PFA catheter, possibly reducing the proarrhythmic potential of incomplete linear ablation. The increased uniformity of lesion sets created by PFA may theoretically reduce the prevalence of organized arrhythmias, while still not eliminating PV reconnection as a major driver of recurrence; however, in the present cohort this remains speculative and is derived largely from prior experimental and clinical reports (20). This result suggests a role for systematic and comprehensive atrial voltage and activation mapping, and trigger provocation with isoproterenol and atrial programmed stimulation, even in patients without clinical evidence of organized AAs prior to the repeat procedure.

In the general population, AF recurrence rates after second ablation procedures range from 17–42%, indicating that repeat procedures are generally more successful than initial ablations (21–23). In a multicenter German registry, Fink et al. found 42% recurrence rates in 738 patients after second ablation over median 15-months follow-up (21). Mulder et al. found 32% recurrence in 140 patients undergoing second PVI-only procedures (22). Another study reported better outcomes with 17% recurrence in 47 patients using cryoballoon technology for repeat procedures after initial radiofrequency ablation (23). In contrast, in our study, 78% of patients experienced recurrent AAs during a median follow-up of 12 months, and 60% required a third ablation procedure. Arrhythmia-free survival rates were estimated at 82.6% at 3 months, 69.6% at 6 months, and 33.5% at 12 months, indicating a substantial recurrence burden especially in the first months following the procedure. These results reflect the persistent challenges of long-term rhythm control in HCM, despite the adoption of advanced mapping systems and modern ablation technologies. The high recurrence rates observed highlight both the complex arrhythmogenic substrate characteristic of HCM and the current limitations of catheter ablation in achieving durable outcomes in this population.

Limitations

Limitations of our work include a small sample size, the retrospective nature of the study and inter-center variability in repeat ablation indications and patient management. Possible selection bias could be linked to the relatively low rate of repeat procedures performed despite high recurrences following the index ablation. Only 23 of the 51 patients with documented recurrence (45%) were ultimately included, after excluding patients who did not undergo a repeat procedure and those without available left atrial electroanatomic mapping data. Patients referred for repeat ablation may differ systematically from those managed conservatively, for instance with respect to the extent of atrial disease, left atrial size, and comorbidity burden; such selection may bias our estimates of PV reconnection and recurrence, and comparative data on patients not selected for a second procedure were not available. The small sample size limits statistical power and precludes reliable subgroup analyses; descriptive data on antiarrhythmic drug management and on the type of repeat procedure depend heavily on center- and operator-specific decisions and should not be extrapolated, and the heterogeneity of the procedures further complicates interpretation of the recurrence analyses. The 40-day blanking period applied after the index ablation and the absence of a blanking period after the repeat procedure may also have influenced the classification of early recurrences. Finally, the cohort was small and predominantly male (74%); although a formal sex-

based analysis was not statistically credible, the cohort should not be assumed homogeneous with respect to sex, and the generalizability of our findings across sexes and genders remains uncertain. Another limitation of our study was the low number of included patients treated with PFA during the first ablation procedure, therefore long-term randomized comparisons would be needed to understand the differences in recurrence mechanisms between energy sources (RF vs CBA vs PFA).

Conclusions In this multicenter study of HCM patients undergoing repeat ablation for atrial arrhythmias, pulmonary vein reconnection and left atrial flutters were particularly frequent. Arrhythmia-free survival at 12 months remained low and PV reconnection was documented in 74% of patients. Over half of the patients required a third ablation, and many remained on antiarrhythmic therapy. These descriptive, hypothesis-generating findings underscore the arrhythmogenic complexity of HCM and the limitations of current ablation strategies, and warrant confirmation in larger, prospective studies. Further technological improvements are needed to ensure adequate lesion delivery and durability in the atria of patients with HCM.

Abbreviations

AA – Atrial Arrhythmia

AAD – Antiarrhythmic Drug

AF – Atrial Fibrillation

AFL – Atrial Flutter

AT – Atrial Tachycardia

CBA – Cryoballoon Ablation

EAM – Electroanatomic Mapping

HCM – Hypertrophic Cardiomyopathy

PFA – Pulsed Field Ablation

PV – Pulmonary Vein

RFA – Radiofrequency Ablation

Declarations

Disclosures:

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Author Contribution

C.P. and M.L. wrote the manuscript and prepared the figures. S.G., T.K. and K.S. participated in patient data collection. All authors reviewed the manuscript.

Tables

Table 1 is available in the Supplementary Files section.

