Where does atrial fibrillation surgery fail? Implications for increasing effectiveness of ablation

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Objective: Surgical ablation of atrial fibrillation is generally safe and effective, but atrial fibrillation redevelops in approximately 20% of patients. We sought to determine anatomic factors, technology factors, or both that contribute to these failures.

Methods: Four hundred eight patients underwent 5 types of atrial fibrillation ablation depending on their atrial fibrillation history and need for concomitant surgical intervention: the classic maze procedure, high-intensity focused ultrasound, the left atrial maze procedure, the biatrial maze procedure, and pulmonary vein isolation. Ninety-five percent of patients with preoperative atrial fibrillation underwent surgical ablation.

Results: Patients undergoing high-intensity focused ultrasound had a high rate of late postoperative percutaneous ablation (37.5%) after surgical intervention (P < .001 vs the other groups). At last follow-up, freedom from atrial fibrillation and need for ablation was as follows: classic maze procedure, 90%; high-intensity focused ultrasound, 43%; left atrial maze procedure, 79%; biatrial maze procedure, 79%; and pulmonary vein isolation, 69% (P < .001 between groups). For those with atrial fibrillation, mapping and ablation were performed in 23.6% (n = 27), and all patients with high-intensity focused ultrasound had failure of the box lesion around the pulmonary veins. Of those with just the left atrial maze procedure or pulmonary vein isolation, the right atrium was the source for failure in 75% (6/8).

Conclusions: Patients undergoing high-intensity focused ultrasound had a high need for postoperative ablation and low freedom from atrial fibrillation. The classic maze procedure had the best results. Left atrial ablation might allow failure from right atrial foci. Matching the technology and lesion set to the patient yields good results and can be applied in 95% of patients. We suggest others obtain late catheter ablation to correct remaining atrial fibrillation, and add to the paucity of late data regarding failure mode. (J Thorac Cardiovasc Surg 2010;139:860-7)
Abbreviations and Acronyms

AAD = antiarrhythmic drug
AF = atrial fibrillation
AFL = atrial flutter
AT = atrial tachycardia
AVR = aortic valve replacement
CAB = coronary artery bypass
EP = electrophysiology
HIFU = high-intensity focused ultrasound
LA = left atrial
MV = mitral valve
PVI = pulmonary vein isolation
RF = radiofrequency
STS = Society of Thoracic Surgeons
TV = tricuspid valve

1 or more failed attempts at catheter ablation, or are not candidates for catheter ablation.\(^7\) Although the document sought to come up with some standardized way of reporting success or freedom from AF, it is a complex subject, and a separate article from the STS also provided guidelines.\(^7\) From the literature, it appears that failures occur in approximately 20% of patients who undergo AF ablation with MV surgery.\(^7\) Risk factors for failure have been determined to be increased left atrial (LA) size, increased age, longer duration of AF, permanent AF, more limited ablation lesion sets, and others.\(^10\) Surgical ablation lines are largely applied based on the anatomy, whereas catheter techniques follow anatomic boundaries but are supplemented with direct mapping data to identify trigger points. In this report we hypothesize that there might be patterns of failure of the surgical ablation techniques. We suspect that failures might be related to incomplete transmural lines or incomplete lesions sets (eg, right atrial origin following LA lesions). Therefore in this report we analyze the patterns of ablation failure and determine whether there are identifiable causes, such as incomplete lesion sets or unreliable technologies. If the patterns of failure can be identified, then potentially other interventions, such as additional lesion sets, new or different technologies, or a more vigorous effort to create full complete transmural lesions, might improve the results of AF ablation surgery.

MATERIALS AND METHODS

From April 1, 2004, until December 31, 2008, 430 patients with a preoperative history of AF presented for surgical intervention, and 94.9% (n = 408) underwent AF ablation either as stand-alone AF surgery (13.7%, n = 56) or concomitant to other cardiac operations (86.3%, n = 352). A single surgeon (PMM) was chosen for this report to standardize the approach to the lesion set. Patients were entered into an institutional review board–approved study (no. 1532-003, Cardiac Surgery Outcomes Registry and N-CORE-STU00008001). It allowed retrospective and prospective collection of preoperative and perioperative data, as well as early and late outcomes.

