# Surgery for atrial fibrillation

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**Abstract** | The field of atrial fibrillation is evolving rapidly. Although a medical rhythm control strategy has not proven to be beneficial for survival, new interventional therapies have improved the rate of sinus restoration and thus have the potential to improve outcomes. In particular, the maze procedure can be performed safely and cures the majority of patients with atrial fibrillation. Over the last two decades, the introduction of new ablation technologies has made the procedure much easier to perform and it is now more widely applied to patients with atrial fibrillation undergoing cardiac surgery. Minimally invasive modifications of the maze using these technologies have offered an important step towards developing a stand-alone procedure for the cure of atrial fibrillation with potentially decreased morbidity. We review the magnitude of the problem, the history of past surgical treatments, current surgical options and the future direction of surgical therapy.

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## Introduction

Atrial fibrillation (AF) is a common problem around the world. In the US, 15% of people over the age of 70 years have AF.[1] Early estimates suggested that this translated into roughly 2.2 million Americans with the disease.[2] More recent estimates suggest that the number of people with AF currently exceeds 6 million and will rise to 10 million by 2030.[3] In Europe and parts of Asia, the incidence of AF is approximately 7% in patients over the age of 65.[4,5] Even at the lower end of estimates, the annual economic impact exceeds US$6.6 billion in the US alone.[6] More importantly, the presence of AF is associated with a twofold increase in mortality in the general population and is even higher in patients with congestive heart failure.[7,8]

Perhaps the most alarming feature of AF is its association with stroke. AF is the second leading cause of stroke in the US and is responsible for at least 75,000 to 88,000 strokes each year.[6,9–12] Strokes caused by AF tend to be more devastating, and AF accounts for up to 30% of all strokes in the elderly.[11,12] Stroke is the third leading cause of death in the US; therefore, AF is a measurable contributor to the nation's mortality. In developing countries with younger populations, the incidence of AF is lower than in the US but the use of anticoagulation is also lower and thus the incidence of stroke is substantially higher.[13] As the population of all societies continues to age, the magnitude of this problem will continue to increase worldwide.

Two strategies exist to treat AF: rhythm control and rate control. Although medical therapy has had limited success in sinus restoration, randomized, controlled trials of medical therapy have not demonstrated a survival advantage for either type of treatment strategy.[14] Catheter and surgical ablation techniques have evolved and seem to achieve higher rates of freedom from AF. Currently, all patients with a history of AF undergoing cardiac surgery should be considered for treatment of AF. For lone AF (that is, AF with no overt structural heart disease), the indications are not as clear. Generally, symptomatic patients with medically refractory AF should be considered for intervention. Catheter ablation is usually the first or second therapy considered. For patients in whom catheter ablation fails, or is likely to fail, surgery offers a chance for cure. Below, the rationale for surgery is described in a framework of historical procedures.

**Competing interests**
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**Key points**

- Medical rhythm control has not proven beneficial for survival
- New interventional therapies have improved the rate of sinus restoration
- The maze procedure offers a high chance of sinus restoration and may reduce stroke in patients with atrial fibrillation
- The maze procedure is currently the standard of care for patients with atrial fibrillation undergoing cardiac surgery
- New minimally invasive techniques are under investigation for lone atrial fibrillation

