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Clinical management after surgical left atrial appendage exclusion

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Abstract

Background Surgical left atrial appendage (LAA) closure is an increasingly utilized approach to mitigate the risk of cardioembolic stroke in patients with atrial fibrillation (AF). Consensus is lacking regarding optimal stroke prevention management after surgical LAA management.

Objective To elucidate real world clinical management of anticoagulation in patients undergoing surgical LAA management.

Methods Over a 7-year period at a single center, 458 participants carried a diagnosis of AF and underwent surgical exclusion of their LAA during concomitant cardiac surgery. Follow-up was catalogued via retrospective chart review; median follow-up was 2 years. Successful LAA ligation was defined as maximal stump depth < 1.0 cm by transesophageal echocardiography (TEE) without distal leak.

Results Among 458 patients, 299 were discharged on OAC (142 DOAC and 157 warfarin). Of these, 31% (94/299) had a follow-up TEE. Among those without a TEE, 32% (65/205) were taken off OAC; among those who underwent TEE, 59% (55/94) were taken off OAC. Using a logistic regression model, there was no relationship between age, sex, CHA_2DS_2-VASc score, or creatinine and the probability of coming off of OAC. Among the 94 patients discharged on OAC who had a follow-up TEE:10 were unable to assess adequacy of closure, 69 were successful, and 15 showed unsuccessful closure. In the group with imaging confirmed successful exclusion of their LAA, 67% (46/69) were taken off their oral anticoagulation, with cessation occurring after the TEE in 93% (43/46) of those patients.

Conclusion Clinical management after surgical LAA management, particularly with regard to LAA imaging and OAC continuation, is highly heterogeneous.

Keywords Left atrial appendage, Atrial fibrillation, Stroke prevention, TEE

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Introduction

Atrial fibrillation (AF) is the most common arrhythmia worldwide and is associated with a five-fold increase in stroke risk when compared to a sex- and age-matched population [1–3]. A vast majority of cardioembolic strokes in patients with AF originate in the left atrial appendage (LAA). (4–5) This can likely be attributed to stasis resulting from anatomical and physiologic characteristics of the LAA including size, contractility, flow pattern, and flow velocity [6–8].

Oral anticoagulation (OAC) with warfarin and newer agents such as direct factor Xa inhibitors and thrombin inhibitors remains the mainstay of thromboembolism prevention therapy in patients with AF. There has been increasing interest, however, in reducing thromboembolism risk in patients with AF via management of the LAA by means of percutaneous or surgical exclusion.

Retrospective studies examining outcomes after surgical left atrial appendage exclusion have yielded conflicting results [9–14]. However, there appears to be a trend in the data toward lower rates of thromboembolism in patients with surgical LAA exclusion, in patients with and without AF. (4, 15–16) The Left Atrial Appendage Occlusion Study (LAAOS III) demonstrated surgical LAA exclusion to be an additive benefit to OAC therapy in patients with AF [13]. In fact, given this promising data, some have considered LAA ligation at the time of cardiac surgery a best practice and the recently published 2023 ACC/AHA/HRS AF management guideline recommends left atrial appendage exclusion at the time of cardiac surgery as a class Ia recommendation in AF patients with a CHA_2DS_2-VASc score of 2 or more [17]. Though studies have shown that percutaneous LAA exclusion can be a safe means to stop therapeutic anticoagulation [18–21]data regarding anticoagulation cessation after surgical LAA exclusion is lacking and practices vary. This is further complicated by the fact that prior data suggests not all surgical LAA exclusion is complete on follow-up imaging [22–24]. Furthermore, there is no standard of care for routine imaging [transesophageal echocardiography (TEE) or CT] after surgical LAA exclusion. Few studies exist that evaluate OAC use following surgical LAA management [11]. There are no studies to date examining OAC practices in patients who have received follow-up TEE.

The purpose of our study is to examine patterns in care, with respect to OAC and follow-up LAA imaging, in patients with AF who undergo surgical LAA exclusion. Specifically, we seek to identify predictive variables driving thromboembolism prevention strategies in these patients.

