Results of a Minimally Invasive Surgical Pulmonary Vein Isolation and Ganglionic Plexi Ablation for Atrial Fibrillation: Single Center Experience with 12-Month Follow-up.

Authors: Frederick T. Han, MD, Vigneshwar Kasirajan, MD, Marcin Kowalski, MD, Robert Kiser, MD, Luke Wolfe, MS, Gautham Kalahasty, MD, Richard K. Shepard, MD, Mark A. Wood, MD, Kenneth A. Ellenbogen, MD

Correspondence:
Kenneth A. Ellenbogen, M.D.
Medical College of Virginia
P.O. Box 980053
Richmond, Va 23298-0053
Phone : 804-828-7565
Fax : 804-828-6082
E-mail : kellenbogen@mcvh.vcu.edu, ken.ellenbogen@gmail.com or kellenbogen@pol.net

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Abstract:

Background – The Cox Maze procedure for treatment of medically refractory atrial fibrillation (AF) is limited by its complexity and requirement for cardiopulmonary bypass. Long-term follow-up and success using criteria established by the HRS/EHRA/ECAS consensus statement have not been reported for surgical AF ablation. We describe the results of using a thorascopic approach and radiofrequency energy to perform bilateral pulmonary vein isolation (PVI) and left atrial (LA) ganglionic plexi (GP) ablation for treatment of AF.

Methods and Results - Forty-five (33 – paroxysmal; 12 – persistent) consecutive patients underwent thorascopic bilateral radiofrequency PVI, GP ablation, Ligament of Marshall ablation, and left atrial appendage (LAA) exclusion by a single surgeon. Forty-three patients were prospectively followed without antiarrhythmic drugs (AAD) for a minimum of 1 year with a 30-day continuous event monitor or pacemaker interrogation at 6 and 12 mos. Failure was defined as any atrial tachyarrhythmia (AT) of > 30 seconds duration occurring more than 90 days after surgery. Mean follow-up was 516 +/- 181 days (202-858 d). Twenty-eight (65%) patients had no AT > 30 seconds by 1 year, and 15 (35%) patients had AT recurrences by 1 year. Eight of 15 patients with recurrent AF had catheter ablation resulting in elimination and/or reduction of AF episodes in 7 of 8 patients. Four of 15 patients had AF elimination or reduction with AAD alone. Three patients did not benefit from surgery and received rate control only. There were no deaths; one phrenic nerve injury and two pleural effusions were the only major complications.

Conclusions - The single procedure success at 1 yr follow-up for surgical PVI and GP ablation is 65%. AT recurrences after surgery are usually responsive to catheter ablation and/or AAD.

Key Words: atrial fibrillation, surgical ablation, cardiac monitoring, catheter ablation
Introduction

Atrial fibrillation (AF) is the most common supraventricular arrhythmia seen in clinical practice, and catheter-based and surgical ablative approaches have been developed for patients with medically refractory symptomatic AF. Although the Cox Maze III surgery is the gold standard for surgical treatment of AF, this procedure has failed to achieve widespread adoption because of its complexity and highly invasive nature\(^1\)-\(^5\). As the electrophysiological mechanisms of AF have become better understood, ablation strategies have been refined to target the pulmonary vein antrum.

The landmark work of Hassiaguerre and colleagues\(^6\)-\(^8\) identified the pulmonary veins as sources of AF. Pulmonary vein isolation (PVI) has emerged as a successful technique for ablation of paroxysmal AF. In addition, Sherlag and colleagues have demonstrated that the parasympathetic and sympathetic efferent neurons present in epicardial ganglionic plexi (GP) and the intrinsic cardiac autonomic nervous system may play an important role in triggering pulmonary vein firing\(^9\)-\(^12\). Several groups have incorporated GP mapping and ablation with pulmonary vein isolation in a minimally invasive approach to surgical AF ablation\(^13\)-\(^15\). The ligament of Marshall (LoM) may also play a role in triggering AF in some individuals\(^16\)-\(^18\). Nevertheless, results of long term follow up using standardized monitoring for AF recurrences after minimally invasive AF surgery have not been reported.

We report a prospective cohort study of patients who underwent minimally invasive bilateral PVI with GP and LoM ablation with 1-year follow-up.

Methods.

Patient Selection:
We prospectively followed a cohort of 45 consecutive patients with AF who underwent minimally invasive surgical epicardial ablation with a minimum of 1-year follow-up. Definitions of paroxysmal and persistent AF, success and failure of ablation, major adverse events, and follow-up monitoring were based on the Heart Rhythm Society consensus statement for the catheter and surgical ablation of AF. Patients were enrolled consecutively by a single investigator’s referral of patients with symptomatic AF who had failed at least one or more AAD(s). Patients were presented with the option of 1) continued antiarrhythmic drug trials (when additional antiarrhythmic drug trials were an option), 2) percutaneous catheter radiofrequency ablation, or 3) minimally invasive surgical ablation. Thirteen patients were preferentially referred for minimally invasive surgical ablation based on clinical factors, such as body habitus (e.g., morbid obesity), recurrent bleeding on warfarin, or difficulty passing catheters from the femoral vein (inferior vena cava filter, or trauma resulting in IVC occlusion). Twelve patients (27%) had a prior unsuccessful catheter ablation for AF.