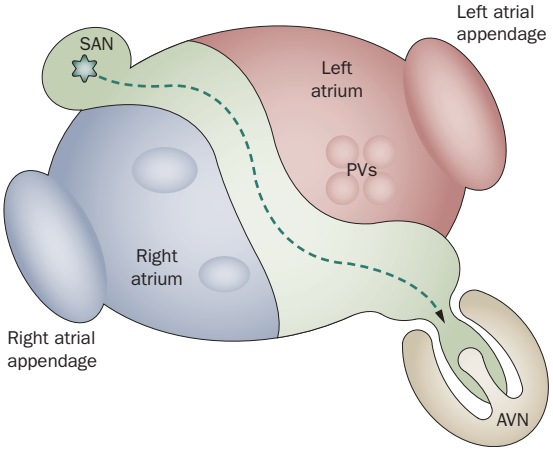


**Figure 1** | The 'corridor' procedure for AF. The corridor procedure was an early surgical procedure for rate control of atrial fibrillation. A pathway is created between two scars that directs the sinus impulse to the AVN in a small area that prohibits re-entry. However, the remainder of the right and left atria continue to fibrillate and, therefore, the thromboembolic risk is unaltered. Abbreviations: AF, atrial fibrillation; AVN, atrioventricular node; PVs, pulmonary veins; SAN, sinoatrial node.

## The first surgical treatments

Surgical treatment of patients with AF involves mechanical destruction of cardiac tissue to produce scar tissue and thus eliminate abnormal electrical conduction. Scar tissue, unlike cardiac tissue, does not conduct electrical impulses. A brief look at the evolution of this therapy helps to understand the present forms of treatment used today.

The earliest mechanical intervention for AF was atrioventricular (AV) nodal ablation with concomitant pacemaker insertion.[15] By destroying the AV node, the ventricle is no longer dependent on the atrium for rate and instead is controlled by the pacemaker. The limitation of this procedure is that it still leaves the atrium fibrillating, so it does not alter the risk of thromboembolic disease and requires anticoagulant therapy in addition to a permanent pacemaker. This therapy still has a limited role in the treatment of AF; however, its most notable contribution to current treatment of AF is the use of scar tissue to alter the conduction system.

The use of scar tissue was applied in a more meaningful fashion in the surgical treatment of Wolff-Parkinson-White (WPW) syndrome in 1976.[16] By making scar tissue that interrupted the accessory circuit, WPW syndrome was quickly cured. The scar interrupts the aberrant pathway so that it can no longer 'override' sinus rate. Eventually, this technique evolved into a catheter-based procedure, but its initial treatment required open-heart surgery. By 1986, an extension of this concept was used for the treatment of atrial flutter, a right-sided process with a single macroreentrant circuit.[17] However, AF is more heterogeneous and complex, as it is not reliant on a single pathway. Treatment of patients with AF, therefore, is more challenging.

In an effort to obtain rate control without the need for a pacemaker, Guiraudon introduced the 'corridor' procedure for AF.[18] By establishing a narrow pathway of scar tissue on either side of healthy cardiac tissue, a 'corridor' is created between the sinus node and AV node, allowing conduction of an electrical impulse from the sinus node to the AV node (Figure 1). The remainder of the atria still fibrillate but does not affect the atrial tissue within the corridor. Thus, rate control is established without the need for a permanent pacemaker.

In 1987, the concept of using scar tissue to direct the electrical impulse from the sinus node to the AV node was taken to a new level with the maze procedure,[19] which was developed by surgeon James Cox in collaboration with cardiologist John Boineau and physiologist Richard Schuessler. The maze procedure, also known as Cox-maze III or the 'cut-and-sew' technique, involves making multiple incisions in the atria to create a series of scars that eliminate every potential area of re-entry. The electrical impulse is forced through a maze of scar (hence the name) that directs the electrical impulse from the sinus node to the AV node (Figure 2). By fixing the refractory period between areas of scar, re-entry is eliminated.

Early results with the maze procedure were quite promising and boasted a sinus restoration of 89%,[20] but follow-up was based on unsophisticated methods such as routine electrocardiography or telephone questionnaires. A few centers joined the original group to apply the maze procedure in clinical practice, with similar results.[21–23] However, challenges such as postoperative pacemaker requirements in up to 40% of patients, fluid retention in more than 30% of patients because of a decrease in atrial natriuretic factor, and questionable atrial function led to frequent modifications of the procedure, including left-only mazes and alternate radial incision patterns.[20,21,24–29] Even with these modifications, the maze remained complex. Largely because of concerns of increased myocardial ischemic time and increased risk of bleeding, the maze was performed at only a handful of centers by a handful of surgeons worldwide.