Methods

This study was designed as a large single center retrospective cohort assessment of outcomes in patients who carry a diagnosis of AF and undergo surgical exclusion of their left atrial appendage. The protocol was approved by the Wake Forest School of Medicine's Institutional Review Board (study number IRB00064192). Eligible patients underwent surgical left atrial appendage exclusion via suture-ligation or device-assistance between October 1st, 2012 and December 31st, 2019 at Wake Forest Baptist Hospital. Demographic data and cardiovascular history, including individual elements of the CHA_2DS_2-VASc score (congestive heart failure, hypertension, age > = 65, age > = 75, diabetes, stroke, vascular disease, and female sex) were collected. The overall cohort included 458 patients.

Surgical techniques

Left atrial appendage exclusion was performed surgically either as a stand-alone procedure or concomitantly with another cardiothoracic procedure, including coronary artery bypass grafting (CABG), valve repairs and replacements, and Cox-Maze procedures. The appendage was ligated via direct excision and oversewing, AtriClip device, or TigerPaw III device. Both median sternotomy and minimally invasive approaches were included. The method of exclusion was recorded.

Outcomes

The primary outcomes included the completion of TEE post-operatively and the cessation of OAC after TEE-confirmed LAA closure. OAC included Warfarin, direct thrombin inhibitors, and anti Xa inhibitors. Adequate LAA exclusion was defined during our retrospective imaging review as measured depth of any residual LAA stump of less than 1.0 cm. Data regarding oral anticoagulation use in the pre-, peri-, and post-operative period was collected. The secondary outcome was defined as stroke occurrence in the postoperative period. Stroke included transient ischemic attack and was defined as any new-onset focal neurological deficit. Strokes were classified into TOAST criteria based on imaging findings as well as specialty consultants.

Echocardiographic measurements

Study TEEs performed by attending echocardiographers for any reason after the initial cardiac surgery were reviewed retrospectively to evaluate the success of the ligation. If more than one TEE had been performed at some point after surgery, the first post-surgical exam was chosen for review. The TEE images reviewed were acquired using multiple generations of Phillips TEE probes (predominantly series S7-3t, X7-2t, X8-2t). Available images of the LAA were evaluated for stump depth,

Table 1 Characteristics of patients with AF undergoing surgical LAA exclusion

	AF patients with post-op TEE ($n = 113$)	AF patients without post-op TEE ($n = 345$)	*p*-value
Average age (years)	66.7 +/- 9.0	67.5 +/- 11.0	0.51
Sex, n (% female)	109 (35.4%)	40 (31.6%)	0.41
Average CHA_2DS_2-VASc score	3.41 +/- 1.53	3.35 +/- 1.54	0.52
Diabetes Mellitus (% total)	39 (34.5%)	96 (27.8%)	0.23
Average Cr	1.09 +/- 0.64	1.18 +/- 0.95	0.33
HTN (% total)	95 (84.1%)	263 (76.2%)	0.06
Average LVEF (%)	49.9 +/- 10.7%	49.7 +/- 12.3%	0.74

Table 2 OAC management in patients receiving TEE after surgical LAA exclusion

TEE result ($n = 113$)	OAC on Discharge	OAC follow-up	Timing of OAC discontinuation
Successful Closure ($n = 83$)	70 discharged with OAC	Off OAC $n = 46$ Stay on OAC $n = 24$	43 after TEE 3 before
Inadequate closure ($n = 19$)	15 discharged with OAC	Off OAC $n = 5$ Stay on OAC $n = 10$	4 after TEE 1 before
UTA ($n = 11$)	9 discharged with OAC	Off OAC $n = 4$ Stay on OAC $n = 5$	4 after TEE

residual flow into the LAA remnant, and the presence of thrombus, pectinate, or residual suture material. Stump depth was measured as the linear distance from the center of the ostium of the LAA to the deepest visible aspect of the appendage remnant. The ostium of the LAA was defined at the level of the left circumflex coronary artery and the plane extending perpendicularly to the limbus from the middle of that coronary landmark. Stump depth was measured in all available previously imaged 2D angles using the ruler tool within the reporting software, and the maximum measured depth was reported. If an adequate 3D image of the LAA had been acquired, Q-Lab software was used to find the maximum 2D depth optimized using adjustable multiplane angles. Successful ligation was defined as maximal stump depth < 1.0 cm in all dimensions imaged [9, 14]. This depth parameter has been suggested in the recently published AF management guidelines. All TEEs were manually re-reviewed and the remnant depths and characteristics were re-measured by a single board-certified echocardiographer who was blinded to the operative approach.

