Surgical and Concomitant Epicardial-Endocardial (Hybrid) Ablation of Persistent and Long-Standing Persistent Atrial Fibrillation

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Abstract: Catheter ablation of atrial fibrillation (AF) has been shown to be effective for paroxysmal AF. However, for patients with persistent or longstanding persistent AF, the success rates for catheter ablation is low. The Cox-Maze procedure is the most effective non-pharmacological treatment of AF. However, due to the need for open-heart surgery and the morbidity associated with the surgical Cox-Maze procedure, minimally invasive and epicardial-endocardial (hybrid) ablation procedures have been developed. This article will review the main surgical and hybrid approaches used for the treatment of persistent and long-standing persistent AF. (Curr Probl Cardiol 2015;40:245–267.)

Introduction

Atrial fibrillation (AF) is the most common cardiac arrhythmia whose prevalence increases with advancing age.1 AF is associated with a 5-fold increased risk of stroke,2 a 3-fold increased risk of heart failure,3-5 and 2-fold increased risk of both dementia6 and mortality.3 Patients with AF may experience debilitating palpitations, fatigue, exercise intolerance, shortness of breath, and symptoms of congestive heart failure secondary to a suboptimal ventricular rate control. In addition, the stasis of blood in the left atrium (LA) can lead to thrombus formation in the left atrial appendage (LAA). The LAA is believed to be the primary source of thrombus formation that leads to cardioembolic stroke.7,8 Approximately
75,000 strokes per year are attributed to cardioembolic events as a result of AF; and the risk for stroke increases from 1.5% for those aged 50-59 years to 23.5% for those aged 80-89 years. The cardiac and neurologic consequences of AF result in significant morbidity and mortality, leading to an estimated $26 billion cost to the US health care bill annually. The prevalence of AF in the United States ranges between 2.7 million and 6.1 million affected adults, which is expected to double over the next 25 years, further adding to the cost burden.

AF occurs when abnormal impulse formation or propagation results from either atrial structural changes or electrophysiological abnormalities within the atria. During AF, normal sinus rhythm is disrupted by interlacing waves of electrical activities from multiple sources, predominantly the pulmonary veins (PVs), but also from the right atrium, the LA, and the LAA. The mechanism for AF can be multifactorial and owing to a firing focus with fibrillatory conduction, a dominant circuit with fibrillatory conduction or multiple reentry circuits.

Treatment of AF is focused on rate control, conversion to sinus rhythm, maintenance of sinus rhythm, and prevention of embolic events. Pharmacological treatment includes administration of β-blockers and calcium channel blockers for rate control, antiarrhythmic drug therapy to maintain sinus rhythm, and oral anticoagulation therapy for the prevention of cardioembolic events. However, the medical management of AF does have its limitations, including low efficacy, toxicities, and in the case of oral OAC therapy, associated bleeding problems.

The observation by Haissaguerre et al of ectopic beats originating from the PVs contributed to the therapeutic approach of catheter ablation for the treatment of AF. Catheter ablation is the least invasive for the treatment of AF with acceptable efficacy rates for paroxysmal AF. However, the long-term efficacy rates for persistent and long-standing persistent AF even after multiple procedures are less than 50%. The inability to effectively treat persistent AF has led surgeons and electrophysiologists to refine both surgical and catheter ablation approaches that offer a cure for persistent and long-standing persistent AF with an acceptable risk-benefit profile. This review focuses on nonpharmacologic surgical approaches, hybrid epicardial-endocardial ablation, and LAA exclusion in the treatment of AF.

**Cox Maze Procedure**

The surgical Cox maze procedure was introduced in 1987, demonstrating the viability of a nonpharmacological strategy for the treatment of AF.
FIG 1. Cox maze procedures. (A) The Cox maze III “cut-and-sew” basic lesion pattern. (B) The simplified Cox maze IV procedure (adapted with permission from Lall et al.60). Blue lines represent surgical incision. Red lines represent radiofrequency ablation. Black dots represent cryoablation.
The Cox maze procedure consists of a complicated “maze” of incisions of both atria designed to interrupt macroreentrant circuits with the aim of restoring atrioventricular synchrony, reestablishing a regular heartbeat, and decreasing the incidence of late stroke.

