Results of a Minimally Invasive Surgical Pulmonary Vein Isolation and Ganglionic Plexi Ablation for Atrial Fibrillation

Single-Center Experience With 12-Month Follow-Up

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

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 Heart Rhythm Society/European Heart Rhythm Association/European Cardiac Arrhythmia Society 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 and left atrial ganglionic plexi ablation for treatment of AF.

Methods and Results—Forty-five (33 paroxysmal; 12 persistent) consecutive patients underwent thorascopic bilateral radiofrequency pulmonary vein isolation, ganglionic plexi ablation, ligament of Marshall ablation, and left atrial appendage exclusion by a single surgeon. Forty-three patients were prospectively followed without antiarrhythmic drugs for a minimum of 1 year with a 30-day continuous event monitor or pacemaker interrogation at 6 and 12 months. Failure was defined as any atrial tachyarrhythmia of ≥30 seconds’ duration occurring >90 days after surgery. Mean follow-up was 516±181 days (202 to 858 days). Twenty-eight (65%) patients had no atrial tachyarrhythmia ≥30 seconds by 1 year, and 15 (35%) patients had atrial tachyarrhythmia 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 antiarrhythmic drugs alone. Three patients did not benefit from surgery and received rate control only. There were no deaths; 1 phrenic nerve injury and 2 pleural effusions were the only major complications.

Conclusions—The single procedure success at 1-year follow-up for surgical pulmonary vein isolation and ganglionic plexi ablation is 65%. Atrial tachyarrhythmia recurrences after surgery are usually responsive to catheter ablation and/or antiarrhythmic drugs.

Key Words: atrial fibrillation • surgical ablation • cardiac monitoring • catheter ablation

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.

Clinical Perspective on p 377

The landmark work of Haissaguerre et al6–8 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, Scherlag et al9–12 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. 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 (K.E.) referral of patients with symptomatic AF who had failed at least 1 antiarrhythmic drug (AAD). Patients were presented with the option of (1) continued AAD trials (when additional AAD 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 (eg, morbid obesity), recurrent bleeding on warfarin, or difficulty passing catheters from the femoral vein (inferior vena cava filter or trauma resulting in inferior vena cava 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 (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, Ohio) on the left atrium, and recordings were made with a physiological 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-ms 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). The end point for pulmonary vein 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 V and 1.5-ms pulse width. Exit block was defined by failure to capture the left atrium when pacing from the pulmonary veins distal to the radiofrequency lesions at 7.5 V and 1.5-ms pulse width. A proprietary algorithm terminated radiofrequency energy (maximum, 28 W) after impedance changes indicated transmural injury. Clamp applications were repeated a minimum of 2 to 3 times after bidirectional block was achieved.

The autonomic ganglia (GPs) were mapped before and after ablation of the pulmonary venous antrum. Bipolar radiofrequency energy at 15 W was delivered through the bipolar pen at sites demonstrating a vagal response. The end point 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. When feasible, patients were extubated in the operating room. When possible, postoperative use of AADs was avoided and warfarin was resumed by discharge. Unless patients had a CHADS2 score ≥2, warfarin was discontinued after the 6-month monitor confirmed the absence of atrial tachyarrhythmia (AT). If patients had a CHADS2 score ≥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 β-blockers in the immediate postoperative state were preferentially treated with amiodarone for 4 to 8 weeks. All AADs 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 after surgery 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 after surgery. Monitoring was performed with an external loop recorder (Cardiolabs, Franklin, Tenn) with an automatically triggered algorithm to detect AF. Success was defined as no episode of AF, atrial flutter, or any AT lasting >30 seconds off AAD. AT was defined as any rhythm other than sinus with a rate >100 bpm.

Statistics

Data were prospectively entered into a database. Separate tables were created for demographic and preoperative data, surgical and
Table 1. Baseline Characteristics (n=45)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Preoperative</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y</td>
<td>64±8.7</td>
<td>43–77</td>
</tr>
<tr>
<td>Sex, 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, mo</td>
<td>74.1±103.9</td>
<td>3–600</td>
</tr>
<tr>
<td>Paroxysmal</td>
<td>81.3±118.9</td>
<td>3–600</td>
</tr>
<tr>
<td>Persistent</td>
<td>59.8±54.9</td>
<td>5–180</td>
</tr>
<tr>
<td>Paroxysmal AF</td>
<td>33 (73)</td>
<td></td>
</tr>
<tr>
<td>Persistent AF</td>
<td>12 (27)</td>
<td></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, n (% of patients)</td>
<td>12 (26.7)</td>
<td></td>
</tr>
<tr>
<td>DM, n (%)</td>
<td>3 (6.7)</td>
<td></td>
</tr>
<tr>
<td>HTN, n (%)</td>
<td>34 (75.6)</td>
<td></td>
</tr>
<tr>
<td>History of CAD, n (%)</td>
<td>8 (17.8)</td>
<td></td>
</tr>
<tr>
<td>Previous CTS, n (%)</td>
<td>4 (8.9)</td>
<td></td>
</tr>
<tr>
<td>Previous stroke/TIA, n (%)</td>
<td>3 (6.7)</td>
<td></td>
</tr>
<tr>
<td>Current smoker, n (%)</td>
<td>5 (11)</td>
<td></td>
</tr>
</tbody>
</table>

LA indicates left atrial; BMI, body mass index; CA, catheter ablation; DM, diabetes mellitus; HTN, hypertension; CAD, coronary artery disease; CTS, cardiothoracic surgery; TIA, transient ischemic attack.

