Surgical Approaches for Atrial Fibrillation

Adam E. Saltman, MD, PhD[a,*], A. Marc Gillinov, MD[b]

KEYWORDS

- Atrial fibrillation • Ablation • Left atrial appendage
- Mitral valve disease • Maze procedure

Although it long has been recognized that atrial fibrillation (AF) is common in patients presenting for mitral valve surgery and other forms of cardiac surgery, ablation of AF in such patients has recently become more popular. This change in surgical practice is attributable to new data clarifying the pathogenesis and dangers of untreated AF along with the development of new ablation technologies that facilitate ablation. For cardiac surgery patients presenting with AF, surgeons now offer a more complete operation that corrects the structural heart disease and the AF simultaneously. In addition, surgeons are rapidly developing easier and more sophisticated, minimally invasive, epicardial, beating-heart approaches for stand-alone AF ablation. The purposes of this review are to (1) review the rationale for surgical ablation of AF in cardiac surgery patients, (2) describe the classic maze procedure and its results, (3) detail new approaches to surgical ablation of AF, (4) emphasize the importance of management of the left atrial (LA) appendage, and (5) consider challenges and future directions in the ablation of AF in cardiac surgery patients.

RATIONALE FOR SURGICAL ABLATION

Atrial Fibrillation Prevalence

Because AF is particularly common in patients who have mitral valve dysfunction, most studies examining concomitant ablation—and surgical ablation in general—focus on this group. AF is present in up to 50% of patients undergoing mitral valve surgery and in 1% to 6% of patients presenting for coronary artery bypass grafting or aortic valve surgery.[1–4] As in the general population, the prevalence of AF in patients who have mitral valve disease increases with increasing patient age. In patients who have mitral valve dysfunction, AF is a marker of advanced cardiovascular disease and often is associated with the onset or exacerbation of heart failure.[5] Compared with patients who have mitral valve dysfunction who do not have AF, those who have AF have higher New York Heart Association functional class, more severe left ventricular dysfunction, and greater left atrial size.[4,6–9]

Risks of Atrial Fibrillation

AF is associated with increased mortality and morbidity in patients who have mitral valve dysfunction and coronary artery bypass graft. In patients who have degenerative mitral valve disease, AF is an independent risk factor for cardiac mortality and morbidity.[1–4] In patients undergoing mitral valve surgery, persistence of postoperative AF is a marker and a risk factor for increased mortality;[10,11] in addition, AF is associated with morbidity that includes stroke, other thromboembolism, and anticoagulant-related hemorrhage. In some patients, AF causes symptomatic tachycardia, reduced cardiac output, and tachycardia-induced cardiomyopathy. This is deleterious particularly in patients who have structural heart disease and reduced cardiac output. For these reasons, the presence of AF should be included in planning the operative strategy for cardiac surgery patients,

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[a] Cardiothoracic Surgery Research, Maimonides Medical Center, 4802 10th Avenue, Brooklyn, NY 11219, USA
[b] Atrial Fibrillation Center, Cleveland Clinic Foundation, 9500 Euclid Avenue, Cleveland, OH, USA
* Corresponding author. Division of Cardiothoracic Surgery, Maimonides Medical Center, 4802 10th Avenue, Brooklyn, NY 11219.
E-mail address: USAadamsaltman@mac.com (A.E. Saltman).

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noting that the risk associated with the added rhythm treatment is low.[12,13]

The onset of AF is a relative indication for mitral valve surgery in those who have known mitral valve dysfunction.[2] And once AF appears, it is uncommon for mitral valve surgery alone to restore sinus rhythm.[6–8] When AF has been present for 3 months or less, particularly if it is paroxysmal, lone mitral valve surgery may convert as many as 80% of patients,[6,7] but when the duration of preoperative AF exceeds 6 months, 70% to 80% of patients remain in AF if they do not undergo rhythm correction.[6,7] Therefore, ablation should be added to a mitral valve procedure in any patient who has had AF for more than 6 months or in whom AF is persistent or permanent. Such procedures, performed on this patient group, uniformly have enjoyed high success in restoring sinus rhythm and improving cardiac function.[14,15]

Atrial Fibrillation Mechanisms and the Implications for Surgical Ablation

The clinical presentation of AF varies widely among individuals. The current treatment guidelines account for this somewhat by classifying AF as paroxysmal, persistent, or permanent.[16] Even though the pathogenesis of all types remains incompletely understood, there is agreement that patients who have persistent and permanent AF most likely have a more complex pathophysiology. Unfortunately, among those who have coexistent mitral valve disease, permanent AF is the most common form.[17,18] It is, therefore, not surprising that there is little consensus concerning which ablation strategy to use at the time of surgery, so procedural details and techniques vary widely.