The original standard incisions of the Cox maze I procedure isolated the sinus node and interrupted the Bachmann bundle, leading to chronotropic incompetence and asynchronous atrial contraction. This led to a series of improvements culminating in the Cox maze III procedure. The Cox maze III procedure includes isolation of the PVs and elimination of the LAA (Fig 1A). It is believed that elimination of the LAA contributes to the success of the procedure by debulking the LA, eliminating potential focal LAA triggers, and allowing for completion of lines of block. Maintenance of sinus rhythm is greater than 96% at 10 years, with freedom from cardioembolic stroke exceeding 99% in patients undergoing the Cox maze III procedure. According to the HRS Consensus Statement, the Cox maze III procedure is the gold standard for surgical treatment of AF.

Christopher J. McLeod, MB, ChB, PhD: This description of the Cox III maze procedure I feel is overzealous in the success that is reflected. No Cox maze procedure has shown 96% freedom from AF at 10 years. The study quoted had a mean duration of 5 years, and it is not clear how many of these patients required antiarrhythmic drugs. It is also very important to note that most Cox maze procedures these days are not cut-and-sew maze procedures. These are done either with cryotherapy or radiofrequency (RF) ablation. In the study cited, the vast majority were cut-and-sew Maze procedures. The difference between cut-and-sew maze procedures is very nicely summarized in an investigation by Stulack et al (Stulak JM, Dearani JA, Sundt TM 3rd, et al. Superiority of cut-and-sew technique for the Cox maze procedure: comparison with radiofrequency ablation. J Thorac Cardiovasc Surg. 2007;133:1022-7. [Epub 2007 Feb 22. PMID: 17382646]). A more balanced representation of the outcomes of maze procedures as far out as 5 years (reflecting success of approximately 50%-80%) is highlighted by an investigation also with Stulack et al (Stulak JM, Suri RM, Burkhart HM, et al. Surgical ablation for AF for two decades: are the results of new techniques equivalent to the Cox maze III procedure? J Thorac Cardiovasc Surg. 2014;147:1478-86. doi: 10.1016/j.jtcvs.2013.10.084. [Epub 2014 Jan 18. PMID: 24560517]).

In addition, the author states that the LAA is a potential trigger for AF. This is highly controversial, and it is very uncommon for true paroxysmal AF to be triggered from the PVs. This is evident in multiple studies.

Furthermore, the references provided involve a large majority of persistent AF. Persistent AF is not thought to be a triggered arrhythmia. There is certainly good evidence that this is a substrate-based arrhythmia and is not driven by focal triggers such as that originating from the LAA. Therefore, removal of the LAA does not necessarily remove focal triggers.

In addition, another issue does need to be brought to the fore. Removing the LAA does not create a line of block across the mitral isthmus. The most common mitral isthmus flutter would not be blocked by the linear ablation...
lesions evident in Fig 1A, and the authors are correct in that it does complete a line of block from the PVs to the appendage, but in fact it does not block the mitral isthmus.

Owing to the extreme complexity of the “cut-and-sew” Cox maze III procedure, few surgeons perform the surgery. In addition, the development of various energy sources and a better understanding of the arrhythmogenic triggers or circuits causing AF has led to the Cox maze IV procedure that has replaced atrial incisions by ablation lines. The Cox maze IV was compared with the Cox maze III procedure and was found to be as effective for curing AF while dramatically simplifying the procedure (Fig 1B). The success of the Cox maze IV procedure has led to the development of minimally invasive surgery performed epicardially and off cardiopulmonary bypass for the treatment of AF.

