New Invasive Approaches to Atrial Fibrillation
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ABSTRACT

PURPOSE: To review the 3 main options for invasive treatment of atrial fibrillation (AF): (1) atrioventricular node ablation with pacemaker insertion; (2) percutaneous AF ablation; and (3) surgical maze procedure.

Epidemiology: The prevalence of AF in the United States is more than 2 million and many of these patients remain symptomatic despite drug therapy. Hospitalizations involving AF have tripled since 1985 and the already high costs of AF-related complications such as stroke and heart failure are expected to increase as the population ages.

Review Summary: Invasive approaches to AF should be considered when drug therapy for rhythm and/or rate control has failed and the patient remains symptomatic. The underlying mechanisms of AF involve focal triggers of rapid depolarization, especially near the pulmonary veins, and alterations in the atrial myocardium that render the atrial substrate more likely to propagate the reentrant wavelets that spawn fibrillation. Ablation of the atrioventricular (AV) node with pacemaker implantation usually is the safest of the invasive approaches to AF but requires lifelong use of a pacemaker and many times leaves patients in AF (requiring continued anticoagulation) and out of AV synchrony. Percutaneous AF ablation carries more procedural risk but it offers a better rate of success in restoring sinus rhythm. Although minimally invasive versions of the maze procedure are being developed, most still involve open-heart surgery and therefore carry the highest procedural risks; however, the maze procedures also seem to provide the highest success rate and the best chance for definitive cure of AF. Patients need to make their own choices about the best invasive approach based on their own preferences, risk tolerance, and clinical situation.

Type of Available Evidence: Cohort studies, controlled trials—randomized and unrandomized, unstructured reviews, nationally recognized treatment guidelines.

Grade of Available Evidence: Fair to good.

Conclusion: Clinicians need to first assess whether an individual might benefit from invasive treatment of AF. If so, clinicians must then consider each AF patient individually to determine which invasive approach might make the most sense in relieving symptoms. Based on the patient’s choices, the clinician can assist with the appropriate referral to either an electrophysiologist or a surgeon with the appropriate training and experience. (Adv Stud Med. 2006;6(6):275-284)
complications associated with chronic AF. Over the past decade, the number of catheter and surgical ablations performed to manage or even cure AF have risen dramatically. This article reviews these new invasive approaches to AF therapy that may be appropriate in select AF cases where medicines have failed and the patient remains symptomatic. Pharmacologic options for the treatment of AF were discussed in a related review in a recent issue of *Johns Hopkins Advanced Studies in Medicine*.

**Atrial Fibrillation in the United States: Common, Costly, and a Leading Cause of Stroke**

Atrial fibrillation is the most common sustained cardiac arrhythmia seen in clinical practice and the prevalence is increasing as the population ages. Statistics from various sources including the Framingham Study and national hospitalization data recently were assembled by the American Heart Association (AHA) and the Centers for Disease Control and Prevention (CDC) and provide a compelling picture of the epidemiology of AF. According to this AHA/CDC synopsis, AF currently affects more than 2 million Americans with the prevalence generally lower than 1% in those under 60 years of age but rising to more than 6% in those over 80 years of age (Figure 1). The close association of AF with age has led some researchers to project that the overall US prevalence of AF will increase to 3.3 million in 2020 and to 5.6 million in 2050.

This large and growing prevalence of AF is concerning because of the known association between AF and embolic stroke. According to the AHA/CDC review, AF is an independent risk factor for stroke, increasing the risk about 5-fold and being directly responsible for about 15% to 20% of all strokes (or about 75,000 strokes per year). Further, in those who have already suffered a stroke, the presence of AF is a risk factor for both stroke recurrence and stroke severity. Those with AF who are not treated with anticoagulants, for example, have a 2.4-fold increased risk for recurrent severe stroke.

