Results of Maze Surgery for Lone Paroxysmal Atrial Fibrillation

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Background—If drug refractoriness to paroxysmal atrial fibrillation (PAF) occurs, arrhythmia surgery that involves channelling and the exclusion of specific atrial areas can abolish atrial fibrillation. The purpose of this study was to establish the effectiveness and safety of maze III surgery to abolish PAF.

Methods and Results—Surgery was performed in 41 selected patients who had long-standing, symptomatic, drug-refractory, lone PAF. At discharge, 35 patients (85%) were arrhythmia free, and 6 patients (15%) showed PAF and paroxysmal atrial tachycardia. Death or stroke did not occur during a mean follow-up of 31 ± 16 months. At the end of follow-up, 39 patients (95%) had no PAF; however, in 2 patients (5%), PAF persisted and eventually required His bundle ablation and pacing. Three months after surgery, nodal escape rhythm was observed in only 1 patient, whereas sick-sinus syndrome emerged late after surgery in 2 patients. Antiarrhythmic drugs were used in 20% of patients during follow-up. The quality of life improved markedly after surgery and remained unchanged afterward. Echocardiographic findings did not alter, but exercise capacity increased.

Conclusions—This pilot study demonstrates the effectiveness and safety of maze III surgery for lone PAF. In patients without sick-sinus syndrome, this intervention offers a sensible alternative to His bundle ablation and lifelong pacemaker dependency. (Circulation. 2000;101:1559-1567.)

Key Words: atrial fibrillation ■ surgery ■ arrhythmia

Antiarrhythmic drugs remain the first-line therapy for the prevention and rate control of paroxysmal atrial fibrillation (PAF). If drug refractoriness emerges, however, catheter His bundle ablation followed by cardiac pacing is often applied; this therapy shows satisfying results. However, pacemaker dependency and the requested continuation of drug therapy after His bundle ablation to maintain sinus rhythm are often disliked by patients. Arrhythmia surgery is an alternative, nonpharmacological therapy that avoids the drawbacks of catheter His bundle ablation.

Atrial fibrillation (AF) is caused by random reentry, and a critical number of circulating reentrant wavelets is necessary to perpetuate the arrhythmia, although sometimes rapidly firing atrial foci may be responsible for the onset of PAF. A reduction of the atrial mass and surface limits the number of wavelets. Therefore, AF cannot be initiated by atrial premature beats or it terminates easily. Surgical exclusion, fractionation, and channeling of atrial areas are tools to suppress AF resulting from random reentry and to preserve atrial contraction and filling and sinus node function. Various surgical concepts, including the corridor procedure, left atrial isolation, maze surgery, pulmonary button isolation, and the atrial compartment operation have been performed in selected patients. However, the long-term results of surgery for PAF in patients without structural cardiac disease are few because this surgery is usually done in conjunction with mitral valve surgery. This study reports our long-term experience with maze III surgery as a treatment for lone PAF.

Methods

Patient Selection

Patients younger than 70 years of age who were suffering from symptomatic, drug-refractory PAF were offered surgery as an alternative treatment. PAF was defined as AF with spontaneous termination, although electrical cardioversion was needed at least once in most cases. Drug refractoriness was defined as the failure of ≥4 different antiarrhythmic drugs or withdrawal from use of the drugs because of side effects. Sick-sinus syndrome, permanent (“accepted”) AF, focal atrial tachycardias, or serious ventricular arrhythmias ruled out surgery. Patients with PAF who also showed structural cardiac disease or who had suspected tachycardiomyopathy were also excluded. Verbal consent for surgery was obtained after oral information about the surgery was given to the patient.

Preoperative Studies

Preoperatively, the duration of PAF and the number of failed antiarrhythmic drugs were noted. Standard ECG, 2-channel Holter

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recordings, and bicycle stress testing with oxygen consumption were used to document PAF and to exclude sinus node disease and abnormal atrioventricular conduction. Two-dimensional and pulsed-wave Doppler echocardiographic studies were performed to measure cardiac chamber size and function and to exclude structural cardiac disease. Left and right heart catheterization and coronary angiography were performed to rule out cardiac abnormalities and to obtain information on the arterial supply of the sinus node area. Catheter mapping of AF for detecting a focal origin or classifying the arrhythmia was not done.