Christopher J. McLeod, MB, ChB, PhD: The authors state that the more novel energy sources such as cryofrequency and RF are as effective for curing AF as a cut-and-sew maze procedure. The literature does not support that, and most alternative energy sources have long-term results similar to catheter ablation with RF energy (Stulak JM, Dearani JA, Sundt TM 3rd, et al. Superiority of cut-and-sew technique for the Cox maze procedure: comparison with RF ablation. J Thorac Cardiovasc Surg. 2007;133:1022-7. [Epub 2007 Feb 22. PMID: 17382646]).

Minimally Invasive Cox Maze Procedure

Alternative energy sources that create either hypothermic (less than −60°C) or hyperthermic (> 50°C) tissue injury as cryotherapy, RF energy, microwave, high-frequency ultrasound, and laser have been employed to create transmural atrial lesions in lieu of the “cut-and-sew” Cox maze III procedure. The most commonly employed off cardiopulmonary bypass minimally invasive surgical approach for stand-alone AF uses the bilateral video-assisted minithoracotomy or thoracoscopic approach. The minimally invasive surgical approach uses a RF bipolar device to create pulmonary vein isolation (PVI) lesions with or without ganglionic plexus (GP) disruption and division of the ligament of Marshall and LAA exclusion. Initial efficacy rates from single centers were observed to be between 75% and 92%. An initial multicenter report demonstrated an overall success rate of 93% for paroxysmal AF, 96% for persistent AF, and 71% for permanent AF, with 61% of these patients able to discontinue antiarrhythmic drugs.
and 65% discontinuing anticoagulation therapy. The complication rate was 13% and consisted of pacemaker implantation, phrenic nerve injury, postoperative hemothorax, and transient ischemic attack. However, there were no deaths or strokes in the 14 months of follow-up. The Atrial Fibrillation Catheter Ablation Versus Surgical Ablation Treatment trial randomized patients with antiarrhythmic drug–refractory AF to minimally invasive surgical ablation or catheter ablation. Outcomes for efficacy and safety during a 12-month follow-up demonstrated an overall increased freedom from AF in the minimally invasive surgery group compared with the catheter ablation cohort; however, the surgical ablation group had significantly more procedural-related adverse events compared with catheter ablation (23.0% vs 3.2%). The main procedural adverse events were pneumothorax and major bleeding.

Christopher J. McLeod, MB, ChB, PhD: It is important for the reader to remember that discontinuation of anticoagulation therapy should not be based on freedom from AF after any procedure. The authors do state that 65% of patients discontinued anticoagulation therapy. The indications for anticoagulation therapy remain well established (CHA2DS2-VASc Score or CHADS2 scoring).

The reader should also recognize that the Factor Seven for Acute Hemorrhagic Stroke trial, as described in this paragraph essentially compared ablation strategies for advanced AF. One arm used catheter ablation to isolate the PVs and create linear lesions in the left atrium; yet the open surgical arm (minimally invasive surgical ablation) in addition to PVI and linear ablation also ablated the GPs and excised the LAA. It is well recognized that the autonomic ganglia play an important role in triggering and maintaining AF, and there are multiple strategies to ablate the GPs (Nakagawa H, Scherlag BJ, Patterson E, Ikeda A, Lockwood D, Jackman WM. Pathophysiologic basis of autonomic ganglionated plexus ablation in patients with atrial fibrillation. Heart Rhythm. 2009;6(suppl. 12):S26-S34. doi: 10.1016/j.hrthm.2009.07.029. [Epub 2009 Oct 24]). In this regard, the conclusion drawn by the author that minimally invasive surgery is superior to catheter ablation needs to be tempered against the fact that GPs were also ablated.