The institutional review board approved the study and all patients gave informed consent for inclusion in this prospective registry. The study was registered in ClinicalTrials.gov (ClinicalTrials.gov Identifier NCT00747838).

Surgical Procedure:

A video of the surgical procedure is provided in the online supplemental data. The surgical procedure was performed under general anesthesia with double lumen endotracheal tube placement for selective lung ventilation. The chest was entered in the third interspace using a non rib-spreading mini-thoracotomy with thorascopic assistance. The right or left side was done first, and then followed by the contralateral side. The pericardium was opened anterior to the phrenic nerve on the right and usually posterior...
to the phrenic nerve on the left. The rhythm was determined by placing a bipolar pen probe (Atricure, Inc., Cincinnati, OH) on the left atrium and recordings were made with a physiologic recorder. Autonomic ganglia were identified by high frequency stimulation to detect a vagal response at 20 predetermined epicardial sites around the pulmonary vein antra. GP mapping was performed by placing the bipolar pen at each site and stimulating with an 18 mV, 1.5 msec pulse width impulse at 1000 pulses per minute from a temporary external pacemaker. A positive response to GP stimulation was defined as prolongation of the sinus cycle or mean AF cycle length by ≥ 50%. A lighted dissector was used to encircle the pulmonary venous antrum after fat was removed from the pulmonary vein trunk. Ablation of the antral area (not the pulmonary veins proper) was performed using a bipolar radiofrequency clamp (Atricure, Inc, Cincinnati, OH). The endpoint for PV antral ablation was complete entrance and exit block into and from the pulmonary veins. Entrance block was defined as failure to capture the pulmonary veins during pacing from the left atrium at 7.5 Volts and 1.5 msec pulse width. Exit block was defined by failure to capture the left atrium when pacing from the pulmonary veins distal to the RF lesions at 7.5 Volts and 1.5 msec pulse width. A proprietary algorithm terminated RF energy (maximum 28 Watts (W)) after impedance changes indicated transmural injury. Clamp applications were repeated a minimum of 2-3 times after bidirectional block was achieved.

The autonomic ganglia (GPs) were mapped prior to and after ablation of the pulmonary venous antrum. Bipolar radiofrequency energy at 15W was delivered through the bipolar pen at sites demonstrating a vagal response. The endpoint for GP ablation was the elimination of a vagal response to stimulation. The LoM was ablated with radiofrequency energy or ligated proximally and distally, and then ablated with radiofrequency energy. The left atrial appendage was stapled closed and excised after
absence of flow was confirmed by intraoperative transesophageal echocardiography (Figure 1). A single chest tube was placed on each side and multiple rib blocks with 0.25% bupivacaine, and/or a subpleural catheter for continuous infusion of bupivacaine was used to supplement postoperative analgesia. Whenever feasible patients were extubated in the operating room. Whenever possible postoperative use of antiarrhythmics was avoided and warfarin was resumed by discharge. Unless patients had a CHADS<sub>2</sub> score $\geq 2$, warfarin was discontinued after the 6-month monitor confirmed the absence of AT. If patients had a CHADS<sub>2</sub> score $\geq 2$, warfarin was continued indefinitely in the absence of contraindications. All procedures were performed by a single surgeon (V.K.) and followed by a single electrophysiologist (K.E.). Symptomatic recurrent AT that could not be controlled with beta blockers in the immediate postoperative state were preferentially treated with amiodarone for 4-8 weeks. All antiarrhythmic drugs were discontinued by the electrophysiologist by 8 weeks.

Long term follow-up:

Any patient not in sinus rhythm was cardioverted before the 3 month follow-up visit. With the exception of patients with a pacemaker, recurrent symptomatic palpitations occurring > 3 months postoperatively were further evaluated with a transtelephonic event monitor (TTM). Three patients had pacemakers, which were used to monitor for AF recurrence. All patients without a pacemaker underwent 30 day continuous monitoring at 6 months, 12 months, and then every 12 months following surgery. Monitoring was performed with an external loop recorder (Cardiolabs, Franklin, TN) with an automatically triggered algorithm to detect AF. Success was defined as no episode of AF, atrial flutter, or any AT lasting longer than 30 seconds off AAD. AT was defined as any rhythm other than sinus with a rate greater than 100 bpm.
Statistics:

