Readmissions Following Isolated Coronary Artery Bypass Graft Surgery in the United States (from the Nationwide Readmissions Database 2010 to 2014)

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Readmission following cardiac surgery is associated with poor outcomes and increased healthcare expenditure. However, a nationwide understanding of the incidence, cost, causes, and predictors of 30-day readmission following coronary artery bypass grafting is limited. The Nationwide Readmissions Database was used to identify all adult patients who underwent isolated coronary artery bypass grafting (CABG) with no other concomitant surgery between 2010 and 2014. The primary outcome was all-cause readmission within 30 days of discharge after surgery. Risk-adjusted multivariable analyses were used to develop a model of readmission risk. Of 855,836 patients, 95,504 (11.2%) had an emergent 30-day readmission following CABG. The most common causes of readmission were related to respiratory complications (17.1%), infection (13.5%), and heart failure (11.9%). Readmission cost an average of $13,392 per patient, accounting for an estimated annual cost of over $250 million. Independent predictors of 30-day readmission encompassed female gender (odds ratio [OR] 1.27; 95% confidence interval [CI] 1.24 to 1.31), emergent index admission (OR 1.29; 95% CI 1.25 to 1.33), and preoperative comorbidities, including atrial fibrillation (OR 1.24; 95% CI 1.21 to 1.28), liver disease (OR 1.29; 95% CI 1.17 to 1.41), renal failure (OR 1.38; 95% CI 1.34 to 1.43), among others. CABG performed at a high CABG volume hospital was protective of readmission (OR 0.95; 95% CI 0.91 to 0.99). In conclusion, we characterized using a national sample the incidence, causes, costs, and predictors of 30-day readmission following CABG. Targeting modifiable risk factors for readmission should be a priority to reduce rates of readmission and decrease healthcare expenditure.   © 2019 Elsevier Inc. All rights reserved. (Am J Cardiol 2019;124:205−210)

Generally associated with poor quality of care and increased healthcare costs, unplanned rehospitalizations are frequently used to evaluate and compare hospital performance, as they have recently been incorporated as a quality metric by the Centers for Medicare & Medicaid Services.[1] Readmissions further contribute to a known and well-documented increase in healthcare expenditures.[2] Interestingly, several studies have analyzed causes of readmission in surgery and found many modifiable risk factors that, if prevented, could result in improved outcomes and reduced healthcare expenditure.[3−5] Coronary artery bypass grafting (CABG) is the most commonly performed open heart operation in the United States, comprising 1.4% of all operating room procedures performed in 2011.[6] Patients who underwent CABG experienced relatively high rates of readmission, increasing resource utilization.[7,8] A focus to reduce rates of readmissions for CABG thus has potential to reduce

healthcare expenditures and improve quality of care. Given the aforementioned high volume and resource use, the present study was performed to characterize 30-day unplanned readmissions following CABG using the Nationwide Readmissions Database (NRD).

Methods

Patient data was collected from the 2010 to 2014 Nationwide Readmissions Database. The NRD is a publicly available database developed as part of the Healthcare Cost and Utilization Project (HCUP) by the Agency for Healthcare Research and Quality (AHRQ).[9] It includes all-payer hospital discharge data from State Inpatient Databases, which contain deidentified unique patient linkage numbers used to track patients across hospitals within a state. The NRD excludes rehabilitation and long-term acute hospitals. It samples up to 57.8% of the total US resident population, and 56.6% of all US hospitalizations.[9] The database includes discharge weights to provide national estimates for readmission.

The study population was identified using International Classification of Disease, Ninth Edition (ICD-9) codes and included adult patients (age ≥ 18) who underwent isolated CABG (ICD-9 36.1x, 36.2, 36.3x) and survived to discharge. Patients with elective 30-day readmission, concomitant operations, including aortic arch interventions,

valve repair/replacement, ventricular assist device, or transplant were excluded. Patients with operations in December were further excluded due to lack of data on 30-day readmission. Patients were then divided into 2 cohorts: those who were readmitted within 30 days of their index discharge following CABG (*Readmit*), and those who were not (*NReadmit*).