In addition to the bilateral video-assisted minithoracotomy or thoracoscopic approach, there have been variations of minimally invasive surgical ablations that have a more limited set of lesions. These include a monolateral right thoracic approach that uses RF ablation to isolate the PVs or a laparoscopic approach. Not having to deflate both lungs is particularly advantageous in patients with underlying lung disease as compared with the bilateral thoracic approach, but neither of these limited minimally invasive surgical procedures excludes the LAA.
Hybrid Approaches

Bilateral Thoracic Approach

Hybrid procedures consisting of minimally invasive surgery combined with electrophysiological mapping and endocardial catheter ablation have been employed in an attempt to overcome the limitations of each technique alone. The goal of the hybrid procedure is to complete and confirm conduction block leading to PVI or produce lesions simulating the Cox maze procedure. The hybrid approach leverages the ability of the surgeon to perform endoscopic epicardial ablations emulating the Cox maze procedure with the electrophysiologist’s ability to map the lines of block, identify any breakthrough conduction, and perform endocardial catheter ablation to complete PVI. Initial results of hybrid approaches demonstrated increased complication rates. Additionally, the hybrid approach requires the surgical and electrophysiology teams to coordinate their expertise and resources, which can become time consuming and a logistical nightmare. However, the need to improve on efficacy rates of ablation for patients with persistent and long-standing persistent AF have encouraged surgeons and electrophysiologists to search for improved approaches.

A common hybrid procedure involves minimally invasive bilateral video-assisted thoracoscopic approach using a bipolar RF probe to create lesions in the posterior LA that replicate the modified maze procedure lesion. The surgery is performed on a beating heart without using heart-lung bypass machine. This procedure is done under general anesthesia with transesophageal echocardiography (TEE) guidance and single lung ventilation by cardiac anesthesia team. CO₂ insufflation is used during the procedure. Three ports are placed in the second, fifth, and seventh intercostal space in the anterior axillary line on both sides that are done sequentially. The lesions include antral lesions around the PVs on both sides and roof and floor lines to connect the lesions around the PVs so that the posterior LA is isolated (Fig 2). They are done with a curved clamp and a straight Coolrail mapping and ablation system (Atricure, West Chester, OH). The ligament of Marshall is visually identified and divided and a clip is placed on the LAA after connecting the left PV lesions to the base of LAA. High-frequency epicardial 50-Hz pacing is performed on the anterior and posterior aspect of the veins based on previous studies showing the location of autonomic ganglia at these sites that innervate the heart. A positive vagal response was identified where a significant drop in heart rate or blood pressure is noted and these sites are marked for performing additional ablation (Fig 3). Epicardial mapping is performed to confirm PVI (Fig 4).
There is a prospective study evaluating the safety and efficacy of this approach in patients with persistent AF called Dual Epicardial Endocardial Persistent Atrial Fibrillation (DEEP) that is registered on ClinicalTrials.gov. This study will involve initial minimally invasive surgical ablation as mentioned earlier followed by standard endocardial catheter ablation at least 6-8 weeks after the surgery (protocol not yet finalized). The primary end points are as follows: (1) composite of prespecified safety end points occurring in the first 30 days after the index procedure or hospital discharge, whichever is longer and (2) absence of AF (clinical symptoms and on auto trigger event monitor) at 12 months.

**Christopher J. McLeod, MB, ChB, PhD:** The hybrid approach for AF as described by the authors has not been shown to be of any clinical superiority. We will have to await the results of the DEEP trial. It also begs the question why a complementary catheter-based arm is necessary. (The authors cite that the electrophysiologist can complete and confirm conduction block and map lines of block identifying any breakthrough conduction, performing endocardial catheter ablation to complete PVI. This should not be necessary if the long-term results are 96% freedom from AF at 10 years.)