## The development of new technology

An explosion of new technologies that could create scars without cutting the tissue brought renewed interest in the maze procedure. During the 1990s, various ablation

technologies that create transmural lesions were investigated, including unipolar radiofrequency ablation (dry and irrigated), bipolar radiofrequency ablation (dry and irrigated), suction-assisted irrigated unipolar radiofrequency ablation, cryothermia, laser, microwave, high-intensity-focused ultrasonography and more.[30,31] These technologies destroy tissue by either heating or cooling it, but leave the structure intact. Over time, the destroyed tissues turn into scar; therefore, the same maze pattern of scar can be created without actually cutting the tissue. However, the ability to create a transmural, full-thickness lesion varies, and thus the efficacy of the procedure varies according to efficacy of the technology. A partial thickness lesion leaves a gap of viable tissue—an area for conduction—and thus causes failure of the procedure.

A meta-analysis of 3,832 patients who underwent surgery for AF compared alternative technologies (radiofrequency, microwave or cryoablation) to the classic 'cut and sew' maze.[32] A higher rate of sinus restoration was reported for the classic maze (84.9%), compared with the 'alternative energy source' group (78.3%). However, a few inherent biases might have contributed to the difference. For example, there was a higher percentage of paroxysmal AF and a higher incidence of lone AF in the classic maze group. In addition, follow-up was inconsistent and not standardized. Nonetheless, a considerably high efficacy was reported when alternative energy sources were used to create the lesions.

Several studies have reported success rates with bipolar radiofrequency ablation and cryothermia comparable to the traditional 'cut and sew' technique.[33–38] Both types of energy sources can make full thickness lines of scar in seconds to minutes. Cryothermia simply freezes the tissue. Over time, the tissue dies and turns into scar, without ever creating a hole in the atrium. This usually requires an arrested heart and is perhaps most effective from the endocardial surface, as the warm blood of a beating heart acts as a 'heat sink' that makes it difficult to completely freeze the endocardial tissue from the epicardial surface of a full heart.

Bipolar radiofrequency ablation is performed by clamping the tissue and heating it between the two electrodes until irreversible protein denaturation occurs. Again, over time, the destroyed tissue dies and turns into scar, leaving the heart structurally intact. One advantage of bipolar radiofrequency is that the energy stays between the two poles and therefore cannot cause collateral damage to surrounding tissues. However, this energy is not optimal for the lesions around the valves, and other energy sources are used in these areas. To connect the box lesion of the maze to the mitral valve, an endocardial approach with a different energy source seems necessary.

Unipolar suction-assisted radiofrequency is a new technology that holds promise[39] but there is little clinical experience with this technique. As with previously used unipolar devices, the energy is in one direction and the tissue is heated. Suction is used to 'stick' the probe evenly to the surface of the atrium. This step was developed to improve on the results of unipolar radiofrequency ablation, in which the probe did not attach to the atrium and provided less reliable transmural lesions. Most unipolar devices in current use are irrigated in some fashion to allow for a more even distribution of the heat energy (that is, it provides a cooler surface that allows deeper penetration and avoids charring and energy block at the surface).

