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Initial Experience of Sequential Surgical Epicardial-Catheter Endocardial Ablation for Persistent and Long-Standing Persistent Atrial Fibrillation With Long-Term Follow-Up

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Abstract

Background—Patients with long-standing persistent (LSP) atrial fibrillation (AF) who have previously undergone catheter ablation represent a challenging patient population. Repeat catheter ablation in these patients is arduous and associated with a high failure rate, whereas surgical ablation can be complicated by multiple flutters. We sought to determine if minimally-invasive surgical ablation, followed by catheter ablation of all inducible flutters, would improve success rates over repeat catheter ablation alone.

Methods—Fifteen patients (Sequential) with persistent or LSP AF who failed at least one catheter ablation and one anti-arrhythmic drug (AAD) underwent surgical ablation, followed by planned endocardial evaluation and catheter mapping with ablation during the same hospitalization. Sequential patients were matched to 30 patients who had previously failed at least one catheter ablation and underwent a repeat catheter ablation (catheter-alone). The primary end point was event-free survival of any documented AF recurrence or AAD use.

Results—All patients underwent uncomplicated surgical ablation and electrophysiology procedure. Five Sequential patients had seven inducible flutters that were mapped and ablated. After a mean follow-up of 20.7 ± 4.5 months, 13/15 (86.7%) Sequential patients, but only 16/30 (53.3%) catheter-alone patients, were free of any atrial arrhythmia and off of AAD ($p = 0.04$). On AAD, 14/15 (93.3%) Sequential patients were free of any atrial arrhythmia recurrence, compared to 17/30 (56.7%) catheter-alone patients ($p = 0.01$).

Conclusions—For patients with atrial fibrillation who have failed catheter ablation, Sequential minimally invasive epicardial surgical ablation, followed by endocardial catheter-based ablation, has a higher early success rate than repeat catheter ablation alone.

Endocardial catheter ablation of persistent and longstanding persistent (LSP) atrial fibrillation (AF) is arduous and has single-procedure success rates of 35–60% [1]. Failures are most often due to recurrence of pulmonary vein (PV) conduction, due to a lack of transmural lesions [2]. In addition, recent data suggests the importance of the left atrial appendage (LAA), ligament of Marshall (LOM), and epicardial ganglia as sources of persistent AF [3–8], which remain difficult to target endocardially.

Surgical epicardial ablation, using bipolar clamps, has been shown to create superior transmural lesions around the PVs [9–12]. In addition, surgical ablation can isolate the

superior vena cava (SVC) without phrenic nerve injury, eliminate the LOM, remove the LAA, and target the ganglia [13–16]. However, surgical ablation is limited by post-ablation flutters, often due to gaps in linear lesions made by unipolar devices [17–19]. In addition, typical right-sided atrial flutter complicates up to 12% of minimally invasive surgical ablation, but could likely be prevented by a cavotricuspid isthmus (CTI) line, which is easily created by endocardial catheters [13].

Patients with LSP AF who have failed previous catheter ablation represent a particularly challenging patient population. Repeat catheter ablation is associated with a high failure rate. Patients with LSP AF and previous failed catheter ablation underwent minimally invasive surgery for lone AF at our institution. Approximately 4 days later, all patients underwent catheter ablation to assess PV isolation, line block, and creation of a typical right sided flutter line. We hypothesized that this Sequential approach, combining minimally invasive surgical ablation (including PV antral isolation, roof line, LOM ablation, LAA removal, and ganglia ablation), followed 3 to 5 days later with planned catheter ablation (including CTI line and mapping of all inducible flutters), would improve AF-free success rates in patients with persistent or LSP AF who had failed at least one previous catheter ablation, compared to a control group of patients who underwent repeat catheter ablation.