*LA diameter measured in parasternal long axis.

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 AF, and by the success or failure of the procedure. Failure was defined as any episode of AF, atrial flutter, or AT lasting >30 seconds detected after the 90-day postsurgical blanking period by follow-up ECG, pacemaker interrogation, or 30-day continuous event monitor performed at 6 and 12 months. Numeric data were compared using t tests or Wilcoxon rank tests, depending on the normality of the data distribution. Categorical data were compared using the Fisher 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. Probability values <0.05 were considered statistically significant, and all statistical tests were 2-tailed.

Results

Perioperative Results

Forty-five patients underwent successful minimally invasive surgery between June 1, 2006, to November 18, 2007. Patient characteristics are shown in Table 1. Mean follow-up was 516±181 days (202 to 858 days). 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 to 18 days). Mean ICU stay for postoperative recovery was 1.7±1.6 days (range, 1 to 10 days). The median length of the surgical procedure was 4.2 hours (range: 3 to 6.5 hours), which includes the time from initial skin incision to skin closure on the contralateral side. Complete information about the number of radiofrequency 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 to 7) times and the left pulmonary venous antrum was clamped a mean of 3.3±1.41 (range, 1 to 8) times. Bidirectional block was achieved in all patients. A mean of 4.6±2.38 (range, 0 to 8) sites on the right side and 2.2±2.55 (range, 0 to 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 AT (AF, atrial flutter, or any supraventricular tachycardia), 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 45 (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 after 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 (no AF recurrence after surgical ablation, 28; no AF recurrences after surgical plus catheter ablation, 4; paroxysmal AF controlled without AAD, 4; recurrent persistent AF, 3) (Figure 4 and Table 2). Four patients (2 with catheter ablation; 2 without) required AAD for control of recurrent paroxysmal AF after surgery. After catheter ablation, 26% (11/43) of patients were still on warfarin (compared with 82% before surgery).

All recurrences and their management are shown in Figure 4 and Table 2. Fifteen of 43 (35%) patients had an AT recurrence occurring >90 days after surgery (Figure 4). The patients with recurrent AT had a mean of 57.5±44.5 (range, 2 to 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 and catheter ablation (Figure 3 and...
Mean time to catheter ablation after surgery was 252.5/73.0 days (range, 100 to 326 days). The 8 patients who underwent catheter ablation have been followed for a mean duration of 376.8/126.8 days (range, 172 to 544 days) after ablation. Five patients were found to have AF, and 3 patients were found to have atrial flutter (1 right atrial flutter, 1 right cavotricuspid 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 with radiofrequency ablation, 2 without). 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 atrioventricular node ablation and VVIR pacemaker implantation. The other 2 patients are on a rate control strategy for persistent AF with atrioventricular 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 sex, diabetes, hypertension, ejection fraction, age, coronary artery disease, prior stroke, and patient age. However, a unique variable found to predict recurrent AF was the presence of a pacemaker.