These patients have been prospectively followed since January 2006, when a dedicated AF clinical/research nurse was hired. The postoperative AF management protocol was standardized in collaboration with electrophysiologists. Patients were discharged on antiarrhythmic drugs (AADs) and anticoagulant medication if not contraindicated (eg, drug intolerance). For any patients with persistent atrial flutter (AFL) or AF past 1 month, cardioversion was recommended. Mobile cardiac outpatient telemetry (CardioNet, CardioNet, Conshohocken, Pa, or ACT Ambulatory Cardiac Telemetry, LifeWatch Corp, Rosemont, Ill) was recommended at 3 months, and if this was not available, attempts were made to have the patient wear an AF Express (LifeWatch Corp) monitor for 30 days or a Holter monitor at the cardiologist’s discretion. Patients with dual-chamber implanted defibrillators or pacemakers had mode-switch parameters activated to track atrial arrhythmias. Monitor results were also obtained from cardiac rehabilitation sessions. AADs were withdrawn at the discretion of the cardiologist and AF nurse if sinus rhythm was documented at 3 months. Patients with persistent AFL, AF, or atrial tachycardia (AT) were offered referral to electrophysiology (EP) for catheter ablation. Monitoring with mobile cardiac outpatient telemetry or 30-day event monitors were performed again at 6 months, and anticoagulation was discontinued for patients maintaining sinus rhythm off AADs at the discretion of the cardiologist. Patients and the referring cardiologists were given copies of these guidelines, and telephone follow-up was made with patients within the first month and again at 3, 6, and 12 months to track progress. Patients participating in the Cardiac Surgery Outcomes Registry were sent surveys at 3, 5, and 12 months and annually. Copies of medical records were obtained for any procedures or hospitalizations to verify self-reported events.

Of the group who underwent concomitant surgical intervention (Tables 1 and 2), the operations primarily consisted of MV surgery (65.4%, n = 267) but were diverse, including tricuspid valve (TV) surgery, AVR, and CAB. Eighty-seven (21.3%) patients were undergoing reoperations. Of those with a history of AF, 94.9% underwent ablation at the time of the operation. The reasons not to add AF ablation surgery were that the addition of AF surgery was thought to increase the risk of the operation or duration of the operation, with the perception that there would be little benefit to the patient. The classic “cut-and-sew” maze procedure (maze III) was performed for young patients with symptomatic AF, many of whom (44.1%, n = 30) had undergone failed percutaneous catheter ablation. This also was applied in some patients with severe LA dilatation in whom the cut-and-sew technique allowed atrial reduction, which reports indicate improves the effectiveness of the procedure.\(^13\) Another group of patients were undergoing MV surgery, and in this group an LA maze procedure was performed, consisting of a box lesion of all 4 pulmonary veins and an MV annular lesion connected to the pulmonary vein isolation (PVI) lesion (LA isthmus lesion). Typically, this approach was used for patients with recent-onset or paroxysmal AF and for patients in whom there was no need to otherwise open the right atrium. A biatrial lesion set was chosen for patients with long-standing AF, patients with symptomatic AF, young patients, or those undergoing right-sided operations (typically TV repair). Also, there was much more use of the biatrial procedure after publication of a meta-analysis indicating better results with biatrial rather than just LA lesions (Figure 1).\(^14\) Finally, after favorable reports from Europe, ablating with high-intensity focused ultrasound (HIFU; St Jude Medical, Inc, St Paul, Minn) was used for a limited period of time for patients undergoing stand-alone procedures using an off-pump minimally invasive procedure through a lower sternotomy that included staple closure of the LA appendage (n = 16).\(^15\) In addition, HIFU was used with concomitant surgical intervention in 8 patients, including 3 undergoing CAB and 5 undergoing MV procedures. The HIFU lesion set consisted of pulmonary vein box lesions and also application of the epicardial “wand” to create a lesion to the MV annulus (n = 20), and additional right atrial lesions were made.
from the inferior vena cava to the tricuspid annulus with the same epicardial wand (n = 15). Conduction block testing was not routinely performed in any of the groups. A variety of energy sources were used. For the majority of cases (268/408 [65.7%]), bipolar radiofrequency (RF; either Medtronic, Minneapolis, Minn, or AtriCure, Inc, West Chester, Ohio) clamps were used, and at least 2 applications of the clamp per lesion were applied. For most patients undergoing reoperative MV surgery (43/73 [58.9%]), HIFU (High-intensity focused ultrasound; ATR, atrial fibrillation. *, Homogeneous groups.