Baseline patient characteristics included age, gender, co-morbidities, median household income, insurance, and discharge disposition among others. Co-morbidities analyzed included anemia, atrial fibrillation, chronic pulmonary disease, coagulopathy, congestive heart failure, depression, diabetes, drug abuse, fluid and electrolyte disorders, hypertension, hypothyroidism, liver disease, neurological disorders, obesity, paralysis, peripheral vascular disorders, psychoses, renal failure, malignancy, and previous myocardial infarction. Hospital characteristics included teaching status, metropolitan status, and hospital annual CABG volume. Hospitals were categorized into low (mean, 119; range, 1 to 186; interquartile range, 66 to 153), medium (mean, 259; range, 187 to 340; interquartile range, 221 to 297), and high (mean, 532; range, 341 to 1136; interquartile range, 404 to 642) volume tertiles based on annual CABG volume. The AHRQ-Comorbidity Measures, defined by ICD-9 and Diagnosis Related Groups (DRG), were used.[9] The Elixhauser co-morbidity index was used to quantify the severity of chronic conditions.[10] Additional co-morbidities were identified using ICD-9 codes, which included atrial fibrillation, previous CABG, and previous myocardial infarction. These co-morbidities were selected and defined based on previous studies that analyzed readmission in other cardiac procedures.[11] Postoperative complications at index hospitalization were similarly defined using ICD-9 codes, and later categorized by organ systems. The primary indication for readmission was identified using DRG, and then stratified into relevant categories and further classified as cardiac and non-cardiac.

The primary outcome of interest was 30 day, all cause readmission rate after CABG. Only the first readmission was considered in patients having multiple readmissions within thirty days of index discharge. Secondary outcomes were index length of stay (LOS), and index and readmission costs of hospitalization. Cost of hospitalization was adjusted for inflation using the NRD Cost-to-Charge ratios and the gross-domestic product adjustments published by the US Bureau of Labor Statistics Consumer Price Index, with 2014 as the baseline.

Statistical analysis was performed using Stata 15 (StataCorp, College Station, Texas). Categorical and continuous variables were compared using survey-weighted univariate chi-squared analysis and Student's *t* test, respectively. Multivariable logistic regression was performed to identify significant independent predictors of 30-day readmission following CABG and were risk-adjusted for baseline patient demographics, hospital characteristics, and postoperative outcomes. Significance was defined by a p value <0.05. This study was deemed exempt from our Institutional Review Board at the University of California, Los Angeles, as the NRD is a publicly available database containing deidentified data.

Results

Of an estimated 1,070,203 adult patients who underwent CABG from 2010 to 2014, 28,076 (2.6%) died during index hospitalization, 188,888 (17.6%) had concomitant cardiac surgery, and 9,328 (0.9%) had elective readmission. All 3 groups were excluded from the study. Of the remaining 855,836 patients, 95,504 (11.2%) had an emergent readmission to the hospital within 30 days of their index discharge.

On univariate analysis, *Readmit* patients were more commonly female, and older compared with the *NReadmit*, as shown in Table 1. The *Readmit* cohort had higher proportions of Medicare and Medicaid coverage, and lower

Table 1
Preoperative patient demographics and hospital characteristics of CABG patients based on thirty-day readmission