Endocardial electrophysiologic mapping has demonstrated that the pulmonary veins and posterior left atrium are critical anatomic sites in humans who have isolated AF.[19,20] Mapping studies performed during concomitant heart surgery also support the importance of the left atrium as the driving chamber in patients who have mitral valve disease.[21–26] Often, regular and repetitive rapid activation can be identified in the posterior left atrium in the regions of the pulmonary vein orifices and LA appendage;[21–25] however, some patients manifest dominant right atrial focal or re-entrant activation.[21]

These findings emphasize the need for an individualized approach to each patient. But until real-time, intraoperative mapping becomes routine,[26] a more-or-less constant, all-encompassing anatomic approach based on empiric results is reasonable. Over the past 5 to 10 years, this line of attack has become the foundation for catheter-based AF ablation; tracking down and destroying individual AF triggers has given way to the complete encirclement of the pulmonary veins and posterior left atrial wall.[27–31] A left atrial procedure that includes a box-like lesion around all four pulmonary veins and a lesion to the mitral annulus seems to eliminate AF in 70% to 90% of patients who have mitral valve regurgitation.[25,32–35] The addition of right atrial lesions in these patients likely confers some benefit with little additional risk.[36,37] Specific omission of a right atrial isthmus lesion, however, leaves some patients at risk for typical atrial flutter and others at risk for continued AF.[38] Therefore, because right-sided lesions can be created quickly and safely, AF ablation in cardiac surgery patients almost always should include a biatrial lesion set.

THE MAZE PROCEDURE

The Cox maze III operation, or maze procedure, is the gold standard for surgical treatment of AF. It is the most effective curative therapy for AF yet devised for any type of AF and for patients who have or who do not have concomitant cardiac disease.[39–41] In the maze procedure, multiple left and right atrial incisions and cryolesions are placed to isolate triggers and interrupt multiple re-entrant circuits (**Fig. 1**). The maze procedure includes en bloc isolation of the pulmonary veins and posterior left atrium along with excision of the LA appendage; these maneuvers are critical to the efficacy of the procedure in the restoration

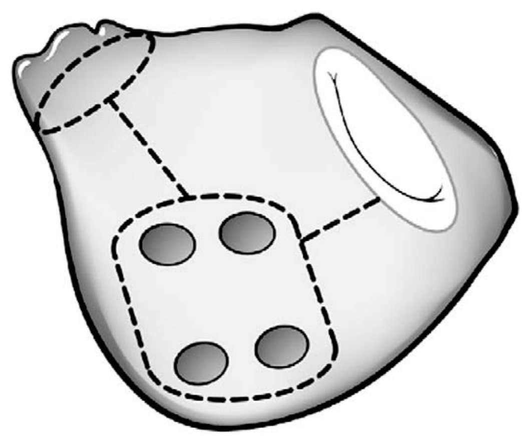

Fig. 1. Left atrial lesion set of the maze procedure. Small circles represent pulmonary vein orifices and white oval represents the mitral valve. Dashed lines represent surgical incisions. (*Reprinted from* The Cleveland Clinic Center for Medical Art & Photography © Copyright 2007. All rights reserved; with permission.)

of sinus rhythm and in the reduction of thromboembolic risk.

Although the maze procedure is a complex operation that adds cardiopulmonary bypass and cardiac arrest time, experienced surgeons have performed the classic operation in large numbers of patients having concomitant cardiac surgery.[1–3,6,41] The addition of a maze procedure does not increase operative mortality or morbidity;[42–44] however, it carries with it a 5% to 10% risk for implantation of a permanent pacemaker.[45] This happens most commonly in patients who have pre-existing sinus node dysfunction or in those undergoing multivalve surgery. Recent data demonstrate that the maze procedure has equivalent long-term efficacy at establishing sinus rhythm in patients undergoing lone operations and concomitant procedures; successful restoration of sinus rhythm has been achieved in 70% to 96% of patients.[42–44]