Although AF usually is not life threatening, it can produce disturbing symptoms—such as shortness of breath, difficulty exercising, dizziness, and fainting—that are due to the irregularity and rapidity of ventricular contractions. Atrial fibrillation also is associated with heart failure and, as mentioned above, stroke. These hemodynamic and thromboembolic consequences result in significant mortality, morbidity, and cost. Framingham data, for example, indicate that the presence of AF is independently associated with a 50% to 90% increase in the risk of death. Atrial flutter together with AF account for 470,000 hospital discharges every year in the United States and they are underlying or contributing causes of death in 77,800 individuals. From 1985 through 1999, hospitalizations for AF as the first-listed diagnosis increased from 154,086 to 376,487; over this same period, admissions listing AF as any diagnosis nearly tripled from 787,750 to 2,283,673.

In short, AF is a costly and increasingly common diagnosis that deserves close attention from primary care physicians. As discussed here, many patients with AF who are appropriately anticoagulated but who continue to be bothered by symptoms despite drug therapy now may benefit from one of the new invasive techniques aimed at eliminating the symptoms of AF or actual restoration of sinus rhythm. In particular, young patients with AF tend to be more troubled by their symptoms and therefore less willing to endure a marginally effective rate control strategy similar to that tested in the landmark Atrial Fibrillation Follow-up Investigation of Rhythm Management (AFFIRM) trial where, it should be pointed out, most patients were older than 65 years of age and many antiarrhythmic regimens proved to be toxic or proarhythmic. The ultimate decision about AF therapy, of course, is the patient’s and must be based on that individual’s risk factors, symptoms, and preferences. The following information is intended to help clinicians guide their patients through the available options.
The Electrophysiologic Mechanism of Atrial Fibrillation: An Interplay of Trigger and Substrate

Speculation about the underlying mechanism of AF has evolved over the years but still consists of 2 main theories. The focal theory developed in the 1940s by Scherf and others states that AF is caused by single or multiple sources of rapidly firing atrial tissue—areas of rapid depolarization called foci—that lead to very rapid and chaotic atrial rhythms. This focal theory highlights the role of triggers and enhanced automaticity in initiating AF. These triggers occur primarily near the pulmonary vein, an area now known to be infiltrated with extensions of very excitable atrial tissue. The focal paradigm of AF provides the mechanistic basis for techniques aimed either at destroying or surrounding and blocking these rogue atrial signals (Figure 2A).

In the 1960s, Moe and others developed the reentrant wavelet theory, which said that in vulnerable atrial myocardial tissue a single wavefront of depolarization can be deflected or split into different tracks. These multiple wavefronts often then “chase their own tails” to instigate or perpetuate an arrhythmia. Apparently, these swirls of daughter wavelets leading to fibrillation can only be sustained in a myocardium with particular types of scarring or stretching. Electrophysiologists believe that such anatomic or structural features alter the conduction velocity and refractory times in different parts of the atria to create a vulnerable substrate for AF. Thus, this reentrant theory describes a situation in which atrial depolarizations from any source in susceptible substrate can become self-perpetuating (Figure 2B). In recent years, it has become apparent that such atrial storms require a mass of atrial tissue that is large enough to allow depolarized tissue time to recover between passing wavelets. Without this critical atrial mass, the tissue is unable to sustain the incoming reentrant wave and the fibrillation ends. This realization that critical mass was key to AF has led directly to procedures aimed at surgically isolating atrial tissue into electrically partitioned regions incapable of propagating coherent wavefronts (Figure 3).

In all likelihood, both trigger- and substrate-related mechanisms are at work to different degrees in different patients. Such a complement of theories in AF may explain, for example, how paroxysmal AF due to ectopic beats will, especially if untreated, eventually lead to a structural remodeling of the atrial myocardium, which, in turn, becomes increasingly prone to reentrant wavefronts at the least provocation from focal sources. Such a scenario certainly offers a mechanistic framework for understanding the clinical observation that “AF begets AF.” Similarly, in patients with valvular disease, coronary disease, or hypertension, the atria may be scarred or stretched in a manner that again makes it extremely vulnerable to even a slight trigger.

