Contemporary left atrial appendage management during adult cardiac surgery

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Video clip is available online.

The debate over surgical left atrial appendage (LAA) management for patients with atrial fibrillation (AF) has been focused in 3 areas: evidence, indications, and technique. Because the LAA is implicated in the vast majority of ischemic strokes in patients with nonvalvular AF, clinical practice guidelines and expert consensus recommendations have advocated for LAA occlusion or obliteration (LAAO) for patients in AF presenting for cardiac surgery, particularly when accompanied by surgical ablation procedures. 1-3 Nevertheless, LAAO adoption rates at the time of operations, with or without surgical ablation, have been inconsistent. 4

There have been many proposed methods for LAA management, each with varying outcomes related to pathoanatomic and technical nuances. Three generally accepted techniques are now the most commonly performed: endocardial double-layer obliteration, epicardial resection and closure, and epicardial LAA clip. This review summarizes pathoanatomic considerations, technical considerations, and the current evidence that may inform the contemporary management of the LAA in the setting of AF at the time of concomitant cardiac surgery.

PATHOANATOMIC CONSIDERATIONS

Patients with AF undergoing cardiac operations are at substantially increased longitudinal risk of stroke, mortality, and major morbidity. 4,5 These risks are inherent in the pathophysiology of the untreated fibrillating LAA, in addition to comorbid risk factors such as age, diabetes, heart failure, hypertension, and peripheral vascular disease. 5-8

The anatomy of the LAA is composed of the orifice or ostium, neck, and body. Variations in anatomy may lead to variations in embolic potential, but also variations in LAAO technical success.

The source of the LAA’s trabeculated body, often implicated in the thrombotic pathology of AF, can be explained by its embryologic origins from the primordial common heart chamber. The left atrium and LAA ostium are derived from the smooth-surfaced embryonic pulmonary vein bud, and the LAA neck is the variable embryologic union between these structures. 5 The LAA courses anteriorly and parallel to the left pulmonary vein and commonly points toward the proximal pulmonary artery, the right ventricular outflow tract, and the left ventricular free wall at the level of the transverse sinus. The ligament of Marshall is the vestigial remnant of the left superior vena cava and serves as a surface landmark between the neck and body of the LAA and the left superior pulmonary vein.
Multiple anatomic variations exist in size, shape, ostial profile, and number of lobes. The chicken wing is the most common (48%), followed by the cactus (30%), the windsock (19%), and the cauliflower (3%). Each configuration has unique associated anatomic features that may influence the effectiveness of LAAO. Selecting the optimal technical approach, particularly if epicardial, should incorporate knowledge of the overall morphology of the neck and body, but also the location of the adjacent structures such as the circumflex coronary artery (Figure 1). For example, if the appendage configuration has a long neck and small ostium, an epicardial LAAO strategy ideal. In contrast, the cauliflower morphology is most often associated with embolic events due to its short overall length, variable number of lobes, thicker mural muscle bundles, and wide irregular neck. Furthermore, the endocardial LAA ostium, located between the left lower pulmonary vein and the lateral posterior mitral annulus, is an oval longitudinal shape in all configurations and almost never a perfect circle.

The recent acceleration of percutaneous endocardial LAAO device implantation has provided an enhancement to the availability of echocardiographic and computed tomography imaging of the LAA to help guide ideal LAAO therapy and predict failures. Common anatomic failures of both endocardial percutaneous therapy and single-layer or purse-string surgical therapy are associated with incomplete occlusion of the orifice and neck. This may lead to residual leak into the LAA, or device-related thrombosis or embolization. Common anatomic failures of epicardial occlusion techniques are incomplete lobar occlusion and/or excessive residual LAA neck or stump >10 mm. Whenever possible, incorporating anatomic knowledge of the LAA orifice, neck, and body is important for the precise delivery of effective LAAO therapy.