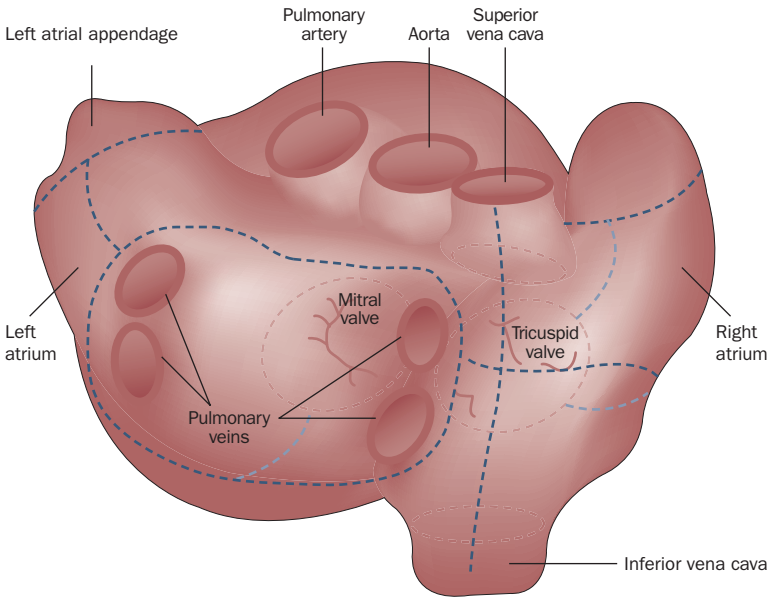


**Figure 2** | The surgical maze. The complete maze forms a series of scars on both the left and right atria, as depicted by dashed lines. The blue lines represent transmural scars. These scars create a fixed pathway from the SA node to the AV node. The pathway completely isolates the pulmonary veins, removes the left atrial appendage and fixes the refractory period over the rest of the atrium. The scars also connect to the mitral and tricuspid annuli. This electronically isolates most of the atrial fibrillation triggers and prevents any re-entrant circuit from occurring. Abbreviations: AV, atrioventricular; SA, sinoatrial.

With the creation of these new technologies (Figure 3) mastering the lesions of the traditional maze procedure became easier, and surgeons embraced it. They no longer had to sew together several pieces of atrial tissue, and the risk of bleeding between the suture lines was eliminated. In a review of the North American experience, approximately 40% of all patients undergoing cardiac surgery with a history of AF received a concomitant ablation procedure, resulting in more than 14,000 AF surgeries each year.[40] Most of these procedures used one of the new energy sources. Unfortunately, the type of energy, number of lesions and intensity of follow-up varies widely. However, the increase in the number of procedures has made it possible to study the maze in much more depth.

Six randomized, controlled studies have been performed that demonstrate the efficacy of the maze in patients undergoing mitral valve surgery (Table 1).[41–46] However, these studies have several limitations: the number of patients is small in each trial; the surgical techniques and technology vary within and between

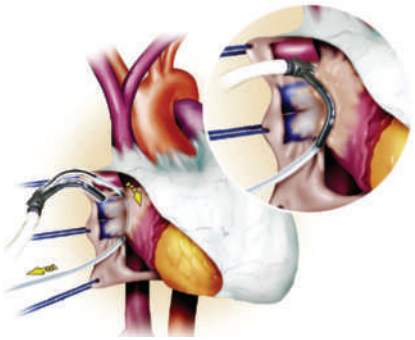

**Figure 3** | Bipolar radiofrequency ablation using Cardioblate® BP2 (Medtronic, Inc., Minneapolis, MN). The jaws of the Cardioblate® BP2 are placed around the right pulmonary veins using a superior-to-inferior approach. The guide is removed only if it blocks electrode-tissue contact. Otherwise ablation can commence. Permission obtained from S. Klein, Medtronic, Inc., Minneapolis, MN.

studies; and the follow-up is inconsistent, but notably better than historical follow-up, with most studies monitoring continuously for at least 24 h. Furthermore, the primary method of creating surgical lesions varies. However, these studies demonstrate a consistently higher sinus restoration after an AF procedure for each of the techniques when compared with mitral valve surgery alone. In addition, patients undergoing the maze are less likely to need antiarrhythmic medications (51% maze versus 90% non-maze) or anticoagulation with warfarin (10% maze versus 100% non-maze).[42,45] The incidence of postoperative pacemaker placement seems similar in both maze and non-maze patients, at about 3–7%.[46,47] On the basis of these studies and the results of large case series, the Heart Rhythm Society, European Heart Rhythm Society and European Cardiac Arrhythmia Society Expert Consensus supported the application of the maze procedure in patients undergoing cardiac surgery (Box 1).[48]