Whereas a normal heart might snap back into sinus rhythm soon after exposure to an extra atrial beat, or a premature atrial contraction (PAC), or a provocation in the electrophysiology laboratory—the vulnerable heart is much more likely to split and echo this extra beat and translate it into AF.

The electrophysiologists and surgeons who are now providing invasive approaches to AF are attuned to the possibility of both the trigger and substrate mechanisms at work in AF patients. The likely contribution of each mechanism to the current clinical disease will be weighed during patient evaluation and will inform the recommendation for a specific procedure.

Figure 2. The 2 Principal Electrophysiologic Mechanisms of Atrial Fibrillation

LA = left atrium; PV = pulmonary vein; ICV = inferior vena cava; SCV = superior vena cava; RA = right atrium.

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Figure 3. Wavelets Require a Critical Atrial Mass

Dividing the atria into smaller electrically isolated segments takes away this critical mass, prevents wavelet propagation, and eliminates atrial fibrillation (AF).
CATHETER AND SURGICAL TECHNIQUES FOR ATRIAL FIBRILLATION

Invasive approaches to AF should be considered when drug therapy has failed and patients are still symptomatic.1 An example of a patient who might be referred to the electrophysiologist or surgeon for AF is a 45- to 60-year-old man with paroxysmal AF of several years’ duration. He has failed to respond to propafenone, flecainide, sotalol, or dofetilide. Amiodarone caused unbearable tremors. His episodes of AF now occur every 2 weeks and last up to 12 hours. Despite adequate rate control, these disturbing and increasingly frequent episodes of AF cause fatigue and lightheadedness.

Although the details of the ideal candidate for invasive AF therapy may vary, the essential characteristics are (1) significant symptoms and (2) the failure of drugs to maintain sinus rhythm. A recent review of clinical studies confirms that only about half of patients taking antiarrhythmic agents are effectively maintained in long-term rhythm and about 10% to 30% withdraw due to adverse events.22 In addition, recent randomized trials studies indicate that many AF patients fall into the unfortunate category of being unable to regain sinus rhythm using conventional pharmacologic therapy and, further, of being unsatisfied with the default strategy of accepting the AF by managing the ventricular rate.16,23 Frequently, as in the example above, it is the younger patient who is more cognizant of the AF symptoms and more anxious for a cure. Fortuitously, it is also the younger patient who is more likely to be eligible for a procedure or surgery and, in terms of economic analysis, to produce the largest benefit in terms of quality life-years gained.

For such a patient, there are 3 main potential nonpharmacologic solutions for achieving the broad objectives of reduced symptoms, improved heart function, and lowered stroke risk. None of them is perfect. Each involves risks and limitations. These procedures are also evolving so rapidly that it is difficult to base decisions today on data gathered and published 5 years ago based on already-obsolete procedures. In fact, specific invasive procedures are currently given little attention in the latest treatment guidelines from the American College of Cardiology and AHA,1 although new guidelines will be published soon. This is why clinicians should try to maintain an up-to-date general understanding of each of these evolving techniques, including their likely outcomes and risks and the current thinking regarding which patients make the best candidates. Such an understanding will help in educating AF patients about their options beyond drug therapy and also about their best choice in terms of referral (ie, electrophysiologist or surgeon).

ATRIOVENTRICULAR NODE ABLATION WITH PACEMAKER IMPLANTATION

One of the most straightforward solutions for AF involves ablation of the connection between the atria and the ventricle—the atrioventricular (AV) node—with implantation of a permanent rate-responsive pacemaker.24 This 1- to 2-hour procedure usually is performed with a radiofrequency-equipped catheter in the electrophysiology laboratory. Because of the extreme responsiveness of modern pacemakers to the patient’s physiologic activity (eg, movement, breathing, O2 saturation) this solution has become more palatable to patients.