**Surgical Procedure**

The technique of maze surgery has been reported in detail previously and can be summarized as follows. Initial dissection consists of extensive mobilization of both caval veins and the roof of the left atrium. After bicaval cannulation, total cardiopulmonary bypass is instituted, and the heart is arrested. The right and left atrium are incised (Figure 1). After suturing all incisions, air is evacuated from the heart, and the patient is weaned from cardiopulmonary bypass. In addition to standard postoperative care, anticoagulant therapy with Coumadin is administered from the first postoperative day for up to 3 months after discharge. This is followed by treatment with aspirin.

**Postoperative Studies**

Pairs of temporary epicardial wires were attached to the left and right atrium and the right ventricle for the diagnosis of postoperative arrhythmias. Before discharge, we attempted to induce AF using programmed electrical stimulation.

**Follow-Up Studies**

All patients were followed in our outpatient department, initially at 3- to 6-month intervals, and then annually after the first year. Patients were asked in particular about palpitations and symptoms of cerebrovascular accidents; daily lifestyle and exercise capacity were also questioned. Holter recordings and bicycle stress tests were performed 6 months after discharge and annually thereafter to detect AF, sinus node dysfunction, and abnormal atrioventricular conduction. Echocardiographic studies were done simultaneously.

**Quality of Life**

Quality of life was assessed before surgery and at 3 and 12 months after surgery using a Dutch translation of the 36-item Short-Form Health Survey questionnaire. This tool was supplemented with a question about perceptions of changes in health and a self-designed questionnaire that assessed cardiac symptoms, sleep, cognitive functioning, mental health, and social functioning. Because the range of scores varied for all subscales, scores were normalized to a scale ranging from 0 to 100; lower scores represent a lower quality of life.

**Definitions**

The primary end point of maze surgery was permanent absence of AF. A second end point was preserved sinus node function. Chronotropic incompetence of the sinus node was defined as symptomatic sinus bradycardia at rest of <60 bpm, a requirement for pacemaker therapy, or an insufficient increase of sinus rate at stress testing, nototropic incompetence of the sinus node was defined as symptomatic.

**Statistical Analysis**

All values are expressed as mean±SD. Hypothesis testing was computed using paired tests. For proportions, the McNemar test was used; for normally distributed data, the paired t test was used; and for non-normally distributed data, the Wilcoxon test was applied. P<0.05 was considered significant.

**Results**

**Patients**

From June 1993 to July 1998, 41 patients with lone PAF underwent maze surgery. Table 1 shows the preoperative clinical

![Figure 1](image-url)
characteristics of this consecutive series. The common patient profile was a 50-year-old man who had PAF for 5 years.

In-Hospital Results
After surgery, neither major complications nor death occurred in any patient. One patient had an immediate recurrence of AF (Figure 2) and showed severe heart failure 1 week after surgery, which required high dosages of diuretics. Before discharge, programmed electrical stimulation was performed in 32 of the 41 patients (78%). AF could not be induced in 29 of these 32 patients (92%); during follow-up, 1 of these 29 patients temporarily showed PAF, and 1 patient showed paroxysmal atrial tachycardia (Figure 3). In 3 of the 32 stimulated patients (8%), AF could be induced: only 1 of these 3 patients suffered intractable PAF requiring His bundle ablation afterward; the other 2 patients remained arrhythmia-free. Postoperative stimulation was not done in 9 patients: 1 patient refused the test, AF was present in 3 patients, and a loss of atrial capture was present in 5 patients. At discharge (Figure 4), 35 of the 41 patients were free from PAF (85%); 4 of these 35 patients showed nodal escape rhythm due to incompetent sinus rhythm. Six of the 41 patients (15%) had PAF (Figure 2), flutter, or atrial tachycardia, which lasted from seconds to a maximum of 4 hours, with spontaneous conversion to normal sinus rhythm. A total of 37 of the 41 patients (90%) were discharged with no antiarrhythmic drug therapy.

