Left atrial appendage closure during cardiac surgery: Safe but underutilized in California

Check for updates

Joseph Hadaya, MD, PhD,[a] Roland Hernandez, MD, JD, MPH,[b] Yas Sanaiha, MD,[a] Beate Danielsen, PhD,[c] Joseph Carey, MD,[d] Richard J. Shemin, MD,[a] and Peyman Benharash, MD[a]

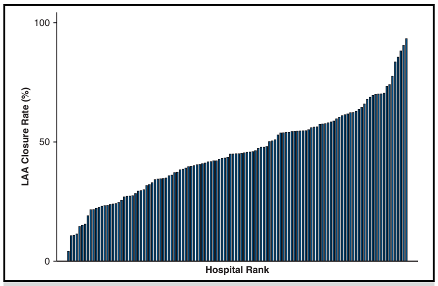
ABSTRACT

Objective: Left atrial appendage (LAA) closure is associated with reduced rates of stroke in patients with atrial fibrillation (AF). We evaluated trends in LAA closure, the association of LAA closure with stroke/systemic embolism, and its safety profile in patients with AF who underwent cardiac surgery in California. We further tested for hospital-level variation in concomitant LAA closure.

Methods: Adults who underwent coronary artery bypass grafting and/or valve surgery with preoperative AF were identified in the 2016 to 2019 Office of Statewide Health Planning and Development databases. Propensity score matching was performed to study risk-adjusted associations of LAA closure with ischemic stroke/systemic embolism. Hospital-level variation was studied using intraclass correlation coefficients.

Results: Among 18,434 patients with AF who underwent coronary artery bypass grafting/valve surgery, 47.7% received LAA closure. Rates of LAA closure increased from 44.4% to 51.4% from 2016 to 2019 ($P < .001$). In 4652 propensity score-matched patients, LAA closure was associated with reduced incidence of stroke/systemic embolism at discharge (1.6% vs 3.1%; $P < .001$) and readmission with stroke/systemic embolism at 1 year (2.9% vs 4.5%; $P = .004$). LAA closure was not associated with acute kidney injury, pulmonary complications, blood transfusion, reoperation, or in-hospital mortality. Approximately 18% of the risk-adjusted variation in LAA use was attributed to the hospital, with median center-level rate of 44.9% (interquartile range, 29.6%-57.4%).

Conclusions: LAA closure was associated with minimal surgical morbidity, and reduced short- and midterm incidence of stroke/systemic embolism. Although the use of LAA closure has increased, substantial variation exists among programs in California, suggesting the need for further standardization of care. (JTCVS Open 2023;13:150-62)



Observed left atrial appendage closure rates according to center.

CENTRAL MESSAGE

A high degree of interhospital variation persists in the use of left atrial appendage closure during cardiac surgery, despite a favorable safety profile.

PERSPECTIVE

Left atrial appendage (LAA) closure is an opportunity to manage AF-associated stroke risk. In a statewide cohort of CABG/valve surgery patients with AF, LAA closure was associated with reduced stroke and no excess morbidity. Although use of LAA closure increased from 2016 to 2019, substantial interhospital variation was present, with centers representing 18% of the variance in its use.

Atrial fibrillation (AF) is associated with increased morbidity, mortality, and health care expenditures.[1-3] Thromboembolism including stroke and adverse sequalae of anticoagulation negatively affect patient longevity and quality of life.[1,4,5] Although pharmacologic and procedural means are used to reduce the risk of stroke in these patients, the utilization of left atrial appendage (LAA) closure among cardiac surgical candidates is not well characterized.[6,7]

Recently, the Left Atrial Appendage Occlusion Study (LAAOS) III trial showed the safety and efficacy of LAA closure in patients who underwent concomitant cardiac surgery.[8] The investigators identified a lower risk of ischemic stroke and systemic arterial embolization in cardiac surgical patients who underwent LAA occlusion in a randomized, multicenter cohort. Despite the benefit of LAA closure, the regularity with which it is performed in cardiac surgery,

From the [a]Division of Cardiac Surgery, David Geffen School of Medicine at UCLA, Los Angeles, Calif; [b]Division of Cardiac Surgery, Swedish Heart and Vascular Institute, Seattle, Wash; [c]Health Information Solutions, Rocklin, Calif; and [d]Division of Cardiothoracic Surgery, University of California Irvine Medical Center, Orange, Calif.

Read at the 48th Annual Meeting of the Western Thoracic Surgical Association, Koloa, Hawaii, June 22-25, 2022.

Drs Carey, Shemin, and Benharash are Western Thoracic Surgical Association members.

Received for publication June 25, 2022; revisions received Oct 14, 2022; accepted for publication Nov 21, 2022; available ahead of print Jan 11, 2023.

Address for reprints: Peyman Benharash, MD, UCLA David Geffen School of Medicine, CHS 62-249, 10833 Le Conte Ave, Los Angeles, CA 90095 (E-mail: Pbenharash@mednet.ucla.edu).

2666-2736

https://doi.org/10.1016/j.xjon.2022.11.016

Abbreviations and Acronyms

AF	= atrial fibrillation
CABG	= coronary artery bypass grafting
ICD-10	= *International Classification of Diseases, 10th Revision*
LAA	= left atrial appendage
LAAOS III	= Left Atrial Appendage Occlusion Study III
OSHPD	= Office of Statewide Health Planning and Development

as well as the efficacy and safety profiles among large real-world cohorts, remains limited. Moreover, although institutional practice patterns are known to influence outcomes in cardiac surgery,[9-11] their effect on performance of atrial appendage closure remains uncharacterized.

In this study, we characterized trends in the use of LAA closure and its safety profile when performed at the time of cardiac surgery among a contemporary cohort of patients across the state of California. We subsequently tested the hypothesis that LAA closure reduces short- or intermediate-term stroke or arterial thromboembolism risk, and evaluated for hospital-level variation in its use.

METHODS

Data Source and Cohort Definitions

In the present study we used the California Office of Statewide Health Planning and Development (OSHPD) patient discharge, ambulatory surgery, and emergency department databases.[12] The OSHPD database captures approximately 4 million inpatient encounters across all nonfederal acute care hospitals in California and is linked to ambulatory surgery and emergency department encounters, with reporting mandated by state law.[12]

All adults (18 years of age and older) who underwent coronary artery bypass grafting (CABG) or valve surgery from 2016 to 2019 were identified using *International Classification of Diseases, 10th Revision* (ICD-10) procedure codes as previously described.[11] Patients who underwent reoperative cardiac surgery were excluded from further study, as were those with a previous encounter for percutaneous LAA closure. Preoperative AF was defined as paroxysmal, persistent, or permanent AF that was present before the surgical hospitalization using previously published ICD-10 diagnosis codes (I48.0, I48.1, I48.2, and I48.91) and the present on-admission indicator.[13] The primary exposure of interest was LAA closure at the time of cardiac surgery, and patients with preoperative AF were divided into 2 groups on this basis.

The State of California Health and Human Services Agency, Committee for the Protection of Human Subjects approved the study protocol and publication of data (number 12-06-0401; date: October 2, 2020). Patient written consent for the publication of the study data was waived by the institutional review board because of the deidentified nature of the data set.