A number of studies have documented good results with AV node ablation and pacemaker insertion in patients with AF. Several small clinical trials (<70 patients) in the early 1990s indicated a long-term (up to 24 months) success rate including symptomatic improvement in 87% to 98% of patients.25-28 More recently, researchers at the Mayo Clinic evaluated the long-term survival rate in 350 drug-refractory AF patients who underwent ablation and found that survival was similar to the rate seen in the >200 AF controls managed on drug therapy; in those individuals without any underlying heart disease, the survival rate essentially matched that of a non-AF population.29 Several other recent studies have documented improvements in quality of life and left ventricular function following AV node ablation.30-32 A meta-analysis combining data from 21 studies showed that AV node ablation led to an improvement in a broad range of clinical outcomes and 1-year mortality rates comparable to those of medical therapy for AF.33
Against these potential benefits, the inherent disadvantages of complete AV node ablation also must be considered. Of course, the main implication of putting a patient into what is essentially complete AV block is the requirement for implantation of a pacemaker. Although the longer battery life (>10 years) of the newer pacemakers and, as mentioned above, the greater responsiveness of these devices to patient activity have lowered this acceptance barrier somewhat for many patients, the lifelong need for a pacemaker remains a significant drawback. In addition, the ablation procedure induces loss of AV synchrony and usually leaves the patient in chronic AF. Whereas ongoing AF is not a problem in most paced patients, it may be problematic in those with a reduced ejection fraction. Also, it typically implies a lifelong commitment of the patient to warfarin therapy in order to reduce the risk of stroke. On the positive side, in regards to drug therapy, those drugs taken specifically for rhythm or rate control often can be stopped in patients undergoing AV node ablation.

Finally, and perhaps most significantly, the perioperative complications of the AV node ablation and pacemaker implantation procedure itself also must be considered. The risk of sudden death has long been a paramount concern. In one series, sudden death was likely or possibly related to AV node ablation in 7 of 334 (2.1%) AF patients. However, most cardiologists now believe that this risk may result from the sudden drop in ventricular rate from pre- to postablation levels. Apparently, myocardial cells adapt to the sustained high heart rates of 95 or 100 beats per minute (bpm) that typically accompany AF. If this chronically high rate suddenly drops into the 60s or 70s, the heart tissue is compromised and the patient’s risk of sudden death due to Torsades de Pointes increases. To avoid this scenario, most electrophysiologists now set the pacemaker at 80 or 85 bpm for the first week and then reduce it gradually in subsequent weeks. With this approach, the risk of serious procedural complications such as bleeding, infection, stroke, and perforation/tamponade in this procedure is extremely low.

Three patient types who may be particularly good candidates for AV node ablation are: (1) those with tachycardia-bradycardia syndrome resulting from their AF (who will likely need a pacemaker eventually if they do not already have one); (2) those with an implantable cardioverter-defibrillator that is delivering inappropriate shocks for AF; and (3) older patients with symptoms mainly related to rapid rates in atrial fibrillation who do not want to take or cannot tolerate rate control medications. Interestingly, many older symptomatic patients now seem to be more open to the idea of pacemaker insertion based on their exposure to friends and colleagues who have already received a device for one reason or another. Again, the AV node ablation procedure is not suited to those patients with infrequent symptoms or to those in whom regaining AV synchrony is desirable.