Follow-Up Results
Rhythm
All patients were alive after a mean follow-up of 31 ± 16 months. Neither neurological nor cardiac complications were observed. Only 1 patient complained of incessant sinus tachycardia; this patient required β-blockers some months after surgery. The proportion of patients with sinus rhythm without atrial arrhythmias increased from 76% immediately after discharge to 92% at the 12-month follow-up; thereafter, this diminished to 85% (Figure 4). After resumed sinus rhythm, the number of patients with nodal escape rhythm without AF diminished to 2 asymptomatic patients at 3 months and to 1 patient after 3 months. Exercise testing of this patient 34 months after surgery initiated sinus tachycardia with a peak rate of 154 bpm (96%) at 89% of maximal exercise. In 2 other patients, infrequent asymptomatic sinus arrests of >4 s were recorded 26 and 27 months after surgery, respectively; 1 patient required atrial pacing. The number of patients with atrial arrhythmias diminished 3 months after surgery (Figure 4). Two patients with recurrent drug-refractory PAF postoperatively underwent His bundle ablation and pacemaker implantation 13 and 29 months after surgery, respectively (Figure 2). The percentage of patients who did not take antiarrhythmic drugs to prevent atrial arrhythmias remained stable (80%).

Figure 2. Electrocardiographic observations after maze surgery failure. This example of surgical failure demonstrates the recurrence of the original pattern of AF after a short interval of organized atrial arrhythmia. A, Preoperative 12-lead ECG showing AF. B, This ECG, recorded 3 days after surgery during the first bout of palpitations, did not show clear atrial deflections. Because of the random QRS intervals, AF with fast ventricular response seems present. C, Ten days after surgery, PAF recurred despite antiarrhythmic drugs. D, ECG again shows PAF that is similar to the preoperative pattern. E, Permanent AF after His bundle ablation. The 12-lead ECG depicts a ventricular escape rhythm with a rate of 60 bpm.
Figure 2. Continued

B  First recurrence of AF after MAZE - 22.06.93

C  10 Days after MAZE - 02.07.93
The mean values of echocardiographic parameters did not clearly change after surgery, except for right atrial volume (Table 2). The average preoperative left atrial volume was markedly larger in the 6 patients with PAF at discharge compared with that of the arrhythmia-free patients (62 ± 17...
and $49 \pm 11$ mL, respectively, [$P=0.03$], but other atrial measurements did not differ. Mitral and tricuspid valve damage was not detected after surgery. The mean left ventricular end-diastolic diameter remained unchanged.

**Exercise Tolerance**
No patient showed PAF during exercise testing after surgery. Exercise capacity, maximal workload, and peak oxygen consumption ($V_{\text{O}}_{2}$) significantly increased (Table 2) after surgery.

**Quality of Life**
This parameter was assessed in 18 of 41 patients (34%). It significantly improved 3 months after surgery and stabilized thereafter (Table 3).

**Discussion**
This prospective study demonstrated very satisfying immediate and midterm results of maze surgery for lone PAF. Twelve months after surgery, PAF was abolished in >90% of patients, and sinus node function remained undisturbed in 97%. In addition, quality of life and exercise tolerance significantly improved, whereas atrial echocardiographic measurements did not show deleterious effects of surgery.

**Atrial Arrhythmias After Surgery**
It has been reported that PAF, atrial tachycardia, and flutter frequently emerge soon after maze surgery and continue for some months because of atrial edema,
pericarditis, surgical trauma, and elevated levels of catecholamines, which inhibit the recovery of preoperatively abnormal atrial electrophysiological properties. Recovery from the surgical trauma takes 2 to 3 months, as evidenced by a spontaneous reduction of atrial arrhythmias, which was also observed in our study (Figure 4). Left atrial size seems more strongly associated with a cure of AF in patients undergoing maze surgery in conjunction with other cardiac surgery than other factors, such as age, sex, and duration of AF. The left atrial volume was markedly larger in our patients with early recurrent PAF than in those without postoperative arrhythmias. Finally, scarring from the atrial incisions can result in de novo atrial tachycardia (Figure 3), although unexcluded atrial foci should be considered as well.