Early postoperative AF is common after a maze procedure, usually abating by 3 months.[42–44] This also is true of catheter-based procedures and should not be confused with a relapse of the presenting disease, although it may be a predictor of long-term outcomes.[46] Although the pathogenesis of failure over the long term is unclear, several risk factors have been identified: increasing left atrial diameter, longer duration of preoperative AF, and advanced patient age all increase the late prevalence of AF.[47–50] Thus, 5 years after a concomitant maze procedure, the predicted prevalence of AF is only 5% in patients who have mitral valve regurgitation who have a 4-cm left atrium; in contrast, the predicted prevalence is 15% in similar patients who have a 6-cm left atrium.[51] Others have identified similar risk factors for AF after the maze procedure, suggesting the possibility that earlier operation and left atrial size reduction in those who have left atrial enlargement (>6 cm) might improve results.[51–53]

The temporal pattern of AF (paroxysmal, persistent, or permanent) does not seem to have an impact on the results of the maze procedure.[44] Similarly, in patients who have mitral valve dysfunction, the cause does not influence results, and there is general agreement that the maze procedure is effective in patients who have rheumatic or degenerative disease.[54,55] Even in patients who have rheumatic disease, biatrial contraction usually is restored.[54]

Beyond restoring sinus rhythm, the maze procedure is associated with additional important clinical benefits in patients who have mitral valve disease. Recent data suggest that restoration of sinus rhythm improves survival in this group,[10] and the risks for stroke, other thromboembolism, and anticoagulant-related hemorrhage likewise are reduced.[10,11,56,57] The reduced risk for late stroke after a maze procedure deserves particular emphasis. In the largest series focusing on this outcome, Cox and colleagues[57] noted a single late stroke at a mean follow-up of 5 years in 300 patients who had a classic maze procedure. This remarkable late freedom from late stroke likely is attributable to restoration of sinus rhythm in the majority of patients and to excision of the LA appendage, an integral component of the maze procedure.

These results confirm the safety of the maze procedure, its efficacy at restoring sinus rhythm, and the resulting clinical benefits, most notably the virtual elimination of late strokes. Despite these excellent results, the maze procedure has been underused, and today it is almost obsolete. Most surgeons are reluctant to add a maze procedure to the operative course of patients who are having mitral valve surgery or other cardiac surgery. With recent advances in the understanding of the pathogenesis of AF and development of new ablation technologies, however, surgeons increasingly are likely to ablate AF using simpler techniques that require only a few minutes of operative time.

NEW APPROACHES TO SURGICAL ABLATION OF ATRIAL FIBRILLATION

Lesion Sets

Like recent approaches to catheter-based ablation, newer surgical techniques for AF ablation create lines of conduction block in the left atrium.[58–60] Because the left atrium is open during mitral valve procedures, precise creation of lesions is possible. A variety of lesion sets have been used to ablate AF in patients who have mitral valve disease. Most include pulmonary vein isolation, excision or exclusion of the LA appendage, and linear left atrial connecting lesions.[58–62] The pulmonary veins may be isolated with a box-like lesion, as in the maze procedure, or with separate right- and left-sided ovals around the pulmonary veins. With the advantage of direct vision, surgeons easily can create a lesion from the left pulmonary veins to the mitral annulus; this lesion improves results, particularly in patients who have permanent AF and mitral valve disease.[63] In patients who have left atrial enlargement (>6 cm), the authors recommend left atrial reduction, as this may increase restoration of sinus rhythm.

The issue concerning the creation of biatrial lesions (more closely mimicking the Cox maze III set) versus creating left atrial lesions alone remains contentious. It is easier and faster to create a more limited lesion set; yet recent data indicate that patients undergoing right and left atrial treatment have a better long-term result at maintaining sinus rhythm.[37] Through the judicious selection of a technology or multiple technologies, it is becoming possible to create right-sided lesions without opening the right atrium or prolonging cardiopulmonary bypass time or aortic cross-clamp time. In this manner, the largest number of patients can be treated in the most efficacious and safest fashion.