### Table 2. AF Recurrences and Management After Surgery

<table>
<thead>
<tr>
<th>Patient</th>
<th>Time to AT Recurrence, d</th>
<th>AF vs AFL</th>
<th>Recurrence Diagnosed</th>
<th>Longest-Duration AF</th>
<th>Management of Recurrence</th>
<th>Recurrence After Additional Therapy</th>
<th>Follow-up After CA</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>165</td>
<td>AFL</td>
<td>ECG, minimally</td>
<td>6 min</td>
<td>CA</td>
<td>None</td>
<td>17 mo</td>
</tr>
<tr>
<td>2</td>
<td>102</td>
<td>AF</td>
<td>ECG, symptomatic</td>
<td>Persistent</td>
<td>AVN ablation + PM</td>
<td>Persistent AF</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>95</td>
<td>AF</td>
<td>Monitor, minimally</td>
<td>&gt;24 h</td>
<td>CA</td>
<td>Rare, brief PAF off AAD</td>
<td>12 mo</td>
</tr>
<tr>
<td>4</td>
<td>184</td>
<td>AF</td>
<td>Monitor, minimally</td>
<td>4 min</td>
<td>CA</td>
<td>None</td>
<td>5 mo</td>
</tr>
<tr>
<td>5</td>
<td>160</td>
<td>AF</td>
<td>Monitor, symptomatic</td>
<td>&gt;24 h</td>
<td>Rate control</td>
<td>Persistent AF</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>107</td>
<td>AF</td>
<td>ECG, symptomatic</td>
<td>&gt;24 h</td>
<td>Sotalol &gt; dofetilide*</td>
<td>Rare PAF</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>227</td>
<td>AF</td>
<td>Monitor, minimally</td>
<td>30 s</td>
<td>AVN blocker</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>204</td>
<td>AF</td>
<td>Monitor, minimally</td>
<td>6 min</td>
<td>CA</td>
<td>None</td>
<td>8 mo</td>
</tr>
<tr>
<td>9</td>
<td>181</td>
<td>AF</td>
<td>ECG, symptomatic</td>
<td>Persistent</td>
<td>CA</td>
<td>Persistent AF</td>
<td>14 mo</td>
</tr>
<tr>
<td>10</td>
<td>101</td>
<td>AFL</td>
<td>Monitor, symptomatic</td>
<td>Persistent</td>
<td>CA, Dofetilide</td>
<td>Rare brief PAF</td>
<td>12 mo</td>
</tr>
<tr>
<td>11</td>
<td>181</td>
<td>AF</td>
<td>Monitor, symptomatic</td>
<td>3 h</td>
<td>CA, Dofetilide</td>
<td>PAF, longest &gt;24 h</td>
<td>13 mo</td>
</tr>
<tr>
<td>12</td>
<td>152</td>
<td>AF</td>
<td>Monitor, asymptomatic</td>
<td>6 min</td>
<td>AVN blocker</td>
<td>Persistent</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>92</td>
<td>AF</td>
<td>Pacemaker, symptomatic</td>
<td>11.75 h</td>
<td>Amiodarone</td>
<td>PAF</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>161</td>
<td>AF</td>
<td>Monitor, minimally</td>
<td>4.4 min</td>
<td>None</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>100</td>
<td>AFL</td>
<td>ECG, symptomatic</td>
<td>Persistent</td>
<td>CA</td>
<td>None</td>
<td>18 mo</td>
</tr>
</tbody>
</table>

AFL indicates atrial flutter; CA, catheter ablation; AVN, atrioventricular node; PAF, paroxysmal AF.

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

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**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 ATs documented as of March 30, 2007 (over 8 months of postsurgical monitoring). This patient was lost to follow-up after this pacemaker interrogation.

**Figure 3.** Kaplan–Meier curve of 1-year AF-free survival. Kaplan–Meier curves represent percentage estimates of patients at risk of AF (Afib) up to 1 year after surgery. The total number of patients (patients with preoperative paroxysmal AF/patients with preoperative persistent AF) at risk of recurrences is at bottom of the figure.
active tobacco use, preoperative AF duration, left atrium size, preoperative diagnosis of persistent versus paroxysmal AF, presence of AF at discharge, use of AAD at discharge, body mass index, 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 catheter ablation (n = 33) and previous catheter ablation (n = 12) (success: no previous catheter ablation, 67%; previous catheter ablation, 33%; \( P = 0.28 \)).

Complications
There were no deaths or conversion to cardiopulmonary bypass. There were 3 patients with hospitalizations >10 days. The first patient had 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 had a pleural effusion (300 mL) requiring drainage before discharge. All 3 patients had a body mass index >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 Heart Rhythm Society/European Heart Rhythm Association/European Cardiac Arrhythmia Society consensus statement on catheter and surgical ablation of AF.5

Our 1-year success (defined as freedom from AF/atrial flutter/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).13–15,19,20 These studies included 7.4% to 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 with 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.13–15,19,20 If our study used a definition of failed ablation as recurrent AT/AF/atrial flutter 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 al21 found that 28% and 47% (of patients with circumferential and segmental pulmonary vein ablation, respectively) had documented recurrence of an asymptomatic AT with a 7-day Holter monitoring at 6-month follow-up. Hindricks et al22 found that after circumferential PVI, 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 with 22% immediately before ablation. Relying only on symptomatic episodes of AF overestimates the efficacy of AF interventional strategies.21

Consistent with the observations by Hindricks et al,22 the mean number of AT episodes and the mean AT duration...
declined in our patients after catheter ablation and/or AAD (Table 2). 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 postoperative AAD for AT within the 90-day blanking period. Lellouche et al found that of 90 patients with AT ≥3 minutes within 1 month of the index catheter ablation, 91% had a late recurrence requiring an additional procedure. 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, and 15) whose AT recurrences were found within 2 weeks of the blanking period; 2 (patients 10 and 15) benefited from an atrial flutter ablation (Table 2). Patient 2 received an atrioventricular node ablation and a VVIR pacemaker for persistent AF; patient 6 has rare paroxysmal AF 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.