**Convergent Approach**

The convergent approach uses an abdominal transdiaphragmatic window to the pericardial space to access the posterior aspect of the LA. The
FIG 3. Stimulation of ganglia. Stimulation of ganglia produces a positive vagal response demonstrated by a decrease in heart rate. In the example, asystole is seen following pacing from the ganglia. The top electrogram of the panel is an atrial electrogram. The bottom electrogram of the panel is of the ganglion.
advantage of this approach is that the procedure avoids deflation of the lungs and dissection of surrounding cardiac tissue. Direct visualization of the posterior LA allows for positioning of the Numeris Guided Coagulation System (nContact, Inc, Morrisville, NC) to create a base set of lesions: (1) between the left and right PVs within the oblique sinus which is bound by the pericardial reflections, (2) linear lesions anterior to the left PVs to the ligament of Marshall, and (3) lesions anterior to the right PVs to the inferior vena cava (Fig 5A). Following completion of the epicardial lesions which isolate the posterior aspect of the LA, the abdominal entry sites are surgically closed and standard left-sided endocardial ablation is performed to complete and confirm PVI by placement of anterior PV lesions and the posterior aspect of the right PV. This is the region of the pericardial reflection that cannot be ablated epicardially unless dissection of the reflection is performed. Initial results with the convergent approach demonstrated that 80% of patients were in sinus rhythm at 12 months, 76% had a single-procedure efficacy without subsequent interventions, and 52% were in sinus rhythm and not taking antiarrhythmic drugs. An 11% adverse event rate was seen. The limitation of the convergent approach is the inability to exclude the LAA.
FIG 5. Convergent procedure. (A) The basic lesion pattern of the convergent procedure. (B) The basic lesion pattern of the convergent procedure with LAA ligation. Blue line represents epicardial radiofrequency ablation. Red lines represent endocardial radiofrequency catheter ablation. Green line represents LAA ligation. I, inferior vena cava; MV, mitral valve; S, superior vena cava; TV, tricuspid valve.
Christopher J. McLeod, MB, ChB, PhD: The results reported in Ref. 41 regarding the convergent approach are similar to a catheter-based ablation strategy; yet it involves an abdominal transdiaphragmatic window with longer recovery times and a high potential for procedural adverse events.

Recently, Drs David Tschopp and Faraz Kerendi (Heart Hospital of Austin, Austin, TX) have modified the convergent approach to include LAA exclusion by ligating the LAA with the LARIAT suture delivery device (SentreHEART, Inc, Redwood City, CA) (Fig 5B).

Ligation of the LAA with the LARIAT device was performed as previously described. Ligation of the LAA with the LARIAT device was initiated with visualization of the RV in 90° lateral projection to aid with a subxyphoid epicardial access. Pericardial access was achieved using a micropuncture kit. Once access was achieved, serial dilatations to a 14-F soft tip guide cannula (SentreHEART Inc, Redwood City, CA) with placement of a second 0.35-mm J wire were performed. After pericardial access was confirmed via TEE and fluoroscopy, heparin was administered to achieve ACT at a goal of greater than 350 seconds. Transeptal puncture was achieved using an 8.5-F SL-1 transeptal catheter and a BRK-1 needle via the right femoral vein under direct TEE and fluoroscopic guidance. Before completion of LAA ligation, an Inquiry Afocus II EB catheter (St. Jude Medical, St. Paul, MN) was positioned into the LA through the SL-1 sheath. A 3-dimensional (3-D) electroanatomic endocardial voltage map of the LA and LAA was obtained with the ESI 3D-mapping system (St. Jude Medical Endocardial Solutions Inc, St. Paul, MN) (Fig 6A).