Data Definitions and Study Outcomes

Patient demographic characteristics, clinical data, and hospital-level variables are reported as defined by the OSHPD including age, sex, race, principal and secondary diagnoses, principal and secondary procedures, and discharge disposition. Comorbidities were derived using ICD-10 coding of principal and secondary diagnoses present before admission. Ischemic stroke and systemic embolism were similarly defined as new events not present at admission at the index hospitalization using previously published ICD-10 diagnosis codes.[13] Mortality was defined as death during the index hospitalization. The primary outcomes of the study were ischemic stroke or systemic embolism at the index hospitalization, at a linked inpatient encounter within 1 year, or at a linked inpatient encounter through follow-up until December 31, 2019. Secondary outcomes included reoperation, need for any blood transfusion, pulmonary complications (pneumonia, reintubation, mechanical ventilation for >24 consecutive hours, and tracheostomy), and hospital length of stay.

Statistical Analysis

Categorical variables are reported as count and percentage and continuous variables as mean with SD or median and interquartile range if non-normally distributed. The significance of temporal trends was studied using Cuzick's nonparametric test.[14] The χ^2 test was used to compare categorial variables, whereas continuous variables were compared using the Student *t* test or the Wilcoxon rank sum test, if non-normally distributed. Because of the imbalance in the cohort of those who received LAA closure, propensity score matching was performed to adjust for baseline characteristics. The propensity score for each patient was derived from a logistic regression model using covariates with a standardized mean difference >0.10 (age, sex, aortic valve operation, mitral valve operation, other valve operation, CABG, Elixhauser Comorbidity Index, nonelective case, race, primary insurer, congestive heart failure, chronic lung disease, pulmonary circulatory disorder, hypertension, previous myocardial infarction, diabetes, coagulopathy, end stage renal disease, chronic liver disease). Patients were matched with Mahalanobis using 1:1 nearest-neighbor matching with a caliper distance of 0.2.[15] The balance of score distributions among the 2 groups was evaluated graphically and by assessing standardized mean differences after matching (Table E1).

To evaluate for the presence of hospital-level variation, a hierarchical regression for LAA closure with hospital identifier as a random effect was used. Bayesian estimates of each center's risk and reliability adjusted probability of LAA closure were generated. These values represent the propensity of each hospital to perform LAA closure independent of patient factors. The fixed effects in the model comprised the same variables adjusted for in the propensity analysis. To confirm our findings, this analysis was repeated in the propensity score-matched cohort with solely the hospital identifier as a random effect.

To quantify the proportion of variance attributable to the hospitals, the intraclass correlation coefficient was calculated. Statistical analyses were performed using Stata Version 16 (StataCorp).

RESULTS

Cohort Characteristics and Trends in LAA Closure

During the study period, 87,928 adults who met study criteria underwent CABG or valve surgery at 127 hospitals in California, of which 21.0% (18,434) had preoperative AF (paroxysmal 45.6%, persistent 32.5%, permanent 21.9%). Among patients with preoperative AF who underwent CABG or valve surgery, 47.7% (8782) underwent concomitant LAA closure. The rate of LAA closure varied with the primary cardiac operation, with rates of 34.6% (of 7478) for isolated CABG, 43.9% (of 4278) for aortic valve surgery with or without CABG, 65.5% (of 3900) for mitral valve surgery with or without CABG, and 64.9% (of 2778) for tricuspid, pulmonic, or multivalve cases with or without

CABG. Over time, concomitant LAA closure increased for all operative categories (Figure 1).

Patients who underwent LAA closure were older (69.8 vs 69.1 years; $P < .001$), more commonly female (32.1% vs 29.4%; $P < .001$), White (74.4% vs 69.8%; $P < .001$), and insured by Medicare (67.3% vs 64.6%; $P < .001$) compared with those who did not undergo LAA closure (Table 1). Patients who did not receive LAA closure more commonly had nonelective cases (45.0% vs 34.6%; $P < .001$) and less commonly received any concomitant surgical ablation (7.1% vs 47.1%; $P < .001$). The overall burden of chronic medical conditions, defined using the Elixhauser Comorbidity Index, was comparable among the study groups. Specific comorbidities such as congestive heart failure (60.3% vs 54.3%; $P < .001$), pulmonary circulatory disorders (23.1% vs 15.9%; $P < .001$) were more common in patients who underwent LAA closure compared with others, whereas conditions such as chronic liver or pulmonary disease or history of myocardial infarction were less prevalent (Table 1).

LAA Closure Is Associated With a Reduction in Ischemic Stroke or Systemic Embolism

To evaluate the efficacy of LAA closure, we examined a composite of postoperative ischemic stroke or systemic embolism at discharge, at linked inpatient encounters within 1 year, and at linked encounters through the end of the follow-up period. The composite end point was significantly reduced by the time of hospital discharge among patients who received LAA closure (2.1% vs 2.7%; $P = .006$), primarily driven by a difference in stroke (1.6% vs 2.3%; $P < .001$). At 1 year, rates of stroke or systemic embolism requiring hospitalization remained significantly lower in the LAA closure group (3.2% vs 4.2%; $P < .001$), similarly driven by a difference in ischemic stroke. At a mean follow-up of 2.1 years postoperatively, stroke or systemic embolism were significantly reduced among those who received LAA closure (4.2% vs 5.2%; $P = .002$).

Because of the baseline differences in the groups, we performed a propensity score-matched analysis to better