**Percutaneous (Catheter-Based) Atrial Fibrillation Ablation**

Several catheter-based techniques are now employed to ablate or block triggers of AF. In most cases, these hot spots of electrical activity are located in the pulmonary veins. The goal may involve mapping and direct ablation of single or multiple foci using radiofrequency energy. More common today is the ablation of wider areas of the atrium to isolate potential ectopic beat sources. These procedures typically take about 3 to 5 hours, with the catheter being threaded into the right atrium and then passed through the intra-atrial septum into the left atrium where it can access and burn tissue near the entry point for the pulmonary veins. For example, the catheter can lay down a circular scar on the left atrium near the junction of a pulmonary vein (the ostia) in order to surround and isolate a cluster of presumed or mapped hot spots (Figure 4). In the same procedure, the electrophysiologist also may create larger circular or linear burns across the atria to block reentry wavelets. Thus, the catheter-based strategies are increasingly being used to deal both with the trigger and substrate attributes of AF pathophysiology. A variety of new catheter technologies and energy sources—including laser, cryoablation, and ultrasound—are now helping electrophysiologists develop even more variations on these so-called focal, segmental, and wide-area circumferential ablation approaches.

Results with catheter-based pulmonary vein ablation show a much better response in patients with paroxysmal AF than in those with persistent AF. In one 5-month study of 70 patients with AF (mean age 53 years), segmental isolation of the pulmonary veins produced freedom from AF recurrence in 70% of patients with paroxysmal AF and 22% of patients with persistent AF ($P < .001$). Overall, 83% of patients with paroxysmal AF had significant improvement in or complete freedom from AF symptoms over this same period. Isolating the pulmonary veins with ablation of wider areas of left atrial tissue can give even better results. In one study, 80 patients with paroxysmal AF were randomized to segmental isolation of the pulmonary veins or wide-area left atrial catheter ablation to encircle the pulmonary veins. At 6 months, 67% of the patients who underwent segmental isolation and 88% of the patients who underwent wide-area left atrial catheter ablation were free of symptomatic AF when not taking antiarrhythmic drug therapy ($P = .02$).

Overall, a wide range of success rates—from about
40% to over 90%—have been reported in other studies involving patients with paroxysmal AF, with the results varying with patient attributes, the number of foci on the pulmonary veins, the technique employed, and the length of the follow-up period. These studies also have indicated that many patients require repeat ablation and/or ongoing antiarrhythmic drug therapy to achieve freedom from AF.

How does catheter ablation compare with medical therapy for AF? In one of the largest long-term comparative (but nonrandomized) studies of nonpharmacologic AF therapy to date, 589 patients undergoing the catheter ablation procedure had significantly higher AF-free follow-up periods than 582 similar AF patients receiving medical therapy. In the ablation group, the percentages of patients free of recurrence were 84%, 79%, and 78% at 1, 2, and 3 years, respectively; in the drug therapy group, the rates were 61%, 47%, and 37% at the same time points ($P < .001$).

Another study comparing radiofrequency catheter ablation with antiarrhythmic drugs—this one randomized—showed that 22 (63%) of 35 patients on medical therapy had at least 1 recurrence of AF in the 1-year follow-up period compared with 4 (13%) of 32 in the ablation group ($P < .001$). Hospitalization rates were lower and quality of life higher in the ablation group. This small study is interesting as it suggests the potential of catheter ablation as a first-line AF therapy (ie, before symptomatic patients have tried antiarrhythmics) but larger and longer-term studies are needed to confirm the safety and efficacy of this approach.

Recent trials have shown impressive results even in patients with chronic AF. In one randomized trial, for example, 146 patients with chronic AF were assigned to receive amiodarone and undergo 2 cardioversions during the first 3 months alone (the control group) or in combination with circumferential pulmonary-vein ablation. Among the 77 patients assigned to ablation, the procedure was repeated in about a third of patients because of recurrent atrial fibrillation (26%) or atypical atrial flutter (6%). An intention-to-treat analysis showed that 74% of patients in the ablation group and 58% of those in the control group were free of recurrent atrial fibrillation or flutter without antiarrhythmic drug therapy at 1 year ($P = .05$). However, among the 69 patients in the control group, 53 (77%) had crossed over to undergo circumferential pulmonary vein ablation for recurrent atrial fibrillation by 1 year and only 3 (4%) were in sinus rhythm without antiarrhythmic-drug therapy or ablation. There were significant decreases in the left atrial diameter ($12 +/- 11\%$, $P < .001$) and the symptom severity score ($59 +/- 21\%$, $P < .001$) among patients who remained in sinus rhythm after circumferential pulmonary vein ablation. Except for atypical atrial flutter, there were no complications attributable to ablation. The authors concluded that sinus rhythm can be maintained long term in the majority of patients with chronic atrial fibrillation by means of circumferential pulmonary vein ablation independently of the effects of antiarrhythmic drug therapy, cardioversion, or both.