Surgical Ablation for Lone Atrial Fibrillation

When considering the number of patients presenting to operating rooms with AF in combination with coronary or valvular disease, even if all undergo concomitant ablation, it is unlikely that more than 40,000 patients would be treated annually. This is a small fraction of the total number of people suffering from this disease. A much larger patient population, therefore, could benefit from standalone AF ablation. It is difficult, however, to justify using cardiopulmonary bypass and cardioplegic arrest, especially through a sternotomy, to open the heart for the surgical treatment of lone AF: witness the relatively poor adoption of the maze procedure over the past 20 years despite its established safety and efficacy.

To bring an effective therapy to the largest number of patients, therefore, there has been recent activity directed toward developing an epicardial approach to ablation that can be performed on a beating heart, preferably through small access incisions or ports. Such an approach should be able to overcome the disadvantages associated with the traditional Cox maze operation (significant morbidity, lengthy operative time, and extended recuperation) and the endocardial, catheter-based techniques (indirect visualization, ablation within a flowing blood pool, and inability to manage the LA appendage).

The first report of such a minimally invasive, epicardial ablation performed on a beating heart appeared in 2003.[64] Since then, three main, less invasive surgical technologies have been developed and used for the ablation of lone AF: robotics,[65] thoracoscopics (endoscopy),[66–68] and minithoracotomies.[69,70] Each has its own advantages and disadvantages but all provide physicians with access to the entire atrial epicardium of a beating heart, whereupon lesions can be placed with precision and immediate visual feedback. Pulmonary vein isolation, for example, is easily accomplished in this manner, and LA appendage management is straightforward.

It is not possible to state conclusively which approach or which ablative technology used in a minimally invasive setting provides superior results. The numbers of patients treated are small and there are technologic hurdles to be overcome (mitral annular and tricuspid isthmus lesion creation, for example). Refinements in approach and technology are progressing rapidly and new tools and methods are becoming available.

A Review of the Available Energy Sources

The classic lesion creation method is cutting and sewing tissue. Once the healing process is complete, there remains a scar composed mostly of collagen and little cellular material. It is not electrically conductive and the lesion is, by definition, transmural. The goal of any energy source, therefore, is to create a similar scar by exposing tissue to extremes of temperature, inducing thermal injury, coagulation necrosis, and healing.

To produce such an irreversible injury, the tissue must be heated to 50°C or frozen to −60°C.[71,72] The quantity of tissue injured usually is directly proportional to the duration of time for which it is held at either temperature. The various energy sources differ mainly in the method by which they transfer energy to the tissue and how deeply that energy is conducted into the tissue. Heat-based energy sources include radiofrequency, laser, microwave, and high-intensity focused ultrasound. Cold-based sources include argon and nitrous oxide gases. As of 2008, all these devices are Food and Drug Administration–labeled for the ablation of soft tissues or cardiac tissue but not for treatment of AF. The specific treatment of AF is considered, therefore, off-label use.

Despite clearly different energy forms and application methods, when applied to the left-atrial endocardium of the arrested heart there seems to be little difference in safety or efficacy among the devices.[73] For example, surveying the use of the dry, unipolar radiofrequency probe (Cobra, ESTECH, San Ramon, California) in more than 1100 patients, Khargi and colleagues[73] found that it was effective at freeing patients from AF between 42% and 92% of the time. But there are several complications attributed to the use of the probe, the most worrisome being esophageal injuries, resulting in death 60% of the time.[74,75] Adverse events can occur with any technology when applied incorrectly,[76] but as more experience is gained and safer methods of ablation developed (eg, placing a cold, wet sponge between the posterior wall of the left atrium and the esophagus or shielding the probe in nonconducting sheaths), these injuries have become a rarity.

THE LEFT ATRIAL APPENDAGE

Between 60% and 90% of stroke-causing emboli in patients who have AF originate in the LA appendage,[77–79] giving it the moniker, "our most lethal human attachment."[80,81] Therefore, excision or exclusion of the LA appendage is a critical component of operations to treat AF; as discussed previously, this may explain in part the exceedingly low risk for stroke after the maze procedure. Ligation of the LA appendage in patients who have mitral valve regurgitation and who have AF reduces the late risk for thromboembolic events even if patients do not have intraoperative ablation.[73]