TECHNICAL CONSIDERATIONS

Many surgical and transcatheter LAAO techniques have been introduced (Table 1). As experience has been gained, the majority of these concepts have been abandoned for 1 broad transcatheter option and 3 surgical options. The most common percutaneous transcatheter LAAO therapy involves device delivery via femoral venous access, across the atrial septum, with antegrade anchoring into the LAA ostium and neck. Although the indications and anticoagulation management of these devices are beyond the scope of this article, if patients are carefully anatomically selected, these devices can be deployed safely and efficaciously, practically on an outpatient basis. If patients are not carefully selected by appropriate anatomy, these devices can be maldeployed, resulting in prothrombotic foreign body elements jutting into the fibrillating left atrium, incomplete occlusion of the LAA neck, or complete embolization, often requiring surgical therapy to correct. Transesophageal echocardiography may assist in the identification of the orifice and neck, or if clot is present, but the precise morphology of the body may be best identified by computed tomography or direct visual inspection at the time of surgery. The 3 most commonly accepted and surgically performed LAAO techniques involve 2 epicardial and 1 endocardial approach.
Epicardial LAA Resection or Clipping

Resection of the LAA was incorporated in the original Cox maze operations and the surgical management of the LAA has been a cornerstone to successful surgical ablation ever since.4,13 Performed optimally on cardiopulmonary bypass and the arrested heart, the LAA is excised either epicardially and oversewn, or inverted through open left atrial exposure and excised and oversewn endocardially. Resection may also be accomplished with an excisional stapling device that is often supported by pericardial strips or buttresses for optimal hemostasis. Epicardial stapling without excision has been fraught with issues of delayed recanalization of the LAA lumen.14 When resection is performed without cardiopulmonary bypass, care is taken to ensure adequate application to the neck or base of the LAA without incorporating adjacent epicardial structures or bleeding. Although an open complete resection of the trabeculated appendage and closure clearly avoids future LAA-related pathology, complications related to this invasive technique are not uncommon and may include bleeding and related pericardial effusions. Thus appropriate steps at the time of excision must be taken to mitigate these potential risks.

Since the advent of epicardial clipping devices and the Food and Drug Administration approval of the AtriClip (Atricure) device, adoption of LAAO has increased. Straightforward to apply, the epicardial clip is navigated in its open configuration around the LAA, often with gentle countertraction on the LAA body, placed as close as possible to the base of the LAA neck, then released to achieve maximal occlusion without incorporating adjacent epicardial structures. Transesophageal echocardiography is used to assess for residual stump on the beating heart with normal loading conditions to confirm effective application. Early randomized evidence has shown the epicardial clip to be safe and effective with initial success rates of 95%.15 Given the relative safety of this device, epicardial clip techniques have become quite common, largely replacing epicardial LAA stapling devices. Recent modifications to the delivery system and configuration of the clip have facilitated increasing minimally invasive thoracotomy or robotic-assisted applications.16 Whereas the clip is most commonly applied on cardiopulmonary bypass, it has been used both in conjunction with open resection and epicardial clipping, as well as a standalone off-pump minimally invasive method with or without epicardial hybrid ablation.

The case selection and technique of epicardial application must be done with care to avoid anatomically based complications. The most common among these is ineffective deployment of epicardial clip or stapling devices that leaves behind residual trabeculated LAA tissue. Most commonly associated with the cauliflower configuration (Figure 2), this can occur with any morphologic should care not be taken to apply the epicardial device properly on the LAA neck. Failure to do so may result in partial or tangential deployment, single lobar deployment in a multilobar LAA, or a residual stump in excess of 10 mm, all predictors of ineffective LAAO and early failure in up to 10%.14,17 When confronted with a multilobar morphology, enhanced precision and clear exposure of the LAA base before application is recommended. Although a goal of <10 mm should be the minimum objective, near complete stump reduction by intraoperative transesophageal echocardiography should be the goal because residual thrombus in the fibrillating atrium may occur with any size stump.18 A serious, but unusual complication of epicardial clip or stapling procedures can be the inadvertent incorporation of adjacent epicardial fat and tissue that may result in partial kinking or obstruction of the circumflex coronary artery.19