Statistical analysis

Baseline characteristics of the study population are reported with means for continuous variables and frequencies for categorical variables. Two-sided *p* values < 0.05 were considered statistically significant. Multivariable logistic regression models were used to determine the relationships between participant characteristics and the odds of the participant undergoing transesophageal echocardiography during the study follow-up period, as well as the odds of discontinuation of oral anticoagulation during the study. Cox proportional hazards models were used to assess the relationships between participant characteristics and their risk of stroke after confirming proportionality of hazards with analysis of residuals. Hazard ratios are reported with 95% confidence intervals. Analyses were conducted using SAS version 9.4 (SAS Institute, Inc.).

Results

Our initial cohort of patients with a preoperative diagnosis of AF who underwent surgical LAA exclusion included 458 patients. Follow-up period was 0-430 weeks (median 100 weeks). From this, we subdivided the cohort based on whether or not they received a TEE; 113 (24.7%) patients received a postoperative TEE while 345 (75.3%) did not. Baseline demographics for these two groups are depicted in Table 1. There were no statistical differences in covariates been the two groups.

Using a logistic regression model, no significant association was found between age, sex, CHA_2DS_2-VASc score, or creatinine and the probability of having a post-operative TEE. Average time to TEE was 36.1 weeks, median time 14.0 weeks. Management of OAC in patients receiving TEE is catalogued in Table 2. Of the 113 patients who ultimately received TEEs, 94 were discharged after their cardiac surgery on OAC. Of the patients who received a post-operative TEE, 11 of these TEE studies were unable to be fully assessed due to insufficient quantity or quality of dedicated images. Of the remaining 102 patients receiving TEEs, 83 were seen to have an adequate LAA closure, whereas 19 showed inadequate closure based on the criteria that we established in the Methods.

On admission to the hospital for surgery, 290/458 patients were on OAC. Due to varied preoperative anticoagulation cessation practices prior to surgery, it was difficult to retrospectively assess how many patients were taking OAC on admission to the hospital for surgery. Factors associated with OAC discontinuation are shown in Table 3. On discharge, 299/458 patients were on OAC (142 DOAC and 157 warfarin). 97 patients were taken off

Table 3 Factors associated with OAC discontinuation after surgical LAA exclusion

Discharged on OAC ($n=299$)	Stop OAC ($n=97$)	Continue OAC ($n=202$)	p value
Average Age (years)	65.6 +/- 10.3	67.3 +/- 10.2	0.17
Sex (% female)	28.9	34.2	0.36
CHA_2DS_2VASc	3.1 +/- 1.7	3.5 +/- 1.5	0.052
LVEF (%)	49.2 +/- 11.1	49.5 +/- 11.6	0.82
Creatinine	1.0 +/- 0.5	1.1 +/- 0.7	0.33
Post-op TEE Performed, n (%) ($n=94$)	55 (56.7)	39 (19.3)	< 0.001
TEE w/ LAA Remnant < 1 cm ($n=70$)	46/70	24/70	< 0.001
TEE Original Interpretation Success (61 studies with comprehensive initial interpretation of which 42 were read as successful)	30/42	12/42	0.010

Table 4 Multivariate analysis of factors associated with OAC discontinuation after surgical LAA exclusion

Clinical variable	Odds ratio [95% CI]	p value
Age	1.00 [0.97–10.4]*	0.96
Sex (female)	0.78 [0.42–1.42]	0.42
CHA_2DS_2VASc	0.83 [0.69–1.06]**	0.14
Post-op TEE performed	5.8 [3.4–10.2]	< 0.001

