Independent Predictors of Readmission following Left-Atrial-Appendage Closure: Insights from the Nationwide Readmissions Database

Malik Bilal Ahmed[1], Wasiq Sheikh[1], Anshul Parulkar[2], Esseim Sharma[2], Kevin Kennedy[3], Zara Ahmed[4], Sanchita Singal Parulkar[1], Brian McCauley[5], Fabio Lima[2], and Antony Chu[2]

[1]Brown University Warren Alpert Medical School
[2]Brown University
[3]Saint Luke's Mid America Heart Institute
[4]University of Alabama at Birmingham School of Natural Sciences and Mathematics
[5]University of Pennsylvania Perelman School of Medicine

May 26, 2020

Abstract

Objective To analyze the incidence, predictors, and cost of 30-day left atrial appendage closure readmissions utilizing the Nationwide Readmissions Database (NRD) and to develop a scoring system to predict readmission risk. Background Determining incidence and predictors of 30-day readmission post-left atrial appendage closure can direct resources towards high-risk patients. Methods International Classification of Diseases, Tenth Revision (ICD-10) codes were used to identify patients. We excluded patients who were discharged or died in December 2016. Influential factors were identified by univariate analysis and clinical suspicion. Continuous variables were compared using the Student's T-test and categorical variables were compared using chi-square or Fisher's exact test. A logistic regression model and scoring system were developed and validated. Results 2975 patients were identified and 243 (8.2%) readmitted within 30 days. Non-routine disposition ($p<0.0001$), chronic pulmonary disease ($p=0.0003$), renal disease ($p<0.0001$), and anemia ($p=0.009$) were significant predictors of readmission. Readmitted patients had longer lengths of stay (2.8 days ± 4.8) and higher charges ($139,869.3 ± 94,574.3). Average length of stay and cost for rehospitalizations were 4.8 days ±4.9 and $62,577± 85,850. Top causes of readmission included atrial fibrillation, atrial flutter, congestive heart failure, sepsis and gastrointestinal bleeding. Mortality during rehospitalization was 1.2%. Our scoring system had a C-statistic of 0.679 (derivation) and 0.633 (validation). Conclusion Readmitted patients have longer and more expensive initial hospital admissions, and chronic cardiac, pulmonary, and renal issues. A simple scoring system may identify patients at risk for readmission

Introduction

Atrial fibrillation (AF) affects an estimated 33.5 million patients worldwide, including 5 million patients in the United States alone[1]. AF is associated with increased stroke risk, particularly among the elderly[2]. In cases of stroke in which a thrombus can be identified, the left atrial appendage (LAA) is implicated in more than 90% of cases[3]. Left atrial appendage closure (LAAC) devices have emerged as a novel alternative option to minimize embolic stroke burden among patients with non-valvular AF as an alternative to indefinite oral anticoagulation. The WATCHMAN (Boston Scientific, Natick, MA) device is the first FDA approved percutaneous approach for LAAC [4]. Approval was granted on the basis of results from two randomized

controlled trials, PROTECT-AF[5] and PREVAIL[6]. However, initially, high rates of serious procedural and device-related events were noted, including pericardial effusion, cardiac tamponade, device-related thrombus, device-related embolism, and stroke[5–7]. Recent data suggests that these event rates have steadily declined since FDA approval[8]. Other percutaneous LAAC devices include the AMPLATZER cardiac plug, the AMPLATZER Amulet device (St. Jude Medical; Saint Paul, MN) and the WaveCrest device (Coherex Medical; Salt Lake City, UT) which are available in Europe. The LARIAT Suture Delivery Device (SentreHEART, Inc; Redwood City, CA) offers an epicardial approach with a success rate of 95%, but concerns remain about device safety[9,10]. With the advent of new diagnostic tools, such as mobile telemetry[11], detection of AF and the volume of LAAC procedures will likely increase.

Since Watchman's FDA approval in March 2015 its use has gained popularity nationwide, however, data regarding readmission rates after device insertion in the post-market era are largely unknown. The Centers of Medicare and Medicaid Services (CMS) increasingly utilizes 30-day readmission rates as a metric of hospital performance. Therefore, we sought to determine the incidence, predictors, and causes of readmissions following LAAC device insertion.

Additionally, we also set out to develop and validate a scoring system to predict 30-day readmission after LAAC device insertion.

Methods

Data Source

The study was deemed exempt by the Rhode Island Hospital Institutional Review Board[12]. Data were obtained from the 2016 Nationwide Readmission Database (NRD), a publicly-accessible database that collects clinical, non-clinical, and procedural data for roughly 36 million yearly discharges, tracking both payers and the uninsured. The data is drawn from state-specific inpatient databases in order to generate approximations of national readmissions. The 2016 NRD database was created from 27 geographically dispersed states with verifiable patient linkage numbers, which were subsequently utilized to track patients across hospitals within a state while maintaining privacy through deidentification of patient information.

Study Population

Patients admitted with a diagnosis of paroxysmal atrial fibrillation, persistent atrial fibrillation, chronic atrial fibrillation or unspecified atrial fibrillation who subsequently underwent a percutaneous left atrial appendage closure procedure were screened for in the NRD (Figure 1).

Figure 1. Flowchart delineating selection criteria for index LAAC hospitalizations.

The International Classification of Diseases, Tenth Revision, Clinical Modification/Procedure Coding System (ICD-10) was first used to identify patients with paroxysmal atrial fibrillation, persistent atrial fibrillation, chronic atrial fibrillation or unspecified atrial fibrillation (ICD 10: I48.0, I48.1, I48.2 and I48.91 respectively). The ICD-10 procedure code 02L73DK was then used as the identifier for left atrial appendage closure with an intraluminal device using a percutaneous approach. Patients aged [?]18 years who met these criteria were included in our initial sample. Patients who were discharged in December 2016 due to lack of 30-day follow up data, patients who died during the index hospitalization, and patients with missing discharge disposition were excluded from analysis. The final sample size was comprised of 2,975 index LAAC procedures.

Patient and Hospital Characteristics

Data collected on this population of patients included a comprehensive list of diagnoses and co- morbidities at readmission as well as demographic, clinical, and hospital data. Hospital variables included size of the facility based on number of beds, teaching designation, and location within rural or metropolitan communities. Demographic data included the age and sex of patients.