<table>
<thead>
<tr>
<th>No. of patients</th>
<th>HIFU</th>
<th>PVI</th>
<th>Left-sided maze</th>
<th>Biatrial maze</th>
<th>Total</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Classic maze procedure</td>
<td>68 (16.7)</td>
<td>24 (5.9)</td>
<td>50 (12.3)</td>
<td>175 (42.9)</td>
<td>91 (22.3)</td>
<td>408</td>
</tr>
<tr>
<td>Sex (male)</td>
<td>38 (55.9)*</td>
<td>20 (83.3)†</td>
<td>41 (82.0)†</td>
<td>88 (50.3)*</td>
<td>42 (46.2)*</td>
<td>229 (56.1)</td>
</tr>
<tr>
<td>Age (y)</td>
<td>56.8 ± 10.7</td>
<td>61.8 ± 11.9</td>
<td>73.0 ± 10.7*</td>
<td>66.8 ± 12.1†</td>
<td>68.7 ± 10.3,* †</td>
<td>66.0 ± 12.2 &lt;.0001</td>
</tr>
<tr>
<td>Congestive heart failure</td>
<td>12 (17.7)*</td>
<td>4 (16.7)*</td>
<td>15 (30.0)* †</td>
<td>83 (47.4)†</td>
<td>34 (38.5)†</td>
<td>149 (36.5) .0001</td>
</tr>
<tr>
<td>NYHA class III and IV</td>
<td>12 (17.9)*</td>
<td>3 (12.5)*</td>
<td>16 (32.0)* †</td>
<td>71 (41.3)†</td>
<td>37 (41.1)†</td>
<td>139 (34.5) &lt;.001</td>
</tr>
<tr>
<td>NYHA class III and IV</td>
<td>8 (11.8)</td>
<td>3 (12.5)</td>
<td>6 (12.0)</td>
<td>18 (10.3)</td>
<td>10 (11.0)</td>
<td>45 (11.0) .2</td>
</tr>
<tr>
<td>Diabetes</td>
<td>1 (1.5)*</td>
<td>0 (0.0)* †</td>
<td>11 (22.0)†</td>
<td>22 (12.6)†</td>
<td>13 (12.3)†</td>
<td>47 (11.5) &lt;.001</td>
</tr>
<tr>
<td>Pulmonary hypertension</td>
<td>6 (8.8)</td>
<td>0 (0.0)</td>
<td>3 (6.0)</td>
<td>8 (4.6)</td>
<td>2 (2.2)</td>
<td>19 (4.7) .2</td>
</tr>
<tr>
<td>Left atrial size (cm)</td>
<td>21 (33.3)* †</td>
<td>4 (16.7)*</td>
<td>16 (42.5)†</td>
<td>102 (65.4)</td>
<td>42 (73.7)</td>
<td>186 (54.7) &lt;.0001</td>
</tr>
<tr>
<td>Ejection fraction (%)</td>
<td>51.4 ± 11.6*</td>
<td>50.9 ± 9.9*</td>
<td>57.6 ± 9.8*</td>
<td>53.0 ± 11.2,* †</td>
<td>52.7 ± 12.9,* †</td>
<td>53.1 ± 11.5 .04</td>
</tr>
<tr>
<td>Mitral regurgitation</td>
<td>4.4 ± 0.9*</td>
<td>4.2 ± 0.1*</td>
<td>4.1 ± 0.6*</td>
<td>4.7 ± 0.8†</td>
<td>4.8 ± 0.9</td>
<td>4.6 ± 0.9 &lt;.001</td>
</tr>
<tr>
<td>Aortic stenosis (moderate/severe)</td>
<td>5.7 (7.4)*</td>
<td>2.8 (3.3)* †</td>
<td>36 (72.0)</td>
<td>35 (20.0)</td>
<td>21 (31.3)</td>
<td>99 (24.3) &lt;.0001</td>
</tr>
<tr>
<td>Mitral insufficiency (≥3/4)</td>
<td>14 (20.5)</td>
<td>5 (20.8)</td>
<td>1 (2.0)</td>
<td>133 (76.0)</td>
<td>58 (63.7)</td>
<td>211 (51.7) .16</td>
</tr>
<tr>
<td>Mitral stenosis (moderate/severe)</td>
<td>13 (19.1)</td>
<td>6 (25.0)*</td>
<td>5 (10.0)* †</td>
<td>15 (8.6)</td>
<td>8 (8.8)</td>
<td>47 (11.5) .04</td>
</tr>
<tr>
<td>Type of AF</td>
<td>Persistent</td>
<td>1 (1.5)* †</td>
<td>2 (8.3)* †</td>
<td>2 (4.0) †</td>
<td>4 (2.3)* †</td>
<td>7 (7.7) †</td>
</tr>
<tr>
<td>Permanent</td>
<td>33 (49.3)* †</td>
<td>4 (16.7) †</td>
<td>12 (24.0)</td>
<td>54 (31.4)* †</td>
<td>50 (55.0) †</td>
<td>153 (37.9)</td>
</tr>
<tr>
<td>Paroxysmal</td>
<td>33 (49.3)* †</td>
<td>18 (75.0)</td>
<td>36 (72.0)</td>
<td>111 (64.5)* †</td>
<td>34 (37.4)</td>
<td>232 (57.4)</td>
</tr>
<tr>
<td>AF duration (y)</td>
<td>7.4 ± 7.1,*</td>
<td>8.0 ± 9.4*</td>
<td>4.0 ± 4.9</td>
<td>4.5 ± 6.4*</td>
<td>7.3 ± 8.2* †</td>
<td>5.7 ± 7.1 .001</td>
</tr>
</tbody>
</table>

Data are presented as counts, with percentages in parentheses. Continuous data are shown as means ± standard deviations. HIFU, High-intensity focused ultrasound; PVI, pulmonary vein isolation; NYHA, New York Heart Association; CVA, cerebrovascular accident; AF, atrial fibrillation. *†, Homogeneous groups.
TABLE 2. Intraoperative and perioperative characteristics