*Per unit change (1 year) within the entire range

**per 1 point change in risk score

anticoagulation in follow-up, and nearly half of this decision-making (46/97 patients, 47.4%) was not imaging-driven. Patients who were continued on their OAC after surgical LAA exclusion trended toward having a higher CHA_2DS_2-VASc score than those who had their OAC discontinued. Of the cohort discharged on OAC, 94/299 had a follow-up TEE and 205/299 did not have a follow-up TEE. Among the cohort who underwent TEE, 58.5% (55/94) were taken off OAC and 53.2% (50/94) came off anticoagulation after the TEE; among those without a TEE, 20.5% (42/205) were taken off OAC. In a multivariable model controlling for age, sex, CHA_2DS_2-VASc score, and TEE imaging, only performance of TEE was associated with OAC cessation. Patients were more than 5 times more likely to come off anticoagulation if a TEE was performed [OR for OAC cessation 5.8 (95% CI 3.4–10.2, $p<0.01$)]. (Table 4) Among patients discharged on OAC with a TEE performed prior to OAC cessation, successful exclusion (by our study's standards, applied retrospectively) was associated OAC cessation, OR 4.1 (95% CI 1.3–13.7). A flowchart of OAC management and TEE follow-up is shown in Fig. 1.

Among the 94 patients discharged on OAC who had a follow-up TEE, 9 were unable to be assessed for adequacy of closure, 70 were successful by our definition, and 15 showed unsuccessful closure by our definition. Among the 85 patients with follow-up TEE in this cohort, 56 had oversew, 24 had Atriclip, and 5 had other closures (TigerPaw or Bovine pericardium). The oversew method resulted in 8/56 (14%) patients with leaks, Atriclip had 5/24 (21%) with leaks, and other methods had 2/5 (40%) with leaks. In the group with successful closure of their LAA, 65.7% (46/70) were taken off their oral anticoagulation, with cessation occurring after the TEE in 93.5% (43/46) of those patients. Recognizing the limitation that our interpretation of successful LAA exclusion may have been different than the care providers at the time, we evaluated the predictive power of the original read with a similar multivariable model as used for our adjudication of successful LAA exclusion. For this predictive variable, if the original TEE read suggested successful exclusion or measured remnant < 1.0 cm, we classified this as success. Among patients with a TEE prior to OAC cessation, the original TEE read suggesting successful LAA closure was also associated with OAC discontinuation [OR 3.0 (95% CI 1.2–7.9)]. Only TEEs with initial reads with description of the LAA ($N=61$) were included for this analysis.

Stroke

8.3% of the total cohort (38/458) had a stroke in the postoperative period without any censoring for early postoperative strokes. Of the 38 postoperative strokes, 21 were within 4 weeks postoperatively. Including *all* strokes (in a multivariable model incorporating age, sex, CHA_2DS_2-VASc score, and OAC on discharge as predictors), only CHA2DS2-VASc score was independently associated with risk of stroke (HR 1.50, 95% CI 1.13-2.00, $p=0.006$, per one-point increase in CHA_2DS_2-VASc score).

Of the 83 patients with TEE-confirmed adequate closure, 7 had postoperative strokes (8.4%); 3 of the 7 strokes occurred within 4 weeks of the procedure. The details of these strokes are available in Table 5.

Discussion

Our study examined patterns of care with regard to OAC use and LAA imaging in patients with a preoperative diagnosis of AF who underwent surgical LAA exclusion during cardiac surgery, whether as a stand-alone MAZE procedure or concomitant to valve or bypass surgery. Our principal findings include: (1) many patients who