Patients and Methods

Approval for this investigation was obtained by the Institutional Review Board of the University of Virginia Health System (HSR# 15100), including a waiver for the need to obtain patient consent. Fifteen consecutive patients with persistent or LSP AF who had failed at least one AAD and one catheter ablation underwent Sequential ablation per clinical guidelines[20]. Patients were excluded, if they had another indication for cardiac surgery, previous cardiac surgery, clot in LAA, significant pulmonary hypertension (right ventricular systolic pressure >60 on transthoracic echocardiography), lung disease, were less than 18 years of age, or had a reversible cause of AF. The last Sequential procedure was performed in October 2009, as our institution began to enroll patients in an FDA trial of hybrid ablation versus catheter ablation.

Minimally-Invasive Surgical Ablation

Patients were maintained on warfarin for at least 1 month prior to surgery and stopped 5 days prior to surgery. Except for amiodarone, anti-arrhythmic drugs (AAD) were stopped five half-lives prior to ablation. Thoracoscopic epicardial ablation without rib spreading or cardiopulmonary bypass was performed, including isolation of all PVs and SVC, placement of roof line, mitral line, elimination of ganglia response, LOM ablation, and LAA exclusion previously described as the Dallas Lesion Set. (Fig 1) [13]. Three 5–10 mm ports were placed into the right chest, during selective left lung ventilation. Briefly, the pericardium was opened and pulmonary veins and carina were checked for evidence of entrance (and exit) block, using a bipolar pen and physiologic recorder (Atricure, West Chester, OH). Next, active autonomic ganglionic plexi (GP), identified by prolongation of the ventricular cycle length by $\geq 50\%$ during high-frequency stimulation, were ablated with the bipolar pen.

A bipolar clamp (Synergy Atricure, West Chester, OH) was placed around the right veins and at least three separate lesions were made on the antrum of the left atrium (Fig 1). The end point for PV ablation was complete entrance (and exit block if in sinus rhythm) block. Up to four additional lesions were created if block was not obtained after the initial clamping.

The left atrial roof line was then performed, using a bipolar unidirectional ablation device (CoolRail, Atricure) in the transverse sinus (Fig 1). An additional line was made from the

roof line anterior to the noncoronary cusp of the aortic valve and the anterior mitral annulus. The SVC was then isolated with a single application of the bipolar clamp, after removing any central venous lines.

Similar ports (5–10 mm) were placed in the left chest. The pericardium was opened and the LOM divided. The left PVs were ablated and tested for evidence of entrance/exit block. With the Coolrail, the roof line lesion was completed. An additional line was created to the left atrial appendage (LAA). The LAA was then removed, using a no-knife green load endoGIA stapler (Ethicon, Blue Ash, OH).

All PV and SVC isolation was confirmed by an electrophysiologist in the operating room. Block across lines was not checked. Patients were then loaded on 300 mg IV of amiodarone over 20 minutes, despite the patient's rhythm, unless they were already on amiodarone. A single chest tube was placed on each side, and multiple rib blocks with local anesthetic were placed bilaterally. All operations were performed by a single surgeon (GA).

Postoperative Care

Patients were maintained on amiodarone 1200 mg a day, while in the hospital, and warfarin therapy was initiated by postoperative day two. Patients were not placed on heparin. Pain was controlled with intravenous narcotics or epidural, per patient choice. Patients were monitored continuously in the hospital. If patients experienced sustained atrial tachyarrhythmias (>1 hr), they were electrically cardioverted.

Electrophysiology (EP) Procedure

Following an average of 4.3 ± 1.3 days after surgery, patients were taken to an electrophysiology lab under conscious sedation. After femoral access, a heparin bolus was given. If a transseptal approach was performed, a continuous heparin infusion was started with a goal activated clotting time (ACT) of 350 seconds. Catheters were placed and moved to the right ventricle, coronary sinus (CS), His bundle, and right atrial (RA) positions, as needed. Phased-array intracardiac echocardiography (ICE, Accunav; Biosense Webster, Diamond Bar, CA) was placed. 3D mapping (NavX, SJM, St Paul MN in 12, CARTO, Biosense in 3) was used in all patients. Ablation was performed with an irrigated tip catheter (Biosense) or 5 mm tip catheter (Boston Scientific, Natick, MA).