Once mapping was completed, a 15-mm EndoCATH balloon catheter (SentreHEART Inc, Redwood City, CA) back-loaded with the magnet-tipped FindrWIRZ guidewire (SentreHEART Inc, Redwood City, CA), was positioned in the LAA under fluoroscopic and TEE guidance. The EndoCATH balloon catheter (SentreHEART Inc, Redwood City, CA) was positioned to confirm the location of the LAA ostium under TEE guidance. Another 0.035 magnet-tipped FindrWIRZ was then advanced through the LAA ligation (A) pre-Lariat and ablation, (B) post-Lariat and epicardial convergent ablation, and (C) post-Lariat and convergent epicardial ablation and endocardial ablation. The gray indicates lack of electrical activity or scar. Purple represents active conduction. Note the ability of the epicardial lesions to form scars on the posterior aspect of the pulmonary veins (B) and the endocardial lesions to form scars on the anterior pulmonary vein. The panels on the left are a anterior posterior view of the heart. The panels on the right are posterior anterior views of the LA.
epicardial access to meet the endocardial magnet at the distal tip of the LAA. The LARIAT delivery system was then inserted through the epicardial access and the snare was advanced along the FindrWIRZ and over the LAA. The snare was tightened using a TenSURE suture tightener (SentreHEART Inc, Redwood City, CA), ligating the LAA, as confirmed by TEE and followed by cutting of the suture with SureCUT suture cutter (SentreHEART, Redwood City, CA).

After successful completion of LAA ligation and reversing the heparin infusion with protamine, the epicardial ablation portion of the convergent procedure was initiated with a 2-cm upper midline abdominal incision and the insertion of a SILS port (Covidian, Mansfield, MA). After insufflation of the abdomen, an incision was made in the pericardium. The EPI-Sense-AF Guided Coagulation System with VisiTrax (nContact Surgical, Inc, Morrisville, NC) was placed through the posterior pericardium. An esophageal temperature probe was placed behind the atrium as confirmed by fluoroscopy. Two series of parallel lesions were produced beginning at the inner aspect of the left-sided PV moving from left to right across the floor of the atrium. The next series of lesions extended from the right superior PV down towards the oblique sinus. In positioning the device near the top of the left-sided PVs, the tip of the LAA as well as the tail of the LARIAT sutures were visualized and carefully avoided. Lesions were generated from the superior to the inferior PVs. On completion of the 30-lesion pattern, a 19-F Blake drain was placed in the posterior pericardium, the pericardium was reapproximated with figure-of-eight stitching using the Endo Stitch device (Covidian, Mansfield, MA) and the incision was closed.

The final portion of the procedure involved the endocardial ablation to complete PVI. A second 3-D voltage map of the LA was generated following the epicardial ablation, revealing residual electrically active areas on the superior aspect of the right and left superior PVs and also along the right inferior PV (Fig 6B). All 4 PVs were successfully isolated using a Celsius ThermoCool D ablation catheter (Biosense Webster, Inc, Diamond Bar, CA) with a total RF time of 33 minutes. Entrance and exit block were confirmed with a lasso catheter and 3-D mapping was repeated, also verifying isolation (Fig 6C). The patient was cardioverted to initiate sinus rhythm.

Attention was then turned to the cavotricuspid annulus for ablation of typical atrial flutter using the Safire bidirectional catheter (St. Jude Medical, St. Paul, MN). Lesions were created along the isthmus until the measured double potential duration from medial to lateral became greater than 115 ms (16 minute RF time). A postablation electrophysiology study was performed without inducible AF or atrial flutter. Intracardiac echocardiograms confirmed no epicardial effusion at the end of the
procedure. The patient initiated anticoagulation therapy (warfarin) 6 hours following the removal of all sheaths and remained overnight in intensive care unit for observation and was discharged home 2 days later without complications. A transthoracic echocardiogram obtained on the day of discharge revealed a small amount of fluid in the pericardium near the apex with no effect on chamber function. At the 3-month follow-up period, the patients ($n = 3$) was seen in the clinic in sinus rhythm with no recurrent symptoms of AF.

Christopher J. McLeod, MB, ChB, PhD: The study described here in detail involves only 3 patients with a 3-month follow-up, and as an electrophysiologist who specializes in catheter ablation, it is difficult to understand why the patient would be subjected to such an in-depth procedure unless long-term success rate for AF is markedly better. We will have to await clinical trials involving larger patient numbers. It does seem reasonable to ligate the LAA using the LARIAT device if patients are unable to take anticoagulation.