**Sinus Node Function After Surgery**
In 4 of our 41 patients, a nodal escape rhythm was present at discharge; it persisted in only 1 patient. Temporary denervation or degeneration of sinus node cells due to

### TABLE 2. Results of Echocardiography and Exercise Testing After Surgery for Lone PAF

<table>
<thead>
<tr>
<th></th>
<th>Baseline (n=41)</th>
<th>12 Months (n=34)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Echocardiography</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left atrial contribution (E/A ratio), n (%)</td>
<td>23 (56)</td>
<td>22 (65)</td>
<td>0.86</td>
</tr>
<tr>
<td>Right atrial contribution, n (%)</td>
<td>20 (49)</td>
<td>26 (76)</td>
<td>0.75</td>
</tr>
<tr>
<td>Left atrial volume, mL</td>
<td>51±13 (29–80)</td>
<td>44±11 (26–73)</td>
<td>0.08</td>
</tr>
<tr>
<td>Right atrial volume, mL</td>
<td>42±13 (16–69)</td>
<td>38±11 (20–62)</td>
<td>0.04</td>
</tr>
<tr>
<td>Left atrial dimension, mm</td>
<td>39.6±4.2 (32–48.4)</td>
<td>37.3±4.6 (31–48.2)</td>
<td>0.14</td>
</tr>
<tr>
<td>Left ventricular end-diastolic diameter, mm</td>
<td>51±5</td>
<td>50±5</td>
<td>0.1</td>
</tr>
<tr>
<td>Mitral regurgitation, grade</td>
<td>0.3±0.5</td>
<td>0.27±0.5</td>
<td>0.8</td>
</tr>
<tr>
<td>Tricuspid regurgitation, grade</td>
<td>0.3±0.5</td>
<td>0.3±0.5</td>
<td>0.6</td>
</tr>
<tr>
<td>Exercise testing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximal work load, W</td>
<td>170±51 (100–260)</td>
<td>180±42 (120–260)</td>
<td>0.01</td>
</tr>
<tr>
<td>Maximal heart rate, bpm</td>
<td>146.5±33 (86–240)</td>
<td>141±18 (110–185)</td>
<td>0.43</td>
</tr>
<tr>
<td>Peak ( \dot{V}O_2 ) mL ( \cdot ) min ( ^{-1} ) ( \cdot ) kg ( ^{-1} )</td>
<td>20.9±6.9 (6–33.8)</td>
<td>24.1±5.7 (17.3–38)</td>
<td>0.05</td>
</tr>
<tr>
<td>Atrial fibrillation, n</td>
<td>10</td>
<td>0</td>
<td>0.001</td>
</tr>
</tbody>
</table>

Values are mean±SD (range), unless otherwise indicated. \( \dot{V}O_2 \) indicates oxygen consumption.