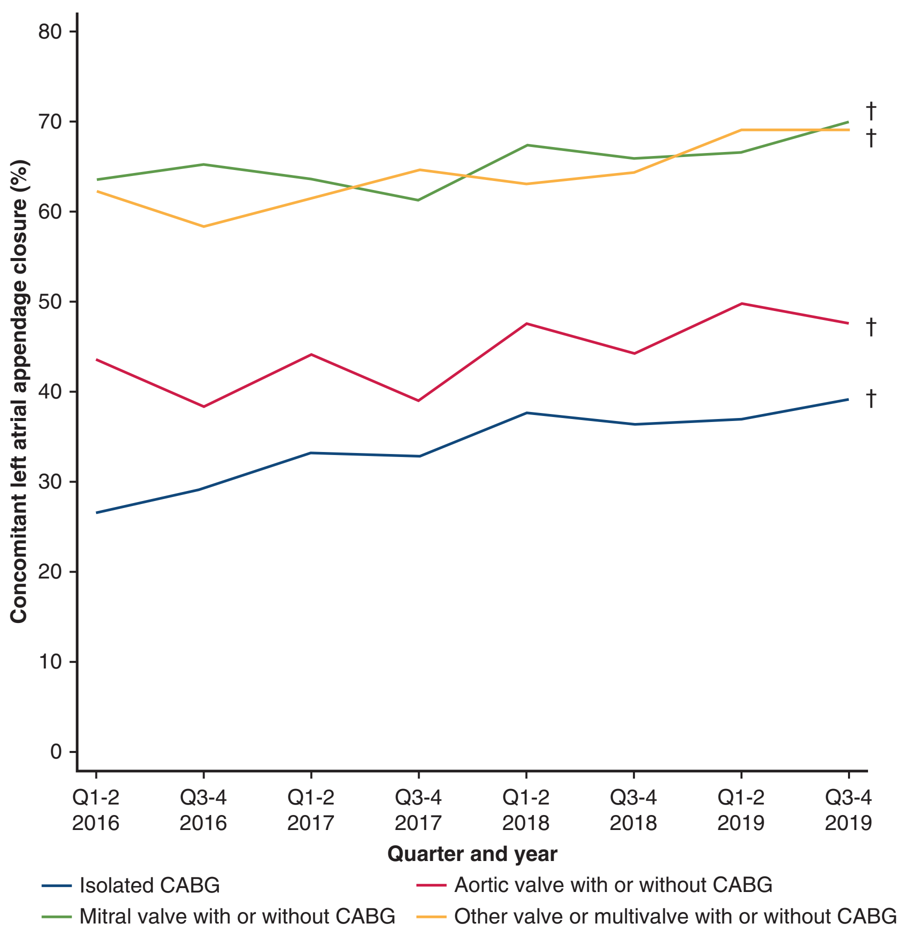


FIGURE 1. Trends in the use of concomitant left atrial appendage closure in patients with atrial fibrillation. Other valve includes multivalve, tricuspid or pulmonic valve surgery, with or without coronary artery bypass grafting (*CABG*). † $P < .05$ for trend.

TABLE 1. Characteristics of patients with AF who underwent CABG or valve surgery in 2016-2019 stratified according to closure of LAA

	No LAA closure (n = 9642)	LAA closure (n = 8792)	*P* value
Mean age (SD), y	69.1 (10.3)	69.8 (9.6)	<.001
Female sex	2837 (29.4)	2818 (32.1)	<.001
Primary payer			<.001
Medicare	6225 (64.6)	5914 (67.3)	
Medicaid	957 (9.9)	695 (7.9)	
Private	2172 (22.5)	1975 (22.5)	
Other payer*	288 (3.0)	208 (2.4)	
Race			<.001
White	6725 (69.8)	6543 (74.4)	
Black	323 (3.4)	257 (2.9)	
Asian or Pacific Islander	1313 (13.6)	993 (11.3)	
Other†	1281 (13.3)	999 (11.4)	
Operative category			<.001
Isolated CABG	4894 (50.8)	2584 (29.4)	
Aortic valve with or without CABG	2399 (24.9)	1879 (21.4)	
Mitral valve with or without CABG	1345 (14.0)	2555 (29.1)	
Other valve or multivalve with or without CABG	1004 (10.4)	1774 (20.2)	
Nonelective case	4343 (45.0)	3045 (34.6)	<.001
Surgical ablation	686 (7.1)	4143 (47.1)	<.001
Elixhauser Comorbidity Index			.17
0-1	569 (5.9)	538 (6.1)	
2-4	4256 (44.1)	3978 (45.3)	
5-8	3932 (40.8)	3537 (40.2)	
>8	885 (9.2)	739 (8.4)	
Comorbidities			
Anemia	503 (5.2)	452 (5.1)	.82
Congestive heart failure	5235 (54.3)	5305 (60.3)	<.001
Chronic liver disease	639 (6.6)	478 (5.4)	.001
Chronic lung disease	2125 (22.0)	1765 (20.1)	<.001
Chronic neurologic disorders	827 (8.6)	687 (7.8)	.06
Coagulopathy	3385 (35.1)	3313 (37.7)	<.001
Diabetes	4113 (42.7)	2926 (33.3)	<.001
End stage renal disease	758 (7.9)	411 (4.7)	<.001
Hypertension	8237 (85.4)	7190 (81.8)	<.001
Hypothyroidism	1244 (12.9)	1242 (14.1)	.02
Malnutrition	541 (5.6)	426 (4.9)	.02
Previous myocardial infarction	2451 (25.4)	1239 (14.1)	<.001
Pulmonary circulatory disorders	1531 (15.9)	2032 (23.1)	<.001
Rheumatologic disorders	240 (2.5)	226 (2.6)	.73

Data are reported as n (%) except where otherwise noted. *LAA*, Left atrial appendage; *SD*, standard deviation; *CABG*, coronary artery bypass grafting. *Other payer includes self-pay, uninsured, or county programs. †Other race includes Native American, Alaska Native, or other.

quantify the effect of LAA closure on risk-adjusted outcomes. Among 2326 well matched pairs (Figure 2), the risk-adjusted composite of stroke or systemic embolism rate was significantly reduced at discharge among those who received LAA closure (1.6% vs 3.1%; *P* = .001). As before, these differences were primarily driven by a reduction of postoperative ischemic stroke (1.4% vs 2.8%; *P* = .001) because systemic embolism rates were low. At 1 year, stroke or systemic embolism remained significantly lower in the LAA closure group (2.9% vs 4.5%; *P* = .004) compared with others, which persisted through follow-up (Table 2).

LAA Closure Is Not Associated With Excess Morbidity or Readmissions

To evaluate the safety of LAA closure, we examined in-hospital outcomes and readmissions in the overall cohort (Table 3). Compared with those who did not receive LAA