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Figures

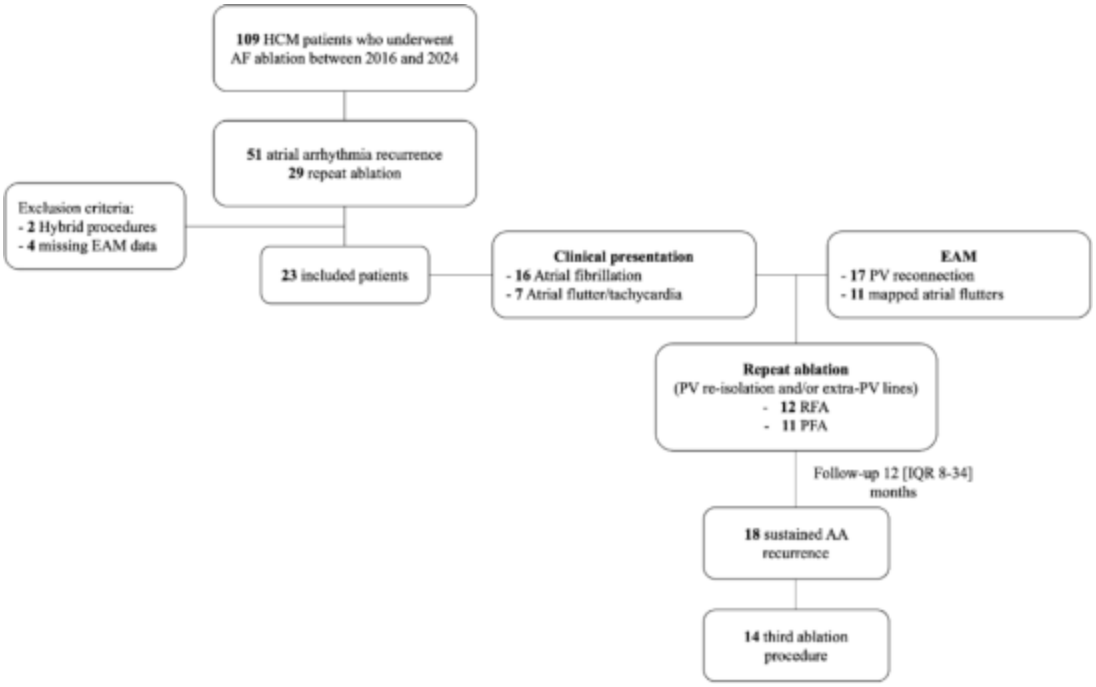


Figure 1

Patient selection flowchart

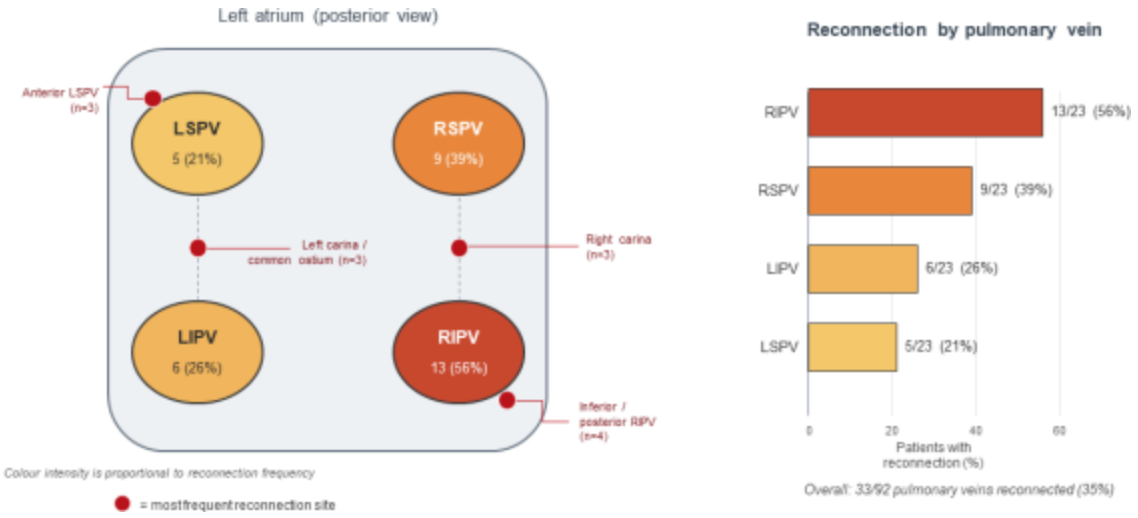


Figure 2

Anatomical distribution of pulmonary vein reconnection at repeat ablation.