These anatomically related complications may be avoided by preoperative and intraoperative imaging and careful intraoperative anatomic assessment of the LAA to confirm that the neck and base are favorable for successful device deployment. Clear visualization is essential to achieve complete occlusion without incorporation of adjacent structures. Further precision of application may be facilitated by division of the ligament of Marshall and gentle blunt dissection of the epicardial fat to more optimally expose and circumferentially visualize the neck or base of the LAA before placement of the epicardial LAAO device. These additional preparatory steps are best performed on cardiopulmonary bypass. If the patient and LAA anatomy are carefully selected and the epicardial clip precisely applied, the result is safe and durable.

**Endocardial LAA Obliteration**

Historically applied techniques of endocardial purse string closure of the LAA ostium and oversewing of the

**TABLE 1. Techniques for left atrial appendage management**

<table>
<thead>
<tr>
<th>Technique</th>
<th>Description</th>
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<tbody>
<tr>
<td>Transcatheter</td>
<td>Epicardial wire-based lasso occlusion</td>
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<tr>
<td>Surgical</td>
<td>Endocardial suture or endoloop without resection</td>
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<td>Epicardial staple exclusion without resection</td>
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<td>Epicardial staple with resection</td>
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<td>Epicardial clip exclusion without resection</td>
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<td></td>
<td>Epicardial clip exclusion with resection</td>
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<td></td>
<td>Endocardial patch with autologous or bovine pericardium</td>
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<tr>
<td></td>
<td>Endocardial suture: Purse-string or linear single-layer closure</td>
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<td></td>
<td>Endocardial suture: Longitudinal double-layer obliteration and plication</td>
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<td></td>
<td>Endocardial resection and suture</td>
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<td>Endocardial resection and epicardial clip</td>
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ostium with monofilament suture in an interrupted or linear fashion have previously been associated with a high frequency of suture line disruption or tearing, resulting in only partial occlusion with residual LAA flow in 10\% to 30\%.\(^{14,20,21}\) These methods were all performed on an arrested heart with the left atrium exposed with a fixed left atrial retractor. Whereas surely all surgeons took steps to ensure their sutures were as secure as possible, certain features of these often single-layer and occasionally double-layer linear techniques might explain rates of recurrence. These include the high tissue tension from a circular purse string applied to an oval and longitudinal LAA ostium, and the potential gaps from a linear suture line when performed on a relatively taut but arrested left atrium exposed by anterior retraction. When the left atrium fills following cardiopulmonary bypass, the taut suture line may disrupt or tear and the loose suture line may have exposed gaps and partial recanalization. Measures taken to avoid these complications and to ensure effectiveness include avoidance of purse-string techniques altogether because this is not congruent with the LAA ostial anatomy, application of a double-layer obliteration technique that incorporates the LAA body and imbricates the left atrial wall, and partially releasing the anterior retraction of the atrium, when the closure pattern, to create a homogeneous and linear closure between the border of left pulmonary vein (ie, coumadin

![FIGURE 2. Epicardial left atrial appendage occlusion. A. Effective epicardial appendage occlusion should be applied to the anatomic neck of the appendage flush with the epicardial cardiac surface to assure complete occlusion without inadvertent involvement of adjacent structures. B. Based on the morphologic type of the appendage, should the neck or base not be clearly visualized, inappropriate placement may result in a residual stump >10 mm from the ostium or trabeculated appendage.](image)