Clinical data consisted of length of stay on index admission, primary expected payer, and final disposition.

A scoring system was devised based on factors that were found to be influential on readmission. This scoring system was applied to the 2016 NRD and was validated with a cohort of LAAC patients from the 2014-2015 NRD. ICD 9 equivalents to the factors were used in the validation process.

Statistical Analysis

Data are shown as mean ± standard deviation (SD) for continuous variables and n (%) for categorical variables. All relevant variables were compared between procedures with and without a 30-day all-cause readmission with Student's T-test or Chi-square as appropriate. To derive independent predictors of readmission we followed the 10EPV guideline which allowed for 24 degrees of freedom for our adjusted model[13]. Based on univariate associations and clinical interest we used the following as potential predictors: elective status at index admission, age, sex, disposition, hospital bed size, cardiomyopathy, chronic pulmonary disease, congestive heart failure (CHF), ischemic heart disease (IHD), obesity, hypertension (HTN), peripheral vascular disease (PVD), diabetes mellitus (DM), renal disease including chronic kidney disease (CKD) and end stage renal disease (ESRD), fluid and electrolyte disorder, anemia, and peptic ulcer disease. These variables were entered into a hierarchical logistic regression model using a random intercept for site, with odds ratios and 95% confidence intervals. Next, we ran a selection

procedure using stepwise methods to obtain a parsimonious list of independent predictors of readmission in our cohort. We then used the beta estimates to create a simple integer scoring system to predict readmission[14]. We then used the applied the scoring system to our derivation cohort and tested the 30-day readmission rate by score. Then using data from the 2014-2015 NRD as a validation cohort, we applied the same integer scoring system to test discrimination with 30-day readmissions. Next, we determined the top causes of readmission using the primary diagnosis code at readmission.[14] For general categorization we used the letter and first 2 numbers of the ICD 10 code. All analysis was done with SAS version 9.4 (Cary, NC) with a p- value of 0.05 marking statistical significance.

Results

Baseline Patient and Hospital Characteristics

Baseline characteristics of the study cohort including patient characteristics, hospital procedures, and hospital outcomes of LAAC patients (n=2975) are summarized in Table 1. The mean age of patients undergoing the procedure was 75.8 ± 8.2, and 38.6% of the cohort were female. LAAC procedures were predominantly done in private, non-profit metropolitan teaching hospitals.

Elective versus non-elective admission Missing
Age in years at admission
Female
Disposition of patient 1 Routine 2 Transfer to Short Term Hospital 5 Transfer Other: SNF, ICF 6 Home Health Care
Length of stay Mean ± SD Median (IQR)
Rehospitalization Length of Stay Mean ± SD Median (IQR) Missing
Primary expected payer 1 Medicare 2 Medicaid 3 Private Insurance 4 Self Pay 6 Other Missing
Patient Location: NCHS Urban-Rural Code 1 Central counties of metro areas of >=1 million population 2 Fringe counti
Patient State is the same as Hospital State
Median household income national quartile for patient ZIP Code 1 2 3 4 Missing
Bed size of hospital 1 Small 2 Medium 3 Large
Control/ownership of hospital 1 Govt 2 Private not-profit 3 Private invest-own
Teaching status of urban hospitals 0 Metro non-teaching 1 Metro Teaching 2 Non Metro

Total Elixhauser Groups per record
Total charges during index admission Missing
Total charges during rehospitalization Missing
Death during rehospitalization Missing
Acute Renal Failure (ARF)
Atherosclerosis
Chronic Kidney Disease (CKD)
Chronic Obstructive Pulmonary Disease
Congestive Heart Failure (CHF)
End Stage Renal Disease (ESRD)
Ischemic Heart Disease
Non-ST Elevation Myocardial Infarction (NSTEMI)
Obesity
Anemia
Elixhauser Variables
  Congestive Heart Failure
  Cardiac Arrhythmia
  Valvular Disease
  Pulmonary Circulation Disorders
  Peripheral Vascular Disorders
  Hypertension Uncomplicated
  Hypertension Complicated
  Paralysis
  Other Neurological Disorders
  Chronic Pulmonary Disease
  Diabetes Uncomplicated
  Diabetes Complicated
  Hypothyroidism
  Renal Failure
  Liver Disease
  Peptic Ulcer Disease excluding bleeding
  AIDS/HIV
  Lymphoma
  Metastatic Cancer
  Solid Tumor without Metastasis
  Rheumatoid Arthritis/collagen
  Coagulopathy
  Obesity
  Weight Loss
  Fluid and Electrolyte Disorders
  Blood Loss Anemia
  Deficiency Anemia
  Alcohol Abuse
  Drug Abuse
  Psychoses
  Depression
Continuous variables compared using Student's T-test. Categorical variables compared using chi-square or Fisher's exact te

Table 1. Baseline characteristics, charges, and in-hospital outcomes of patients readmitted and not readmitted for LAAC procedures.

There was no difference in the expected primary payer (Medicare, Medicaid, private or self-pay) between both groups. Compared to patients who were not readmitted within 30 days, readmitted patients had a statistically significant longer length of stay during the index admission (2.8 days vs 1.5 days, p<0.001), significantly higher transfer to Skilled Nursing Facility (SNF) or Intermediate Care Facility (ICF) (7.0% vs 2.6 %, p<0.001), and a significantly higher likelihood of being in the same state as the hospital during the index admission. In addition, patients who had the procedure performed at a private non-profit hospital were less likely to be readmitted than patients who underwent the procedure at a private for-profit or government hospital. While hospitals with the smallest volume of cases in 2016, defined as 1 to 4 cases, had the highest readmission rate at 12%, the relationship between hospital procedure volume and readmission rate was non-significant (p = 0.350).