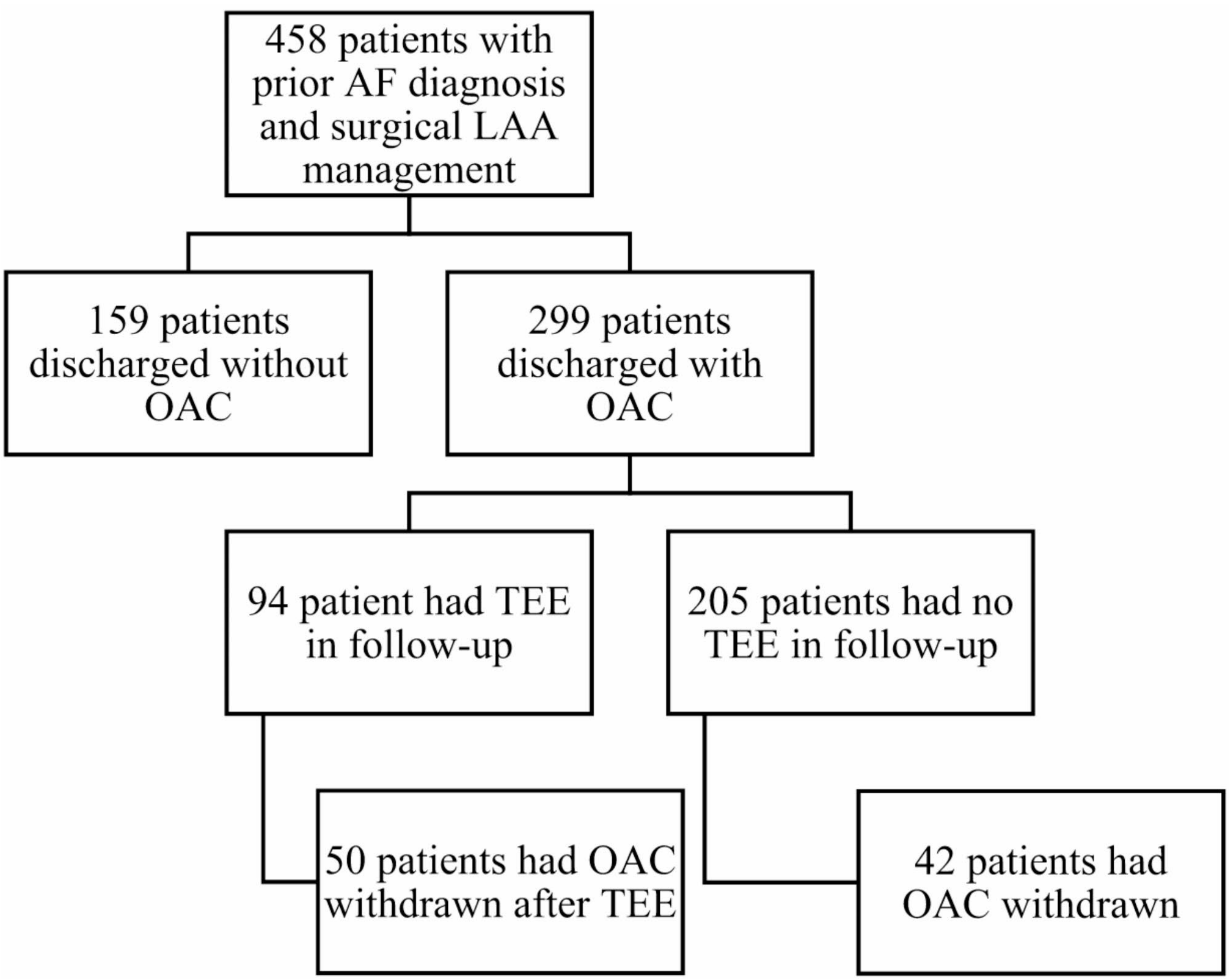

Fig. 1 TEE follow-up in patients discharged on OAC after surgical LAA exclusion

Table 5 Subjects ($N=7$) with successful LAA closure who suffered post-operative stroke

Timing of TEE (weeks post-op)	Timing of Stroke (weeks post-op)	TOAST	OAC Cessation	Timing of OAC cessation (weeks post-op)
10	0	Probable cardioembolic	Y	14
2	0	Stroke of undetermined etiology (cardioembolic or large artery)	Y	22
5	4	Probable cardioembolic	N	N/A
60	60	Probable cardioembolic	N	N/A
108	82	Possible cardioembolic	Y	81 (due to subdural hematoma)
142	75	Undetermined (likely small vessel)	N (was not on OAC at discharge, but placed on OAC at 30 weeks)	N/A
134	190	Small artery occlusion	Y	141

undergo surgical closure never undergo postoperative verification of adequacy of closure; (2) the time-course is highly variable among patients who do undergo postoperative imaging; (3) anticoagulation cessation practices in the postoperative setting are highly variable and nearly half of patients who had their stopped anticoagulation did not undergo a TEE before discontinuing OAC; and (4) obtaining a TEE and confirming adequate LAA closure were the only significant predictors of anticoagulation cessation.