<table>
<thead>
<tr>
<th>Procedure Type</th>
<th>Classic maze procedure</th>
<th>HIFU</th>
<th>PVI</th>
<th>Left-sided maze procedure only</th>
<th>Biatrial maze procedure</th>
<th>Total</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of patients</td>
<td>68 (16.7)</td>
<td>24 (5.9)</td>
<td>50 (12.3)</td>
<td>175 (42.9)</td>
<td>91 (22.3)</td>
<td>408</td>
<td></td>
</tr>
<tr>
<td>CAB</td>
<td>2 (2.9)</td>
<td>5 (20.8)*</td>
<td>30 (60.0)</td>
<td>51 (29.1)*</td>
<td>24 (26.4)</td>
<td>112 (27.5)</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>MVR</td>
<td>22 (32.4)*</td>
<td>5 (20.8)*</td>
<td>2 (4.0)</td>
<td>162 (92.6)</td>
<td>76 (83.5)</td>
<td>267 (65.4)</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>AVR</td>
<td>3 (4.4)*</td>
<td>0 (0.0)*</td>
<td>42 (84.0)</td>
<td>42 (24.0)</td>
<td>25 (27.5)</td>
<td>112 (27.5)</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>TVA</td>
<td>12 (17.7)*</td>
<td>1 (4.2)*</td>
<td>3 (6.0)*</td>
<td>58 (33.3)</td>
<td>51 (56.0)</td>
<td>125 (30.6)</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Reoperation</td>
<td>7 (10.3)*</td>
<td>0 (0.0)*</td>
<td>4 (8.0)*</td>
<td>47 (26.9)</td>
<td>29 (31.9)</td>
<td>87 (21.3)</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Previous ablation</td>
<td>30 (44.1)</td>
<td>5 (20.8)</td>
<td>0 (0.00)</td>
<td>9 (5.2)</td>
<td>5 (5.6)</td>
<td>49 (12.1)</td>
<td>&lt;.0001</td>
</tr>
</tbody>
</table>

Complications

- Operative bleeding: 1 (1.5) | 0 (0.0) | 2 (4.0) | 7 (4.0) | 0 (0.0) | 10 (2.5) | >.2
- Deep sternal infection: 0 (0.0) | 0 (0.0) | 0 (0.0) | 1 (0.6) | 0 (0.0) | 1 (0.2) | >.2
- Permanent stroke: 1 (1.5) | 0 (0.0) | 0 (0.0) | 2 (1.1) | 2 (2.2) | 5 (1.2) | >.2
- Transient ischemic attack: 0 (0.0) | 0 (0.0) | 0 (0.0) | 1 (0.6) | 2 (2.2) | 3 (0.7) | >.2
- Coma: 0 (0.0) | 0 (0.0) | 0 (0.0) | 1 (0.6) | 0 (0.0) | 1 (0.2) | >.2
- Prolonged vent: 1 (1.5) | 0 (0.0) | 3 (6.0) | 18 (10.3) | 9 (9.9) | 31 (7.6) | .07
- Dialysis required: 0 (0.0) | 0 (0.0) | 1 (2.0) | 6 (3.4) | 2 (2.2) | 9 (2.2) | >.2
- Heart block: 4 (5.9) | 0 (0.0) | 1 (2.0) | 12 (6.9) | 11 (12.1) | 28 (6.9) | .15
- LOS (d): 5.0 (5.0–7.0) | 5.0 (4.0–7.0) | 6.0 (5.0–8.0) | 7.0 (5.0–9.0) | 7.0 (6.0–9.0) | 6.0 (5.0–8.0) | <.0001
- In-hospital mortality: 0 (0.0) | 0 (0.0) | 0 (0.0) | 4 (2.3) | 0 (0.0) | 5 (1.2) | >.2
- 30-D Mortality: 0 (0.0) | 0 (0.0) | 1 (2.0) | 4 (2.3) | 2 (2.2) | 7 (1.7) | .19
- Discharge rhythm: AF/AF: 4 (5.9) | 0 (0.0) | 17 (34.0) | 39 (22.3) | 27 (29.7) | 98 (24.0) | <.0001
- Rhythm follow-up (mo): 15 (4-13) | 22 (14-35) | 9 (4-16) | 13 (6-26) | 8 (4-13) | 12 (6-24) |
- No. of ablations/failure >90 d: 3/8 (37.5) | 9/14 (64.2) | 2/14 (14.3) | 6/53 (11.3) | 7/25 (28) | 27/114 (23.6) |

Data are presented as counts, with percentages in parentheses. Continuous data are shown as medians, with interquartile ranges in parentheses. Continuous variables were summarized as means ± standard deviations or medians and interquartile ranges. Length of stay was positively skewed, and therefore a natural logarithm transformation was applied to this variable before analyses. Categorical variables were analyzed by using χ² and Fisher’s exact tests for both omnibus and post hoc comparisons.