### TABLE 3. Quality of Life of Patients Operated on for Lone PAF (n=18)

<table>
<thead>
<tr>
<th></th>
<th>Preoperative</th>
<th>3-Month Follow-Up</th>
<th>12-Month Follow-Up</th>
<th>P*</th>
<th>P†</th>
</tr>
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<tbody>
<tr>
<td>SF-36</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>General health</td>
<td>54.44</td>
<td>74.14</td>
<td>70.00</td>
<td>0.002</td>
<td>0.308</td>
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<tr>
<td>Physical functioning</td>
<td>56.39</td>
<td>88.06</td>
<td>90.21</td>
<td>0.0055</td>
<td>0.296</td>
</tr>
<tr>
<td>Bodily pain</td>
<td>83.45</td>
<td>84.24</td>
<td>88.44</td>
<td>0.855</td>
<td>0.361</td>
</tr>
<tr>
<td>Mental health</td>
<td>63.33</td>
<td>74.44</td>
<td>77.56</td>
<td>0.005</td>
<td>0.371</td>
</tr>
<tr>
<td>Role functioning–physical</td>
<td>15.28</td>
<td>45.83</td>
<td>66.67</td>
<td>0.023</td>
<td>0.083</td>
</tr>
<tr>
<td>Role functioning–emotional</td>
<td>59.26</td>
<td>79.63</td>
<td>66.67</td>
<td>0.094</td>
<td>0.261</td>
</tr>
<tr>
<td>Social functioning</td>
<td>56.25</td>
<td>81.94</td>
<td>83.33</td>
<td>0.001</td>
<td>0.707</td>
</tr>
<tr>
<td>Vitality</td>
<td>40.83</td>
<td>68.89</td>
<td>70.00</td>
<td>&lt;0.0005</td>
<td>0.754</td>
</tr>
<tr>
<td>Change in health</td>
<td>23.61</td>
<td>91.67</td>
<td>91.67</td>
<td>&lt;0.0005</td>
<td>1.000</td>
</tr>
<tr>
<td>SDQ</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Physical functioning</td>
<td>50.12</td>
<td>82.17</td>
<td>81.33</td>
<td>&lt;0.0005</td>
<td>0.804</td>
</tr>
<tr>
<td>Mental health</td>
<td>66.67</td>
<td>75.00</td>
<td>69.44</td>
<td>0.138</td>
<td>0.298</td>
</tr>
<tr>
<td>Social functioning</td>
<td>40.97</td>
<td>65.44</td>
<td>72.22</td>
<td>0.006</td>
<td>0.299</td>
</tr>
<tr>
<td>Sleep</td>
<td>55.28</td>
<td>70.28</td>
<td>68.89</td>
<td>0.001</td>
<td>0.735</td>
</tr>
<tr>
<td>Cognitive functioning</td>
<td>56.85</td>
<td>72.78</td>
<td>76.85</td>
<td>0.007</td>
<td>0.385</td>
</tr>
</tbody>
</table>

Values are means. SF-36 indicates the 36-item Short Form Health Survey questionnaire, and SDQ, the self-designed questionnaire.

*P for preoperative vs 3-month follow-up values.
†P for 3-month vs 12-month follow-up values.
atrial surgery is the supposed mechanism of this dysfunction,24 although an impairment by PAF cannot be excluded.25 The surgical trauma sometimes also causes a temporary reduction of the circadian variations of autonomic nerve activity24,26 or incessant sinus node tachycardia24; only 1 of our 41 patients transiently experienced incessant sinus tachycardia. The heart rate response to exercise can be reduced soon after maze surgery, but it usually normalizes within 1 year.24,27 An unchanged average maximal heart rate at exercise 12 months after surgery was observed in our patients (Table 2). Although sick-sinus syndrome was ruled out before surgery, in 2 patients, longstanding sinus arrests emerged >2 years later. Our findings confirm the previously reported progression of atrial disease in AF as evidenced by sick-sinus syndrome.28,29

Atrial Function After Surgery
Preoperative left and right atrial contraction could only be observed in half of our patients (Table 2), probably because of PAF.30 Twelve months after surgery, the number of patients with atrial contraction had not clearly increased. This finding suggests that surgery is detrimental to atrial contraction due to the multiple atrial incisions and sutures and the subsequent scarring, particularly of the left atrium,31 because contraction of the right atrium was more frequently seen than contraction of the left atrium.31,32 A second reason for this difference could be a diminished synchronization between the left atrium and ventricle due to the surgically created prolonged route of conduction from the right to left atrium.31 Maze surgery did not markedly reduce mean atrial volumes and diameters (Table 2) or adversely affect mitral or tricuspid valve or ventricular function. Longitudinal studies of atrial function are needed to establish the risks of maze surgery on atrial contractility.31