Mounting evidence from recent literature suggests a benefit to surgical LAA exclusion in patients with AF.

A meta-analysis of patients undergoing surgical LAA exclusion during cardiac surgery demonstrated a significant reduction in stroke risk in patients with exclusion at short-term and most recent follow-up [25]. More recently, the Left Atrial Appendage Occlusion Study III (LAAOS III) demonstrated clinical efficacy for stroke prevention among patients with AF undergoing LAA exclusion at the time of cardiac surgery [13]. This enthusiasm has been further bolstered by a growing body of literature suggesting the efficacy of percutaneous LAA exclusion as an alternative to systemic anticoagulation (PROTECT AF, PREVAIL, PRAGUE-17) [18–21]. Anticoagulation cessation after percutaneous LAA exclusion is guided by standardized imaging surveillance.

Unlike with percutaneous LAA exclusion, the optimal strategy for oral anticoagulation management and LAA remnant imaging after surgical LAA exclusion is not well established. In our study, we found that the majority of patients did not receive follow-up TEE imaging to assess adequacy of LAA closure. There were no predictive factors identified elucidating practice patterns for both follow-up imaging and OAC cessation likely suggesting that the practice is provider-dependent rather than standardized. In the LAAOS III study, the benefit of surgical LAA exclusion with respect to the outcome of embolic events was demonstrated independent of anticoagulation status [13]. To our knowledge, literature examining surgical LAA exclusion as an alternative to anticoagulation has not been published. Decision-making regarding the risk-benefit evaluation of anticoagulation cessation is thus left largely to the provider.

Further complicating decision-making, available literature examining the success of surgical LAA exclusion by imaging shows that ideal closure occurs about 60% of the time and may depend in part on the experience level of the surgeon [9, 22]. This has not been well examined except in a few studies. In one of the largest series (72 patients), Aryana et al. evaluated ischemic stroke and systemic embolization risk in patients with left atrial appendage exclusion and closure determined via computed tomography [26]. In their study, 64% of patients had a complete LAA ligation. Importantly, their analysis shows that incomplete surgical ligation (as determined by CTA) is an independent risk factor for embolic events.

The combination of data supporting the value of LAA exclusion in stroke risk reduction and further data reporting inconsistent LAA exclusion raises a few issues. These findings of inconsistent surgical exclusion success highlight the potential importance of follow-up in patients with surgical LAAO. Imaging follow-up is considered standard of care in percutaneous LAA exclusion as a prerequisite to anticoagulation cessation, but there are no such recommendations in patients undergoing surgical exclusion. Furthermore, there are no evidence-based recommendations to guide either the method of LAA remnant evaluation or to guide decision-making regarding anticoagulation management in these patients. Stroke risk, specifically cardioembolic stroke risk, was significantly associated only with CHA_2DS_2-VASc score.

The importance of this data is clear: there is no consensus on long-term thromboembolism prevention strategies in patients with AF who undergo cardiac surgery. Further randomized control trials examining stroke risk mitigation in these patients are needed, but guidance for providers is needed in the meantime. We believe that an organized, multidisciplinary approach is necessary in the care of patients with AF who are to undergo cardiac surgery. Foremost among these is collaborations between electrophysiology, cardiac surgery, and structural imaging providers. Specifically, pre-operative discussions are needed on whether to exclude or excise the LAA during the cardiac surgery. Next, the use of oral anti-coagulation in the post-operative period should be addressed in a multi-disciplinary fashion, and proper electrophysiology and cardiac surgery follow-up is essential for the patient being referred for TEE to assess the success of LAA exclusion. We feel that interpretation of TEE findings requires an experienced echocardiographer, as clear standards for what constitutes adequate surgical LAA management are lacking. A standard of LAA remnant < 1 cm in depth has been proposed in recently published AF guidelines, but this is based primarily upon a small published series using CT as the imaging standard [17, 26]. Lastly, based on the imaging findings, a long-term OAC strategy can be determined with involvement from electrophysiology, general cardiology, and primary care. We have proposed such a model in Supplementary Fig. 1.