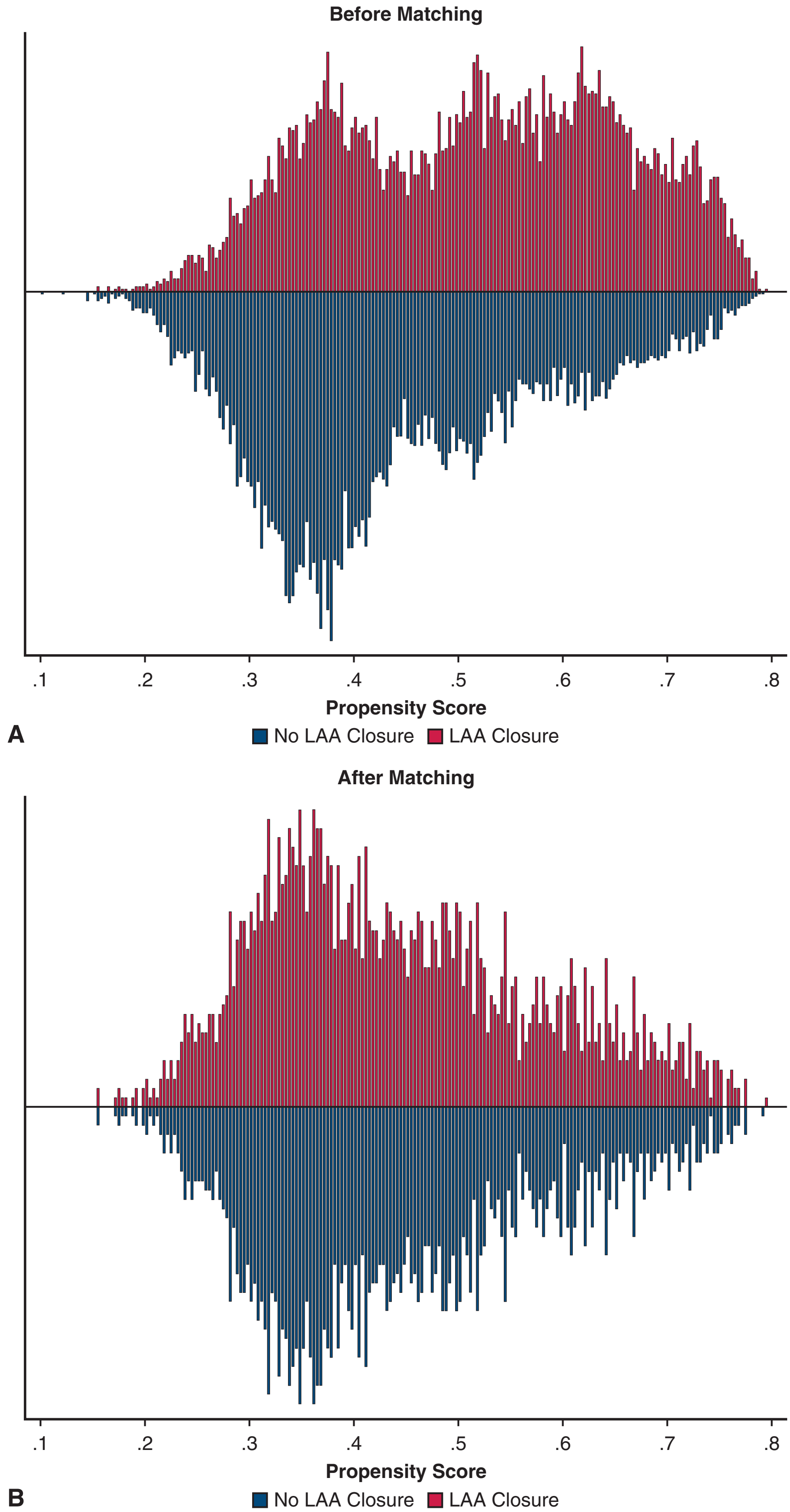


FIGURE 2. Distribution of propensity scores for left atrial appendage (*LAA*) closure (A) before and (B) after matching.

TABLE 2. Association of LAA closure with reduction in the incidence of ischemic stroke or systemic embolism

	Unadjusted			Propensity score-matched		
	No LAA closure (n = 9642)	LAA closure (n = 8792)	*P* value	No LAA closure (n = 2326)	LAA closure (n = 2326)	*P* value
Composite at discharge	262 (2.7)	184 (2.1)	.006	71 (3.1)	37 (1.6)	.001
Ischemic stroke	225 (2.3)	141 (1.6)	<.001	64 (2.8)	33 (1.4)	.001
Systemic embolism	45 (0.5)	32 (0.4)	.23	7 (0.3)	4 (0.2)	.37
Composite at 1 y	407 (4.2)	281 (3.2)	<.001	105 (4.5)	68 (2.9)	.004
Ischemic stroke	357 (3.7)	246 (2.8)	.001	94 (4.0)	61 (2.6)	.007
Systemic embolism	51 (0.5)	36 (0.4)	.24	11 (0.5)	8 (0.3)	.49
Composite at maximum follow-up time	498 (5.2)	368 (4.2)	.002	123 (5.3)	91 (3.9)	.03
Ischemic stroke	433 (4.5)	323 (3.7)	.005	107 (4.6)	80 (3.4)	.04
Systemic embolism	73 (0.8)	49 (0.6)	.09	17 (0.7)	13 (0.6)	.46

Unadjusted and propensity score-matched composite end point (ischemic stroke or systemic embolism) data are reported as n (%). Outcomes are reported at discharge, 1 year, and maximum follow-up time of cohort, and only represent events requiring hospitalization. *LAA*, Left atrial appendage.

closure, patients who underwent concomitant LAA closure had lower unadjusted rates of in-hospital mortality (2.8% vs 3.6%; *P* < .001). Complications including pneumonia, reintubation, and prolonged mechanical ventilation (>24 hours continuous) were comparable among the 2 groups. Moreover, the rate of any blood transfusion (34.8% vs 33.9%; *P* = .22) as well as reoperation (1.6% vs 1.4%; *P* = .23) were similar for those who received LAA closure compared with others. Postoperative length of stay was similarly comparable among the 2 groups (median, 7 vs 7; *P* = .35), as were readmissions at 30 and 90 days among those who survived to hospital discharge (Table 3).

Using the propensity score-matched cohort, in-hospital mortality was not significantly different among the 2 groups (3.7% for no LAA closure vs 3.4% for LAA closure; *P* = .56). The rates of all studied pulmonary complications, as well as reoperation and blood transfusion, remained comparable for both groups (Table 3). Similarly, there was no significant association between LAA closure and postoperative length of stay or readmission at 30 or 90 days (Table 3).

A High Degree of Hospital-Level Variation Exists for Use of Concomitant LAA Closure

To study hospital-level variation in LAA closure, we first examined unadjusted center-level rates of LAA closure among patients with AF. Significant variation was evident, with a median hospital-level incidence of LAA closure of 44.9%, with an interquartile range of 29.6% to 57.4% (Figure 3, *A*). Because LAA closure is dependent on patient factors, we generated Bayesian estimates of each center's risk and reliability adjusted probability of LAA closure after accounting for patient comorbidities and hospital case mix. These estimates represent the propensity of each

TABLE 3. Safety profile for concomitant LAA closure during CABG or valve surgery in California from 2016 to 2019

	Unadjusted			Propensity score-matched		
	No LAA closure (n = 9642)	LAA closure (n = 8792)	*P* value	No LAA closure (n = 2326)	LAA closure (n = 2326)	*P* value
Complications						
Acute kidney injury	2878 (29.9)	2528 (28.8)	.10	734 (31.6)	722 (31.0)	.58
Pneumonia	659 (6.8)	570 (6.5)	.34	168 (7.2)	159 (6.8)	.61
Tracheostomy	144 (1.5)	119 (1.4)	.42	35 (1.5)	27 (1.2)	.31
Reintubation	412 (4.3)	357 (4.1)	.47	114 (4.9)	122 (5.3)	.59
Prolonged mechanical ventilation*	348 (3.6)	302 (3.4)	.52	95 (4.1)	102 (4.4)	.61
Blood transfusion	3269 (33.9)	3056 (34.8)	.22	811 (34.9)	841 (36.2)	.36
Reoperation	134 (1.4)	141 (1.6)	.23	35 (1.5)	34 (1.5)	.90
In-hospital death	351 (3.6)	247 (2.8)	.001	86 (3.7)	79 (3.4)	.58
Postoperative LOS	7 (5-10)	7 (5-10)	.35	7 (5-10)	7 (5-10)	.24
Readmission at 30-d	1979 (21.3)	1773 (20.8)	.37	484 (21.6)	513 (22.8)	.32
Readmission at 90-d	2549 (27.4)	2328 (27.2)	.78	636 (28.4)	666 (29.6)	.36

Unadjusted and propensity score-matched outcomes are reported as n (%) for categorical variables, and median (interquartile range) for postoperative LOS. Readmission studied only for patients who survived to discharge. *LAA*, Left atrial appendage; *LOS*, length of stay. *Prolonged mechanical ventilation defined as >24 hours of continuous mechanical ventilation.