![FIGURE 3. Endocardial left atrial appendage obliteration. Effective double-layer endocardial obliteration includes incorporation of the neck and body in the first suture line, and a left atrial plication in the second suture line to create a homogenous longitudinal closure.](image)
ridge) and the anteromedial border of the LAA ostium (Video 1). When performing the second layer of this obliteration technique, care must be taken not to incorporate too much atrial tissue in close proximity to the mitral annulus to avoid any alteration to annular function and possible focal regurgitation. This technique of endocardial LAA obliteration can be applied to all anatomic morphologies of the LAA, and it has been associated with <1% per year risk of stroke when combined with surgical ablation.2,1

CURRENT EVIDENCE

There have been many institutional series that have documented safety and longitudinal efficacy of surgical LAAO, but large clinical registry and randomized evidence has been rare.2,4,14,15,21 The lack of level A evidence led to Class II recommendations for concomitant LAAO in the 2017 clinical practice guidelines based on Level C evidence.1 Despite consistent institutional experiences documenting the merits of surgical LAAO as part of an AF management strategy during concomitant cardiac operations, clinical practice has been inconsistent and barriers to adoption of AF management relating to knowledge and technical comfort continue to exist.4,22-24

Recently, 2 major contributions to the literature provide level A evidence in support of surgical LAAO as part on an AF management strategy at the time of cardiac surgery.25,26 These have the potential to influence future clinical practice guideline recommendations.

In their 2018 JAMA article, Friedman and colleagues25 performed a national cohort study linking US Medicare patients from the Centers for Medicare and Medicaid Services database to the Society of Thoracic Surgeons Adult Cardiac Surgery Database to examine the longitudinal impact of LAAO on readmission for thromboembolism and mortality. Their study cohort included 10,534 patients with AF at the time of cardiac surgery: 3892 patients received concomitant surgical LAAO, 6632 did not. Patients undergoing any form of surgical ablation were included, but patients with preoperative shock or endocarditis were excluded. Following comprehensive propensity matching inclusive of CHA2DS2-VASc score (congestive heart failure, hypertension, age ≥ 75 years, diabetes mellitus, stroke or transient ischemic attack, vascular disease, age 65 to 74 years, sex category) the authors determined that the inclusion of LAAO lowered risk of thromboembolism (hazard ratio [HR], 0.83), all-cause mortality (HR, 0.88), and a composite primary end point of thromboembolism, hemorrhagic stroke, or death (HR, 0.69). This very large national cohort study was the first to clearly establish the longitudinal outcome benefit in favor of concomitant LAAO for patients with AF presenting for cardiac surgery.

The results of the prospective randomized LAAOS III clinical trial that started enrolling 10 years ago, were published in the New England Journal of Medicine during 2021.26 Whitlock and colleagues26 laudably examined a total of 4770 patients with AF at the time of cardiac surgery: 2379 received LAAO, and 2391 did not. Patients were enrolled between July 2012 and October 2018. The LAAO was performed by resection, epicardial clip, epicardial stapler without resection, or endocardial double-layer linear closure. All patients received oral anticoagulation throughout the entirety of follow-up until March 2021 that averaged 3.8 years. Preoperative shock and active endocarditis were exclusions. Concomitant surgical ablation was performed in 809 of the LAAO patients (34%) and in 753 of the no LAAO patients (31.5%). Half of the patients received LAA resection and the remainder received an equal distribution of endocardial linear suture, epicardial stapler, and epicardial clip LAAO. They performed a time-to-event analysis utilizing Kaplan-Meier survival estimates. Within the overall cohort, the mean CHA2DS2-VASc score was 4.2, 92% received the assigned LAA management, there was no difference in crossclamp or cardiopulmonary bypass times, and the compliance with oral anticoagulation at 3 years was 77%. The primary outcome was all-cause stroke or systemic embolism that ultimately revealed a significant benefit of LAAO (HR, 0.67), the largest benefit observed in patients beyond 30 days (HR, 0.58), with a net stroke reduction of 2%. Unlike the contribution from Friedman and colleagues,25 the study by Whitlock and colleagues26 did not find a difference in all-cause mortality (HR, 1.0) or major bleeding between groups.