Our study has several limitations to acknowledge. Because of its retrospective nature, follow-up (imaging and management) was not standardized. The reasons why patients were or were not prescribed oral anticoagulation could not always be fully elucidated; similarly, we were unable to specify the rationale behind why some patients came off of oral anticoagulation (whether due to imaging-confirmed LAA exclusion or other reasons). Additionally, we do not have the indication for our TEEs and it is likely that many TEEs were not ordered with the intention of evaluating the LAA remnant. Our data is taken from a single center EHR, so any events diagnosed or imaging studies performed at another institution would not be available for inclusion in the dataset.

Conclusions

Based on our data and analysis of the current literature, there is a clear need for a more consistent, protocolized approach to confirmatory TEE and OAC withdrawal in patients with surgical exclusion. Further studies with clear enrollment criteria defining anticoagulation and imaging practices should be considered in order to better understand the clinical efficacy of surgical left atrial appendage exclusion with and without long-term OAC.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s13019-025-03378-x.

Supplementary Material 1: **Supplementary Figure 1**: Proposed Care Model

Author contributions

PB supervised the project, drafted and revised the manuscript. KD collected data and drafted portions of the manuscript. SC drafted portions the manuscript and provided edits. MS provided critical revisions/edits. JB provided critical revisions/edit. KR provided critical revisions/edits. All authors reviewed the manuscript.

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Data availability

No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate

Not applicable.
The protocol was approved by the Wake Forest School of Medicine's Institutional Review Board (study number IRB00064192).

Competing interests

The authors declare no competing interests.