	Not readmitted (n = 760,332)	Readmitted (n = 95,504)	p Value
Age (year)	64.9	66.4	<0.001
Age > 75 Years	126,975 (16.7%)	21,393 (22.4%)	<0.001
Female	189,323 (24.9%)	31,803 (33.3%)	<0.001
Median Household Income			
0 − 25th Percentile	222,777 (29.3%)	30,179 (31.6%)	<0.001
26th − 50th Percentile	209,091 (27.5%)	25,786 (27.0%)	0.159
51st − 75th Percentile	183,240 (24.1%)	22,443 (23.5%)	0.039
76th − 100th Percentile	145,223 (19.1%)	17,000 (17.8%)	<0.001
Insurance			
Private	250,910 (33.0%)	21,202 (22.2%)	<0.001
Medicare	401,455 (52.8%)	59,499 (62.3%)	<0.001
Medicaid	47,141 (6.2%)	8,500 (8.9%)	<0.001
Other	60,827 (8.0%)	6,399 (6.7%)	<0.001
Comorbidities			
Anemia	136,860 (18.0%)	23,494 (24.6%)	<0.001
Atrial Fibrillation	208,331 (27.4%)	33,235 (34.8%)	<0.001
Chronic Pulmonary Disease	163,471 (21.5%)	27,028 (28.3%)	<0.001
Congestive Heart Failure	12,165 (1.6%)	2,865 (3.0%)	<0.001
Depression	57,025 (7.5%)	8,977 (9.4%)	<0.001
Diabetes	326,943 (43.0%)	48,421 (50.7%)	<0.001
Drug Abuse	11,405 (1.5%)	1,910 (2.0%)	<0.001
Fluid and Electrolyte Disorders	210,612 (27.7%)	33,808 (35.4%)	<0.001
Hypertension	610,547 (80.3%)	77,358 (81.0%)	0.005
Liver Disease	10,645 (1.4%)	2,006 (2.1%)	<0.001
Neurological Disorders	27,372 (3.6%)	5,348 (5.6%)	<0.001
Obesity	169,554 (22.3%)	24,067 (25.2%)	<0.001
Peripheral Vascular Disorders	111,008 (14.6%)	18,432 (19.3%)	<0.001
Renal Failure	105,686 (13.9%)	22,539 (23.6%)	<0.001
Tumor without Metastasis	8,364 (1.1%)	1,337 (1.4%)	<0.001
Prior Myocardial Infarction	118,612 (15.6%)	15,854 (16.6%)	<0.001
Elixhauser Comorbidity Index	3.6	4.4	<0.001
Transfer	76,033 (10.0%)	12,893 (13.5%)	<0.001
Hospital CABG Volume			
Lowest Tertile	254,711 (33.5%)	33,426 (35.0%)	<0.001
Middle Tertile	267,637 (35.2%)	31,898 (33.4%)	<0.001
Highest Tertile	237,984 (31.3%)	30,179 (31.6%)	0.577

percentages of private insurance. *Readmit* patients suffered from higher rates of co-morbidities. Lastly, after consideration of CABG volume, receiving an operation at the lowest volume tertile hospitals was associated with significantly increased likelihood of readmission. Significant differences were observed in index length of stay and procedural costs between the 2 cohorts, as depicted in Table 2. *Readmit* patients experienced longer lengths of stay, and higher costs. The cost of CABG readmission was found to be on average $13,392, accounting for an estimated annual US excess expenditure of $255,797,914. Additionally, *Readmit* patients were less likely to be discharged home and more likely to be discharged to a skilled nursing facility. Lastly, overall operative complications were significantly higher in *Readmit* patients. The most common causes of cardiac and noncardiac 30-day readmissions are highlighted in Figure 1. Thirty-day readmissions were more likely to be noncardiac in origin. In noncardiac readmissions, respiratory and

infectious complications were the most common causes (Figure 1). The most common cause of cardiac readmission was heart failure (Figure 1).