AF surgery with HIFU were younger and more symptomatic than the other groups. The group undergoing the LA and biatrial maze procedures were typically older patients who required valve surgery.

Patients’ characteristics were compared by using analysis of variance and Student–Newman–Keuls post hoc tests for continuous variables. Continuous variables were summarized as means ± standard deviations or medians and interquartile ranges. Length of stay was positively skewed, and therefore a natural logarithm transformation was applied to this variable before analyses. Categorical variables were analyzed by using χ² and Fisher’s exact tests for both omnibus and post hoc comparisons.

Time to first postsurgical catheter ablation for the different maze procedures was plotted by using Kaplan–Meier curves. The differences in survival times to first ablation were compared with the log-rank test. Recurrence of AF/AFL/AT among surgical groups was compared in 3 ways. First, the rhythm documented on the last follow-up outside of the 90-day blanking window after surgical intervention was used to indicate freedom from AF, AFL, or AT. Proportions of patients by AF surgery type were compared by using χ² tests. Second, we also estimated 1-year AF-free survival for patients with at least 1 rhythm available in the 8- to 15-month window after surgical intervention. Again, the last available rhythm was used to determine the success of AF surgery. Finally, catheter ablation was combined with AF, AFL or AT at the time of the last follow-up to define ablation failure. The χ² method was used to analyze this aggregate end point.

A 2-tailed significance level of 5% was used for all comparisons.

RESULTS

Thirty-day mortality was 1.7%, 0% for stand-alone AF surgery, and 0% for primary MV/maze procedure (n = 194). Follow-up was 95% complete, and median follow-up was 12 months, with an interquartile range of 5.5 to 24 months (Table 2). Perioperative complications included permanent stroke in 1.2%, transient ischemic attack or reversible ischemic neurologic deficit in 0.7%, placement of a new pacemaker in 6.9%, and reoperation for bleeding in 2.5%. No complications were related to AF ablation. Mean length of stay was 6.0 days and was shortest for the classic maze procedure and HIFU (P < .001 between groups, Table 2). Discharge rhythm was AF or AFL in 24% (n = 98) and was significantly lower for the classic maze procedure (5.9%, P < .001). At the most recent follow-up (beyond the 3- to 6-month weaning period), 16.1% of patients were taking AADs, and 43.6% were receiving warfarin anticoagulation.

At 12 months, freedom from AF was 85% (n = 177) overall. By using this method, there was no significant difference (P = .254) between groups, and success varied from 73% to 94% (Table 3). By most recent rhythm, it was 83.3% (n = 347) and varied (P = .016) from 72% to 95%. When ablations were added to the failure count, the overall AF-free rate was 78% and varied (P < .001) between 43% for HIFU and 0% for the classic maze procedure.

After the perioperative inflammatory effects were allowed to subside (3 months), catheter mapping and ablation were suggested for patients with recurrent AF or AFL if they had symptoms or other indications to seek return of sinus rhythm. Catheter ablation was performed in 23.6% of these patients and varied among groups, being highest for HIFU.
The majority of ablations (21/27 [77.8%]) were performed at Northwestern Memorial Hospital. Records were obtained for 3 of the 6 patients who had ablations performed elsewhere and were supplemented as necessary with further information from the EP analysis. Of the 24 patients who had HIFU ablation, 37.5% (n = 9) had ablation. Mapping disclosed that there was a failure of the encircling lesion in 100% of patients. Other sources for failure included macroreentry arrhythmias in the right atrium (n = 4). Among the 9 patients, 13 cardioversions were performed before ablation or between ablation attempts. One patient had 2 ablations. One patient had right AFL ablated, and LA arrhythmias were identified but not treated. Five of the patients achieved sinus rhythm after ablation, ablation failed in 2 patients, and the outcome is unknown for 2 patients.

Of those who had PVI, catheter ablation was performed in 4% (n = 2). In these patients no failure of PVI was identified. The location for arrhythmia was the cavotricuspid isthmus in both patients. One patient had a cavotricuspid isthmus lesion in both patients. The outcome of the second patient is unknown.

Of those who had the classic maze procedure, 4.4% (n = 3) had follow-up ablation. Among these patients, failure of right upper PVI (despite cut-and-sew lesions) was identified in 1 patient. Failure of the MV isthmus line was identified in 2 patients. Other arrhythmias were macroreentry within the right atrium. Among the 3 patients, a cardioversion was attempted before ablation in 2 patients. No patients had multiple ablations after the maze procedure, and all achieved sinus rhythm.

Of those who underwent the LA maze procedure, 3.4% (n = 6) had follow-up ablation. Failure of the PVI box lesion was identified in 1 patient (cryoablation in a reoperation). Other sources for failure included the MV isthmus lesion in 2 patients and right atrial focus in 5 patients. Among the 6 patients, 2 cardioversions were performed before the ablation attempt. No patients had more than 1 ablation, and 3 patients achieved sinus rhythm. Ablation failed in 2 patients, and the outcome of 1 patient is unknown.