These 2 important contributions clearly show that for a patient with AF presenting for cardiac surgery, the addition of LAAO as part of an AF management strategy can reduce the longitudinal risk of stroke and improve survival.

Surgical Ablation With LAA Management Versus LAA Management Alone

The findings of these 2 contributions on the merits of LAAO may now beg the question, Is LAAO enough or
does one need to perform surgical ablation in addition to LAAO? Both the studies by Friedman and colleagues and Whitlock and colleagues included surgical ablation patients in their LAAO groups. However, neither study included late rhythm assessment, nor were they powered to assess the influence of surgical ablation on stroke risk. Similarly, neither study determined the optimal technique of LAAO management, nor the role of oral anticoagulation or its absence on the outcome of the LAAO treated patients. Perhaps further subanalyses of these data might provide clarity to these residual questions.

This noted, in a recent analysis of surgical ablation from the Society of Thoracic Surgeons Adult Cardiac Surgery Database, LAAO was performed in 87% in valvular and coronary artery bypass grafting patients undergoing surgical ablation, and in 64% of patients undergoing stand-alone or hybrid surgical ablation. When 28,739 patients receiving surgical ablation were propensity matched to 28,739 who did not, a 30-day relative risk reduction in favor of surgical ablation was noted for mortality (relative risk, 0.92) and stroke (relative risk, 0.84). Finally, in a recent longitudinal analysis of US Medicare recipients with AF undergoing isolated coronary artery bypass grafting, patients who received concomitant surgical ablation had a cost-effective 2-year risk-adjusted survival benefit (HR, 0.71). These findings, combined with several contributions categorized by 1-year outcomes with rhythm and survival end points, informed 3 professional associations to provide a Class I, level of evidence A, recommendation for the addition of surgical ablation for the management of AF at the time of concomitant cardiac surgery.

Neither the study by Friedman and colleagues nor the study by Whitlock and colleagues was powered to detect the influence of the addition of surgical ablation to LAAO in more than 30% of their cohort. National data on surgical ablation reveal incomplete use of LAAO between 10% and 30%. However, both show improvements in survival and stroke. Thus, when combined with the multitude of additional evidence on surgical ablation, it would be safe to extrapolate that the influence of surgical ablation on longitudinal stroke and survival is significant and surgical ablation in combination with LAAO should be performed whenever possible.

Evidence now supports LAA management as a minimum. However, when faced with a patient with AF needing cardiac surgery for other reasons, interpretation of recent data might also be summarized by evidence supported goal-directed therapy. Influencing factors may be advanced age, multidecade AF duration, a giant left atrium >10 cm, a calcified left atrium, an emergency salvage operation, and surgeon safety and experience with surgical ablation. If the goal is restoration of normal sinus rhythm and longitudinal survival, then a surgical ablation and LAAO, preferably a biatrial Cox maze, should be performed. If, based on influencing factors, the goal is attempted stroke mitigation only, perhaps LAAO may suffice.

CONCLUSIONS

Clear evidence has emerged to support surgical LAA management for patients in AF presenting for cardiac surgery. Three principle techniques may be utilized to achieve effective LAA obliteration, including LAA resection and closure, epicardial clip, and endocardial LAA double-layer obliteration. Each technique can be very effective if patients are approached with knowledge of LAA pathoanatomy and good surgical technique. Concomitant to surgical ablation, or less commonly as an isolated procedure, it matters less how one performs appendage obliteration, as long as it is done precisely.

Conflict of Interest Statement

Drs Rankin, Lee, and McCarthy serve as consultants to Attucure. Dr Badhwar serves as a nonremunerative consultant to Abbott. Dr Wei had reported no conflicts of interest.

The Journal policy requires editors and reviewers to disclose conflicts of interest and to decline handling or reviewing manuscripts for which they may have a conflict of interest. The editors and reviewers of this article have no conflicts of interest.

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