Superior vena cava isolation was confirmed with a multipolar catheter. Next, using ICE and fluoroscopy, a CTI (typical flutter) line was performed at 35–50W and bidirectional block confirmed. CS ablation was then performed from the distal CS to the os, using ICE to ensure ablation on LA side, considering its documented importance in persistent AF [21]. Power was limited to 25W. Since all patients were in sinus rhythm, complex fractionated atrial electrograms (CFAE) were not used at this point. Patients were administered isoproterenol 5 mcg/min, which was increased to 20 mcg/min every 2 minutes or until mean blood pressure was less than 60 mmHg (Fig 2).

If atrial flutter was induced, it was mapped and ablated. Once in sinus rhythm, PV isolation and block across roof line was confirmed. We then administered isoproterenol again and targeted any additional flutters.

If AF (defined as an atrial rhythm with beat-to-beat variation in activation sequence) was induced, a multipolar catheter was used to check PV isolation. Next, mitral isthmus (LI-MI) line and CFAEs were performed as previously described [22]. After 30 minutes of CFAEs, if there was no conversion to atrial flutter or sinus, electrical CV was performed. PV isolation and roof line block were subsequently checked. No further induction was attempted. Programmed stimulation was not used for any cases to attempt to trigger AF. If

arrhythmia was not induced, transseptal puncture was not performed, and left-sided lesions were not checked during EP procedure.

Follow-Up Algorithm

Amiodarone was reduced to 400 mg a day at discharge until day 30, then to 200 mg a day until day 90, and then stopped. If patients were intolerant to amiodarone, they were placed on dofetilide at a dose appropriate for renal function. Warfarin (goal INR 2–3) was continued for 3 months and indefinitely for CHADS₂ score ≥ 2 . Any recurrence during the 3 month blanking period was aggressively electrically cardioverted (CV) within 72 hours. If atrial arrhythmia occurred after 90 days, patients were electrically CV and started on dofetilide.

Follow up by an electrophysiologist of Sequential patients at our and referring centers consisted of: (1) Office visits with EKG at 1, 3, 6, 9, and 12 months, and then every 6 months thereafter; (2) 7-day, continuous autotriggered monitor at 3, 6, and 12 months; (3) Telephone follow-up at 15 and 18 months; (4) 24-hour Holter monitor at 9, 18 and 24 months; and (5) If patients had any palpitations, monitoring was ordered to document AF.

Endpoints

The primary endpoint was event free survival of any atrial arrhythmia longer than 30 seconds off AAD. Secondary endpoints included freedom from atrial arrhythmia on AAD, repeat hospitalization for any cause, and repeat EP procedures. Symptoms of palpitations required documented AF to be considered as a failure. Once a patient had an AF recurrence, the patient was counted in the failure group.

Catheter-Alone Control Group

We identified consecutive persistent and LSP AF patients who had failed at least one previous ablation and underwent a repeat catheter ablation from August 2007– November 2009. Three hundred and sixty-one patients were screened. Patients were then matched in a 2:1 fashion for LA size by echo, duration of AF in years, type of AF, use of post-ablation AAD, lack of prior cardiac surgery, and left ventricular ejection fraction. To be included, catheter patients also had to have an ablation strategy that included at least antral ablation, roof line, and CTI line. Catheter-alone patients underwent AF ablation using ICE and 3D Mapping. Lesion sets were variable but, at a minimum, included antral isolation, roof line, and CTI line. A mitral line was made in 17 cases, CS ablation performed in 9 cases, SVC isolated in 11 cases, and CFAEs performed in 12 cases.

Patients were maintained on warfarin for at least 3 months. All patients were discharged on AAD. They were encouraged to be followed with a Holter or 30-day auto-triggered monitor at 3, 6, and 12 months and to have a monitor for symptoms. The presence of symptoms required AF to be documented by monitor, in order to be counted as a recurrence. Additional telephone or direct physician follow-up was utilized to assess recurrence and use of AAD as clinically indicated.