Data was prospectively entered into a database. Separate tables were created for demographic and preoperative data, surgical and in-hospital postoperative data, outpatient follow-up data, and home monitoring data. Statistical analyses were performed using SAS®9.13. Patients were compared by preoperative diagnosis, persistent or paroxysmal atrial fibrillation, and by the success or failure of the procedure. Failure was defined as any episode of atrial fibrillation, atrial flutter, or atrial tachyarrhythmia lasting greater than 30 seconds detected after the 90-day post-surgical blanking period by follow-up EKG, pacemaker interrogation, or 30-day continuous event monitor performed at 6 and 12 months. Numerical data were compared using T-tests or Wilcoxon Rank Tests depending on the normality of the data distribution. Categorical data were compared using Fisher’s Exact Test. Postoperative AF free survival curves were calculated using the Kaplan-Meier method. Logistic regression was used to identify preoperative risk factors that were independent predictors of failure. P-values less than 0.05 were considered statistically significant and all statistical tests were two-tailed tests.

RESULTS

Perioperative results:

Forty-five patients underwent successful minimally invasive surgery between June 1, 2006 - November 18, 2007. Patient characteristics are shown in Table 1. Mean follow-up was 516 +/- 181 days (202-858 d). There were 33 patients with paroxysmal AF and 12 with persistent AF (10/12 with long-standing persistent AF). Mean length of hospital stay was 5.9 +/- 2.6 days (range: 3-18 days). Mean ICU stay for postoperative recovery was 1.7 +/- 1.6 days (range: 1-10 days). The median length of the surgical procedure
was 4.2 hours (range: 3 – 6.5 hours), which includes the time from initial skin incision to skin closure on the contralateral side. Complete information about the number of RF clamps and lesions delivered at the autonomic ganglia were available in 34 patients. The right pulmonary venous antrum was clamped a mean of 3.6 +/- 1.22 (range: 1-7) times and the left pulmonary venous antrum was clamped a mean of 3.3 +/- 1.41 (range: 1-8) times. Bidirectional block was achieved in all patients. A mean of 4.6 +/- 2.38 (range: 0-8) sites on the right side and 2.2 +/- 2.55 (range: 0-8) sites on the left side of the left atrium produced a vagal response. After GP ablation, no site produced a vagal response.

No blood transfusions were needed and no procedures required conversion to cardiopulmonary bypass. There were no deaths. Extubation was performed in the operating room in 84% of the patients and 9% (4 of 45) of patients were extubated within 6 hours in the ICU. Three of 45 (7%) were extubated after 16 hours in the ICU. Twenty-three (51%) patients were discharged on AAD (amiodarone 16/23 70%). Thirty-seven (82%) patients were discharged on warfarin. Eleven (24%) patients were cardioverted within the 90-day blanking period.

Follow-up:

There was 100% compliance with the continuous 30-day monitors at 6 months, and 96% compliance with TTM at 12 months. For the patients with recurrent atrial tachycardia (AF, AFL, or any SVT) information on whether or not the recurrent arrhythmias were persistent or paroxysmal, the longest duration of recurrent paroxysmal episodes, and management of recurrent episodes are included in Table 2. Of the 15 patients with recurrent AT, 4 patients had persistent AT. Complete follow-up was available in 96% of patients. Two of the forty-five (4%) patients did not complete the 1-year monitoring and
were lost to follow-up. The first patient had no arrhythmias on the 6-month TTM and the second patient had no AT recorded on pacemaker interrogation from the end of the blanking period to 8 months following surgery (Figure 2). These patients are not included in long-term follow-up.

At 1 year, 28 of 43 (65%) patients were in sinus rhythm off AAD with no AT > 30 seconds noted on office follow-up, on 30-day TTM, or on pacemaker interrogation (Figure 3). At 1 year, 29 of 43 (67%) patients were off warfarin. After catheter ablation for recurrent AF, 39 of 43 (91%) patients were off AAD (28 – no AF recurrence after surgical ablation, 4 – no AF recurrences after surgical + catheter ablation, 4 - PAF controlled without AAD, 3 – recurrent persistent AF) (Figure 4 and Table 2). Four patients (2 - catheter ablation (CA); 2 – without catheter ablation) required AAD for control of recurrent paroxysmal AF after surgery. After CA, 26% (11/43) of patients were still on warfarin (compared to 82% preoperatively).

All recurrences and their management are shown in Figure 4 and Table 2. Fifteen of 43 (35%) patients had an AT recurrence occurring > 90 d post surgery (Figure 4). The patients with recurrent AT had a mean of 57.5 +/- 44.5 (range 2-137) AT-free days after the blanking period until documented AT. The last recurrence was detected 227 days after surgery, thus, there were no new recurrences detected at the 12-month time point.