Surgical technique has an impact on results of LA appendage ligation, with incomplete ligation increasing the risk for thromboembolism.[82,83] Currently used techniques include exclusion by suture ligation or noncutting stapler and excision with suture closure or stapling.[83] The authors currently favor surgical excision of the appendage with standard cut-and-sew techniques as complete elimination with minimal cul-de-sac formation is most likely. Development of devices designed specifically for management of the LA appendage will facilitate this procedure. Published preclinical experience with several new LA appendage management devices is promising, and clinical trials are anticipated in the near future (**Figs. 2** and **3**).[84–87]

CHALLENGES AND FUTURE DIRECTIONS

One of the most significant obstacles facing the widespread adoption of surgical AF ablation is lack of data. Large, controlled studies describing well-defined patient populations, detailed techniques, and outcomes are missing from the literature. Electrophysiology colleagues are addressing this need and studies are underway. The advances necessary to improve AF ablation in cardiac surgery patients, therefore, must include (1) uniform definitions and methodology for reporting results, (2) improved technology to facilitate the ablation procedure and its intraoperative assessment, and (3) refinement of minimally invasive procedures.

Reporting Results

Standard terminology and methodology for reporting results has been absent from the cardiac surgery literature, and current reporting is haphazard and rightly subject to criticism.[88–90] Although there are guidelines for categorizing the clinical pattern of AF, these are applied inconsistently. Techniques for postablation rhythm assessment vary, with no generally accepted standard. Technologies for long-term and continuous rhythm monitoring are becoming available but they are costly and not yet convenient. Data obtained with such systems could be analyzed in uniform fashions to determine (1) absolute freedom from AF, (2) changes in the AF burden for individual patients, and (3) prevalence of AF in treated populations.[88–90]

Ablation Technology and Intraoperative Assessment

Current surgical ablation technology has several limitations. No single ablation device can create all of the maze lesions from the epicardial aspect.[91,92] When working from the endocardium, collateral tissue injury is possible. In addition, because real-time mapping is not yet available, the exact ablation procedure cannot yet be tailored to each patient's particular electrophysiologic

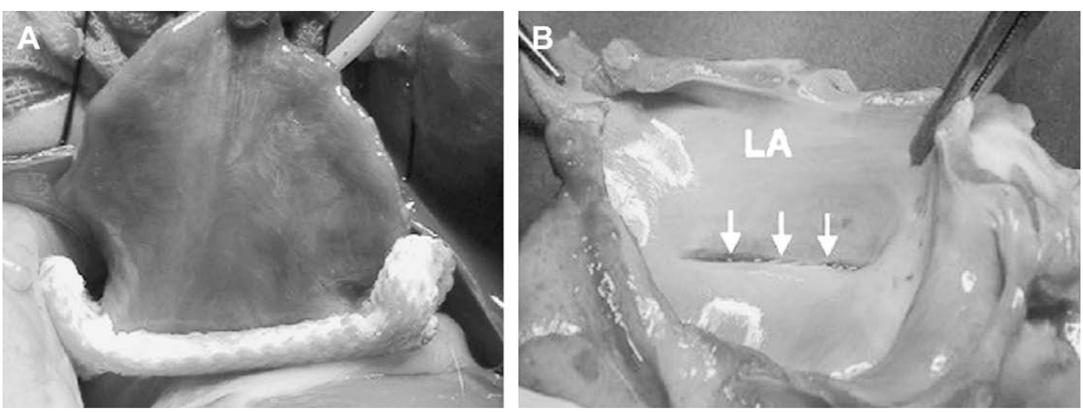

Fig. 2. LA appendage exclusion with a specially designed, cloth-covered clip. (*A*) Epicardial view of the clip placed on the canine LA appendage. (*B*) Endocardial view of the excluded appendage orifice 90 days after clip application. Arrows indicate residual LA appendage ostium.