Statistical Analysis

Patient demographics, procedural features, and postoperative outcomes were compared between the 2 matched groups, using Chi-square or Fisher's exact tests, where appropriate for categorical variables, and Student's *t* test for continuous outcomes. Categorical variable comparisons are expressed as a percentage of the group of origin. Continuous variables are reported as means $\pm$ standard deviation (SD). Freedom from recurrence of atrial arrhythmias or use of AAD was compared for catheteralone and Sequential patient groups, using Kaplan-Meier analysis and the log-rank test.

Results

Patient Demographics

A total of 45 patients underwent either Sequential ($n = 15$) AF ablation or catheter-alone ($n = 30$) from August 2007–November 2009 at the University of Virginia. Baseline characteristics are displayed in Table 1. Sequential and catheter-alone patients were similar with respect to age, LA size, and number of failed AADs. Sequential patients had lower EF, more previous ablations, and greater body mass index (BMI).

Operative Details

Total procedure time was 450.1 ± 19.8 minutes for Sequential patients (including both surgical epicardial and catheter procedures) and 302.0 ± 65.0 minutes for catheter-alone patients (Table 2). Total time for the electrophysiologist (including OR time) for Sequential patients was 172.0 ± 45.0 minutes and 302.0 ± 65.0 minutes for catheter-alone patients ($p = 0.01$). All 15 Sequential patients had antral isolation with a mean number of clamps of 3.7 ± 1.1 per side and confirmed entrance and exit block. All Sequential patients had SVC isolation and roof line placement, with ganglia ablation in 14 patients.

Among Sequential patients, 93% (14/15) had successful LAA exclusion confirmed by ICE and TEE with Doppler at end of the case. The remaining patient had a broadbased LAA precluding safe removal. A total of 80% (12/15) of Sequential patients spontaneously converted to sinus rhythm during surgical ablation. There were no procedural complications in the Sequential patients.

An amiodarone (300 mg IV) load was provided to 87% (13/15) of patients at the conclusion of the procedure. The remaining 2 patients were started on dofetilide postoperatively, because they were known to be intolerant of amiodarone.

EP Procedure Details

All 15 Sequential patients underwent EP procedures 4.3 ± 1.3 days after surgical procedure. Baseline rhythm was sinus in all 15 patients (mean CL $1,012.0 \pm 82.0$ microsecond). SVC isolation was complete from surgery in all 15 patients. CTI line was created with ablation and block confirmed. ICE guided CS ablation was performed in all (ablation time 127.0 ± 41.0 seconds) 15 patients.

Isoproterenol was administered to a mean dose of 12.0 ± 4.0 mcgs/min. Eight patients remained in sinus rhythm. On initial testing, 5 patients went into five atrial flutters. These included three mitral-isthmus dependent flutters that terminated after creation of a line from left inferior PV to LI-MI, including ablation in the CS burns. There were also two roof line flutters that used gaps in the roof line within 10 mm of the left superior PV. After termination of flutter, repeat testing found two more flutters, including a perimitral flutter and a roof dependent flutter with a gap found near the left superior pulmonary vein (LSPV). Finally, pacing maneuver found an additional gap in 1 patient in the roof line near the LSPV. Although no flutter was induced using this gap, it was ablated.

On initial testing, 2 patients had inducible AF. AF did not convert to flutter or sinus rhythm with ablation of CFAEs and LI-MI line and required CV. All 7 patients who underwent transeptal had confirmed PV isolation. Thus, overall, 5 patients had seven inducible flutters, and 2 patients had AF only. Patient and procedure related characteristics for this subset of patients are detailed in Table 2. We found 8 gaps in linear lines (Fig 3 and Fig 4).