As just noted, one of the main potential complications associated with catheter-based ablation for AF is atrial flutter. This type of flutter, which occurs as a result of creation of a new reentry circuit around the scar, frequently requires a second procedure. In addition, each of the following serious complications occurs in about 1% of cases: stroke, cardiac perforation with tamponade, and pulmonary vein stenosis. Esophageal perforation with resulting sepsis is another rare but potentially serious complication of percutaneous ablation. The potential for

### Table 1. Rates of Major Complications With Percutaneous Ablation of Atrial Fibrillation

<table>
<thead>
<tr>
<th>Complication Type</th>
<th>No. of Patients</th>
<th>% of Patients</th>
</tr>
</thead>
<tbody>
<tr>
<td>For all types of procedures (N=8745 patients)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Periprocedural death</td>
<td>4</td>
<td>0.05</td>
</tr>
<tr>
<td>Tamponade</td>
<td>107</td>
<td>1.22</td>
</tr>
<tr>
<td>Sepsis, abscesses, or endocarditis</td>
<td>1</td>
<td>0.01</td>
</tr>
<tr>
<td>Pneumothorax</td>
<td>2</td>
<td>0.02</td>
</tr>
<tr>
<td>Hemorrhage</td>
<td>14</td>
<td>0.16</td>
</tr>
<tr>
<td>Permanent diaphragmatic paralysis</td>
<td>10</td>
<td>0.11</td>
</tr>
<tr>
<td>Femoral pseudoaneurysm</td>
<td>47</td>
<td>0.53</td>
</tr>
<tr>
<td>Arteriovenous fistulae</td>
<td>37</td>
<td>0.42</td>
</tr>
<tr>
<td>Valve damage</td>
<td>1</td>
<td>0.01</td>
</tr>
<tr>
<td>Aortic dissection</td>
<td>1</td>
<td>0.03</td>
</tr>
<tr>
<td>For procedures involving left atrial ablation (N=7154 patients)</td>
<td></td>
<td></td>
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<tr>
<td>Stroke</td>
<td>20</td>
<td>0.28</td>
</tr>
<tr>
<td>Transient ischemic attack</td>
<td>47</td>
<td>0.66</td>
</tr>
<tr>
<td>PV stenosis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. with &gt;50% stenosis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acute</td>
<td>23</td>
<td>0.32</td>
</tr>
<tr>
<td>Chronic</td>
<td>94</td>
<td>1.31</td>
</tr>
<tr>
<td>No. with closure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acute</td>
<td>2</td>
<td>0.03</td>
</tr>
<tr>
<td>Chronic</td>
<td>15</td>
<td>0.21</td>
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<tr>
<td>Patients with symptoms</td>
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<td></td>
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<tr>
<td>Acute</td>
<td>3</td>
<td>0.04</td>
</tr>
<tr>
<td>Chronic</td>
<td>41</td>
<td>0.57</td>
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<tr>
<td>Patients undergoing intervention</td>
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<tr>
<td>Percutaneous</td>
<td>51</td>
<td>0.71</td>
</tr>
<tr>
<td>Surgical</td>
<td>2</td>
<td>0.03</td>
</tr>
<tr>
<td>Grand total</td>
<td>524</td>
<td>5.9</td>
</tr>
</tbody>
</table>

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Surgical Maze Procedure

The surgical maze procedure was developed originally to create a linear electrical barrier to reentrant waves in the atria. It has evolved over the years to include incisions meant to isolate foci in the pulmonary veins. Thus, just as catheter ablation techniques have expanded from focal- to substrate-aimed mechanistic goals, the intent of the surgical maze procedures have shifted in the opposite direction: from prevention of wavelet propagation by reduction of critical mass to the blocking of focal sources of AF initiation.