Predictors of 30-day readmissions and Model Discrimination

The 30-day readmission rate was 8.2% (n=243). By univariate analysis, patients who were readmitted had a higher prevalence of CHF (36.6% vs 26.2%, p<0.001), ischemic heart disease (52.3% vs 43.2%, p=0.006), atherosclerosis (5.3% vs 1.9%, p<0.001) NSTEMI (1.6% vs 0.2%,

p=0.006), anemia (20.6% vs 10.9%, p<0.001), obesity (13.6% vs 9.3%, p=0.028), acute kidney failure (4.9% vs 2.0% p=0.003), end stage renal disease (5.8% vs 2.2%, p<0.001), chronic kidney disease (26.7% vs 15.1%, p<0.001), and chronic obstructive pulmonary disease (26.3% vs 11.6%, p<0.001) noted during their index admission (Table 1). Of the Elixhauser Comorbidity Index variables, readmitted patients had statistically significant higher prevalence of CHF, peripheral vascular disorders (23.9% vs 16.3%, p=0.002), complicated hypertension (34.6% vs 20.8%, p<0.001), chronic pulmonary disease, complicated diabetes (13.6% vs 6.7%, p<0.001),

renal failure, obesity, fluid and electrolyte disorders (8.6% vs 3.6%, p<0.001), anemia, and drug abuse (1.2% vs 0.2%, p=0.031). In contrast, patients who were not readmitted had a statistically significant higher prevalence of uncomplicated hypertension (62.8% vs 52.3%, p=0.001). After multiple regression analysis, non-routine disposition (HR 2.19 [1.5-3.21], p<0.0001), such as discharge to Home Health Care (HHC) or a Skilled Nursing Facility (SNF)**,** chronic pulmonary disease (HR 1.76 [1.3-3.29], p=0.0003), renal disease (HR 1.96 [1.44-2.67]), p<0.0001), and anemia (HR 1.55 [1.12-2.17], p=0.009) were significant predictors of readmission in this cohort (Figure 2). Peripheral vascular disease approached significance in this analysis (HR 1.39 [0.98- 1.98], p=0.0686). Notable non-predictors included age, sex, diabetes, cardiomyopathy and HTN. Of the available peri-procedural complications, including pericardial effusion, cardiac tamponade, cerebral infarction, device thrombosis, venous or arterial thrombosis, intra- or post- procedure cardiac arrest, arteriovenous fistula formation, and acute renal failure, only acute renal failure (p = 0.003) and venous thromboembolism (p = 0.002) were predictive of readmission in a statistically significant fashion (Table 3). Cerebral infarction approached significance but was ultimately found to be non-significant (p = 0.054). Overall, the C-statistic of the model was 0.70.

Figure 2. Multivariable model of 30-day readmissions in patients undergoing LAAC procedures. Parentheses indicate 95% confidence intervals.

Complication	**Total Number of Events (n = 2975)**	**Events in Readmitted Patients (n = 24**
Pericardial Effusion	77 (2.6%)	8 (3.3%)
Cardiac Tamponade	17 (0.6%)	1 (0.4%)
Cerebral Infarction	11 (0.4%)	3 (1.2%)
Device Thrombosis	0 (0.0%)	0 (0.0%)
Device Embolus	0 (0.0%)	0 (0.0%)
Acute Renal Failure	67 (2.3%)	12 (4.9%)
Post-procedure Cardiac Arrest	2 (0.1%)	0 (0.0%)
Intra-procedure Cardiac Arrest	1 (0.0%)	0 (0.0%)
Arterial Thromboembolism	4 (0.1%)	0 (0.0%)
Venous Thromboembolism	4 (0.1%)	3 (1.2%)

Complication	Total Number of Events (n = 2975)	Events in Readmitted Patients (n = 2
Arteriovenous Fistula Formation	1 (0.0%)	0 (0.0%)
Aneurysm	0 (0.0%)	0 (0.0%)

Table 3. Peri-procedural complication rates for LAAC procedures.

Length of Stay, Charges and Causes of Readmission

Patients who were readmitted were more likely to have a longer length of stay during the index admission (2.8 days ± 4.8 vs 1.5 ± 2.7 days, p<0.001). Total charges accrued during the index admission were also different ($139,869.3 ± 94,574.3 vs $115,358 ± 72,523.8, p<0.001). The average length of stay for a rehospitalization was 4.8 days ±4.9 days and the average charge of rehospitalization was $62,577± 85,850 (Table 1). Broadly speaking, the top categories for readmissions included: cardiac (26.36%), gastrointestinal (26.33%) and pulmonary (12.36%) (Figure 3). More specifically, atrial fibrillation and atrial flutter (8.23%) and congestive heart failure (8.23%) were both equal in frequency as the primary causes of readmission, followed by gastrointestinal diseases (7.41%), sepsis (6.17%), diverticular disease (3.70%), vascular disorders of the intestine (3.29%), acute kidney failure (3.29%), hypertensive heart and chronic kidney disease (2.47%), respiratory failure (2.47%), other cardiac arrhythmias (2.06%), and COPD (2.06%) (Table 2). The ICD 10 category containing gastrointestinal diseases includes hematemesis and melena. Importantly, cerebral infarction represented the cause for 1.23% of readmissions and transient ischemic attacks represented 0.41% of readmissions. A top ten list of causes of readmission is displayed in Table 2. The mortality rate during readmission was 1.2%.

Figure 3. Broad categories for primary diagnosis of 30-day LAAC readmissions

Top Ten Causes of Readmission	n	Percent	Cumulative Frequency	Cumulative Percent	Cat
Atrial fibrillation and flutter	20	8.23	20	8.23	Car
Heart failure	20	8.23	40	16.46	Car
Other diseases of digestive system	18	7.41	58	23.87	Gas
Other Sepsis	15	6.17	73	30.04	Sep
Diverticular disease of intestine	9	3.7	82	33.74	Gas
Vascular disorders of intestine	8	3.29	90	37.04	Gas
Acute renal failure	8	3.29	98	40.33	Ren
Hypertensive heart and chronic kidney disease	6	2.47	104	42.8	Car
Respiratory failure, not elsewhere classified	6	2.47	110	45.27	Pul
Other cardiac arrhythmias	5	2.06	115	47.33	Car

Table 2. Top 10 causes of 30-day readmissions in patients undergoing LAAC procedures sorted by percentage and primary diagnosis

Derivation and Validation of a Scoring System to Predict LAAC Readmissions

A simple scoring system was devised based on non-routine disposition and the presence of chronic pulmonary disease, peripheral vascular disease, chronic kidney disease/end stage renal disease and anemia. Non-routine disposition, chronic pulmonary disease and renal disease were assigned 2 points each, while peripheral vascular disease and anemia were given 1 point each (Figure 4). In the derivation cohort, the scoring system had a stepwise discriminatory ability in predicting readmission. For example, patients with a score of 1 had a readmission rate of 4.2%,

while a score of 5 or more had a readmission rate of 23.1% (Figure 5). The C-statistic for the scoring system for the derivation cohort was 0.6787.