Short-Term Outcomes

Total hospital length of stay was longer in Sequential patients (5.3 ± 0.1 vs. 1.13 ± 0.1 days, $p < 0.001$, Table 3). Despite longer total procedure times among Sequential patients, time in the left atrium with catheters (18.4 ± 1.1 vs. 105.0 ± 8.0 minutes, $p < 0.001$) and fluoroscopy times (17.6 ± 1.3 vs. 42.3 ± 2.1 minutes, $p < 0.001$) were longer among catheter-alone patients.

One patient in the catheter-alone group had tamponade requiring pericardiocentesis. There were no other acute complications in either group.

Freedom From Atrial Arrhythmias

After a mean follow-up of 20.7 ± 4.5 months, 86.7% (13/15) of Sequential patients were free of any atrial arrhythmias and off AAD, compared to 53.3% (16/30) of catheter-alone patients (Fig 5, log-rank $p = 0.04$). On AAD therapy, freedom from AF was 93.3% (14/15) among Sequential patients, compared to 56.7% (17/30) for catheter-alone patients (Fig 6, log-rank $p = 0.01$).

Monitoring was performed at 3, 6, 12, 18 and 24 months among 100%, 46%, 94%, 82%, and 100% of Sequential patients, respectively. Similarly, it was performed at 3, 6, 12, 18, and 24 months in 73%, 40%, 57%, 0%, and 27% of catheter-alone patients, respectively.

Need for Repeat Procedure

No Sequential patient underwent repeat ablation, and 3/30 catheter-alone patients required repeat ablation (0.0% vs. 10.0%, $p = 0.15$). Two Sequential patients and 7 catheter-alone patients needed electrical cardioversion after the blanking period (13.3% vs. 23.3%, $p = 0.70$).

Comment

Our data suggests that a Sequential surgical, followed by catheter based approach, has better 18-month success rates than a repeat catheter ablation alone in patients with persistent and LSP AF who have failed at least one prior catheter ablation. Most series report success rates for surgical ablation of persistent and LSP AF of 58 – 65% and minimally-invasive surgical ablation of paroxysmal AF have been shown to have excellent success rates in excess of 80.8% [23]. Although Sirak and colleagues have reported 87.5% success in persistent and long standing persistent patients with thoracoscopic AF ablation at 6 months, these outstanding results have not been reproduced by others [24].

Our antiarrhythmic protocol in the Sequential patients is aggressive with high dose amiodarone (300 mg IV load). Although this unlikely has any lasting effect on recurrence after the blanking period, we employ this protocol to minimize the risk of AF in the early postoperative period, when patients following thoracoscopic AF ablation have significant pain and pericarditis. We have not seen any pulmonary complications with this approach, but we are very aggressive with pain control, early diuresis, and pulmonary toilet in the postoperative period.

The cause of failure with catheter ablation for AF is often reconnection of PVs, which may be due to the inability to get consistent transmural lesions with catheters, especially in think atria. Animal experiments have shown that surgical ablation with bipolar clamps is the most reliable method to achieve circumferential transmural PV lesions [9]. Furthermore, catheter ablation cannot target all the substrates that maintain AF. In particular, it cannot easily target the LAA, LOM, and epicardial ganglia. Surgical approaches can target these structures.

However, surgical ablation of AF is limited by macroreentrant flutters, due to gaps in lines. These can usually be mapped and ablated using catheter ablation. In the present study, by doing a catheter study soon after surgery, we may have ablated these gapdependent flutters before they became clinically apparent.

Consistent with the presented data, Han and colleagues reported a 65% success rate, following minimally invasive surgical ablation alone. They improved the success rate to 91%, by performing an EP study and ablation *after* recurrent AF or flutter. In this series, they primarily ablated macroreentrant flutters [14]. However, the additional EP procedure for recurrence required at least one of the following: readmission to the hospital, electrical cardioversion, or emergency room visit. With the Sequential approach, our goal was to eliminate all postsurgical flutters prior to discharge and, thus, avoid recurrent arrhythmia. We added the additional right sided lines, roof line, and mitral line, as we believe that pulmonary vein isolation alone is not sufficient in persistent AF patients. The gaps in the roof line with unipolar energy sources could have led to refractory atrial flutters. As such, an incomplete connecting lesion is likely worse than not performing this lesion. Thus, testing and reinforcing these epicardial lines via an endocardial catheter approach is important to ensuring success of this procedure.