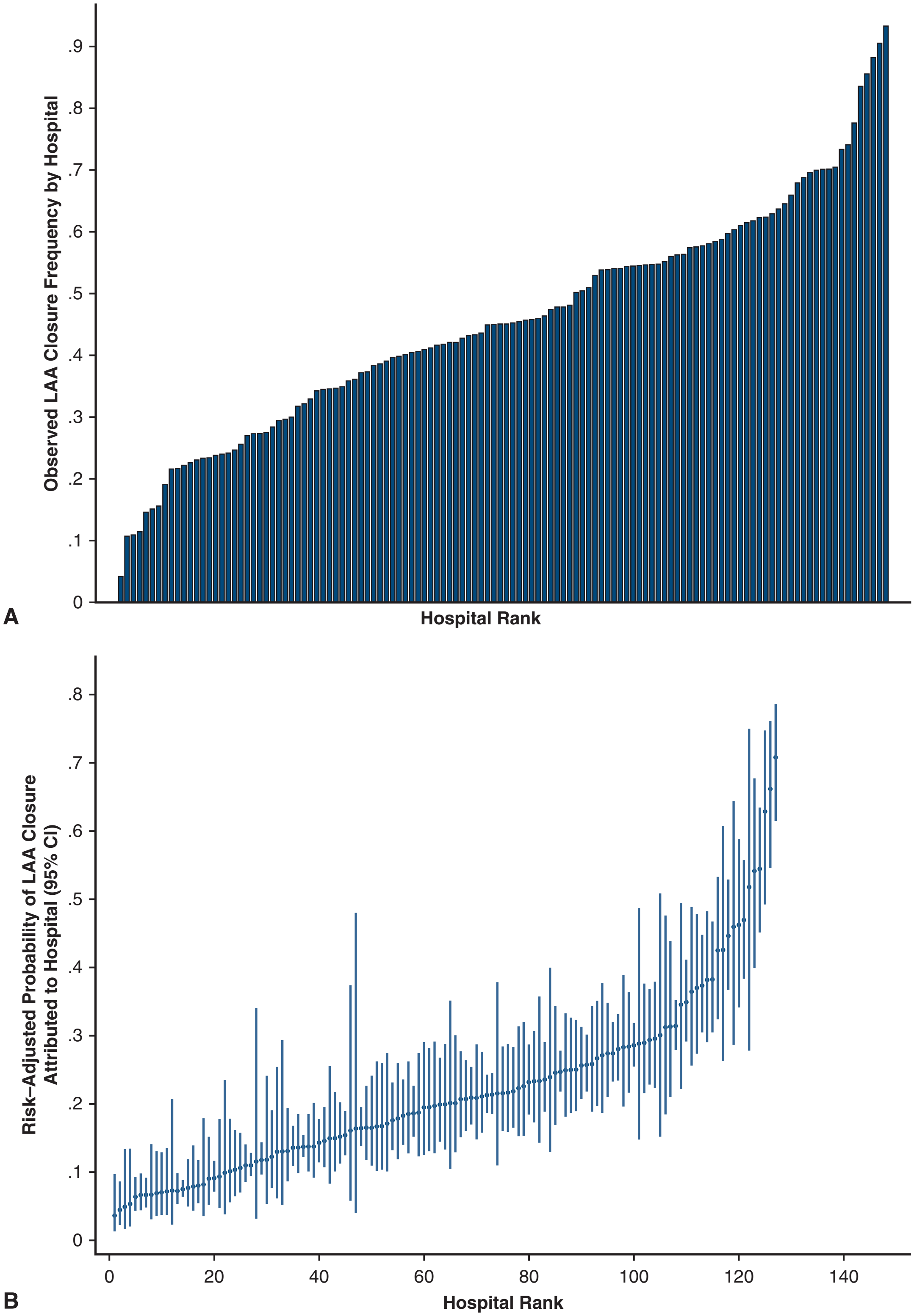


FIGURE 3. Hospital-level variation in concomitant left atrial appendage (*LAA*) closure. A, Observed incidence of LAA closure according to center for cases performed from 2016 to 2019. B, Risk and reliability adjusted probability of LAA closure according to center, adjusted for patient and case mix. Each estimate represents probability of LAA attributed to the institution, and reported with its 95% CI. *CI*, Confidence interval.

hospital to perform LAA closure independent of patient factors. As is shown in Figure 3, *B*, significant variation in the probability of LAA closure attributable to the hospital was evident, with median probability attributed to the hospital of 0.20 with interquartile range of 0.13 to 0.27 (range, 0.04-0.71). In other words, the probability of LAA closure, solely attributed to the operating hospital and independent of patient factors, ranged from 0.04 (4%) to 0.71 (71%). Using the intraclass correlation coefficient, approximately 17.6 $\pm$ 2.2% of the absolute variation in LAA closure was attributed to the hospital level in the overall cohort. These findings were similar in analysis of the 2326 propensity score-matched pairs, with 17.9 $\pm$ 2.8% of the variation in LAA closure attributed to the hospital level. There was no significant change in hospital-level variation over the study period (Table E2).

DISCUSSION

The present work showed increased adoption of LAA closure at the time of cardiac surgery in patients with AF across California, which was more common after valvular procedures compared with bypass grafting. LAA closure was not associated with excess morbidity at the index hospitalization, including comparable rates of blood transfusion and reoperation. Furthermore, LAA closure was associated with a significant reduction in the incidence of ischemic stroke or systemic embolism at the index hospitalization, at 1 year, and through a mean follow-up of 2.1 years. Hospitals accounted for nearly 20% of the observed variation in LAA closure rates among patients with AF (Figure 4).

Limited studies have examined recent trends in adoption of LAA closure at the time of cardiac surgery. In a study of 10,524 Medicare beneficiaries with AF who underwent CABG or valve surgery, approximately 37% of patients underwent LAA closure for cases performed from 2011 to 2012.[6] In our analysis of a more contemporary cohort of patients who underwent surgery, the overall LAA closure rate increased to 47.7% among those with AF, suggesting greater adoption of this technique over time, though our cohort was younger and included all payers. As expected, in our study LAA closure was more common at the time of mitral valve or multivalve surgery, and less common at the time of isolated CABG or aortic valve surgery. This finding is likely related to the fact that the atrial chambers are opened during mitral valve or multivalve surgery, such that the addition of LAA closure adds minimal operative time or risk. Similar findings have been reported for surgical ablation for AF by Badhwar and colleagues,[16] whereby those with AF who underwent left-sided valvular procedures had greater rates of AF ablation. Operative complexity might often deter surgeons from the addition of a full Cox maze IV procedure, particularly in patients who underwent extensive surgery or those less likely to revert to sinus rhythm such as those with extensively remodeled or giant left atria and with a long duration of AF. As recently reviewed by McCarthy,[17] and Badhwar and colleagues,[18] closure of the LAA should