Figure 4. Multivariable model of 30-day readmissions in patients undergoing LAAC procedures with scoring system integrated. Parentheses indicate 95% confidence intervals.

Figure 5. Readmission scoring model correlating likelihood of readmission within 30 days with numerical score using the derivation cohort.

This scoring system was applied to the 2014-2015 NRD using the ICD-9 codes for the risk factors noted above. The scoring system maintained predictive ability and is represented in Figure 6. The C-statistic in the validation cohort was 0.633.

Figure 6. Readmission scoring model correlating likelihood of readmission within 30 days with numerical score using the validation cohort.

Discussion

Analysis of 30-day all-cause readmissions after the LAAC procedure revealed several important findings. First of all, 8.2% of patients who received the LAAC device were readmitted within 30 days. Independent predictors of readmission included non-routine disposition such as discharge to Home Health Care (HHC) or a SNF**,** chronic pulmonary disease, renal disease, and anemia.

Both cardiac and non-cardiac causes accounted for readmission, with atrial arrhythmias and congestive heart failure being the most common. Charges varied significantly between readmitted and non-readmitted patients on index admissions. The readmission rates of LAAC procedures seem to be lower when compared with those of other cardiac procedures and diseases**,** including readmissions for congestive heart failure, TAVR, or PCI[15–17]. This may reflect the fact that procedural success has increased since FDA approval, while complication rates have decreased[8]. Interestingly, neither hospital procedural volume nor peri-procedural complications correlated significantly with readmission rate, save for peri-procedural acute renal failure and venous thromboembolism, though this may be a function of the low number of reported complication rates (Table 3).

Since 30-day readmissions are viewed as a quality performance measure, this study is an important one in identifying patients at risk for readmission and directing resources towards them. Our results suggest that patients with kidney disease, COPD, CHF, ischemic heart disease, and anemia are at elevated risk for readmission within 30 days. Interestingly, though the readmission rate for LAAC devices was lower than in TAVR, the predictors for readmission are strikingly similar, likely reflecting the fact that patients with greater disease burden in general are at elevated risk of readmission[16]. Our multivariable model had modest discriminatory ability in predicting these readmission (ROC 0.70), which is on par or better than many rehospitalization prediction models[18].

These predictors of readmission reflect the fact that patients with increased comorbidities are at higher risk of readmission. Patients who are discharged to HHC or SNF often require greater care, have a greater number of comorbidities, incur higher inpatient charges, and are generally frailer than patients who are discharged home—a common pattern among post-surgical, acute care, trauma, stroke, post-cardiac surgery, and heart failure patients[19–23]. Medicare data examining characteristics predisposing SNF residents to readmission found that ˜21% of residents had been readmitted within 30 days, with a significant percentage of residents presenting with an admission diagnosis of cardiac conditions [24,25]. Therefore, it is not surprising that these patients are more likely to be readmitted after receiving a LAAC device.

Anemia is an especially common comorbidity encountered in LAAC patients, as the primary criterion for LAAC selection is the desire to avoid indefinite anticoagulation, generally due to

bleeding risk[26]. Current guidelines recommend that patients who undergo WATCHMAN continue on anticoagulation for at least 45 days[5]. Speculatively, it is possible that patients who are anemic during their index hospitalization may be anemic because of an increased predisposition towards bleeding and would have

greater difficulties tolerating post-procedural anticoagulation, leading to increased readmission. Further study regarding the possible utility of post-procedural hemoglobin monitoring or alternative post-procedural anticoagulation strategies is warranted.

Major causes of readmissions included arrhythmia (atrial fibrillation and flutter), heart failure, gastrointestinal disease, and sepsis. Readmissions for cerebral infarction made up only 1.63% of readmissions (n=3). One of the major causes of rehospitalization is congestive heart failure, and numerous studies are underway to investigate strategies to aid in reducing overall readmissions for heart failure[27,28]. Interestingly, however, neither congestive heart failure nor cardiomyopathy during the index admission were predictive of readmissions on multivariate analysis. This discrepancy may reflect hemodynamic changes caused by LAA occlusion itself. In animal studies, occlusion of the left atrial appendage results in increases in left atrial filling pressures, which results in diastolic dysfunction[29]. One single center study reported increases in mitral E/E' ratios three months after left atrial occlusion on echocardiography, indicative of increases in left- sided filling pressures.[30] Further study is needed in this area.

Interestingly, gastrointestinal disease was not an independent risk factor for readmission but was a top cause of readmission. The subcategories of the general ICD-10 code for gastrointestinal disease include hematemesis, melena, hemorrhage, mucositis, and unspecified. Therefore, the gastrointestinal disease code likely captured many patients with bleeding complications after LAAC. While gastrointestinal disease was not an independent risk factor for readmission, anemia was an independent risk factor. Patients who undergo LAAC usually have contraindications to anticoagulation, and therefore the required 45 days of anticoagulation afterwards may predispose to bleeding complications, particularly gastrointestinal bleeding.

Further studies examining anticoagulation strategies after WATCHMAN are needed, given the significant portion of readmissions post-WATCHMAN implantation that are related to gastrointestinal hemorrhage.

Atrial fibrillation and atrial flutter as causes of readmission may reflect the arrhythmic burden in patients who receive the procedure, as all patients who receive the device have atrial fibrillation. When compared with 30-day readmission rates in patients who are admitted for atrial fibrillation, readmissions for atrial fibrillation after LAAC appear lower. A 2017 study of 388,340 patients admitted for atrial fibrillation and subsequent 30-day readmissions found that atrial fibrillation was the most common readmission diagnosis and accounted for 27.1% of readmissions, followed by heart failure, accounting for 11.4%. In contrast, in the current study, only 8.23% of readmissions after LAAC were due to atrial fibrillation, and 8.23% of readmissions were secondary to CHF [31].