Of those who had biatrial lesion sets, 7.7% (n = 7) had catheter ablation. Of these, 5 patients had failure of the box lesion; 2 patients had failure of the MV isthmus lesion. Two patients had failure of the right atrial lesion, and 1 patient had focal right AT. Among the 7 patients, 6 cardioversions were performed. Three patients had more than 1 ablation procedure; 6 patients achieved sinus rhythm, and ablation failed in 1 patient. Overall, of the 27 patients who had ablation, 18 (67%) achieved sinus rhythm.

\[ P < .001, \text{Figure 2}\]. The majority of ablations (21/27 [77.8%]) were performed at Northwestern Memorial Hospital. Records were obtained for 3 of the 6 patients who had ablations performed elsewhere and were supplemented as necessary with further information from the EP analysis.

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Of those who underwent the LA maze procedure, 3.4% (n = 6) had follow-up ablation. Failure of the PVI box lesion was identified in 1 patient (cryoablation in a reoperation). Other sources for failure included the MV isthmus lesion in 2 patients and right atrial focus in 5 patients. Among the 6 patients, 2 cardioversions were performed before the ablation attempt. No patients had more than 1 ablation, and 3 patients achieved sinus rhythm. Ablation failed in 2 patients, and the outcome of 1 patient is unknown.

Of those who had biatrial lesion sets, 7.7% (n = 7) had catheter ablation. Of these, 5 patients had failure of the box lesion; 2 patients had failure of the MV isthmus lesion. Two patients had failure of the right atrial lesion, and 1 patient had focal right AT. Among the 7 patients, 6 cardioversions were performed. Three patients had more than 1 ablation procedure; 6 patients achieved sinus rhythm, and ablation failed in 1 patient. Overall, of the 27 patients who had ablation, 18 (67%) achieved sinus rhythm.
DISCUSSION

The principal findings of this study confirm the general success of surgical treatments for AF with a low perioperative risk and 84% off AADs at the last follow-up, that there was a high failure rate using HIFU technology related to incomplete transmural encircling lesions, that LA lesions alone allow for AF failure from right atrial foci, and that the mitral isthmus lesion is another potential source of failure. Unlike some other surgical studies, this was a “real-world” study using various techniques and technologies adapted for a variety of concomitant or stand-alone operations. This series also benefited from a prospective, protocol-driven approach to patients after recruiting an AF nurse specialist starting in 2006.

Determining success is always problematic, but the classic maze procedure had a low rate of ablation in follow-up, and 95% were free from AF at last follow-up. This was usually performed for very symptomatic, relatively young patients (mean age, 57 years); 44% had prior ablation, and 49% had permanent AF. On the other hand, HIFU was also performed frequently for symptomatic AF (mean age, 62 years), and only 18% had permanent AF (75% had paroxysmal AF). Ablation after surgical intervention was required much more commonly (37.5%) in the HIFU group than for other surgical groups, and at the last follow-up, only 73% of patients undergoing HIFU were free of AF. Some studies have also shown better results with the classic maze procedure than with bipolar RF, although others have found similar results with the classic and maze IV bipolar RF-assisted surgery. Our freedom from AF rate for HIFU is a little lower than that seen in published reports, and to achieve that success required a high rate of postoperative ablation. Other HIFU series included patients undergoing MV surgery with a history of preoperative paroxysmal AF, a group who frequently return to sinus rhythm without any AF ablation. In contrast, our HIFU series included many symptomatic patients with AF seeking an off-pump, minimally invasive treatment. If these patients return to AF, they are likely to seek further ablation for AF. However, in the classic maze group, who were also very symptomatic, only 4.4% had postoperative ablation. We abandoned HIFU in 2005 based on the findings from mapping at the time of ablation.

EP mapping in the HIFU group was instructive in that the box lesion was incomplete or no ablation line could be identified in any patient. The cause for failure can only be speculated; whether it was from inadequate device contact with the left atrium, device malfunction, bubbles in the stream of saline that would disperse the ultrasound wave, or some other issue is unknown. However, the anatomic pattern of failure was very consistent in all patients undergoing HIFU who underwent mapping and was much different from that of any other AF ablation lesion set group or technology.