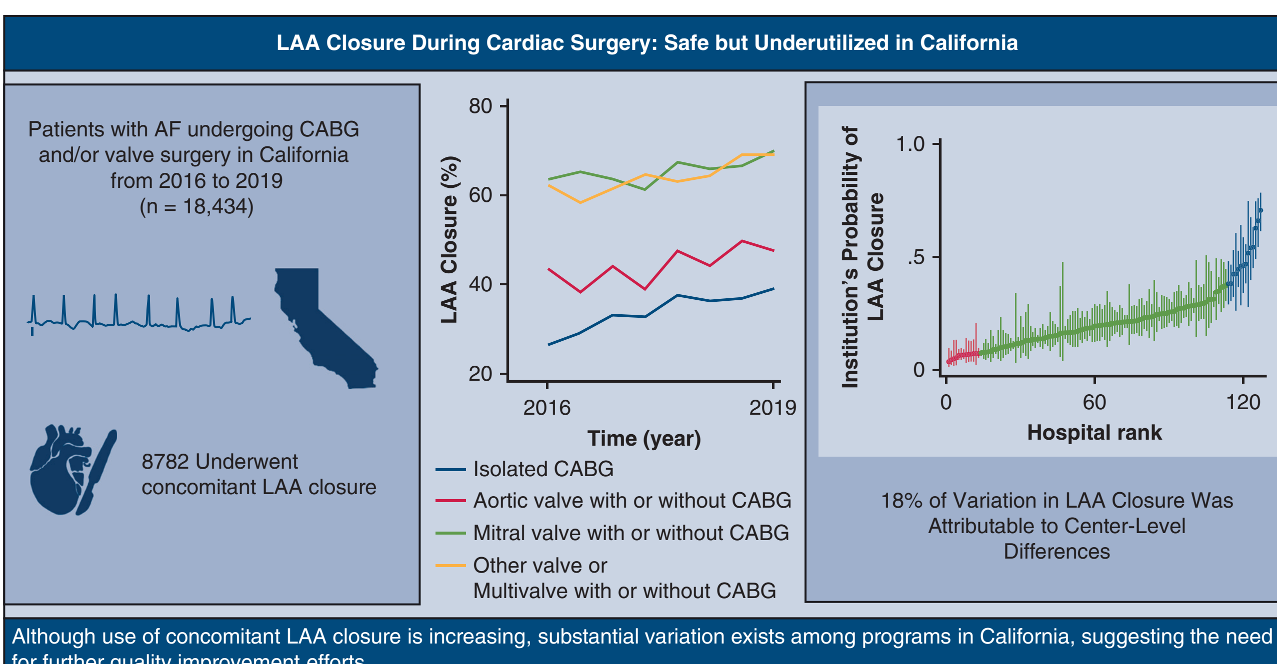


FIGURE 4. Although concomitant left atrial appendage (*LAA*) closure during coronary artery bypass grafting (*CABG*) and valve surgery is increasingly used, a high degree of center-level variation in its use is evident. *AF*, Atrial fibrillation.

be a priority because of its ease and clearly established benefit, with additional concomitant ablation on the basis of the goals of the primary operation and underlying disease. Such approaches, if uniformly adopted across hospital systems, might ultimately reduce variability in care and lead to improved surgical management of AF.

Although initial studies suggested greater surgical morbidity rates among patients who underwent LAA closure, more contemporary analyses suggest that this practice is safe, feasible, and can be routinely incorporated into surgical practice. Epicardial approaches to close the LAA have traditionally included resection and closure with or without pericardial or felt buttress, as well as stapling.[19] However, these approaches have fallen out of favor because of greater risk of bleeding, time required, or recanalization.[18,20,21] Recent adoption of epicardial clip-based closure has increased the reproducibility of LAA closure.[22] In the present work, which includes a study period from 2016 to 2019, we found comparable rates of re-exploration and blood transfusion requirement among patients who received LAA closure, although in our analysis we could not control for certain clinical factors including bypass time or left ventricular function. In a previous national study of 253,287 patients who underwent isolated CABG from 2010 to 2014 it was reported that LAA closure was associated with greater rates of respiratory failure, acute kidney injury, and readmission, hypothesized to be related to loss of atrial natriuretic peptide and the hemodynamic consequences of LAA exclusion.[23] In the present work, which captured only those with preoperative AF, we found no association between LAA closure and pulmonary complications, acute kidney injury, or readmission. As such, this study supports the existing literature that LAA closure can be safely performed without additional excess morbidity.

A growing body of evidence has shown a reduction in stroke and arterial thromboembolism among AF patients who undergo LAA closure.[13] A meta-analysis of 7 studies that comprised 3897 patients who underwent cardiac surgery with or without LAA closure showed a reduction in 30-day mortality and cerebrovascular accidents, predominantly driven by patients with a history of preoperative AF.[24] The strongest evidence to support LAA closure stems from the recently completed LAAOS III randomized controlled trial, which showed a 0.67-fold reduced hazard of stroke at a mean of 3.8 years of follow-up among those who received LAA closure compared with others, establishing causality between LAA closure and reduction of stroke.[8] An analysis of the Medicare population showed that among elderly patients, LAA closure was associated with a lower hazard of thromboembolism on discharge without anticoagulation, but not among those who required anticoagulation.[6] The present work expands further on previous observational work because patients of all ages and insurance status were examined. Surgical ablation of AF to restore sinus rhythm, in addition to LAA closure, might confer a further reduction in stroke or a survival benefit, which could not be adequately studied in our data set. This notion is best supported by 2 retrospective studies that showed lower rates of mortality among Medicare beneficiaries with AF who underwent CABG with or without concomitant surgical ablation, although data regarding LAA management were limited.[25,26] Surprisingly, an analysis of the Society of Thoracic Surgeons Adult Cardiac Surgery Database showed that approximately 87% of patients who underwent nonemergent cardiac surgery with concomitant surgical ablation also had atrial appendage closure, whereas only 64% of patients who underwent isolated or hybrid surgical ablation of AF also underwent LAA closure,[18] again showing potential room for expansion of LAA closure.

Variation in care and institutional practice patterns have been implicated in cardiac surgical outcomes.[9,11,27,28] Indeed, efforts to benchmark and publicly report hospital performance have been emphasized at state, national, and societal levels.[29,30] However, limited data exist regarding how surgeon or institutional practice patterns influence operative delivery of care such as performance of LAA closure at the time of cardiac surgery.[31] Our study showed that approximately 20% of the total variation in LAA closure is attributed to the hospital level. Furthermore, our Bayesian analysis showed wide variability in baseline use of LAA closure among patients with AF, with hospitals ranging from a baseline closure rate as high as 80% whereas others were as low as 10%. These findings might be related to surgeon preference, perception about safety of closure, comfort with techniques for LAA closure, or availability of closure devices. These findings underscore the importance of education and peer guidance regarding safety of closure and incorporation of closure techniques into practice. Importantly, because of the wide variability observed, concomitant LAA closure for patients with AF should be re-emphasized in cardiac surgical guidelines, particularly because the LAAOS III trial established a causal reduction in stroke.[8] Greater adoption of this technique might indeed improve outcomes of cardiac surgical patients on a national level, because of how underutilized it appears to be in some centers.