The average length of stay during index admission for readmitted patients was nearly twice the length of stay for non-readmitted patients (2.8 days versus 1.5 days). This difference may explain the discrepancy in accrued charges observed between both groups ($139,869 versus $115,258).

Unfortunately, given the constraints of the NRD, it was not possible to elucidate the reason for the prolonged stay during the index readmission. To our knowledge, there is no standardized guideline for length of stay for LAAC procedures. This is considerably less than the average length of stay for TAVR, percutaneous ASD closure, and transcatheter mitral valve repair, which are all reported to be greater than 5 days based on analysis of national databases[32–35].

Given the relative lack of medical guidelines for defining an appropriate length of stay post LAAC, further investigation may be warranted. Standardization of post-LAAC length of stay will result in significant charge savings, given that the average charge of the readmitted hospital stay was nearly 50% of the cost of the index admission ($62,577). Similar efforts are underway for elective percutaneous coronary intervention (PCI), as evidenced by a recent study highlighting roughly $5,000 worth of savings from employing a same-day discharge strategy, rather than one involving overnight stay, without a corresponding increase in adverse events[36].

The role of 30-day readmissions as a quality performance measure underscores the importance of this analysis as a vital first step in elucidating risk factors for readmission after the LAAC procedure. Recent data suggest

that quality of life improves after the WATCHMAN procedure, when compared with quality of life of patients reliant on lifelong warfarin[37]. Atrial fibrillation diagnoses are expected to double by 2050, and it is likely that left atrial appendage occlusion will continue to gain favor as a method of stroke prevention, due to decreasing rates of periprocedural complications, overall safety, and patient preference[1,38]. The results of this study will be useful in identifying patients at high-risk of 30-day readmission after LAAC and developing strategies to lower readmission rates.

Readmission scoring systems are of particular interest since CMS implemented the Hospital Readmissions Reduction Program (HRRP), and robust models are scarce. Mortality models fare reasonably well, but readmissions models are less discriminatory with an average c statistic of 0.63[39]. The CMS-endorsed Readmission Risk Score (RRS), a composite of 37 variables, has a c statistic of 0.6 for 30 day all-cause readmissions for CHF[40]. Similarly, the HOSPITAL score, designed to predict avoidable all-cause 30 day readmission, has a c statistic of 0.71[41]. Countless additional scores exist, and there is considerable overlap between variables used in mortality scores with high predictive ability and readmissions scores that do not fare as well.

Our readmission scoring system had modest discriminatory ability with a C-statistic of 0.67 in derivation and 0.63 in validation. Our scoring system is on par with most readmission models and may be more clinically useful given its simplicity. We suggest designating patients with a score of 1 or less as "low" risk, 2 to 3 as "moderate" risk, and 4 and above as "high" risk.This may aid clinicians in risk stratifying patients at greater risk for being readmitted post-LAAC

Limitations

There are few limitations to this study. This analysis is based solely on diagnostic and administrative variables, and there is a noted absence of procedural or detailed clinical data. Details on LAAC device size, type, echocardiographic variables, such as LAA dimensions and

the degree of para-device leak, were not available. Additionally, the cause of readmission was elucidated through discharge diagnosis codes, an approach that is utilized extensively in 30-day readmissions analyses. Furthermore, the NRD does not contain data on patients who are readmitted to a hospital in another state, which may result in an underestimation of the true readmission rate. For the scoring system, ICD9 and ICD10 codes are not 1:1, so potential data points may have been either not counted for or incorrectly included. Efforts were made to minimize this. Finally, the NRD does not track mortality, and so the influence of mortality on the rates of readmission cannot be accounted for.

Conclusion

LAAC is a safe and effective procedure that has a comparably lower rate of readmission relative to other cardiac procedures, with non-routine disposition, chronic pulmonary disease, renal disease, and anemia emerging as risk factors for 30-day readmission. Important causes of readmission include arrhythmia, GI hemorrhage, heart failure, and sepsis. Understanding these risk factors may help dictate resource-utilization and further reduce both costs and readmission rates. As the burden of atrial fibrillation grows and use of non-pharmacologic methods of stroke prevention increase, development of strategies to help reduce readmission rates after LAAC are crucial to help reduce healthcare costs and increase cost-effectiveness.

References

1. Chugh SS, Havmoeller R, Narayanan K, et al. Worldwide Epidemiology of Atrial Fibrillation: A Global Burden of Disease 2010 Study. doi:10.1161/CIRCULATIONAHA.113.005119
2. Benjamin EJ, Virani SS, Callaway CW, et al. Heart Disease and Stroke Statistics-2018 Update: A Report From the American Heart Association.*Circulation* . 2018;137(12):e67- e492. doi:10.1161/CIR.0000000000000558