Schematic posterior view of the left atrium showing the proportion of patients with reconnection of each pulmonary vein (right inferior 56%, right superior 39%, left inferior 26%, left superior 21%; 35% of all pulmonary veins, 33/92, were reconnected) and the most frequent sites of reconnection (anterior left superior pulmonary vein, left carina/common ostium, right carina, and the inferior/posterior right inferior pulmonary vein).

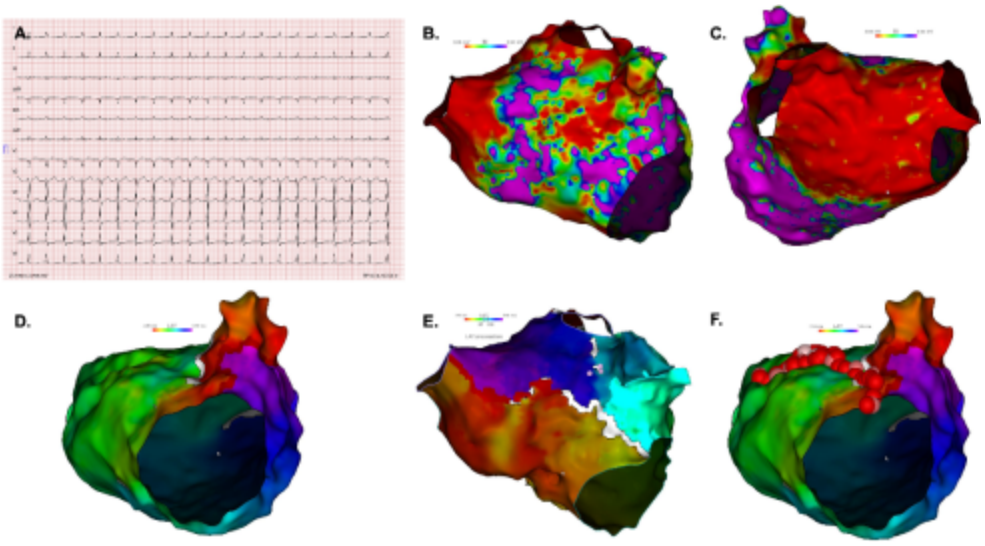


Figure 3

Case-example of a redo atrial arrhythmia ablation in a patient with HCM.

A 73-year-old patient with HCM and significant left ventricular outflow tract obstruction underwent a first AF ablation in June 2022, including PVI and posterior wall isolation, using a pentaspline PFA catheter. A recurrence of AFL occurred in October 2022, prompting a repeat ablation in May 2023. A: 12-lead ECG of the AFL. B.&C. Bipolar voltage mapping shows durable PVI and posterior wall isolation, with a large anterior wall scar (<0.05 mV) and diffuse low-voltage areas (0.05–0.5 mV). D.&E. Activation mapping revealed a perimitral AFL circuit revolving around the anterior wall scar. F. RF ablation was performed to connect the anterior scar to the RIPV and the roof, resulting in AFL termination and non-inducibility. The patient experienced AFL recurrence in January 2024. A third ablation revealed epicardial reconnection of the anterior line, which was successfully re-ablated using HD mapping and a combination of PFA and RF catheters.

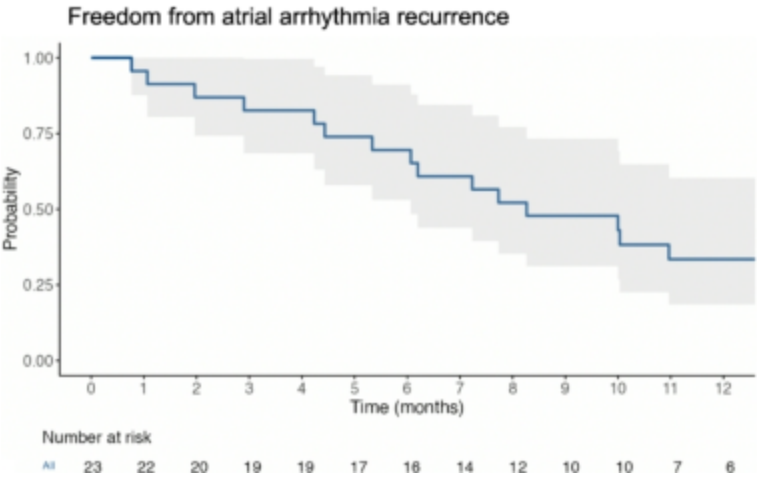


Figure 4

Freedom from atrial arrhythmia recurrence

Supplementary Files

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- **Table1.docx**