Studies suggest that patients with persistent AF are best treated with antral ablation. This can be difficult to achieve endocardially, since the antral atrium may be thicker in persistent and LSP AF patients. Bipolar epicardial clamps are more likely to lead to consistent transmural lesions in thick tissue, in part, because they temporarily arrest blood flow in the antrum. It is also less likely to damage the esophagus, since the clamp only delivers energy towards the LA. However, it should be noted that true antral ablation requires significant dissection.

The most common locations of gaps following epicardial ablation were in the roofline and line to mitral valve. This is consistent with data that shows that the linear and pen ablation tools used in this study often fail to create consistent lesions deeper than 4 – 6 mm [25]. Nonetheless, linear lesions seem to increase success rates in persistent and LSP AF [26]. By inducing and ablating gaps prior to discharge, we hoped to prevent clinically relevant flutters. Importantly, we observed no PV gaps in those 7 patients that had left atrial access.

LAA Removal and LOM Ablation

Besides its likely contribution to strokes, the LAA is important as a substrate and, in some studies, a driver of AF in up to 28% of patients [21, 27]. In this study, 94% (14/15) Sequential patients, and none of the catheter-alone patients, had LAA exclusion with no blood flow and no electrical activity. Similarly, LOM ablation was performed in all Sequential patients, but was not specifically targeted in the catheter-alone group. This may partly explain our high arrhythmia-free rates in the Sequential group [28].

SVC Isolation

Superior vena cava trigger rates approach 12%, but ablation is limited by the risk of phrenic nerve injury [29–31]. Surgical ablation allows SVC isolation with no phrenic injury, since it is visualized and can be protected during ablation. Thus, it was performed in all 15 Sequential patients, but was only performed in 11/30 of those undergoing catheter alone. This may also partially account for the higher success rates in the Sequential group. It is possible that SVC isolation could damage the sinus node, but we attempted to avoid this by clamping above the SVC-RA junction. No patients required placement of a new pacemaker.

Alternatives

One alternate approach would have been to perform surgical ablation alone, first, and proceed with endocardial ablation only in patients that develop clinically relevant arrhythmias. Specifically, epicardial surgical ablation alone with the same lesion set in patients with persistent and LSP AF, as in this study, has been shown to achieve success in 58% of patients at 1 year [14]. Since 66% (10/15) of Sequential patients did not have inducible flutter during the catheter ablation and 60% (9/15) did not have gaps in linear lesions, the argument can be made to wait for catheter ablation until evidence of recurrent arrhythmias, thereby avoiding an unnecessary procedure in most patients. We developed this Sequential plan, as our patients come from significant distances, given our unique geographic location. As such, our patients prefer to undergo any procedure that will ensure the greatest chance of success after a single hospital visit. Moreover, there are currently no means to prospectively identify which patients would benefit from additional catheter ablation for creation of flutter lines prior to presentation with atrial arrhythmia. When recurrences occur, many of these failures require hospitalization, electrical cardioversion, and repeat ablation [14]. Although the endocar-dial portion of our procedure adds cost (although no hospital days), these unplanned admissions and procedures have costs as well. Our Sequential technique adds endocardial catheter ablation during the standard postsurgical hospital stay and seeks to avoid postsurgical flutters. In our experience, this did not appear to create a safety hazard or prolong hospital length of stay. Another option is to only isolate the PVs and SVC with a bipolar clamp and target ganglia. This avoids the issue of gaps in linear lesions made by unipolar ablation, which was the most common gap in our study and others. However, a previous publication with this approach showed a success rate of only 65% [32]. This suggests the importance of isolating the posterior wall and creating a cavotricuspid isthmus line in persistent AF [1, 18]. It is possible to speculate that a repeat endocardial catheter ablation in 4 days could improve success rates over a single catheter ablation. However, repeat catheter ablation cannot target ganglia or isolate the appendage or SVC easily.