The classic Cox Maze III procedure involves open-heart surgery with a removal of the 2 atrial appendages (which limits stroke risk) and isolation of the pulmonary vein panel. A series of further cut-and-sew lines (and/or scars created with radiofrequency energy) are added elsewhere, including along the superior and inferior vena cava. The exact technique and pattern of stitching will vary from patient to patient and from surgeon to surgeon, but the end result is an atrial surface encircled by many lines of stitches and/or lesions. The goal is a patchwork of compartmentalized atrial zones incapable of propagating reentry wavelets.

The success rate for this Cox Maze III procedure as originally reported was extremely high. Long-term maintenance of sinus rhythm was 97% to 99% at some centers. A review encompassing published results from a broader sampling of institutions reported an overall rate of 85% with the classic cut-and-sew procedure (N=1553) and 78% for AF surgeries involving alternative sources of energy (N=2279).

Despite this relatively high success rate, and notwithstanding the recent trend toward less invasive techniques, the Cox Maze III remains a demanding procedure with significant risks. It therefore is still reserved usually for patients who require a thoracotomy and external bypass pumping for another reason such as valve replacement or coronary artery bypass grafting. Even in those patients having the classic Cox Maze III without any other concomitant procedure (ie, “lone maze”), the rate of perioperative complication is high (Table 2). In the large review mentioned above, for example, bleeding due to the multiple incisions occurred in 4.9% of individuals having a Cox Maze procedure, sinus node dysfunction with need for pacing occurred in 5.8% of cases, and stroke was seen in 0.5% of patients. The 1-month mortality rates in the studies reviewed ranged from 0% to 7%.

To limit side effects and make the surgical approach potentially more appropriate for more AF patients, many centers are now offering a modified maze procedure. In this abbreviated procedure, 1 appendage is removed and a limited set of ablation lines are delivered only to the left side of the atrium—which is presumed to be the main source of AF triggers—and mainly around the pulmonary veins. The limited scope of this modified maze procedure has allowed many centers to perform this in a minimally invasive fashion via ports on each side of the chest. Energy sources now available for the modified maze include radiofrequency and cryoablation (most commonly) as well as microwave, ultrasound, and laser.
A recent review\(^{49}\) of small studies from institutions using a left-side partial maze approach shows success rates of approximately 70% or 80% (Table 3).\(^{50-58}\) These rates of sinus rhythm maintenance at 3 to 4 years are lower than those seen with the classic Cox Maze III. Yet, given that many patients in these surgery studies had persistent AF, these partial maze results likely reflect a greater intrinsic efficacy than attainable with catheter-based techniques. Thus, the surgical maze procedures are probably the most effective invasive therapy for AF available today. They have the highest success rates and they rarely require a repeat surgery. Again, the drawbacks are the need for open-heart surgery and at least 3 days of hospitalization and the related serious risks such as stroke and death.

The prime candidates for a surgical maze procedure are those who have failed antiarrhythmic drugs, who want a definitive cure for their AF, and who are undergoing another cardiac surgery. Because not all cardiac surgeons have experience with the maze techniques, helping patients identify an appropriate surgeon is vital.

**OTHER TECHNOLOGIES**

Several other noninvasive approaches to AF have been used in attempts to prevent AF. Some device companies, for example, have developed algorithms to suppress AF with atrial pacing. Others have experimented with the pacemaker approach by placing 2 leads in the atria (ie, “multisite atrial pacing”). Both of these techniques have proved to be only minimally effective. Results with atrial defibrillators have been similarly disappointing, which is not too surprising—except perhaps to the poor patients who receive the unexpected shock during an asymptomatic run of AF. Many patients with these devices ask that they be turned off. Finally, AV nodal modification has been tried as a less radical form of AV node ablation that avoids the need for a pacemaker. However, ablating just a portion of the AV node is extremely difficult and many patients having this modification procedure still end up requiring a pacemaker.