3. Blackshear JL, Odell JA. Appendage obliteration to reduce stroke in cardiac surgical patients with atrial fibrillation. *Ann Thorac Surg* . 1996;61(2):755-759. doi:10.1016/0003- 4975(95)00887-X
4. Department of ehalth and Human Services. Premarket Approval (PMA).*03/13/2015* . 2002;510(2). https://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfpma/pma.cfm?id=P130013. Accessed October 20, 2018.
5. Holmes DR, Reddy VY, Turi ZG, et al. Percutaneous closure of the left atrial appendage versus warfarin therapy for prevention of stroke in patients with atrial fibrillation: a randomised non-inferiority trial.*Lancet* . 2009;374(9689):534-542. doi:10.1016/S0140- 6736(09)61343-X
6. Holmes DR, 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. *J Am Coll Cardiol* . 2014;64(1):1-12. doi:10.1016/j.jacc.2014.04.029
7. 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(4):417-424. doi:10.1161/CIRCULATIONAHA.110.976449
8. Reddy VY, Gibson DN, Kar S, et al. *Post-Approval U.S. Experience With Left Atrial Appendage Closure for Stroke Prevention in Atrial Fibrillation* .; 2017. doi:10.1016/j.jacc.2016.10.010
9. Lakkireddy D, Afzal MR, Lee RJ, et al. Short and long-term outcomes of percutaneous left atrial appendage suture ligation: Results from a US multicenter evaluation. *Hear Rhythm* . 2016;13(5):1030-1036. doi:10.1016/j.hrthm.2016.01.022
10. Price MJ, Gibson DN, Yakubov SJ, et al. Early safety and efficacy of percutaneous left atrial appendage suture ligation: results from the U.S. transcatheter LAA ligation consortium. *J Am Coll Cardiol* . 2014;64(6):565-572. doi:10.1016/j.jacc.2014.03.057
11. Jaakkola J, Jaakkola S, Lahdenoja O, et al. Mobile Phone Detection of Atrial Fibrillation With Mechanocardiography. *Circulation* . 2018;137:1524-1527. doi:10.1161/CIRCULATIONAHA.117.032804
12. Healthcare Cost and Utilization Project (HCUP). NRD Database Documentation. https://www.hcup-us.ahrq.gov/db/nation/nrd/nrddbdocumentation.jsp. Accessed February 26, 2019.
13. Peduzzi P, Concato J, Kemper E, Holford TR, Feinstein AR. A simulation study of the number of events per variable in logistic regression analysis. *J Clin Epidemiol* . 1996;49(12):1373-1379. doi:10.1016/S0895-4356(96)00236-3
14. Sullivan LM, Massaro JM, D'Agostino RB. Presentation of multivariate data for clinical use: The Framingham Study risk score functions.*Stat Med* . 2004;23(10):1631-1660. doi:10.1002/sim.1742
15. Bergethon KE, Ju C, DeVore AD, et al. Trends in 30-Day Readmission Rates for Patients Hospitalized with Heart Failure: Findings from the Get with the Guidelines-Heart Failure Registry. *Circ Hear Fail* . 2016;9(6). doi:10.1161/CIRCHEARTFAILURE.115.002594
16. Kolte D, Khera S, Sardar MR, et al. Thirty-Day Readmissions After Transcatheter Aortic Valve Replacement in the United States.*Circ Cardiovasc Interv* . 2017;10(1). doi:10.1161/CIRCINTERVENTIONS.116.004472
17. Wasfy JH, Strom JB, Waldo SW, et al. Clinical Preventability of 30-Day Readmission After Percutaneous Coronary Intervention. *J Am Heart Assoc* . 2014;3(5). doi:10.1161/JAHA.114.001290
18. Kansagara D, Englander H, Salanitro A, et al. Risk Prediction Models for Hospital Readmission. *JAMA* . 2011;306(15):1688. doi:10.1001/jama.2011.1515
19. Allen LA, Hernandez AF, Peterson ED, et al. Discharge to a skilled nursing facility and subsequent clinical outcomes among older patients hospitalized for heart failure. *Circ Heart Fail* . 2011;4(3):293-300. doi:10.1161/CIRCHEARTFAILURE.110.959171
20. Hakkarainen TW, Arbabi S, Willis MM, Davidson GH, Flum DR. Outcomes of patients discharged to skilled nursing facilities after acute care hospitalizations. *Ann Surg* . 2016;263(2):280-285. doi:10.1097/SLA.0000000000001367
21. Tian W. *An All-Payer View of Hospital Discharge to Postacute Care, 2013: Statistical Brief #205* .; 2006. http://www.ncbi.nlm.nih.gov/pubmed/27441335. Accessed December 30, 2018.

22. Morrisey MA, Sloan FA, Valvona J. Shifting medicare patients out of the hospital. *Health Aff* . 1988;7(5):52-64. doi:10.1377/hlthaff.7.5.52
23. Edgerton JR, Herbert MA, Mahoney C, et al. Long-term fate of patients discharged to extended care facilities after cardiovascular surgery.*Ann Thorac Surg* . 2013;96(3):871- 877. doi:10.1016/j.athoracsur.2013.04.041
24. Yoo JW, Jabeen S, Bajwa T, et al. Hospital Readmission of Skilled Nursing Facility Residents: A Systematic Review. *Res Gerontol Nurs* . 2015;8(3):148-156. doi:10.3928/19404921-20150129-01
25. Neuman MD, Wirtalla C, Werner RM. Association between skilled nursing facility quality indicators and hospital readmissions. *JAMA - J Am Med Assoc* . 2014;312(15):1542-1551. doi:10.1001/jama.2014.13513
26. Reddy VY, Möbius-Winkler S, Miller MA, et al. Left atrial appendage closure with the watchman device in patients with a contraindication for oral anticoagulation: The ASAP study (ASA plavix feasibility study with watchman left atrial appendage closure technology). *J Am Coll Cardiol* . 2013;61(25):2551-2556. doi:10.1016/j.jacc.2013.03.035
27. Krumholz HM, Amatruda J, Smith GL, et al. Randomized Trial of an Education and Support Intervention to Prevent Readmission of Patients With Heart Failure. *J Am Coll Cardiol* . 2002;39:83-89. doi:10.1016/S0735-1097(01)01699-0
28. Wan TTH. Strategies to Modify the Risk for Heart Failure Readmission: A Systematic Review and Meta-analysis. In: *Population Health Management for Poly Chronic Conditions* . Cham: Springer International Publishing; 2018:85-112. doi:10.1007/978-3- 319-68056-9_6
29. Hoit BD, Shao Y, Tsai L-M, Patel R, Gabel M, Walsh RA. *Altered Left Atrial Compliance After Atrial Appendectomy Influence on Left Atrial and Ventricular Filling Downloaded From* .; 2017. http://circres.ahajournals.org/. Accessed December 29, 2018.
30. Jalal Z, Iriart X, Dinet M-L, et al. Evaluation of left atrial remodelling following percutaneous left atrial appendage closure.*J Geriatr Cardiol* . 2017;14:496-500. doi:10.11909/j.issn.1671-5411.2017.08.002
31. Munir MB, Sharbaugh MS, Ahmad S, et al. Causes and Predictors of 30-Day Readmissions in Atrial Fibrillation (from the Nationwide Readmissions Database). *Am J Cardiol* . 2017;120(3):399-403. doi:10.1016/j.amjcard.2017.04.040
32. Arora S, Strassle PD, Kolte D, et al. Length of Stay and Discharge Disposition After Transcatheter Versus Surgical Aortic Valve Replacement in the United States. *Circ Cardiovasc Interv* . 2018;11(9). doi:10.1161/CIRCINTERVENTIONS.118.006929
33. Zhan C, Baine WB, Sedrakyan A, Steiner C. Cardiac Device Implantation in the United States from 1997 through 2004: A Population-based Analysis. 2007. doi:10.1007/s11606- 007-0392-0
34. Mojadidi MK, Mahmoud AN, Mahtta D, et al. Incidence and Causes of 30-Day Readmissions after Surgical Versus Percutaneous Secundum Atrial Septal Defect Closure: A United States Nationwide Analysis.*Struct Hear* . December 2018:24748706.2018.1559963. doi:10.1080/24748706.2018.1559963
35. Ahmed A, Akintoye E, Adegbala O, et al. In-hospital outcomes of transcatheter mitral valve repair with Mitraclip in patients with pulmonary hypertension: Insights from the National Inpatient Sample.*Catheter Cardiovasc Interv* . December 2018. doi:10.1002/ccd.27997
36. Amin AP, Pinto D, House JA, et al. Association of Same-Day Discharge after Elective Percutaneous Coronary Intervention in the United States with Costs and Outcomes. *JAMA Cardiology* . http://cardiology.jamanetwork.com/article.aspx?doi=10.1001/jamacardio.2018.3029. Published November 1, 2018. Accessed December 29, 2018.
37. Alli O, Doshi S, Kar S, et al. Quality of Life Assessment in the Randomized PROTECT AF (Percutaneous Closure of the Left Atrial Appendage Versus Warfarin Therapy for Prevention of Stroke in Patients With Atrial Fibrillation) Trial of Patients at Risk for Stroke With Nonvalvular Atrial . *JAC* . 2013;61:1790-1798. doi:10.1016/j.jacc.2013.01.061
38. Aonuma K, Yamasaki H, Nakamura M, et al. Percutaneous WATCHMAN Left Atrial Appendage Closure for Japanese Patients With Nonvalvular Atrial Fibrillation at Increased Risk of Thromboembolism – First Results From the SALUTE Trial –. *Circ J* . 2018. doi:10.1253/circj.CJ-18-0222
39. Ouwerkerk W, Voors AA, Zwinderman AH. Factors influencing the predictive power of models for