A multivariable model was constructed to identify significant independent predictors of readmission (C-statistic = 0.65), as shown in Table 3. Factors found to be significant independent predictors of readmission within 30 days of discharge included female gender, age over 75 years, LOS greater than 14 days, emergent admission, and Medicare and Medicaid insurance compared with private insurance. Co-morbidities associated with increased odds of readmission included anemia, atrial fibrillation, chronic pulmonary disease, diabetes, liver disease, obesity, peripheral vascular disorders, renal failure, among others. Finally, previous myocardial infarction, postoperative infectious complications, and discharge to a skilled nursing facility were also found to be independent predictors of readmission. Factors associated with lower rates of CABG readmission included high median household income, LOS less than 7 days, hypertension, and operations performed at hospitals with medium or high CABG volume compared with low volume. Two multivariable models were created to analyze significant independent predictors of cardiac and noncardiac readmission (C-statistic = 0.65). Independent predictors of cardiac readmissions included gender, age over 75 years, emergent admission, Medicare and Medicaid insurance, atrial fibrillation, fluid and electrolyte disorders, neurological disorders, obesity, postoperative infectious complications, and discharge destination when compared with discharge home (Table 4). Independent predictors of noncardiac readmissions included emergent admission, Medicaid insurance, coagulopathy, and discharge destination in comparison to discharge home (Table 5).

Discussion

With the evolution of value-based healthcare delivery in the United States, reducing postoperative readmission has become a priority. Postoperative rehospitalizations within 30 days of discharge occur often, are associated with poor outcomes, and add a significant economic burden on the healthcare system.[12] Understanding the main predictors and causes of rehospitalizations are critical to alleviating the burden of readmission.[13]

Several studies have attempted to characterize the incidence and predictors of 30-day readmission following CABG. However, 2 studies using the New York State Cardiac Surgery Reporting System were limited by small sample sizes and nonstringent inclusion criteria.[7,8] They included planned readmissions within their study cohort, thereby overestimating the rates of readmissions, and underestimating their financial impact on the healthcare system. One study by Shahian et al. found significant predictors of 30-day readmission following CABG using the Society of Thoracic Surgeons National Database. However, the database only included Medicare recipients and the investigators did not examine the financial burden of readmission or the impact of hospital procedural volume on 30-day readmission.[14]

Our study overcame these limitations using a large all-payer nationwide database and excluding planned