Patient Improvement
In view of the large physical impact of surgery for PAF, long-term patient improvement is the crucial objective, but it was not an end point of this study. Although long-term arrhythmia monitoring was limited to regular Holter recordings and ECG at exercise, clinical experience shows that these patients with longstanding symptomatic PAF before surgery became very sensitive to palpitations. Interruption of their normal heart rhythm after surgery would be readily noticed, and they would ask for new examinations. The arrhythmia history of these patients can, therefore, provide reasonable insight into the long-term surgical result. At the end of follow-up, 95% of the patients had no PAF and 80% were drug-free; thus, it is not surprising that the quality of life, as documented in the patients who were operated on most recently (40%), dramatically improved after surgery and remained unchanged afterward. This was also true for the improvement in exercise tolerance.

Because atrial function and dimensions did not change (Table 2), one can conclude that suppression of atrial arrhythmias is the crucial contribution to patient improvement.

Comparison With Other Surgical Methods
A technical obstacle of corridor surgery was the sometimes irreducible conduction between the left atrium and corridor compartment through the muscle tissue of the coronary sinus, which resulted in postoperative recurrences of PAF.17,18 Sometimes, this technical failure is also observed when applying left atrial isolation.10,11 In maze surgery, the isolation of the coronary sinus is done more laterally to the coronary os, where the amount of accompanying muscular tissue to be destroyed diminishes strongly and where conduction is more easily interrupted. Our maze surgery results with lone PAF clearly surpass our previous results with corridor surgery in 36 comparable patients.18

At 3.5 years of follow-up in the patients who had corridor surgery, the actuarial freedom of atrial arrhythmia without drugs was 72±9%, actuarial freedom of sinus node dysfunction was 81±7%, and chronic pacing was needed in 16%.17,18 Comparisons with the outcomes of surgery for left atrial isolation,10,11 the atrial compartment procedure,15,16 and pulmonary button isolation14 in patients with lone PAF cannot be made because these interventions were mostly done in conjunction with mitral valve surgery. In the accumulated maze surgery series (n=178) of Cox et al,13,32 58% of patients had lone AF and 66% underwent arrhythmia surgery only. The authors reported a combined recurrence of atrial flutter and AF of 2% in the 118 patients who had maze III surgery; they also reported blunted sinus node chronotropy in 6% of patients, and iatrogenic sinus node injury was absent in the 82 patients without preoperative sick-sinus node disease.

Limitations
As discussed earlier, the true incidence of PAF recurrence could not be determined because Holter recordings were done at intervals; symptoms during follow-up were always a reason for further arrhythmia analysis. Event recorders can undoubtedly provide better information, but the devices must be activated by the patient and asymptomatic arrhythmia will escape recording. This study was designed to validate maze III surgery for PAF; therefore, these results cannot provide a recommendation for selection between focal catheter ablation, His bundle ablation, or surgery in patients with problematic PAF. A larger patient population with more variables (such as atrial size)33–35 and a longer follow-up time are needed to assess the contribution of this surgery to the suppression of AF and to prove its superiority over other methods.26 Finally, because PAF was only diagnosed by ECG, recommendations for surgery for specific types of PAF cannot be given.

Conclusions
Successful surgery for lone PAF involves abolishment of the arrhythmia, undisturbed sinus node function, no mortality, and a low morbidity risk. In addition, the intervention must be widely applicable, not cause a deterioration in hemodynamic parameters and, finally, diminish the thromboembolic risk of AF. The consequence is an improved quality of life after surgery. This pilot study showed that these goals can be achieved with maze III surgery provided that surgical experience with atrial arrhythmia is available and sick-sinus syndrome can be ruled out before surgery. Longitudinal evaluation of atrial contraction and filling and of sinus node function is needed to define the position
of maze surgery in the management of lone PAF. Finally, more information on the mechanism and pattern of PAF is needed to optimize the selection of surgery for drug-refractory PAF.

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References


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