Eight of the 15 patients with recurrent AT underwent an electrophysiology study (EPS) and catheter ablation (Figure 3, Table 2). Mean time to CA after surgery was 252.5 +/- 73.0 days (range: 100-326 days). The 8 patients who underwent CA have been followed for a mean duration of 376.8 +/- 126.8 days (range: 172-544 days) following ablation. Five patients were found to have AF, and 3 patients were found to have atrial flutter (1 right atrial flutter, 1 right cavitricuspid isthmus dependent flutter, 1 left atrial flutter). All 5
patients with recurrent AF had paroxysmal AF. Six months after catheter ablation, 4 of 5 patients (80%) were free of AF on TTM.

Four of 15 (27%) patients are treated with AAD for recurrent paroxysmal AF (2 RFA, 2 no RFA). Eight of 15 (53%) are maintained on anticoagulation. Three of 15 patients failed to receive any benefit from any intervention. One patient was treated with an AVN ablation and VVIR pacemaker implantation. The other 2 patients are on a rate control strategy for persistent AF with AV nodal blocking drugs only. By managing recurrences with catheter ablation and medication, control of recurrent symptomatic AF increased to 93% (40/43 patients).

Univariate and multivariate analysis of variables that failed to predict recurrent AF include: gender, diabetes, hypertension, ejection fraction, age, CAD, prior stroke, active tobacco use, preoperative AF duration, LA size, preoperative diagnosis of persistent vs. paroxysmal AF, presence of AF at discharge, use of AAD at discharge, BMI, ICU length of stay, total length of hospitalization, and previous cardiac surgery (all p > 0.05). There was no statistically significant difference in the risk of failure between the paroxysmal (n=33) and persistent groups (n=12) (success: paroxysmal = 70%, persistent = 58%, P = 0.50, Figure 3) or between no previous CA (33) and previous CA (12) (success: no previous CA: 67%, previous CA: 33%, P = 0.28).

Complications:

There were no deaths or conversion to cardiopulmonary bypass. There were 3 patients with hospitalizations longer than 10 days. The first patient developed bilateral pneumothoraces that required new chest tubes and mechanical ventilation > 24 hours. The second patient required mechanical ventilation > 24 hours for hypoventilation. The third patient developed a pleural effusion (300 cc) requiring drainage prior to discharge.
All 3 patients had a BMI > 37. One patient had permanent paralysis of the right phrenic nerve. One patient had a pleural effusion drained 1 month after surgery on office follow-up.

Discussion

This report describes our experience with a minimally invasive surgical approach that combines pulmonary vein antral isolation with GP and LoM mapping and ablation. Our experience is important because it presents a single procedure success rate for a consecutive cohort of patients with systematic 1-year follow-up. We have carefully applied the follow-up model and procedural success definitions proposed by the 2007 HRS/EHRA/ECAS consensus statement on catheter and surgical ablation of AF.

Our 1-year success (defined as freedom from AF/atrial flutter [AFL]/AT off AAD) of 65% is based on ECG and home monitoring data from 96% of our subjects regardless of the presence or absence of symptoms. Previously published surgical and catheter ablation studies failed to use a rigorous follow-up strategy for documentation of AF recurrence and applied variable definitions of success (Table 3). These studies included 7.4% - 32% of patients who had failed at least 1 prior catheter ablation procedure. Despite having a higher proportion of patients with prior failed catheter ablation compared to 3 other studies, a more aggressive monitoring algorithm, a longer follow-up duration, and a stricter definition of success, we found a similar overall success rate to previously published surgical studies. If our study employed a definition of failed ablation as recurrent AT/AF/AFL greater than 10 minutes similar to other published studies of AF ablation, then our success rate would have been 79%.

Our observations indicate that even with minimally invasive surgical ablation, a significant proportion (19%) of patients have asymptomatic AF (percentage free from
symptomatic AF = 81%, percentage free from any AF = 62%) after ablation (Figure 5). Karch et al found that 28% and 47% (of circumferential and segmental PV ablation patients, respectively) had documented recurrence of an asymptomatic AT with a 7-day Holter monitor at 6-month follow-up\textsuperscript{21}. Hindricks et al. found that after circumferential pulmonary vein isolation, 36% of patients had completely asymptomatic recurrences at 12-month follow-up using a continuous 7-day ECG monitor and an AF symptom log, compared to 22% immediately before ablation\textsuperscript{22}. Relying only on symptomatic episodes of AF overestimates the efficacy of AF interventional strategies\textsuperscript{21}.

Consistent with the observations by Hindricks et al., the mean number of AT episodes and the mean AT duration declined in our patients after catheter ablation and/or AAD (Table 2)\textsuperscript{22}. Thus, surgical ablation in conjunction with AAD or catheter ablation for recurrent AT allowed us to achieve symptomatic relief from AF in 93% of our patients.