Table 2
Postoperative outcomes of CABG patients based on thirty-day readmission

|	Not readmitted (n = 760,332)	Readmitted (n = 95,504)	p Value
Index Length of Stay (days)	9.5	12.3	<0.001
Index CABG Cost	$41,072	$49,386	<0.001
Cost of Readmission	N/A	$13,392	N/A
Discharge Destination			
Home	354,315 (46.6%)	32,949 (34.5%)	<0.001
Home Health Care	295,009 (38.8%)	37,533 (39.3%)	0.273
Skilled Nursing Facility	105,686 (13.9%)	23,876 (25.0%)	<0.001
Short-term Hospital	4,562 (0.6%)	1,051 (1.1%)	<0.001
Against Medical Advice	532 (0.07%)	143 (0.15%)	<0.001
Complications	335,306 (44.1%)	47,752 (50.0%)	<0.001
Cardiovascular			
Bleeding	15,207 (2.0%)	2,388 (2.5%)	<0.001
Cardiac Arrest	20,529 (2.7%)	3,247 (3.4%)	<0.001
Myocardial Infarction	218,976 (28.8%)	31,039 (32.5%)	<0.001
Post-Operative Shock	9,124 (1.2%)	1,624 (1.7%)	<0.001
Infectious			
Sepsis	8,364 (1.1%)	2,101 (2.2%)	<0.001
Septicemia	5,322 (0.7%)	1,337 (1.4%)	<0.001
Wound Infection	4,562 (0.6%)	955 (1.0%)	<0.001
Gastrointestinal Bleed	2,281 (0.3%)	382 (0.4%)	<0.001
Respiratory			
Iatrogenic Pneumothorax	15,207 (2.0%)	1,624 (1.7%)	0.008
Pneumonia	26,612 (3.5%)	4,107 (4.3%)	<0.001
Prolonged Ventilation	15,967 (2.1%)	3,820 (4.0%)	<0.001
Pulmonary Collapse	93,521 (12.3%)	12,129 (12.7%)	0.148
Pulmonary Edema	4,562 (0.6%)	669 (0.7%)	0.161
Tracheostomy	6,083 (0.8%)	1,337 (1.4%)	<0.001
Renal	3,802 (0.5%)	1,242 (1.3%)	<0.001
Neurological			
Delirium	4,562 (0.6%)	860 (0.9%)	<0.001
Seizure	2,281 (0.3%)	573 (0.6%)	<0.001
Stroke	13,686 (1.8%)	2,292 (2.4%)	<0.001
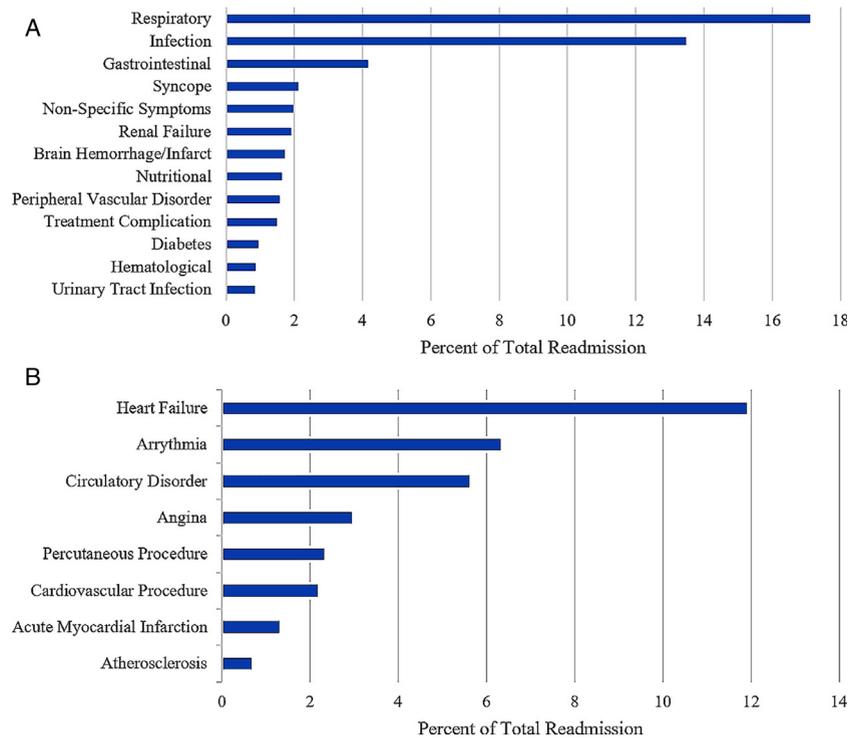
Figure 1. Causes of cardiac and noncardiac readmission. (*A*) Causes of noncardiac readmission. (*B*) Causes of cardiac readmission.

readmission within 30 days of discharge. In this large-scale study, we found a 11.2% rate of emergent 30-day readmission in 855,836 CABG patients. Our stated rate of readmission was slightly lower than previously reported rates,[7,8,14] which was likely due to our analysis of all-payer data and exclusion of planned readmission. Furthermore, we found independent predictors of readmission that were similarly described in previous literature,[7,8,15−17] including gender, age, preoperative co-morbidities, emergent index admission, low socio-economic status, discharge to a destination other than home, and postoperative infection. Several of our findings deserve further discussion.

Our analyses provided unique insight and robust evidence for the association between hospital volume and 30-day readmission following CABG. We found that hospital CABG volume independently impacted outcomes of patients related to readmission. Compared with low volume hospitals, medium and high-volume hospitals were associated with decreased odds of readmission following CABG. We hypothesize that centers with higher CABG procedural volume may have decreased odds of readmission because of greater access to experienced surgeons and highly trained staff members. Furthermore, higher procedural centers often have robust preoperative patient care and optimized postoperative management. We suggest that high-risk patients planning on undergoing CABG be referred to centers of excellence for better outcomes and reduced risk for readmission.