One challenge to defining outcomes after an AF procedure has been the liberal application of the term 'maze' to multiple variations of AF procedures. The traditional maze consists of lesions to both right and left sides. Some surgeons only perform a complete left-sided maze when not otherwise opening the right side of the heart. Others eliminate the right side and the lesion to the mitral annulus on the left side. In minimally invasive approaches, often only pulmonary vein isolation, either as a complete box or two separate islands, is typically performed. Depending on the technique and type of AF (paroxysmal, persistent, long-standing persistent), different results should be expected.[49,50] In general, the complete maze will yield the best results for all forms of AF; however, for paroxysmal AF, pulmonary vein isolation alone may be adequate. By liberally calling each of these distinct procedures a 'maze', scientific comparisons are impossible. The term 'maze' should be reserved only for the classic lesion pattern and the variations clearly described.

## Does maze surgery reduce stroke risk?

In the follow-up of Cox's original series of 306 patients, stroke rates were minimal. In total, 265 patients were followed for a mean of 3.7 years (3 months to 11.5 years). Of these patients, 58 had a prior thromboembolic event, placing them at higher subsequent risk. In addition, 45 patients received long-term anticoagulant therapy for mechanical mitral prosthesis; 220 patients did not receive long-term anticoagulation. Only one patient had a stroke in the long-term follow-up;[51] however, other studies have reported a higher incidence of stroke after the maze procedure. In a series of 332 patients with a median follow-up of 3 years, stroke or transient ischemic attack occurred in 34 patients (12%). In patients undergoing isolated maze procedures, the long-term rate of a neurological event was 1.3%, despite freedom from anticoagulant therapy in 88% of patients.[52] Both event rates are lower than would be predicted for this population. In one randomized study, there was a nonsignificant trend towards reduction of postoperative neurological events, but the sample size was underpowered, and follow-up for the randomized studies remains too short to assess the effect of the maze procedure on stroke reduction.[44]

Two mechanisms have been proposed to account for a reduction in thromboembolic events after the maze procedure: restoration of atrial contraction and removal of the left atrial appendage. Accurate determination of atrial function has remained somewhat elusive. However, using left atrial ejection fraction by magnetic resonance or Doppler echocardiography, as well as the ratio of peak late filling to early filling velocity, restoration of atrial function after the maze procedure seems to occur in most patients, but it does seem to be decreased when compared with normal controls.[26,27,53,54] Any contribution to stroke reduction remains speculative but extensive echocardiographic studies suggest that low velocity of flow in the left atrial appendage is an important risk factor for stroke, even in sinus rhythm.[55–57]

A growing body of indirect evidence suggests that the left atrial appendage might be the site of thrombus in as many as 90% of AF stroke patients without rheumatic disease.[58] Logically, removing the left atrial appendage should decrease the risk of stroke; however, this has not been proven. Safe removal of the left atrial appendage is possible with minimally invasive techniques and might decrease the risk of stroke in patients at high risk who cannot be anticoagulated.[59,60] In a retrospective study of 205 patients with mitral valve abnormalities, absence of left atrial appendage ligation was an independent risk factor for subsequent embolic events.[61] Current ACC/AHA/ESC guidelines recommend removal of the left atrial appendage in patients undergoing cardiac surgery who are at risk of AF.[62] However, the data are not clear. In a large study of 812 patients, only the restoration of sinus rhythm reduced subsequent stroke; ligation of the left atrial appendage had no effect.[63] In a series of 285 patients undergoing mitral valve replacement, a similar conclusion was drawn.[64] Part of the explanation for