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References

1. Wolf PA, Abbott RD, Kannel WB. Atrial fibrillation as an independent risk factor for stroke: the Framingham study. Stroke. 1991;22:983–8.
2. Schnabel RB, Yin X, Gona P, et al. 50 Year trends in atrial fibrillation prevalence, incidence, risk factors, and mortality in the Framingham heart study: a cohort study. Lancet. 2015;11:154–62.
3. Colilla S, Crow A, Petkun W, Singer DE, Simon T, Liu X. Estimates of current and future incidence and prevalence of atrial fibrillation in the U.S. Adult population. Am J Cardiol. 2013;15:1142–7.
4. Park-Hansen J, Holme SJV, Irmukhamedov A, et al. Adding left atrial appendage closure to open heart surgery provides protection from ischemic brain injury six years after surgery independently of atrial fibrillation history: the LAACS randomized study. J Cardiothorac Surg. 2018;13:53.
5. Blackshear JL, Odell JA. Appendage obliteration to reduce stroke in cardiac surgical patients with atrial fibrillation. Ann Thorac Surg. 1996;61:755–9.
6. Al-Saady NM, Obel OA, Camm AJ. Left atrial appendage: structure, function, and role in thromboembolism. Heart. 1999;82:547–54.
7. Beigel R, Wunderlich NC, Ho SY, Arsanjani R, Siegel RJ. The left atrial appendage: anatomy, function, and noninvasive evaluation. JACC Cardiovasc Imaging. 2014;7:1251–65.
8. Goldman ME, Pearce LA, Hart RG, et al. Pathophysiologic correlates of thromboembolism in nonvalvular atrial fibrillation: I. Reduced flow velocity in the left atrial appendage (The stroke prevention in atrial fibrillation [SPAF-III] study). J Am Soc Echocardiogr. 1999;12:1080–7.
9. Healey JS, Crystal E, Lamy A, et al. Left atrial appendage occlusion study (LAAOS): results of a randomized controlled pilot study of left atrial appendage occlusion during coronary bypass surgery in patients at risk for stroke. Am Heart J. 2005;150:288–93.
10. Zheng Y, Rao CF, Chen SP, He L, Hou JF, Zheng Z. Surgical left atrial appendage occlusion in patients with atrial fibrillation undergoing mechanical heart valve replacement. Chin Med J (Engl). 2020;133:1891–9.
11. Johnsrud DO, Melduni RM, Lahr B, Yao X, Greason KL, Noseworthy PA. Evaluation of anticoagulation use and subsequent stroke in patients with atrial fibrillation after empiric surgical left atrial appendage closure: A retrospective case-control study. Clin Cardiol. 2018;41:1578–82.
12. Melduni RM, Schaff HV, Lee HC, et al. Impact of left atrial appendage closure during cardiac surgery on the occurrence of early postoperative atrial fibrillation, stroke, and mortality: a propensity score-matched analysis of 10 633 patients. Circulation. 2017;135:366–78.
13. Whitlock RP, Belley-Cote EP, Paparella D, et al. Left atrial appendage occlusion during cardiac surgery to prevent stroke. N Engl J Med. 2021;384:2081–91.
14. Whitlock RP, Vincent J, Blackall MH, et al. Left atrial appendage occlusion study II (LAAOS II). Can J Cardiol. 2013;29:1443–7.
15. Friedman DJ, Piccini JP, Wang T, et al. Association between left atrial appendage occlusion and readmission for thromboembolism among patients with atrial fibrillation undergoing concomitant cardiac surgery. JAMA. 2018;319:365–74.
16. Atti V, Anantha-Narayanan M, Turagam MK, et al. Surgical left atrial appendage occlusion during cardiac surgery: A systematic review and meta-analysis. World J Cardiol. 2018;10:242–9.
17. Joglar JA, Chung MK, Armbruster AL, et al. 2023 ACC/AHA/ACCP/HRS guideline for the diagnosis and management of atrial fibrillation: A report of the American college of cardiology/american heart association joint committee on clinical practice guidelines. Circulation. 2024;149:e1–156.
18. Reddy VY, Holmes D, Doshi SK, Neuzil P, Kar S. Safety of percutaneous left atrial appendage closure: results from the watchman left atrial appendage system for embolic protection in patients with AF (PROTECT AF) clinical trial and the continued access registry. Circulation. 2011;123:417–24.
19. Holmes DR Jr, Kar S, Price MJ, et al. Prospective randomized evaluation of the watchman left atrial appendage closure device in patients with atrial fibrillation versus long-term warfarin therapy: the PREVAIL trial. J Am Coll Cardiol. 2014;64:1–12.
20. Osmancik P, Herman D, Neuzil P, et al. Left atrial appendage closure versus direct oral anticoagulants in high-risk patients with atrial fibrillation. J Am Coll Cardiol. 2020;75:3122–35.
21. Reddy VY, Doshi SK, Sievert H, Buchbinder M, Neuzil P, Huber K, Halperin JL, Holmes D. PROTECT AF investigators. Percutaneous left atrial appendage closure for stroke prophylaxis in patients with atrial fibrillation: 2.3-Year Follow-up of the PROTECT AF (Watchman left atrial appendage system for embolic protection in patients with atrial Fibrillation) trial. Circulation. 2013;127:720–9.
22. Katz ES, Tsiamtsiouris T, Applebaum RM, Schwartzbard A, Tunick PA, Kronzon I. Surgical left atrial appendage ligation is frequently incomplete: a transesophageal echocardiograhic study. J Am Coll Cardiol. 2000;36:468–71.
23. Ellis CR, Aznaurov SG, Patel NJ, et al. Angiographic efficacy of the atriclip left atrial appendage exclusion device placed by minimally invasive thoracoscopic approach. JACC Clin Electrophysiol. 2017;3:1356–65.
24. Lee R et al. Oct. A Randomized, Prospective Pilot Comparison of 3 Atrial Appendage Elimination Techniques: Internal Ligation, Stapled Excision, and Surgical Excision. The Journal of Thoracic and Cardiovascular Surgery, vol. 152, no. 4, 2016, pp. 1075–80.
25. Tsai YC, Phan K, Munkholm-Larsen S, Tian DH, La Meir M, Yan TD. Surgical left atrial appendage occlusion during cardiac surgery for patients with atrial fibrillation: a meta-analysis. Eur J Cardiothorac Surg. 2015;47:847–54.
26. Aryana A, Singh SK, Singh SM, et al. Association between incomplete surgical ligation of left atrial appendage and stroke and systemic embolization. Heart Rhythm. 2015;12:1431–7.

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