predicting mortality and/or heart failure hospitalization inpatients with heart failure. *JACC Hear Fail* . 2014;2(5):429-436. doi:10.1016/j.jchf.2014.04.006

40. Keenan PS, Normand SLT, Lin Z, et al. An administrative claims measure suitable for profiling hospital performance on the basis of 30-day all-cause readmission rates among patients with heart failure. *Circ Cardiovasc Qual Outcomes* . 2008;1(1):29-37. doi:10.1161/CIRCOUTCOMES.108.802686
41. Donze J, Aujesky D, Williams D, Schnipper JL. Potentially avoidable 30-day hospital readmissions in medical patients: Derivation and validation of a prediction model. *JAMA Intern Med* . 2013;173(8):632-638. doi:10.1001/jamainternmed.2013.30

Figure 1. Flowchart delineating selection criteria for index LAAC hospitalizations.

Table 1. Baseline characteristics, charges, and in-hospital outcomes of patients readmitted and not readmitted for LAAC procedures.

Figure 2. Multivariable model of 30-day readmissions in patients undergoing LAAC procedures. Parentheses indicate 95% confidence intervals.

Figure 3. Broad categories for primary diagnosis of 30-day LAAC readmissions

Figure 4. Multivariable model of 30-day readmissions in patients undergoing LAAC procedures with scoring system integrated. Parentheses indicate 95% confidence intervals.

Table 2. Top 10 causes of 30-day readmissions in patients undergoing LAAC procedures sorted by percentage and primary diagnosis

Figure 5. Readmission scoring model correlating likelihood of readmission within 30 days with numerical score using the derivation cohort.

Figure 6. Readmission scoring model correlating likelihood of readmission within 30 days with numerical score using the validation cohort.

Table 3. Peri-procedural complication rates for LAAC procedures.

Hosted file

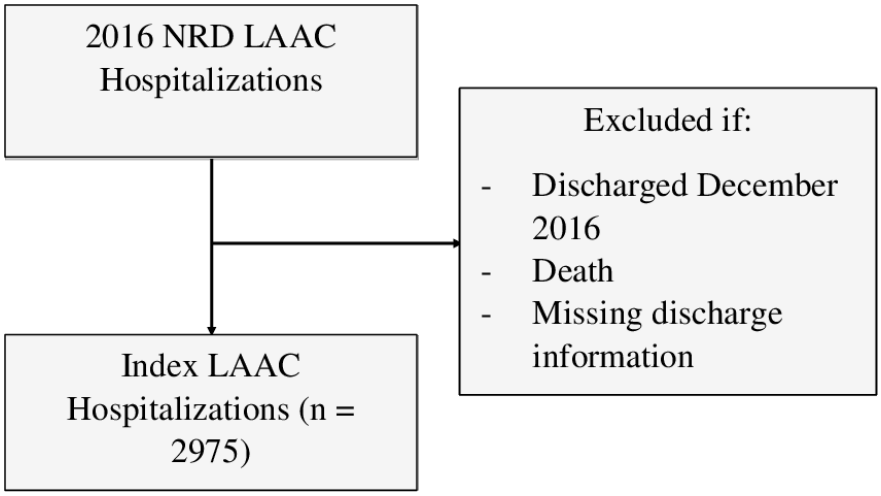
`LAAC Table 1.docx` available at https://authorea.com/users/326039/articles/453948-independent-predictors-of-readmission-following-left-atrial-appendage-closure-insights-from-the-nationwide-readmissions-database