We did not pursue interventions other than direct current cardioversion and post-operative AAD for AT within the 90-day blanking period. Lellouche et al. found that of 90 patients with AT \( \geq 3 \) minutes within 1 month of the index catheter ablation, 91% had a late recurrence requiring an additional procedure\textsuperscript{23}. These early recurrences served as a marker for patients who were at risk of AT recurrence after the blanking period. In our cohort there were 4 patients (patients 2, 6, 10, 15) whose AT recurrences were found within 2 weeks of the blanking period; two (patients 10, 15) benefited from an atrial flutter ablation (Table 2). Patient 2 received an AVN ablation and a VVIR pacemaker for persistent AF; patient 6 has rare PAF controlled with AAD (Table 2). However, since our TTM protocol was not designed for the purposes of early detection and catheter ablation of AT recurrences, the significance of these recurrences and their successful treatment remains to be determined.
Whether GP ablation improves the success rate of AF ablation compared to surgical PVI alone is unknown. Although canine models have shown an important role for GP ablation, long-term human data for GP ablation do not exist. Discrepant results regarding the inclusion of GP ablation from surgical studies fail to provide a definitive answer to this question.

Other studies have found a significant difference between the efficacy of catheter-based and surgical ablation for paroxysmal compared to persistent AF. Our experience found no significant difference in the success rate of patients with paroxysmal compared to persistent AF. Our success rate with persistent AF is high, likely because of the small sample size of persistent AF patients and the fact that LA size was not markedly enlarged in either group. However, the success rate with persistent AF could also represent modification of the atrial substrate: 1) Oral et al. showed that 22% of persistent AF patients had successful elimination of AF, 2) a large area of the LA cuffs are ablated with each RF clamp application, 3) ablation of the LoM and GPs eliminates the contribution of the autonomic ganglia to the triggering of pulmonary vein firing from the left atrial antrum, and 4) we performed extensive dissection in the inter-atrial areas to include as much left atrial tissue as possible. This improvement in the single procedure success for treatment of persistent AF compared to catheter ablation will need to be validated as more patients undergo surgical ablation. Finally, it should be noted that comparing our results to single procedure success for catheter ablation, the mean age of our patients was 2-12 years older than that reported by Noheria et al. in their systematic review of catheter AF ablation.

Limitations
Although we have noted a significant success rate and symptomatic improvement in patients, we did not conduct a formal assessment of quality of life. Although our success rate is less than that reported in other series, the lack of a previous consensus definition for single procedure success and the varied definitions of success and follow-up likely account for this difference. This is supported by the high rate of symptomatic AF reduction/elimination with a combination of AAD/catheter ablation for AF recurrences after surgical ablation. As future studies emerge for both surgical and catheter-based AF ablation, application of the HRS consensus criteria for procedural success will improve the accuracy of comparing different ablation techniques.

Our study may be subject to referral bias based on a preference for surgery in patients with obesity, patients who could not tolerate or desired to discontinue warfarin, and patients who had abdominal or pelvic anatomy complicating catheter ablation. In addition, patients may have been biased in their decision to pursue surgical ablation when presented with the potential for repeat procedures after catheter ablation.

The limited numbers of patients in this single-center study prevent definitive conclusions from being drawn with univariate and multivariate regression analyses. As the number of patients undergoing minimally invasive pulmonary vein isolation with GP and LoM ablation increase, the application of multivariate regression analyses will be critical to confirming the results of our analysis.

Conclusions

A minimally invasive surgical approach employing pulmonary vein isolation combined with the mapping and ablation of autonomic GP for medically refractory AF has a single procedure success rate of 65% at 1 year. Recurrences can be managed with catheter ablation and AAD.
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Dr. Vigneshwar Kasirajan has received research support from Atricure, Incorporated.

Dr. Mark A. Wood has received research support from Atricure, Incorporated.

Conflict of Interest Disclosures:

Luke Wolfe and Drs. Frederick T. Han, Marcin Kowalski, Robert Kiser, Gautham Kalahasty, and Richard K. Shepard have no conflicts of interest to disclose.

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References:


Table 1. Baseline characteristics (N = 45)