Monolateral Right Thoracic Approach

A staged approach consisting of the monolateral right thorascopic closed-chest approach and endocardial catheter ablation has been performed.\(^4^3\) The epicardial “box” lesion was performed with the RF monopolar device with suction adherence (Cobra Adhere XL; Estech, San Ramon, CA). Approximately 1 month after the epicardial ablation, an electrophysiology study was performed demonstrating bidirectional block in 79.1% (19/24 patients), with gaps observed at the level of the box lesion in 20.8% (5/24 patients). Additional transcatheter endocardial right- and left-sided lesions were performed in 62.5% of cases (15/24 patients). At a mean follow-up of 28 months (range: 1-55 months), 87.5% (21/24 patients) are in sinus rhythm, and the incidence of left atrial flutter was 0%.\(^4^3\) The limitation of this approach is that the LAA was not eliminated.

Christopher J. McLeod, MB, ChB, PhD: The monolateral right thoracic approach has not been investigated in large numbers of patients such as with catheter ablation. The data provided by this small study do suggest there is a relatively high incidence of gaps in the lesions around the PVs. This may be similar to catheter ablation and would nevertheless entail a thorascopic approach in addition to the endocardial catheter ablation approach.

Recently, the monolateral right thoracic approach has been adopted to include LAA ligation with the LARIAT device (Fig 7). LAA ligation with the LARIAT device is performed via a subxyphoid access into the
pericardial space\textsuperscript{42} followed by the monolateral right thoracic approach. Although LAA ligation before the right monolateral approach is preferred owing to the potential pericardial adhesion formation after the monolateral right thoracic approach, we have performed LAA ligation with the LARIAT device up to 3 weeks after the monolateral right thoracic approach. However, our experience with performing LAA ligation after the epicardial ablation is limited to suggest this can be routinely performed without pericardial adhesion formation.

**LAA Ligation as Adjunctive Therapy to Catheter Ablation**

Catheter ablation has been shown to be more effective and cost-effective than antiarrhythmic drugs for the treatment of paroxysmal AF.\textsuperscript{17} However, long-term efficacy rates of catheter ablation for persistent and long-standing persistent AF are low despite multiple procedures.\textsuperscript{18} Additionally, catheter ablation is less effective than the surgical Cox maze III procedure or surgical ablation.\textsuperscript{34,44} A main difference between catheter ablation and the surgical approaches is the exclusion of the LAA in the surgical approaches. The LAA has long been known to be a source of atrial tachycardias,\textsuperscript{45} and a cause for recurrent AF.\textsuperscript{13,14} This has led to the surgical exclusion of the LAA for the treatment of failed catheter ablation.
for atrial tachycardias originating in the LAA.\textsuperscript{46,47} Additionally, LAA electrical isolation as part of PVI has improved outcomes in patients with persistent and long-standing persistent AF.\textsuperscript{13,14} LAA isolation during catheter ablation is associated with the risk of perforation, cardiac tamponade, and electromechanical dissociation, resulting in the potential for LAA thrombus formation.\textsuperscript{13} These potential complications are eliminated if the LAA is ligated before the endocardial ablation. LAA occlusion implants have been employed concomitantly with PVI.\textsuperscript{48,49} However, catheter ablation cannot be performed for reconnection of LAA electrical activity or LAA triggers once the LAA occlusion implant has been deployed in the LAA.

Christopher J. McLeod, MB, ChB, PhD: Once again, it is important for the reader to remember that atrial tachycardias originating from the LAA are rare. The most common sites would be the PVs and then after that, the right atrium and coronary sinus. There is still not a lot of evidence for proving that LAA is a trigger for persistent AF and long-standing persistent AF, as is described in this particular paragraph. At the moment, left atrial occlusion can be viewed primarily as an approach to mitigate the risk of thromboembolic stroke in patients who cannot take OAC.