Limitations

First, this is a small pilot study, but its results should serve as a proof of concept to justify future studies, including randomized trials. In fact, these data were, in part, used to justify an FDA-approved randomized trial (DEEP-AF) of a modification of our technique versus catheter ablation. It is for this reason that we cannot add patients to our Sequential arm and expand our study. Second, although we attempted to match patients for variables considered clinically important, there may have been other important between-group differences that could not be accounted for, due to the nonrandomized nature of the study. However, the 58% success rates observed in our catheter ablation group are comparable to other published reports in persistent and LSP patients. A second limitation is that the lesion sets were not equivalent in both groups. For example, all Sequential patients, but no catheter-alone patients, received ganglia ablation, which may improve AF-free rates [8]. Furthermore, our electrophysiologists are aggressive in their performance of catheter ablations. Follow-up was more consistent and rigorous in the Sequential group. However, this likely biases our findings towards worse outcomes in the Sequential group. The postprocedure AAD strategy was different. This may have biased immediate and short-term results in favor of the Sequential group. However, in all Sequential patients, we discontinued amiodarone use at 3 months. Thus, after a follow-up of at least 1 year, we would expect the amiodarone effect to not be the cause of the higher success. In fact, at 1 year, more catheter-alone patients were on AAD and still had a higher incidence of AF. Another limitation is the absence of a surgery-alone group. However, the literature suggests a 65% success rate at 1 year with minimally invasive surgery alone, which is lower than with our approach [14]. Furthermore, since almost half of our patients had gaps after surgery alone, this suggests that some of

these patients would have had recurrent flutter had they not undergone subsequent catheter ablation.

Conclusion

In this pilot study, a combined epicardial-surgical and endocardial-catheter approach has higher 18 month AF-free rates in patients with persistent and LSP AF who have failed one prior catheter ablation. These results justify the performance of future randomized trials.

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Fig 1.
Schematic representation of epicardial (bold) and endocardial (dashed) ablation lines for Sequential procedure.

Fig 2.

Electrophysiology procedure flow chart. (AF = atrial fibrillation; CFAE = complex fractionated atrial electrogram; CS = coronary sinus; CV = cardioversion; LI-MI Line = from left inferior pulmonary vein to mitral valve; PVs = pulmonary veins; SVC = superior vena cava.)

Fig 3.

Results of Sequential electrophysiology study. Atrial fibrillation (AF)-alone was induced in 2, and 7 atrial flutters were induced in 5. (CFAE = complex fractionated atrial electrogram; CTI = cavotricuspid isthmus; CV = cardioversion; LAA = left atrial appendage; LSPV = left superior pulmonary vein; PV = pulmonary vein; SR = sinus rhythm; SVC = superior vena cava.)

Fig 4.

Location of gaps found at electrophysiology study: 4/15 gaps on roof line, and 4/15 had a presumed gap in line to mitral valve.

Fig 5. Overall freedom from recurrence of atrial arrhythmia or anti-arrhythmic drug (AAD) use for all patients undergoing Sequential versus catheter-alone ablation.

Fig 6.

Overall freedom from recurrence of atrial fibrillation for all patients undergoing Sequential versus catheter-alone ablation, while on anti-arrhythmic drug (AAD) therapy.