**Table 1** | Randomized, controlled studies: maze versus non-maze

| Authors | *n* | Technique for lesion creation | Follow-up (months, mean) | Sinus rhythm without maze | Sinus rhythm with maze | *P* |
|---|---|---|---|---|---|---|
| Abreu Filho *et al.* (2005)[46] | 70 | Irrigated monopolar radiofrequency | 12 | 27% | 79% | 0.001 |
| De Lima *et al.* (2004)[45] | 60 | Cut and sew | 18 | 40% | 80–90% | 0.044 |
| Apkinar *et al.* (2003)[44] | 67 | Irrigated monopolar radiofrequency | 10 | 9.4% | 93.6% | 0.0001 |
| Khargi *et al.* (2001)[43] | 30 | Irrigated monopolar radiofrequency | 12 | 27% | 80% | 0.01 |
| Jessurun *et al.* (2003)[42] | 35 | Cut and sew | 12 | 20% | 92% | 0.00007 |
| Srivastava *et al.* (2008)[41] | 160 | Bipolar radiofrequency plus cryothermia | 42 | 20% | 58% | 0.001 |

the disparity arises from the manner in which the left atrial appendage is occluded. One of the most common techniques of occluding the left atrial appendage is by sewing it off from the inside. This internal ligation can be incomplete in 40–77% of procedures.[65–67] Because it produces a small orifice with flow, this technique might actually increase thrombus formation and subsequent stroke.[61,67,68] New devices and techniques to eliminate the left atrial appendage from both an epicardial and endocardial approach are under investigation.[69–71] Time will tell whether they will be effective in achieving complete exclusion. Although studies using catheter-placed atrial excluders are underway, no definitive conclusion about the left atrial appendage and its involvement in stroke risk can be drawn at the present time.

## New surgical approaches for lone AF

The growth of surgery for lone AF has not paralleled that for AF associated with other types of heart disease. The traditional sternotomy approach has not achieved widespread application, despite its efficacy. Instead catheter-based procedures are used more often for lone AF. In 2007, only 700 procedures for lone AF were reported for that year in the Society for Thoracic Surgeons database, with only 41 cut and sew mazes recorded.[72] There are two likely reasons for the limited application. First, no difference in survival has been demonstrated with medical attempts at sinus restoration.[14] It is difficult, therefore, to justify a substantially more invasive option with a potentially similar result. Second, sternotomy and cardiopulmonary bypass are still perceived as invasive techniques. Although patients are willing to accept them for coronary and valvular disease, they have been reluctant to embrace them for the treatment of AF. With the advent of new technology and more expertise in minimally invasive approaches, a host of combinations have been attempted. Although this topic is often the subject of presentations at national meetings, limited data exist.

Three main approaches have been attempted and reported: first, a beating heart right-sided thoracoscopic pulmonary vein isolation with multiple technologies; second, an arrested heart right-sided thoracotomy; and third, a beating heart bilateral thoracotomy with bipolar radiofrequency ablation.

### Right-sided thoracoscopic approach

A right-sided port approach with two or three ports has been described by several authors.[73–77] Initially, microwave technology, followed by laser and unipolar suction-assisted radiofrequency was used. This approach is promising and reports suggest short hospital admissions (1–4 days).[74,78] So far, however, significant published assessments are lacking and the only substantial reports available are for microwave technology. Early reports of 22 patients and 44 patients offered success rates of 80%.[74,79] However, only one study continued a thorough follow-up and published long-term results.[80] In the follow-up of 100 patients treated using a thoracoscopic approach with microwave technology, only 42% remained in sinus rhythm, with 30% requiring postoperative catheter-based interventions. The authors concluded that "long-term relief from atrial fibrillation had not been achieved".[80] New technologies such as laser and unipolar, suction-assisted, irrigated radiofrequency are being investigated, but no significant series have been reported at the present time. Future limitations with this approach potentially include the inability to remove the left atrial appendage.

### Right-sided thoracotomy

A full maze lesion set using a right thoracotomy and a beating heart on cardiopulmonary bypass has been performed clinically with cryothermia and reported in the laboratory with bipolar radiofrequency for lone AF.[81,82] However, most of the published experience comes from concomitant mitral valve surgery and cryothermia. In a series of 32 patients with lone AF, the success of sinus restoration 6 months after the procedure approached 90%.[35] If these results are sustained and the technology advances, this approach could have an important role in the treatment of lone AF.