Noncardiac readmissions comprised the majority of total readmissions, with respiratory and infectious complications being the most common. Predictors for noncardiac readmission were more frequently related to system-related factors such as hospital characteristics, insurance status, and discharge destination than patient characteristics. Therefore, system-related interventions, such as improved discharge interventions or thorough follow-up after surgery, may reduce rates of noncardiac readmission. Multiple studies have found that implementing nurse specialists into the discharge planning, patient education, and follow-up reduces rates of readmission.[18−21] In the setting of cardiac readmission, we found that in addition to hospital characteristics, patient characteristics such as age, gender, and co-morbidities, were also predictive for readmission. The existing literature on interventions aimed to improve outcomes after cardiac surgery is limited. A meta-analysis by Burgess et al. showed that interventions using antiarrhythmic drugs effectively reduced postoperative atrial fibrillation after cardiac surgery, but did not find any differences in readmissions.[22] Mitchell et al. showed that while prophylactic amiodarone decreased incidence of atrial tachyarrhythmias following CABG, it did not reduce rates of readmission within 6 months of discharge.[23] Overall, these studies indicate that multifaceted interventions, rather than single faceted interventions, may have a greater impact on reducing 30-day readmission.

A concerning finding of the study was the financial impact of short-term readmission following CABG on the healthcare system. We found that the cost of an unplanned readmission was significant, and almost equivalent to a third of the cost of an index CABG operation. The estimated annual costs of CABG readmissions exceed $250 million in the United States. Additionally, patients who were readmitted were associated with a higher cost of index hospitalization. This finding potentially stems from the association between readmitted patients and prolonged

Table 3
Independent predictors for CABG readmission

	OR	95% CI	p Value
Female	1.27	1.24 − 1.31	<0.001
Age > 75 Years	1.07	1.03 − 1.11	<0.001
Emergent Index Admission	1.29	1.25 − 1.33	<0.001
Length of Stay < 7 Days	0.77	0.74 − 0.81	0.004
Length of Stay 7 − 14 Days	1.06	1.02 − 1.11	<0.001
Length of Stay > 14 Days	1.37	1.32 − 1.42	<0.001
Median Household Income			
0 − 25th Percentile	Reference	Reference	Reference
26th − 50th Percentile	0.94	0.90 − 0.97	<0.001
51st − 75th Percentile	0.93	0.89 − 0.96	<0.001
76th − 100th Percentile	0.90	0.86 − 0.94	<0.001
Insurance			
Private	Reference	Reference	Reference
Medicare	1.29	1.25 − 1.34	<0.001
Medicaid	1.65	1.56 − 1.74	<0.001
Other	1.12	1.06 − 1.19	<0.001
Comorbidities			
Anemia	1.12	1.09 − 1.16	<0.001
Atrial Fibrillation	1.24	1.21 − 1.28	<0.001
Chronic Pulmonary Disease	1.23	1.19 − 1.27	<0.001
Collagen Vascular Disease	1.12	1.03 − 1.22	0.006
Depression	1.08	1.04 − 1.14	0.001
Diabetes	1.19	1.15 − 1.22	<0.001
Drug Abuse	1.20	1.10 − 1.31	<0.001
Fluid and Electrolyte Disorders	1.09	1.05 − 1.12	<0.001
Hypertension	0.94	0.91 − 0.98	0.001
Liver Disease	1.29	1.17 − 1.41	<0.001
Neurological Disorders	1.24	1.16 − 1.33	<0.001
Obesity	1.08	1.05 − 1.11	<0.001
Peripheral Vascular Disorders	1.12	1.08 − 1.16	<0.001
Renal Failure	1.38	1.34 − 1.43	<0.001
Tumor without Metastasis	1.12	1.01 − 1.25	0.027
Prior Myocardial Infarction	1.07	1.04 − 1.11	<0.001
Complications			
Infection	1.22	1.12 − 1.32	<0.001
Hospital CABG Volume			
Lowest Tertile	Reference	Reference	Reference
Middle Tertile	0.93	0.89 − 0.96	<0.001
Highest Tertile	0.95	0.91 − 0.99	0.015
Discharge Destination			
Home	Reference	Reference	Reference
Home Health Care	1.17	1.13 − 1.21	<0.001
Skilled Nursing Facility	1.58	1.52 − 1.65	<0.001
Short-term Hospital	1.61	1.40 − 1.86	<0.001
Against Medical Advice	1.84	1.33 − 2.56	<0.001