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<thead>
<tr>
<th>Variable</th>
<th>Preoperative</th>
<th>Range</th>
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</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>64 +/- 8.7</td>
<td>43-77</td>
</tr>
<tr>
<td>Gender (Female/Male)</td>
<td>44%/56%</td>
<td></td>
</tr>
<tr>
<td>Ejection Fraction (%)</td>
<td>56% +/- 8.0</td>
<td>30-70%</td>
</tr>
<tr>
<td>Duration of AF (Months)</td>
<td>74.1 +/- 103.9</td>
<td>3-600</td>
</tr>
<tr>
<td>Paroxysmal AF</td>
<td>81.3 +/- 118.9</td>
<td>3-600</td>
</tr>
<tr>
<td>Persistent AF</td>
<td>59.8 +/- 54.9</td>
<td>5-180</td>
</tr>
<tr>
<td>LA diameter (cm)*</td>
<td>4.3 +/- 0.6</td>
<td>3-5.8</td>
</tr>
<tr>
<td>BMI</td>
<td>31.0 +/- 6.8</td>
<td>21.4 – 54.3</td>
</tr>
<tr>
<td>BMI &gt; 40</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Hemoglobin (g/dl)</td>
<td>14.9 +/- 1.4</td>
<td>10.1 – 18.0</td>
</tr>
<tr>
<td>Creatinine (mg/dl)</td>
<td>0.9 +/- 0.2</td>
<td>0.6-1.3</td>
</tr>
<tr>
<td>Previous CA (% of patients)</td>
<td>12 (26.7%)</td>
<td></td>
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<tr>
<td>DM (%)</td>
<td>3 (6.7%)</td>
<td></td>
</tr>
<tr>
<td>HTN (%)</td>
<td>34 (75.6%)</td>
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<tr>
<td>Condition</td>
<td>Count (%)</td>
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<tr>
<td>History of CAD (%)</td>
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<tr>
<td>Previous CTS (%)</td>
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<tr>
<td>Previous stroke/TIA (%)</td>
<td>3 (6.7%)</td>
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</tr>
<tr>
<td>Current smoker (%)</td>
<td>5 (11%)</td>
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Table 2. Atrial fibrillation recurrences and management after surgery.

*Pt was initially started on sotalol for control of her recurrent paroxysmal atrial fibrillation. After 6 months, sotalol was changed to dofetilide after patient complained of 3 PAF episodes with symptom of dyspnea on exertion lasting > 24 hours.

Abbreviations:
AT – atrial tachyarrhythmia, AF – atrial fibrillation, AFL- atrial flutter, ECG – electrocardiogram, CA – catheter ablation, Mins – minutes, Hrs – hours, Secs – seconds, AVN – atrioventricular node, AAD – antiarrhythmic drugs, PAF – paroxysmal atrial fibrillation, Mos – months

<table>
<thead>
<tr>
<th>Patient</th>
<th>Time to AT recurrence (days)</th>
<th>AF vs AFL Recurrence diagnosed with ECG vs monitor</th>
<th>Longest duration of recurrence</th>
<th>Management after additional therapy</th>
<th>Recurrence after CA</th>
<th>F/u after CA</th>
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<tbody>
<tr>
<td>1</td>
<td>165</td>
<td>AFL ECG – symptomatic</td>
<td>6 mins CA</td>
<td>None</td>
<td>None</td>
<td>17 mos</td>
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<tr>
<td>2</td>
<td>102</td>
<td>AF ECG – symptomatic</td>
<td>Persistent AVN ablation + PM</td>
<td>Persistent AF</td>
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<td>-</td>
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<tr>
<td>3</td>
<td>95</td>
<td>AF Monitor – symptomatic</td>
<td>&gt; 24 hrs CA</td>
<td>Rare, brief PAF</td>
<td>PAF off AAD</td>
<td>12 mos</td>
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<tr>
<td>4</td>
<td>184</td>
<td>AF Monitor – symptomatic</td>
<td>4 mins CA</td>
<td>none</td>
<td>5 mos</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>160</td>
<td>AF Monitor – symptomatic</td>
<td>&gt; 24 hrs Rate control</td>
<td>Persistent AF</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>107</td>
<td>AF ECG – symptomatic</td>
<td>&gt; 24 hrs Sotalol -&gt; Dofetilide*</td>
<td>Rare PAF</td>
<td>-</td>
<td></td>
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<tr>
<td>7</td>
<td>227</td>
<td>AF Monitor – symptomatic</td>
<td>30 secs AVN blocker</td>
<td>None</td>
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<td>Procedure</td>
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<td>CA</td>
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<td>9</td>
<td>181</td>
<td>AF</td>
<td>ECG</td>
<td>Persistent</td>
<td>CA</td>
<td>Persistent AF</td>
</tr>
<tr>
<td>10</td>
<td>101</td>
<td>AFL</td>
<td>Monitor</td>
<td>Persistent</td>
<td>CA, Dofetilide</td>
<td>Rare brief PAF</td>
</tr>
<tr>
<td>11</td>
<td>181</td>
<td>AF</td>
<td>Monitor</td>
<td>3 hrs</td>
<td>CA, Dofetilide</td>
<td>PAF, longest &gt; 24 hours</td>
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<tr>
<td>12</td>
<td>152</td>
<td>AF</td>
<td>Monitor</td>
<td>6 mins</td>
<td>AVN blocker</td>
<td>Persistent PAF</td>
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<tr>
<td>13</td>
<td>92</td>
<td>AF</td>
<td>Pacemaker</td>
<td>11.75 hrs</td>
<td>Amiodarone</td>
<td>PAF</td>
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<td>14</td>
<td>161</td>
<td>AF</td>
<td>Monitor</td>
<td>4.4 mins</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>15</td>
<td>100</td>
<td>AFL</td>
<td>ECG</td>
<td>Persistent</td>
<td>CA</td>
<td>None</td>
</tr>
</tbody>
</table>
Table 3. Comparison to other minimally invasive surgical studies.