This study has several limitations related to its retrospective nature and design. Diagnosis codes were used to ascertain ischemic stroke and systemic embolism and might introduce bias compared with a clinically derived end point. To mitigate this, codes that were identical to previous published studies were used.[13] Although the LAAOS III trial included transient ischemic attack confirmed on imaging as a component of the composite end point, our study and other retrospective studies[6] did not, because no information on neurological imaging is available in our database. Because of the structure of the OSHPD databases, data on outpatient events are not captured. Although anticipated to be negligible and similar in both study groups, patients who experienced stroke and did not have a subsequent inpatient or emergency encounter were misclassified, resulting in an underestimate of the true incidence of these events. Data on death in a nonhospital setting is similarly not captured in the OSHPD databases, and limited linked probabilistic death data files are presently available for the study cohort. Because loss to follow-up was difficult to ascertain in the cohort, we limited our end point analysis to cumulative incidence of stroke or systemic embolism in full and propensity score-matched cohorts, potentially leading to underestimates of these rates. In our analysis, there was a high degree of collinearity between LAA closure and surgical ablation and, as such, we were unable to adequately adjust for surgical ablation in the propensity score-matched cohort. Moreover, information regarding anticoagulant use, rhythm at discharge, and method of LAA closure were unavailable for study. As a result, a portion of the observed benefit of LAA closure in this study might be attributable to surgical ablation. Because surgeon identifiers are not available in the OSHPD data, we could not further evaluate variation according to surgeon versus institution. Certain clinical factors, such as the Society of Thoracic Surgeons risk score and were not available for risk adjustment, such that potential unmeasured confounding variables might exist. In addition, other outcomes of interest such as cardiopulmonary bypass time or operating room time were not available for study. Nonetheless, our study builds on existing knowledge regarding the safety and efficacy of concomitant LAA closure in a statewide cohort, and describes substantial variation in the use of this procedure.

CONCLUSIONS

The incidence of concomitant LAA closure during CABG or valve surgery significantly increased in California from 2016 to 2019. In a propensity score-matched cohort, LAA closure was associated with reduced short- and midterm incidence of stroke and systemic embolism, with no excess morbidity at the index hospitalization. The use of concomitant LAA closure significantly varied according to center, with nearly 20% of the statewide variation in use attributed to the institution where the operation was performed. Because of recent level 1 evidence[8] for stroke reduction among patients who received concomitant LAA closure, efforts to emphasize LAA closure in practice guidelines and reduce variation in its utilization might improve neurologic outcomes for cardiac surgical patients with AF.

Conflict of Interest Statement

R.J.S. serves as a consultant to the Edwards Lifesciences Advisory Board. P.B. serves as a proctor for AtriCure. All other authors 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.

References

1. January CT, Wann LS, Calkins H, Chen LY, Cigarroa JE, Cleveland JC Jr, et al. 2019 AHA/ACC/HRS focused update of the 2014 AHA/ACC/HRS guideline for the management of patients with atrial fibrillation: a report of the American College of Cardiology/American Heart Association task force on clinical practice guidelines and the Heart Rhythm Society. *J Am Coll Cardiol*. 2019;74:104-32.
2. Schnabel RB, Yin X, Gona P, Larson MG, Beiser AS, McManus DD, et al. 50 Year trends in atrial fibrillation prevalence, incidence, risk factors, and mortality in the Framingham Heart Study: a cohort study. *Lancet*. 2015;386:154-62.
3. Kim MH, Johnston SS, Chu BC, Dalal MR, Schulman KL. Estimation of total incremental health care costs in patients with atrial fibrillation in the United States. *Circ Cardiovasc Qual Outcomes*. 2011;4:313-20.
4. Staerk L, Sherer JA, Ko D, Benjamin EJ, Helm RH. Atrial fibrillation: epidemiology, pathophysiology, and clinical outcomes. *Circ Res*. 2017;120:1501-17.
5. Benjamin EJ, Wolf PA, D'Agostino RB, Silbershatz H, Kannel WB, Levy D. Impact of atrial fibrillation on the risk of death: the Framingham Heart Study. *Circulation*. 1998;98:946-52.
6. Friedman DJ, Piccini JP, Wang T, Zheng J, Malaisrie SC, Holmes DR, 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.
7. Reddy VY, Doshi SK, Kar S, Gibson DN, Price MJ, Huber K, et al. 5-Year outcomes after left atrial appendage closure: from the PREVAIL and PROTECT AF trials. *J Am Coll Cardiol*. 2017;70:2964-75.
8. Whitlock RP, Belley-Cote EP, Paparella D, Healey JS, Brady K, Sharma M, et al. Left atrial appendage occlusion during cardiac surgery to prevent stroke. *N Engl J Med*. 2021;384:2081-91.
9. Tsai TC, Joynt KE, Orav EJ, Gawande AA, Jha AK. Variation in surgical-readmission rates and quality of hospital care. *N Engl J Med*. 2013;369:1134-42.
10. Hadaya J, Downey P, Tran Z, Sanaiha Y, Verma A, Shemin RJ, et al. Impact of postoperative infections on readmission and resource use in elective cardiac surgery. *Ann Thorac Surg*. 2022;113:774-82.
11. Hadaya J, Sanaiha Y, Tran Z, Shemin RJ, Benharash P. Defining value in cardiac surgery: a contemporary analysis of cost variation across the United States. *J Thorac Cardiovasc Surg Open*. 2022;10:266-81.
12. California Department of Health Care Access and Information. HCAI data documentation. Accessed April 7, 2022. https://hcai.ca.gov/data-and-reports/request-data/data-documentation
13. Yao X, Gersh BJ, Holmes DR Jr, Melduni RM, Johnsrud DO, Sangaralingham LR, et al. Association of surgical left atrial appendage occlusion with subsequent stroke and mortality among patients undergoing cardiac surgery. *JAMA*. 2018;319:2116-26.
14. Cuzick J. A Wilcoxon-type test for trend. *Stat Med*. 1985;4:87-90.
15. Leuven E, Sianesi B. PSMATCH2: Stata module to perform full Mahalanobis and propensity score matching, common support graphing, and covariate imbalance testing. Accessed April 7, 2022. https://ideas.repec.org/c/boc/bocode/s432001.html
16. Badhwar V, Rankin JS, Ad N, Grau-Sepulveda M, Damiano RJ, Gillinov AM, et al. Surgical ablation of atrial fibrillation in the United States: trends and propensity matched outcomes. *Ann Thorac Surg*. 2017;104:493-500.
17. McCarthy PM. The maze IV operation is not always the best choice: matching the procedure to the patient. *J Thorac Cardiovasc Surg Tech*. Published online June 28, 2021. https://doi.org/10.1016/j.xjtc.2021.06.031
18. Badhwar V, Scott Rankin J, Lee R, McCarthy PM, Wei LM. Contemporary left atrial appendage management during adult cardiac surgery. *J Thorac Cardiovasc Surg*. February 24, 2022 [Epub ahead of print]. http://doi.org/10.1016/j.jtcvs.2022.02.029
19. Cox JL, Churyla A, Kislitsina ON, Chris Malaisrie S, McCarthy PM. Cardiac anatomy pertinent to the catheter and surgical treatment of atrial fibrillation. *J Cardiovasc Electrophysiol*. 2020;31:2118-27.
20. Kanderian AS, Gillinov AM, Pettersson GB, Blackstone E, Klein AL. Success of surgical left atrial appendage closure: assessment by transesophageal echocardiography. *J Am Coll Cardiol*. 2008;52:924-9.
21. Lee R, Vassallo P, Kruse J, Malaisrie SC, Rigolin V, Andrei A, et al. A randomized, prospective pilot comparison of 3 atrial appendage elimination techniques: internal ligation, stapled excision, and surgical excision. *J Thorac Cardiovasc Surg*. 2016;152:1075-80.
22. Ailawadi G, Gerdisch MW, Harvey RL, Hooker RL, Damiano RJ Jr, Salamon T, et al. Exclusion of the left atrial appendage with a novel device:

early results of a multicenter trial. *J Thorac Cardiovasc Surg*. 2011;142: 1002-9, 1009.e1001.