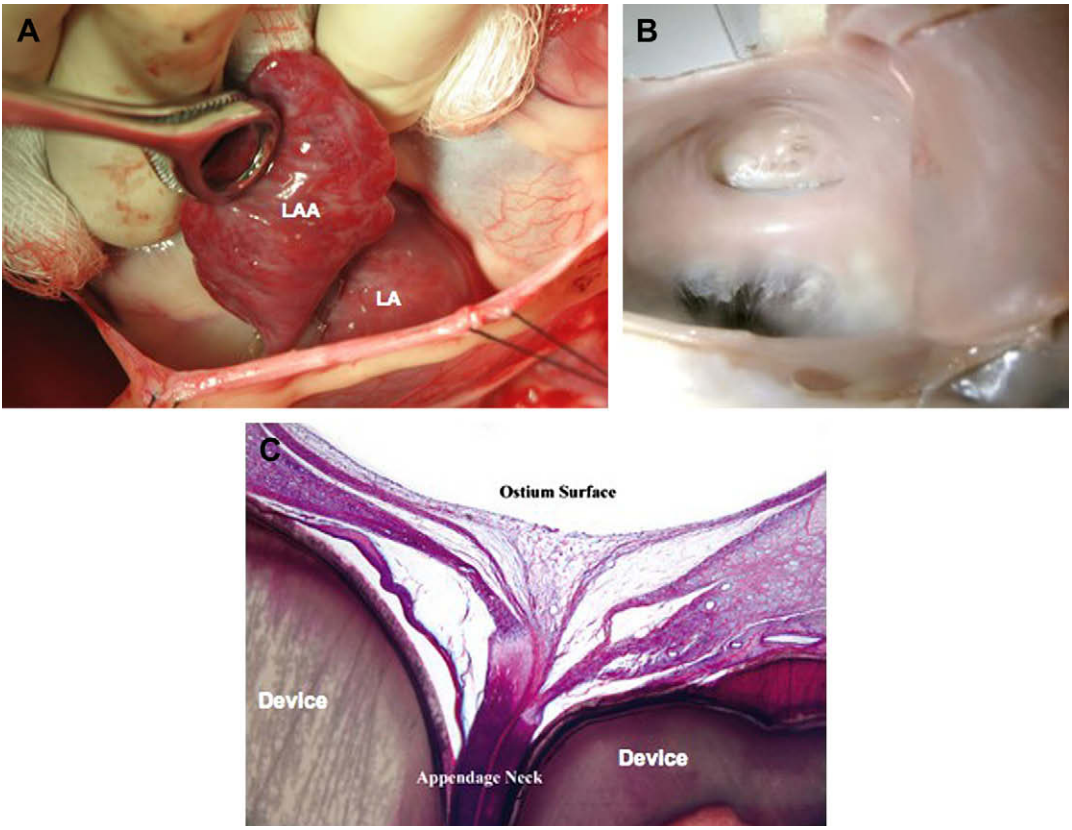

Fig. 3. LA appendage exclusion with a specially designed transmural fixation device. (*A*) Epicardial view of the clip placed on the canine LA appendage (LAA). (*B*) Endocardial view of the excluded appendage orifice 30 days after clip application. (*C*) Photomicrograph of a section taken transversely across the appendage orifice, showing complete endothelialization of the orifice without thrombus.

characteristics. Many of these problems are not unique to surgeons and their instruments but are shared by the electrophysiologists and are among the foremost challenges facing the device industry today. It is safe to say, however, that the next generation of ablation tools, capable of measuring impulse conduction and lesion effectiveness in real time, will greatly improve results and permit for the first time a tailored and more effective approach.

Minimally Invasive Approaches

Although most valve surgeries are performed via the median sternotomy, it is now possible to perform minimally invasive procedures and achieve excellent results with less morbidity and mortality.[93–96] Ablative procedures—stand alone and concomitant—also are being done through these small right thoracotomies or partial upper sternotomies with a variety of technologies.[97–107] They are technically challenging, however, as minimally invasive or keyhole approaches remain hampered by difficult access to the posterior left atrium and LA appendage. Additional refinements in exposure, manipulation, ablation technology, and lesion assessment are necessary to facilitate the widespread application of minimally invasive cardiac surgery with ablation.

SUMMARY

AF is common in patients presenting for cardiac surgery. Left untreated, AF increases morbidity and jeopardizes survival. Recent data demonstrate that AF ablation improves outcomes in these patients. Therefore, virtually all cardiac surgery patients who present with AF should receive a concomitant AF ablation procedure. The cut-and-sew maze procedure is obsolete, replaced by operations that use alternate energy sources to create lines of conduction block rapidly with little risk for bleeding. Minimally invasive cardiac surgery for AF ablation now is possible. Continued progress will facilitate tailored ablation approaches for individual patients and improve results. Development of new devices to facilitate minimally invasive exclusion of the LA appendage may offer a new alternative to patients who have AF and are at risk for stroke.

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