Not surprisingly, if LA ablation only is performed, then there is a risk for failure because of right atrial sources. Excluding the patients undergoing HIFU discussed above and excluding patients undergoing the biaatrial and classic maze procedures (who have right atrial ablation lesions), there were right-sided foci in 6 of the 8 mapped patients with just LA lesions or PVI. There were other foci in the LA group as well (mitral isthmus in 2 and cryoablation failure of the box lesion in 1 reoperation). Although this shows a high rate of right atrial lesions at mapping, this comprises only 8 of the 225 patients who had PVI or the LA maze procedure, and freedom from AF at last follow-up was consistent with most literature reports (81% for the left-sided maze procedure and 72% for PVI). Nevertheless, to increase effectiveness, it would make sense that more right-sided lesions will improve effectiveness, and this appears to be the case, with 95% and 87% free from AF at last follow-up for classic maze and biaatrial lesions. This has also been reported by a meta-analysis showing 87.1% to 92.0% effectiveness for biaatrial lesions versus 73.4% to 86.1% for just LA lesions. As a practical matter, however, a surgeon might not be willing to perform those lesions. For instance, in elderly patients (average age, 73 years in the PVI group and 67 years in the left-sided maze group) with fragile tissue, the right atriotomy might add some bleeding risk and add to the operative time. Especially for a patient with paroxysmal AF (72% in the PVI group and 65% in the left-sided maze procedure group), who might return to sinus rhythm anyway, it might not be worth that risk. Biaatrial lesions were chosen more commonly for those with permanent or persistent AF (63%).

In total, 334 patients had a mitral isthmus line placed (classic maze procedure, n = 68; left maze procedure, n = 175; biaatrial maze procedure, n = 91), and of these, mapping and ablation were performed in 16. Of these, failure of the mitral isthmus was identified in 6 (38%) patients. Also, 7 (44%) patients (5 in the biaatrial group done with bipolar RF, 1 undergoing cryoablation in the LA group, and 1 undergoing the classic maze procedure) had failure of the PVI or box lesion. This seems to be a good track record and might be explained by the predictability of the RF clamps. One patient undergoing the classic maze procedure had a reported failure of the PVI at the right upper pulmonary vein 9 months after the operation. Because this was an early failure after the cut-and-sew maze procedure, it cannot be explained by lack of transmurality or reinnervation across the suture line. We hypothesize that the left atriotomy in Waterston’s groove was made partially in the right upper pulmonary vein and might have left pulmonary vein tissue on the LA side that could serve as a trigger.

EP reports of findings after surgical treatment of AF included allegedly cut-and-sew maze procedures (there were no surgeon coauthors on this article), and the
operations were performed by a number of surgeons at various centers.\textsuperscript{21} Failure of the box lesion and incisional AFL were found more frequently in this series.\textsuperscript{22} Atypical electrocardiographic appearance of flutter after the maze procedure was common, making rhythm diagnosis difficult from surface recordings, as discussed in another article.\textsuperscript{22} EP mapping confirmed the mitral annulus and cavitricuspid isthmus as common sites of failure, and ablation successfully treated these rhythms.\textsuperscript{22} We suggest that others also try to obtain late catheter ablation to correct remaining AF and add to the paucity of late data regarding failure mode. Also, successful ablation was achieved in 67% of our patients.

This report is limited in that only those patients who returned for mapping provided information; most asymptomatic patients would not return for mapping. Also, the PVI group was older, and other mechanisms (eg, failure of the PVI lesions) might be underreported. Conceivably, patients with asymptomatic recurrences who did not seek ablation might have had different mechanisms, although there is no reason to suspect that. Although most of the group was followed prospectively, for 18 months before 2006, management of the patients was less directed, and follow-up was retrospective. This would not affect the EP findings, however.

In summary, late mapping and ablation found a high rate of failure with HIFU for patients with AF undergoing stand-alone operations. Isolated left-sided surgical procedures allow for right-sided sources of AF that might cause symptomatic failure. We now perform more biatrial procedures, especially if the right atrium needs to be opened anyway (eg, tricuspid surgery). Mitral isthmus failure and failure of PVI or the box lesion can occur, and care must be taken to create complete transmural lesions. Because of a low need for late ablation and the high success rate of the classic maze procedure, it is still the gold standard procedure for symptomatic patients.

References


Discussion

Dr Chuen-Neng Lee (Singapore, Singapore). Where does AF surgery fail? I think this is a complex and difficult subject, and Dr McCarthy should be complimented for providing information on this subject. This study has several problems. There is obvious inherent patient selection bias with significantly differing subsets, each of which have different mechanisms for AF. The study design is complicated, attempting to delineate 5 techniques (3 different surgical approaches), each with a modality of having inherent modes of failure, different ability to deliver transmural, inadequate design of the instrument, and varying ability to produce lesion sets.

The study is further complicated by having 4 ways to compare outcomes, and the study was switched halfway from a retrospective study to a prospective study. It is unclear what percentage of the patients actively returned for mapping in each category, although it seemed to be a very small minority. No mention was made of the results of cryoablation versus RF ablation.
The article did provide valuable information on the patterns of failure, but at the end of the day, the choice of AF techniques remained a maze procedure. I think further work will need to be focused on this mechanism.

I have just one question for Dr McCarthy. What are the statistical power and α numbers needed for such a study with varying subsets of patients? Did we achieve this with the 408 patients we have in this series?

Thank you.