23. Mahmood E, Matyal R, Mahmood F, Xu X, Sharkey A, Chaudhary O, et al. Impact of left atrial appendage exclusion on short-term outcomes in isolated coronary artery bypass graft surgery. *Circulation*. 2020;142:20-8.
24. Ad N, Suri RM, Gammie JS, Sheng S, O'Brien SM, Henry L. Surgical ablation of atrial fibrillation trends and outcomes in North America. *J Thorac Cardiovasc Surg*. 2012;144:1051-60.
25. Malaisrie SC, McCarthy PM, Kruse J, Matsouaka RA, Churyla A, Grau-Sepulveda MV, et al. Ablation of atrial fibrillation during coronary artery bypass grafting: late outcomes in a Medicare population. *J Thorac Cardiovasc Surg*. 2021;161:1251-61.e1.
26. Rankin JS, Lerner DJ, Braid-Forbes MJ, McCrea MM, Badhwar V. Surgical ablation of atrial fibrillation concomitant to coronary-artery bypass grafting provides cost-effective mortality reduction. *J Thorac Cardiovasc Surg*. 2020;160:675-86.e13.
27. Gelijns AC, Moskowitz AJ, Acker MA, Argenziano M, Geller NL, Puskas JD, et al. Management practices and major infections after cardiac surgery. *J Am Coll Cardiol*. 2014;64:372-81.
28. Glotzbach JP, Sharma V, Tonna JE, Pettit JC, McKellar SH, Eckhauser AW, et al. Value-driven cardiac surgery: achieving "perfect care" after coronary artery bypass grafting. *J Thorac Cardiovasc Surg*. 2018;156:1436-48.e2.
29. Jacobs JP, Shahian DM, D'Agostino RS, Mayer JE Jr, Kozower BD, Badhwar V, et al. The Society of Thoracic Surgeons National database 2018 annual report. *Ann Thorac Surg*. 2018;106:1603-11.
30. Shahian DM, Grover FL, Prager RL, Edwards FH, Filardo G, O'Brien SM, et al. The Society of Thoracic Surgeons voluntary public reporting initiative: the first 4 years. *Ann Surg*. 2015;262:526-35; discussion 533-5.
31. Mehaffey JH, Krebs E, Hawkins RB, Charles EJ, Tsutsui S, Kron IL, et al. Variability and utilization of concomitant atrial fibrillation ablation during mitral valve surgery. *Ann Thorac Surg*. 2021;111:29-34.

Key Words: left atrial appendage closure, left atrial appendage occlusion, atrial fibrillation, coronary artery bypass grafting, valve surgery, mitral valve, variation in care

TABLE E1. Patient characteristics before and after propensity score matching

	Unmatched: no LAA closure	Unmatched: LAA closure	SMD	Matched: no LAA closure	Matched: LAA closure	SMD
Mean age	69.8	69.1	0.065	69.1	68.8	0.026
Female sex	0.08	0.08	−0.011	0.09	0.09	−0.008
Medicare	0.32	0.28	0.083	0.64	0.63	0.018
Medicaid	0.08	0.10	−0.071	0.09	0.11	−0.076
Private insurance	0.22	0.23	−0.002	0.25	0.23	0.038
Other payer*	0.02	0.03	−0.037	0.03	0.03	−0.013
White race	0.74	0.70	0.104	0.68	0.68	−0.003
Black race	0.03	0.03	−0.024	0.03	0.03	−0.012
Asian or Pacific Islander race	0.11	0.14	−0.070	0.13	0.15	−0.051
Other race	0.11	0.13	−0.059	0.16	0.14	0.060
Aortic valve surgery	0.30	0.30	−0.001	0.28	0.32	−0.085
Mitral valve surgery	0.47	0.21	0.561	0.26	0.23	0.075
CABG	0.48	0.64	−0.329	0.64	0.62	0.040
Other valve surgery	0.14	0.07	0.232	0.07	0.08	−0.020
Elective case	0.65	0.55	0.214	0.55	0.53	0.027
Surgical ablation	0.47	0.07	1.008	0.44	0.07	0.940
Mean Elixhauser Comorbidity Index	6.01	5.91	0.049	6.06	6.03	0.016
Anemia	0.05	0.05	−0.003	0.05	0.05	0.006
Congestive heart failure	0.60	0.54	0.120	0.59	0.56	0.041
Chronic liver disease	0.05	0.07	−0.050	0.07	0.07	0.024
Chronic lung disease	0.20	0.22	−0.048	0.23	0.24	−0.034
Coagulopathy	0.38	0.35	0.054	0.37	0.36	0.007
Diabetes	0.33	0.43	−0.194	0.43	0.43	<0.001
End stage renal disease	0.05	0.08	−0.131	0.08	0.07	0.026
Hypertension	0.80	0.84	−0.104	0.83	0.82	0.011
Hypothyroidism	0.14	0.13	0.036	0.13	0.12	0.020
Malnutrition	0.05	0.06	−0.034	0.05	0.06	−0.021
Previous myocardial infarction	0.03	0.05	−0.128	0.05	0.05	0.022
Pulmonary circulatory disorder	0.23	0.16	0.184	0.19	0.18	0.026
Rheumatologic disorder	0.03	0.02	0.006	0.02	0.03	−0.027

Data are reported as percentage except where otherwise noted. *LAA*, Left atrial appendage; *SMD*, standardized mean difference; *CABG*, coronary artery bypass grafting. *Other payer includes self-pay, uninsured, or county programs.

TABLE E2. Hospital-level variation in LAA closure over time

Year	Percentage of absolute variation in LAA closure attributable to hospital (overall cohort)	Percentage of absolute variation in LAA closure attributable to hospital (PS-matched cohort)
2016	18.7 ± 2.9%	16.7 ± 4.1%
2017	16.8 ± 2.6%	22.9 ± 4.8%
2018	17.8 ± 2.7%	14.9 ± 3.7%
2019	19.0 ± 3.0%	16.3 ± 3.9%
Overall	17.6 ± 2.2%	17.9 ± 2.8%

Intraclass correlation coefficients were used to evaluate absolute variation in LAA closure according to year. *LAA*, Left atrial appendage; *PS*, propensity score.