**Box 1** | Indications for surgical ablation to treat AF

- Patients with symptomatic AF undergoing other cardiac surgery
- Selected patients with asymptomatic AF undergoing cardiac surgery in whom ablation can be performed with minimal risk
- Stand-alone surgery for AF should be considered for patients with symptomatic AF who prefer a surgical approach, have failed one or more attempts at catheter ablation, or are not candidates for catheter ablation

Abbreviation: AF, atrial fibrillation.

### Bilateral mini-thoracotomies

The most widely examined approach to lone AF has been video-assisted bilateral mini-thoracotomy or thoracoscopic pulmonary vein island creation and left atrial appendage excision, usually with ganglionic plexi evaluation and destruction. This technique has been described with dry and irrigated radiofrequency.[83,84] Early reports of 23 and 27 patients showed success of sinus restoration exceeding 90% after 3 months. As follow-up continued, this approach seemed durable, especially for paroxysmal AF.[85] In a series of 83 patients, sinus restoration was better for paroxysmal AF (82.1%) than for other types (55.6%).[86]

The largest series to date with this approach comes from a multicenter series of 100 patients with a mean follow-up of 13.6 months.[87] Sinus restoration was achieved in 87% of patients and no mortality occurred at any time point in this group. The length of stay was 5 days and the complication rate was 10%. These complications included 5% of patients needing pacemakers, 3% with hemothorax, 3% with phrenic nerve injury, 1% with transient ischemic attack and 1% with pulmonary embolism. Freedom from antiarrhythmic therapy was 62% and freedom from anticoagulant therapy was 65%. Bilateral mini-thoracotomy seems more useful for paroxysmal and persistent AF with success exceeding 90% in these groups. However, for long-standing persistent AF, the success rate was only 70%. Success will probably continue to fall in this group. Subsequently, other authors have moved to a completely thoracoscopic bilateral approach using bipoalar radiofrequency, with good initial results.[88,89] As technology evolves, newer approaches will certainly follow.

### Indications

At the present time, reasonable indications for these procedures include symptomatic patients with medically refractory AF in whom catheter ablation has failed or who are not candidates for a catheter-based approach (atrial septal defect devices, anticoagulation intolerance, prior stroke during ablation, etc). As with catheter ablation, the highest success rates should be expected in patients suffering from paroxysmal AF. With more data, this approach might prove to deserve an even larger role. Given its potential for stroke reduction by elimination of the left atrial appendage, it could become a reasonable first-line intervention.

## Future directions

The future directions for treatment of concomitant and lone AF are distinct, although some overlap exists. Patients with AF undergoing cardiac surgery should be treated. As our understanding of new techniques and technology grows, the 40% of patients receiving AF therapy should increase to approach 100%. Any estimate of stroke reduction or cost savings in this population alone is astonishing. As evidence and experience grow, surgery for AF should become the standard of care.

On the other hand, much closer monitoring will be mandatory for postoperative AF. The current guidelines of the Heart Rhythm Society may eventually expand to include implantable AF monitors in all patients. As nearly half of all AF episodes are asymptomatic, more intense monitoring will be necessary to make decisions on cessation of antiarrhythmic and anticoagulation therapies. The long-term consequences of these decisions also need close observation.