*One patient excluded.

Right-sided atrial tachycardias and atrial flutters were not considered a failure of surgical ablation.


<table>
<thead>
<tr>
<th>Study</th>
<th>N (Paroxysmal/Persistent)</th>
<th>Surgical technique</th>
<th>Minimum follow-up duration</th>
<th>Follow-up</th>
</tr>
</thead>
<tbody>
<tr>
<td>Han et al. (2005)</td>
<td>45 (33/12)</td>
<td>RF PVI, GP and LoM</td>
<td>1 year (96%)</td>
<td>Office visits @ 3, 6, 12 visits, mos, yearly, and as needed</td>
</tr>
<tr>
<td>Wolf et al. (2007)</td>
<td>27 (18/9)</td>
<td>RF PVI and LoM</td>
<td>3 months (85%)</td>
<td>Office visits, phone calls</td>
</tr>
<tr>
<td>McClelland et al. (2008)</td>
<td>21 (11/9)*</td>
<td>RF PVI, LAA exclusion</td>
<td>1 year (95%)</td>
<td>Office visits @ 1, 2, 3, 6 wks; 3 and 6 mos and every 6 mos</td>
</tr>
<tr>
<td>Wudel et al. (2008)</td>
<td>22 (14/8)</td>
<td>RF PVI, LoM</td>
<td>1 year (100%)</td>
<td>Office visit 3 mos, 6 mos, and yearly 6 mos</td>
</tr>
<tr>
<td>Edgerton et al. (2008)</td>
<td>74 (46/28)</td>
<td>RF PVI, LAA exclusion</td>
<td>6 months (89%)</td>
<td>Office visits 1, 3 mos</td>
</tr>
</tbody>
</table>
### Outpatient Monitoring

<table>
<thead>
<tr>
<th>ECG at office visits,</th>
<th>ECG at f/u; 24-48</th>
<th>ECG 3 mos, Holter at end of study, 6 mos, 11 PM, 31</th>
</tr>
</thead>
<tbody>
<tr>
<td>30-day TTM TTM (11)</td>
<td>Holter/TTM for sx only</td>
<td>questionnaire 14-21-d TTM, 24 24-hr Holter</td>
</tr>
<tr>
<td>6 &amp; 12 mos, yearly</td>
<td>24-48</td>
<td>6 mos, 11 PM, 31</td>
</tr>
</tbody>
</table>

### Definition of Success

- **No AT > 30s off AAD**
- **No AF on ECG or TTM**
- **No AF/left AT and AAD after 90-d blank period**
- **No AF on ECG/end of study Holter**
- **No AF > 15s at 6 mos**

### Previous failed catheter ablation

<table>
<thead>
<tr>
<th>27%</th>
<th>7.4%</th>
<th>Not described</th>
<th>32%</th>
<th>27%</th>
</tr>
</thead>
</table>

- **No recurrence/AAD**
  - 28/43 (65%) 15/23 15/20 (75%) 1 20/22 (91%) 38/66
  - (65%) excluded*, 2
  - RA flutter †

- **Absent/minimal sx after additional CA/AAD**
  - 40/43 (93%) 21/23 15/20 (75%) 22/22 (100%) 49/66
  - (91%) (74%)

### Complications

| 11% | 17% | 5% | 9% | 5% |

---

*Not described*

† RA flutter
Figure Legends.

Figure 1. A. Pre left atrial appendectomy. 1B. Post left atrial appendectomy.

Figure 2. Pacemaker histogram of atrial arrhythmias.

This patient had his surgical ablation on July 7, 2006. After the 90-day blanking period there were no atrial tachyarrhythmias documented as of March 30, 2007 (over 8 months of post-surgical monitoring). This patient was lost to follow-up after this pacemaker interrogation.

Figure 3. Kaplan-Meier curve of 1-year atrial fibrillation free survival.

The Kaplan-Meier curves represent percentage estimates of patients at risk of atrial fibrillation up to one-year post surgery. The total number of patients (preoperative paroxysmal AF/preoperative persistent AF patients) at risk of recurrences is at bottom of the figure.

Figure 4. Treatment diagram.


Figure 5. Kaplan-Meier curve of atrial tachyarrhythmia symptom-free survival.