Table 1

Patient Characteristics and Preoperative Risk Factors for Patients Undergoing Catheter-Alone Versus Sequential Atrial Fibrillation Ablation

Variable	Sequential (n = 15)	Catheter-Alone (n = 30)	p-Value
Patient age	59.5 ± 2.4	59.2 ± 1.5	0.90
Gender (Female)	7 (46.7%)	11 (36.7%)	0.54
Cardiomyopathy	7 (46.7%)	9 (30.0%)	0.33
Hypertension	7 (46.7%)	20 (66.7%)	0.22
Diabetes mellitus	3 (20.0%)	4 (13.3%)	0.67
Atrial septal defect	—	—	—
Hyperlipidemia	4 (26.7%)	16 (53.3%)	0.19
Pulmonary hypertension	3 (20.0%)	1 (3.3%)	0.10
Obstructive sleep apnea	3 (20.0%)	4 (13.3%)	0.67
New York Heart Association Class			0.37
No heart failure	8 (53.3%)	21 (70.0%)	
Class I	1 (6.7%)	4 (13.3%)	
Class II	4 (26.7%)	3 (10.0%)	
Class III	2 (13.3%)	2 (6.7%)	
Atrial fibrillation type			0.17
Persistent	9 (60.0%)	24 (80.0%)	
Long standing persistent	6 (40.0%)	6 (20.0%)	
Left atrial size (mm)	52.3 ± 10.3	45.3 ± 5.3	0.004
Ejection fraction (%)	47.0 ± 3.0	54.7 ± 2.1	0.04
Years of atrial fibrillation	5.4 ± 0.6	4.9 ± 0.6	0.61
Number of anti-arrhythmic drugs	2.3 ± 0.2	2.8 ± 0.2	0.83
Prior amiodarone use	9 (60.0%)	18 (60.0%)	>0.99
Total number of ablations	1.7 ± 0.2	1.2 ± 0.1	0.01

Table 2

Patient Characteristics for Subset of Patients (n = 5) With Inducible Atrial Flutters

Variable	n (%)	Mean $\pm$ SD	Median [IQR]
Age		57.8 $\pm$ 8.1	60.0 [50.0–64.5]
Gender (Female)	4 (80.0%)		
Cardiomyopathy	3 (60.0%)		
Hypertension	4 (80.0%)		
Diabetes mellitus	2 (40.0%)		
Atrial septal defect	0 (0.0%)		
Hyperlipidemia	2 (40.0%)		
Pulmonary hypertension	2 (40.0%)		
Obstructive sleep apnea	2 (40.0%)		
NYHA Class			
No heart failure	2 (40.0%)		
Class I	1 (20.0%)		
Class II	2 (40.0%)		
Left atrial size (mm)		56.6 $\pm$ 5.7	57.0 [51.0–62.0]
Ejection fraction (%)		48 $\pm$ 7.6	50.0 [40.0–55.0]
Total procedure time (minutes)		365.4 $\pm$ 14.0	360.0 [358.0–376.0]
Left atrial catheter time (minutes)		22.4 $\pm$ 4.5	21.0 [20.0–26.0]
Fluoroscopy time (minutes)		22.4 $\pm$ 1.7	22.0 [21.0–24.0]
Catheter ablation time (minutes)		10.8 $\pm$ 3.7	11.0 [7.5–14.0]
Hospital length of stay (days)		5.2 $\pm$ 0.5	5.0 [5.0–5.5]

IQR = interquartile ratio

NYHA = New York Heart Association.

Table 3

Post-Procedural Outcomes for All Patients Undergoing Catheter-Alone Versus Sequential Atrial Fibrillation Ablation

Outcome	Sequential (n = 15)	Catheter-Alone (n = 30)	p-Value
Total procedure time (minutes)	450 ± 20	302.0 ± 65	<0.001
Left atrial catheter time (minutes)	18.4 ± 1.1	105.0 ± 8.0	<0.001
Fluoroscopy time (minutes)	17.6 ± 1.3	42.3 ± 2.1	<0.001
Mean follow-up (months)	15.7 ± 1.5	19.1 ± 1.0	0.06
Stroke	0 (0.0%)	0 (0.0%)	—
Tamponade	0 (0.0%)	1 (3.3%)	>0.99
Hematoma	0 (0.0%)	2 (6.7%)	0.55
Hospital length of stay (days)	4.13 ± 0.10	1.13 ± 0.1	<0.001
On anti-arrhythmic drug at follow-up	1 (6.7%)	11 (36.7%)	0.04