The future of surgery for lone AF will focus on two areas: better understanding of the mechanisms for AF, and developing techniques that are less invasive. In understanding the mechanisms of AF, more studies are now focusing on the autonomic ganglia. New hypotheses suggest that parasympathetic ganglia have a major role in initiation and maintenance of AF.[90] One clinical report suggests that triggers of AF reside outside the pulmonary veins in almost 50% of patients.[91] Studies in animal models indicate that autonomic ganglia modulate refractory periods and that stimulation of the autonomic ganglia can induce and maintain AF.[90] Ablating them might inhibit modulation and decrease the ability to induce AF.[92,93] As autonomic ganglia are located around the pulmonary veins, there is some speculation that these could be the true triggers. If findings from a canine model translate into clinical practice, then pure electrical isolation of the pulmonary veins without ablation of autonomic ganglia might not be effective.[94] However, an area of controversy is that the autonomic ganglia could potentially reconnect or regrow.[95] If true, this will limit the durability of therapies based on ablation of autonomic ganglia. However, as a minimally invasive surgical procedure, the role of autonomic ganglia and their destruction in AF remains an area of active investigation.[87,96–98]

Broader application of surgery will require techniques that are even less invasive and more successful. Future success will probably rely on a combination of available therapies—medical, catheter and surgical—because some of the maze lesions, in particular the lesion to the mitral annulus, are very difficult to create on a closed beating heart.

Although no publications have described a combined approach, two variations are under investigation. The first is a one-stage, single approach creating all the maze lesions at once, using simultaneous epicardial

and endocardial ablation on the beating heart (through a right-sided thoracoscopic approach to create a box lesion) with a transseptal percutaneous approach for the mitral lesions (M. La Meir, personal communication). At present, this technique uses suction-assisted unipolar radiofrequency. Removal of the left atrial appendage requires a left-side approach.

The other approach is a two-stage 'hybrid maze' developed at our institution. This technique combines minimally invasive surgery on a beating heart to create pulmonary vein islands and to remove the left atrial appendage. This step is followed by a delayed catheter-based approach to create the remaining lesions of the maze, if required. On the basis of published data on the beating heart approach, this strategy should avoid the risk of endocardial complications in most patients and removes the left atrial appendage in all.[87]

However, we must proceed with caution and all future results should be compared to those that can be achieved by the surgical maze. These techniques should be evaluated critically before broad application. Only patients in whom isolated catheter ablation is likely to succeed (that is, large atria, persistent AF, failed prior ablation, etc) should be considered. In addition the procedures should be performed only at institutions that will closely follow-up their patients with Heart Rhythm Society guidelines. This is often a cost-prohibitive undertaking, but a favorable risk-benefit profile must be established before widespread implementation.

## Conclusion

AF treatment continues to progress. Future work will better clarify the mechanism or mechanisms that underlie AF. As our understanding improves, we could tailor individual therapies to individual patients. Medical therapy will always have a role in the treatment of AF, but as technology continues to advance, so will the application of catheter and surgical techniques. In addition, the ability to accurately monitor patients in a standardized fashion will be crucial in comparing therapies.

The time has come for a large, randomized, controlled study that compares medical therapy, catheter ablation and surgical ablation with identical measures of success. The idea that these therapies exist in isolation is outdated. The goal should be to restore sinus rhythm and reduce stroke in a manner that decreases overall patient risk. Achieving this aim will inevitably require multimodality therapy in a number of patients. Treatment centers also need to evolve to better coordinate expertise among AF specialists. A team-based approach with a range of therapeutic options will provide optimal, individualized care for patients.

This is an exciting time for patients with AF. We are beginning to understand the significance of this disease and its impact on our society. We are also beginning to understand the mechanisms of AF and how it can initiate embolic stroke. Most importantly, we are developing ways to effectively treat it and prevent its complications. With the inevitable increase in the incidence of this disease, we as physicians have a tremendous opportunity to help a substantial number of patients over the next decade and beyond.

### Review criteria

Papers selected for this Review were identified on Medline using the search terms "atrial fibrillation", "cardiac surgery" and "maze". Until April 2009, 552 published articles contained both "atrial fibrillation" and "maze"; 541 contained "atrial fibrillation" and "cardiac surgery". All articles were reviewed and references were selected on the basis of historical contribution, number of patients and new contributions to the field. Biographies of reviewed articles were also searched for relevant manuscripts.


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