The Kaplan-Meier curves represent percentage estimates of patients at risk of AF recurrences up to one-year post-surgery. The number of patients at risk of symptomatic recurrences (endpoint represented by blue dashed line) is noted at the bottom of the figure; the number of patients at risk of any recurrence (endpoint represented by red solid line) is noted in parentheses.
AT/AF Burden Trend

Circulation Arrhythmia and Electrophysiology
Journal of the American Heart Association
The graph illustrates the free survival rate over different days after surgery for three groups: All, Paroxysmal, and Persistent. The survival rate is shown on the y-axis, ranging from 0.00 to 1.00. The x-axis represents the days after surgery, ranging from 0 to 360.

- **Pts at risk** for each time point:
  - 45(33/12) at 0 days
  - 33(24/9) at 30 days
  - 30(23/7) at 120 days
  - 28(21/7) at 210 days
  - 28(21/7) at 300 days
  - 28(21/7) at 360 days
Surgical ablation
N = 45

F/u completed
N = 43

Lost to f/u
N = 2

No AF
N = 28

Recurrent AF
N = 15

RFA
N = 8

No AAD
N = 4

AAD
N = 2

AVN ablation + PM
N = 1

No AF & no AAD
N = 4

PAF controlled without AAD
N = 4 (1 RFA, 3 no RFA)

PAF controlled with AAD
N = 4 (2 RFA, 2 no RFA)

Persistent AF & no AAD
N = 3
Results of a Minimally Invasive Surgical Pulmonary Vein Isolation and Ganglionic Plexi Ablation for Atrial Fibrillation: Single Center Experience with 12–Month Follow-up

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SUPPLEMENTAL MATERIAL

Video File Legends:

1. Left lateral decubitus positioning for left thorascopic access
2. Transesophageal echocardiogram (TEE) of left atrium (LA)
3. Left thorascopic access incision with simultaneous TEE image of LA in bottom right corner
4. Thorascopic port access with electrocardiogram (ECG) monitor in bottom right corner
5. Thorascopic view of left pleural surface during left anterior axillary line thorascopic port access incision
6. ECG, arterial line, ventilator monitor during left anterior axillary line thorascopic port access incision (in bottom right corner)
7. Dissection and opening of left side of pericardium (posterior to left phrenic nerve)
8. Exposure and dissection of LA epicardial antrum and left pulmonary veins (PV). Left lung on right side of video, left atrium and pericardium on left side of video.
9. A 20 pole lasso catheter placement around left superior PV.
10. Surface ECG (top two leads) and a 20 pole lasso catheter recording of left superior PV potentials during atrial fibrillation
11. Ganglionic plexi (GP) stimulation (with an 18 mV, 1.5 msec pulse width impulse at 1000 pulses per minute) using a bipolar pen probe demonstrating a vagal response (≥ 50% reduction of mean cycle length)
to GP stimulation on surface ECG leads III and V1 during atrial fibrillation.

Video of GP stimulation with pen probe in bottom right corner.

12. Dissection of pericardial fat from epicardial LA antrum

13. Pulmonary vein isolation with bipolar radiofrequency (RF) clamp ablation.

14. Surface ECG (top two leads) and 20 pole lasso catheter recording of left superior PV during ablation. Video of RF clamp on PV antrum in bottom right corner.

15. ECG, arterial line, ventilator monitor demonstrating restoration of sinus rhythm after left PV isolation with bipolar RF clamp ablation. Video of LA antrum in bottom right corner.

16. Exclusion of left atrial appendage with stapling device.

17. Closure of left pericardial incision

18. Left thorascopic access port site bupivicaine injections viewed from pleural surface.

19. Right pericardial surface. Right lung is on left side of video. Right phrenic nerve is adjacent to right lung.

20. Dissection and isolation of right pulmonary veins.

21. A 20 pole lasso catheter placed around right superior PV.

22. Surface ECG (top two leads) and a 20 pole lasso catheter recording of right superior PV potentials during atrial fibrillation.

23. GP stimulation (with an 18 mV, 1.5 msec pulse width impulse at 1000 pulses per minute) using a bipolar pen probe demonstrating vagal response on ECG monitor in bottom right corner of video.
24. ECG, arterial line, and ventilator monitor demonstrating vagal response after GP stimulation during atrial fibrillation with ventricular rate of 53 bpm.

25. Dissection of interatrial groove with lasso catheter around right superior PV.

26. Right PV isolation with bipolar RF clamp on right PV antrum and lasso catheter around right superior PV.

27. Surface ECG (top two leads) and 20 pole lasso catheter recordings during right PV antrum ablation.

28. Surface ECG (top two leads) and 20 pole lasso catheter recordings after right PV antrum ablation.

29. ECG, arterial line, and ventilator monitor demonstrating atrial fibrillation during right GP ablation with bipolar pen probe. Bipolar pen probe for GP ablation in bottom right corner of video.

30. Right thorascopic access port site bupivicaine injections viewed from pleural surface.

31. ECG, arterial line, and ventilator monitor demonstrating restoration of sinus rhythm at conclusion of surgery.