Dr McCarthy. Thanks, Dr Lee. First, it is a complex study in that it reflects the reality of the complexity of the patients we face every day. For instance, a simple study would be to do a classic maze procedure on all comers, but of course, that is not realistic because you are not going to do that in an 82-year-old patient undergoing a redo double-valve operation. Another overly simple study would be to do PVI in all patients, but that would not reflect the needs of very symptomatic patients who failed catheter ablation and were referred for surgical intervention. Therefore this study reflects what cardiac surgeons see every day and how can they best treat these patients.

We did transition from a retrospective to a prospective study 16 months after the beginning of the study, but the AF nurses then went back and aggressively followed up with all the patients from before to put them into the protocol. Therefore they are not “lost,” as many patients are in a retrospective study.

The statistical question I did not totally understand about how many patients we would need in different groups. I was not clear about that question. Could you repeat that?

Dr Lee. To differentiate so many different modalities of treatment, do you have enough numbers to tell the difference statistically?

Dr McCarthy. No, we did not ask the statistician, for instance, how we would be able to do that in terms of determining how many patients in each group would need to be put into different groups to randomize that. We just asked him to analyze the patient group that we had actually studied.

Dr Niv Ad (Falls Church, Va). Pat, I enjoyed your presentation, and I think it is a very important one. Because you were one of the first adopters of HIFU, and obviously the technology failed, do you have any conclusions regarding the next technology coming to your hospital? Will it change anything in the way you assess technology and adopt it?

Dr McCarthy. Good question. We were disappointed with HIFU. I know they are still working on it to try to tweak it and make it better. I still, as discussed yesterday, am a big believer in bipolar RF and also cryoablation. Therefore the vast majority of patients had those technologies applied to create the lesion sets, as well as the cut-and-sew procedure. At this point, people have tried things like lasers, but I believe that company is out of business, and we have combined endocardial and epicardial approaches in the laboratory that perhaps would be available for truly minimally invasive procedures as sort of a hybrid approach, but all of that is still in the design phase. We are still waiting for the perfect technology that we will be able to use to do truly port-access, minimally invasive AF surgery.

Dr Jason Sperling (Ridgewood, NJ). Thanks, Dr McCarthy. Great talk. I have 2 questions. One is technical and relates to the failures in the LA isthmus. Specifically, I was interested to know what your technique was in the isthmus. Did you cut down onto the coronary sinus itself and cryoablate the coronary sinus, or was this just cryoablation over the region endocardially? The second question is related to the HIFU failures. To your recollection, is there any chance that all or a lot of those ablation line failures were in the dome of the left atrium given that the technique went through the transverse sinus as opposed to being directly on the dome? Perhaps that was a modality of failure?

Dr McCarthy. The technique to the MV annulus for the classic maze procedure was cut-and-sew to the MV annulus, but we also would apply cryoablation over it. For the others, we did not actually take a knife and open to the MV annulus but used cryoablation with a 5-mm Frigitronics probe, and in the last approximately 80 patients, we have been using 2 Frigitronics probes next to each other to create a very wide line after we found some failures of the MV annulus lesion.

The failures of HIFU varied. There were some in which there was no evidence at all that there had been a line created. In others where there was evidence of block, it appeared that the breakthrough was most commonly near the left upper pulmonary vein. Because the HIFU creates a round cinch but the atria is actually more oblong, we thought that perhaps it would not have been very good contact with the atrial wall in the round cinch, perhaps on the part farthest away from the surgeon, and you would not have been able to see that very well.

Dr Thorsten Hanke (Lübeck, Germany). In the HIFU group most of the patients seemed to have a fairly high grade of mitral regurgitation. Were those also the patients with an enlarged left atrium, so that maybe that is why they had a high failure rate? In the operating room did you check for conduction block? Maybe those patients could have been selected before.

Dr McCarthy. We go into the HIFU group to a greater extent in the manuscript. The majority of those patients actually underwent stand-alone procedures. Of the patients who did have MV surgery, they were typically myxomatous patients with a high grade of mitral regurgitation, and they did have a more dilated left atrium. However, most patients undergoing HIFU were actually patients undergoing stand-alone procedures with mild LA enlargement.

We did check for conduction block in the operating room in the patients undergoing HIFU from the right-sided pulmonary veins, but we were doing minimally invasive, very small incisions, lower sternotomy, and we could not get access to the left-sided pulmonary veins and check conduction block at that point.

Dr Sacha Salzberg (Zurich, Switzerland). Dr McCarthy, I saw that in your PVI group there were 28% of patients who had either persistent or permanent AF. Was that because these patients were too high risk to undergo a long procedure; is it a selection bias? Because in starting an AF program we often get comments that this 85-year-old man who needs an AVR and has persistent AF, well, let’s try and decrease the clamp time and get out as quickly as possible. I wonder whether you could comment on that.

Dr McCarthy. The PVI group had a relatively small number of patients, and PVI was used for patients who were older, undergoing operations in whom we were not otherwise opening the left atrium. Therefore that would typically be that older patient population with AVR or CAB. Occasionally, we would also use it in that group because they had only paroxysmal AF. Therefore there was selection bias. That was the technique we chose for that group.