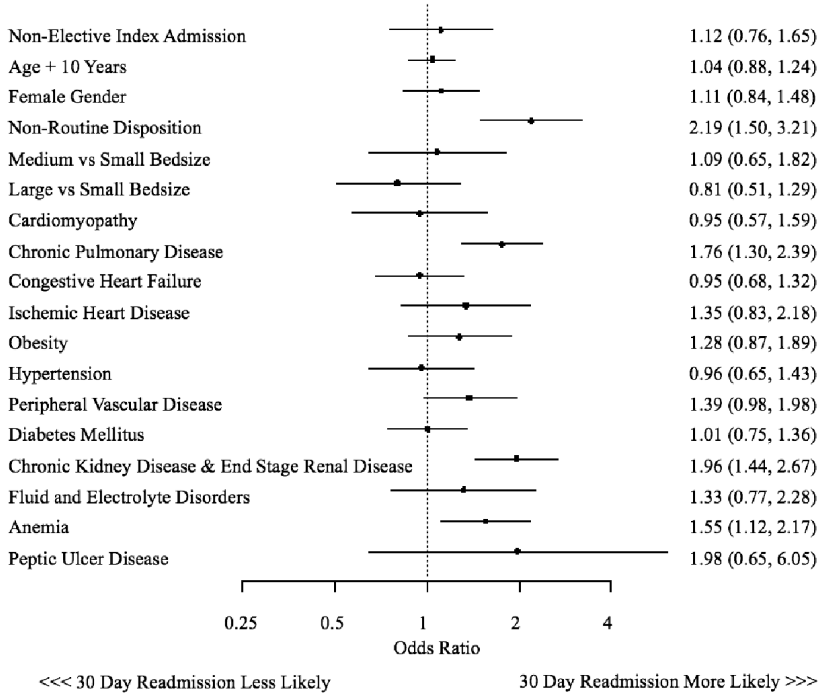
Hosted file

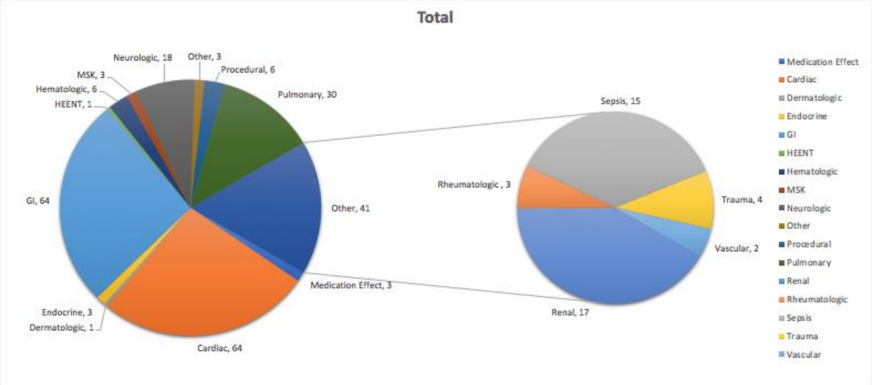
`LAAC Table 2.docx` available at https://authorea.com/users/326039/articles/453948-independent-predictors-of-readmission-following-left-atrial-appendage-closure-insights-from-the-nationwide-readmissions-database

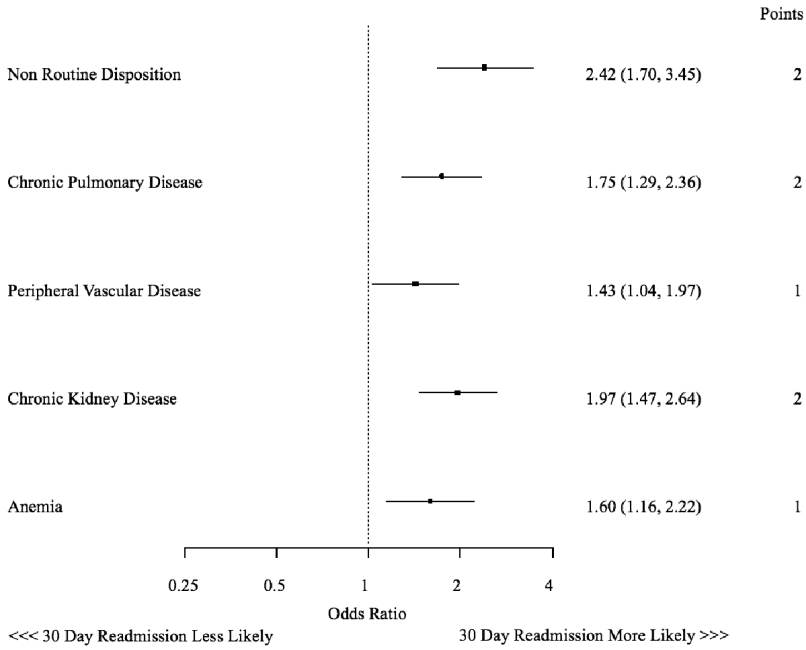
Hosted file

`LAAC Table 3.docx` available at https://authorea.com/users/326039/articles/453948-independent-predictors-of-readmission-following-left-atrial-appendage-closure-insights-from-the-nationwide-readmissions-database

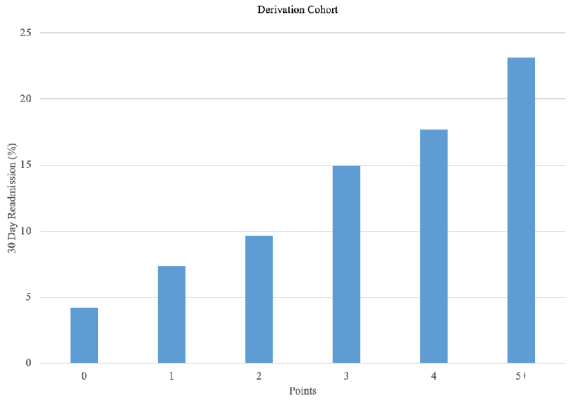








Variable	Points
Non-Routine Disposition	2
Chronic Pulmonary Disease	2
Renal Disease	2
Peripheral Vascular Disease	1
Anemia	1



Variable	Points
Non-Routine Disposition	2
Chronic Pulmonary Disease	2
Renal Disease	2
Peripheral Vascular Disease	1
Anemia	1