Other studies have found a significant difference between the efficacy of catheter-based and surgical ablation for paroxysmal compared with persistent AF. Patients with paroxysmal AF have a lower recurrence rate compared with persistent AF, even with successful ablation. In our experience, patients with paroxysmal AF have a higher success rate with surgical ablation compared with catheter ablation.

Table 3. Comparison With Other Minimally Invasive Surgical Studies

<table>
<thead>
<tr>
<th>Han et al</th>
<th>Wolf et al</th>
<th>McClelland et al</th>
<th>Wudel et al</th>
<th>Edgerton et al</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. (paroxysmal/persistent)</td>
<td>45 (33/12)</td>
<td>27 (18/9)</td>
<td>21 (11/8)*</td>
<td>22 (14/8)</td>
</tr>
<tr>
<td>Surgical technique</td>
<td>RF PVI, GP, and LoM ablation, LAA exclusion</td>
<td>RF PVI</td>
<td>RF PVI, GP, and LoM ablation, LAA exclusion</td>
<td>RF PVI, LooM ablation, LAA exclusion</td>
</tr>
<tr>
<td>Minimum follow-up duration (% completed follow-up)</td>
<td>1 y (96%)</td>
<td>3 mo (85%)</td>
<td>1 y (95%)</td>
<td>1 y (100%)</td>
</tr>
<tr>
<td>Follow-up</td>
<td>Office visits at 3, 6, 12 mo, yearly, and as needed</td>
<td>Office visits, telephone calls</td>
<td>Office visits at 1, 2, 3, 6 wk; 3 and 6 mo and every 6 mo</td>
<td>Office visit 3 mo, 6 mo, and yearly</td>
</tr>
<tr>
<td>Outpatient monitoring</td>
<td>ECG at office visits, 30-d TTM 6 and 12 mo, yearly</td>
<td>ECG (10), outpatient TTM (11)</td>
<td>ECG at follow-up; 24–48 Holter/TTM for Sx only</td>
<td>ECG 3 mo, Holter at end of study, questionnaire</td>
</tr>
<tr>
<td>Definition of success</td>
<td>No AT ≥30 s off AAD after 90-d blank period</td>
<td>No AF on ECG or TTM</td>
<td>No AF/left AT and AAD after 90-d blank period†</td>
<td>No AF on ECG/end of study Holter</td>
</tr>
<tr>
<td>Previous failed catheter ablation</td>
<td>27%</td>
<td>7.4%</td>
<td>Not described</td>
<td>32%</td>
</tr>
<tr>
<td>No recurrence/AAD</td>
<td>28/43 (65%)</td>
<td>15/23 (65%)</td>
<td>15/20 (75%)</td>
<td>20/22 (91%)</td>
</tr>
<tr>
<td>Absent/minimal Sx after additional CA/AAD</td>
<td>40/43 (93%)</td>
<td>21/23 (91%)</td>
<td>15/20 (75%)</td>
<td>22/22 (100%)</td>
</tr>
<tr>
<td>Complications</td>
<td>11%</td>
<td>17%</td>
<td>5%</td>
<td>9%</td>
</tr>
</tbody>
</table>

LAA indicates left atrial appendage; Sx, symptoms; CA, catheter ablation; RA, right atrial; PM, pacemaker.

*One patient excluded.
†Right-sided ATs and atrial flutters were not considered a failure of surgical ablation.
of the small sample size of persistent AF patients and the fact that left atrium 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 patients with persistent AF had successful elimination of AF, (2) a large area of the left atrium cuffs are ablated with each radiofrequency 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 interatrial areas to include as much left atrial tissue as possible. This improvement in the single-procedure success for treatment of persistent AF compared with catheter ablation will need to be validated as more patients undergo surgical ablation. Finally, it should be noted that in comparing our results with single-procedure success for catheter ablation, the mean age of our patients was 2 to 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 probably 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 PVI 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 using PVI 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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Disclosures
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**CLINICAL PERSPECTIVE**

Minimally invasive surgical pulmonary vein isolation with ganglionic plexi and ligament of Marshall ablation has emerged as an alternative to catheter ablation and the Cox Maze III procedure for the treatment of medically refractory atrial fibrillation. We report the results of a consecutive series of patients undergoing this procedure with 1-month continuous ECG monitoring at 6 and 12 months to determine its efficacy according to the Heart Rhythm Society/European Heart Rhythm Association/European Cardiac Arrhythmia Society guidelines. The 12-month success rate free of atrial fibrillation without antiarrhythmic medications was 65% and demonstrates that this procedure represents an alternative to catheter ablation in appropriately selected patients. Additional multicenter studies with long-term follow-up are needed to help refine guidelines for optimal patient selection for minimally invasive surgical or catheter ablation.
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.