**CHOOSING THE RIGHT APPROACH FOR YOUR PATIENT**

In general, patients with AF should first be tried on drug therapy. If they continue to have symptomatic AF, one of the invasive approaches to AF outlined above can be considered. There are no large studies comparing these strategies directly. However, in general, AV node ablation with pacemaker implantation is preferred for older patients. Percutaneous (catheter-based) atrial fibrillation ablation and the surgical maze procedure are preferred for younger patients who are more likely to tolerate longer and more invasive approaches. Ultimately, choosing the best strategy for given patients involves talking to them about their willingness to undergo lengthy procedures and their willingness to assume the related risks.

**CONCLUSION**

Invasive approaches to AF can be considered when medicines fail and when the patient is still symptomatic. Although these approaches have not yet been definitively shown to reduce mortality, risk of stroke, or need for warfarin, they have been shown to reduce the symptoms from AF. Internists and cardiologists need to assess each AF patient individually to determine which invasive approach might make the most sense. To summarize:

- AV node ablation with pacemaker implantation is usually the safest route of the 3 main options discussed. However, it requires the lifelong use of the pacemaker and it also usually leaves the patient in AF and out of AV synchrony.
- Percutaneous ablation is a procedure with more significant risks (eg, stroke, perforation, death) but it is often successful at restoring sinus rhythm, especially in patients with paroxysmal AF. Many patients, however, may require a second procedure for lasting success.
- The surgical maze procedures still carry the highest procedural risks but they also seem to provide the highest success rates and the best chance for a definitive “cure” to AF.

As the pros and cons of these options for invasive AF therapy are explained, patients can make their own decision about the best fit based on their own preferences, risk tolerance, and clinical situation. Based on this

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**Table 3. Efficacy of Left-Sided Partial Maze Approach**

<table>
<thead>
<tr>
<th>Study</th>
<th>No. of Patients</th>
<th>Lesion Type</th>
<th>% Patients in Sinus Rhythm at Follow-up</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kondo 2003(^{50})</td>
<td>31</td>
<td>Cryoablation, radiofrequency (RF)</td>
<td>79%</td>
</tr>
<tr>
<td>Kress 2002(^{51})</td>
<td>23</td>
<td>RF</td>
<td>86%</td>
</tr>
<tr>
<td>Wellens 2002(^{52})</td>
<td>30</td>
<td>RF</td>
<td>65%</td>
</tr>
<tr>
<td>Guden 2002(^{53})</td>
<td>23</td>
<td>RF</td>
<td>81%</td>
</tr>
<tr>
<td>Benussi 2002(^{54})</td>
<td>132</td>
<td>Epicardial RF</td>
<td>77%</td>
</tr>
<tr>
<td>Deneke 2002(^{55})</td>
<td>21</td>
<td>RF</td>
<td>82%</td>
</tr>
<tr>
<td>Mohr 2002(^{56})</td>
<td>234</td>
<td>RF</td>
<td>81%</td>
</tr>
<tr>
<td>Knaut 2002(^{57})</td>
<td>105</td>
<td>Microwave</td>
<td>61%</td>
</tr>
<tr>
<td>Pasic 2001(^{58})</td>
<td>48</td>
<td>RF</td>
<td>92%</td>
</tr>
</tbody>
</table>

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patient-directed choice, the clinician can further assist the patient by a referral to either an electrophysiologist or surgeon with the appropriate training and experience.

Prior to undergoing peer review, this article was developed with the assistance of a staff medical writer. The author had final approval of the article and all its contents.

REFERENCES