\textbf{Christopher J. McLeod, MB, ChB, PhD:} Once again, it is important for the reader to remember that atrial tachycardias originating from the LAA are rare. The most common sites would be the PVs and then after that, the right atrium and coronary sinus. There is still not a lot of evidence for proving that LAA is a trigger for persistent AF and long-standing persistent AF, as is described in this particular paragraph. At the moment, left atrial occlusion can be viewed primarily as an approach to mitigate the risk of thromboembolic stroke in patients who cannot take OAC.

\textbf{FIG 8.} LAA ligation and PVI basic lesion pattern. Red lines represent endocardial radiofrequency ablation. Green line represents LAA ligation. Blue lines represent potential radiofrequency ablation lines to isolate the posterior left atrium. IVC, inferior vena cava; MV, mitral valve; SVC, superior vena cava; TV, tricuspid valve.
We have demonstrated that LAA ligation with the LARIAT device produces LAA electrical isolation and a decrease in the burden of AF.\textsuperscript{50,51} We have also demonstrated the feasibility of performing LAA ligation with the LARIAT device concomitantly or as a staged procedure.\textsuperscript{52} The new approach allows for the potential of a percutaneous Cox maze procedure (Fig 8). Initial clinical results demonstrated entrance and exit block in 19 of the 20 patients undergoing PVI. At 3 months, 13 of 19 (68.4\%) patients were in sinus rhythm; 4 patients underwent a second PVI. At 6 months, 15 of 20 (75\%) patients were in sinus rhythm.\textsuperscript{52} There were no periprocedural complications such as pericardial effusions, tamponade, surgery, stroke, or death.

LAA ligation not only eliminates potential triggers arising from the LAA, it also debulks the LA. The elimination of the LAA should also decrease macroreentrant circuits and conduction abnormalities within the LAA due to heterogeneous fiber orientation of the LAA.\textsuperscript{53} LAA ligation produces a transmural lesion and fibrosis around the orifices of LAA and LA.\textsuperscript{54} The combination of LAA ligation and more extensive ablation along the left upper pulmonary vein and LAA aspects of the lateral ridge may affect epicardial structures, including the ligament of Marshall and autonomic ganglia plexi that lie between the left upper pulmonary vein and LAA within 3 mm from the endocardial surface.\textsuperscript{53,55,56} Interruption of the ligament of Marshall and autonomic nerve bundles contribute to improved AF ablation outcomes.\textsuperscript{55,57-59} Prospective randomized trials are being organized to determine whether LAA ligation with catheter ablation will decrease AF burden, reduce recurrence of AF, and reduce stroke.

Christopher J. McLeod, MB, ChB, PhD: The contribution of the autonomic ganglia to the triggering and maintenance of AF is well established. However, there are no data so far that confirm that by ligating the LAA, the autonomic ganglia are affected in any way that is antiarrhythmic both in the short- and long-term management of persistent or long-standing AF.

Conclusion

Persistent and long-standing persistent AF continue to be a major health problem and economic burden. Promising hybrid approaches have been developed along with a percutaneous catheter-based approach that simulates the surgical Cox maze procedure. Although initial promising results have been demonstrated with each of these techniques, further
prospective studies are required to determine the efficacy and safety of each of these approaches.

Christopher J. McLeod, MB, ChB, PhD: This review very nicely summarizes the current techniques for surgical and hybrid approaches to address AF and isolate the LAA. There is no large, randomized study thus far proving that these approaches are more efficacious than catheter ablation alone. Persistent and long-standing persistent AF still prove to be especially difficult for the clinician to manage from an antiarrhythmic standpoint. Long-term results are suboptimal, and better strategies are necessary. The data presented are somewhat in favor of the surgical and hybrid approach. It will need to wait for larger studies to confirm efficacy in this problematic patient group.

The clinician should currently be utilizing left atrial occlusion for patients who are unable to take OAC for AF, and no procedure should alter the recommendations for anticoagulation. This should be based on the risk factors for stroke and not on short- or long-term success or freedom from atrial fibrillation.

REFERENCES