Table 4
Independent predictors for CABG cardiac readmissions

Variable	Odds ratio	95% confidence interval	p Value
Female	1.11	1.04 − 1.18	0.002
Age > 75 Years	1.14	1.05 − 1.23	0.001
Emergent Index Admission	1.10	1.03 − 1.17	0.003
Insurance			
Private	Reference	Reference	Reference
Medicare	1.20	1.12 − 1.29	<0.001
Medicaid	1.21	1.09 − 1.35	0.001
Comorbidities			
Atrial Fibrillation	1.27	1.19 − 1.35	<0.001
Fluid and Electrolyte Disorders	1.09	1.02 − 1.16	0.008
Hypertension	0.91	0.84 − 0.99	0.023
Neurological Disorders	1.19	1.03 − 1.36	0.016
Obesity	1.14	1.06 − 1.22	<0.001
Complications			
Infection	1.34	1.12 − 1.60	0.002
Discharge Destination			
Home	Reference	Reference	Reference
Home Health Care	1.15	1.07 − 1.23	<0.001
Skilled Nursing Facility	1.17	1.07 − 1.27	0.001
Short-term Hospital	1.52	1.12 − 2.07	0.007
Against Medical Advice	3.35	1.46 − 7.65	0.004

are generated using procedural and diagnostic codes. Certain variables that have been shown to impact readmission, such as race, laboratory values, ejection fraction, or medications, are not reported in the NRD and not included in this analysis. Lastly, while analyses were risk adjusted, our prediction model like many others produced a suboptimal C-statistic. This limitation is common when building models for 30-day readmission and similar C-statistics of 0.62[7] and 0.65[8] have been reported in previous CABG readmission studies.

In conclusion, 30-day readmissions remain a common issue after CABG and continue to burden our healthcare system. Our study is the first to present the causes, costs, and predictors of 30-day readmission following isolated CABG on a nationwide level. Improved management of

Table 5
Independent predictors for CABG noncardiac readmission

	Odds ratio	95% confidence interval	p Value
Emergent Index Admission	1.18	1.11 − 1.25	<0.001
Insurance			
Private	Reference	Reference	Reference
Medicaid	1.11	1.01 − 1.22	0.039
Comorbidities			
Chronic Pulmonary Disease	0.89	0.84 − 0.95	0.001
Coagulopathy	1.08	1.01 − 1.15	0.021
Discharge Destination			
Home	Reference	Reference	Reference
Short-term Hospital	1.30	1.02 − 1.65	0.031
Against Medical Advice	2.67	1.27 − 5.62	0.010

length of stay or increased rates of postoperative complications. Given that CABG readmissions cost a yearly estimate of over a quarter of a billion dollars, reducing readmissions should thus remain a priority to reduce the economic burden on patients and decrease expenditures to our healthcare system.

The present study has several important limitations including those inherent to its retrospective nature. The NRD is subject to reporting biases as the variables in NRD

preoperative co-morbidities and optimization of postoperative discharge should be a priority in reducing readmissions and decreasing unnecessary costs related to readmission.

Disclosures

The authors have no conflicts of interest to disclose.

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