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ORIGINAL RESEARCH

Outcomes of Reoperative Coronary Artery Bypass Graft Surgery in the United States

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BACKGROUND: There is a paucity of data on the trends and outcomes of reoperative coronary artery bypass graft (CABG) surgery during the current decade in the United States.

METHODS AND RESULTS: We queried the National Inpatient Sample database (2002–2016) for all hospitalizations with isolated CABG procedure. We reported the temporal trends and outcomes of reoperative CABG versus primary CABG procedures. The main outcome was in-hospital mortality. Among 3 212 768 hospitalizations with CABG, 46 820 (1.5%) had reoperative CABG. Over the 15-year study period, there were no changes in the proportion of reoperative CABG (1.8% in 2002 versus 2.2% in 2016, P_{tren}=0.08), and the related in-hospital mortality (3.7% in 2002 versus 2.7% in 2016, P_{trend}=0.97). Reoperative CABG was performed in patients with increasingly higher risk profile. Compared with primary CABG, hospitalizations for reoperative CABG were associated with higher in-hospital mortality (3.2% versus 1.9%, P<0.001), cardiac arrest, cardiogenic shock, vascular complications, and respiratory complications. Among hospitalizations for reoperative CABG, the predictors of higher mortality included history of heart failure and chronic kidney disease.

CONCLUSIONS: In this 15-year nationwide analysis, reoperative CABG procedures were increasingly performed in patients with higher risk profile. In-hospital mortality rates were relatively low and did not change during the examined period. Compared with primary CABG, reoperative CABG is associated with higher in-hospital mortality.

Key Words: coronary artery bypass grafting ■ redo bypass grafting ■ reoperation

Coronary artery bypass grafting (CABG) is the revascularization strategy of choice for patients with multivessel coronary artery disease, particularly those with complex lesions and high SYNTAX scores, those with diabetes mellitus, and those with left ventricular systolic dysfunction.[1,2] Approximately 10% to 20% of patients undergoing CABG require repeat revascularization within 10 years.[3] Percutaneous coronary intervention is preferred in most patients given the increased risks of redo sternotomy, including reported perioperative mortality up to 10% in some studies.[1,2,4] Ghanta et al[5] conducted the largest analysis (n=72 431) of reoperative CABG performed between 2000 and 2009, but there are limited data on the contemporary trends and outcomes of reoperative CABG.[6] Thus, we performed a comprehensive analysis using the largest available national inpatient database to examine the trends in risk profiles and outcomes of patients undergoing reoperative CABG in the contemporary era and compare them to those undergoing primary CABG procedures.

METHODS

Data Source

The data source for this study was the National Inpatient Sample (NIS) database. The NIS is part of

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CLINICAL PERSPECTIVE

What Is New?

- Despite an overall reduced number of hospitalizations for any coronary artery bypass grafting (CABG) procedure, there was no change in the proportion of hospitalizations for reoperative CABG.
- Patients undergoing reoperative CABG procedure were increasingly sicker, however, the in-hospital mortality rate did not change during the study period.
- Compared with primary CABG procedures, hospitalizations for reoperative CABG were associated with higher in-hospital mortality, cardiac arrest, cardiogenic shock, vascular complications, and respiratory complications.

What Are the Clinical Implications?

- Although reoperative CABG remains associated with higher mortality compared with primary CABG, the observed mortality rates were lower than earlier reports, and suggests improved safety profile regarding renal, bleeding, and cerebrovascular complications.
- Further studies are needed to explore the long-term outcomes for reoperative CABG in the contemporary era.

Nonstandard Abbreviations and Acronyms

CABG	coronary artery bypass grafting
HF	heart failure

the Health Care Cost and Utilization Project and is considered the largest inpatient care database in the United States. The NIS comprises data from all payers, including individuals covered by Medicare, Medicaid, and private insurance, and uninsured individuals. For Medicare, the NIS includes Medicare Advantage patients, a population that is often missing from Medicare claims data but comprises as much as 30% of Medicare beneficiaries.[7] The NIS contains over 100 clinical and nonclinical data elements from ≈7 million unweighted hospital stays each year, which represents roughly 20% of hospital admissions in the United States.[8] Data quality assessments are performed annually to maintain the internal validity of the NIS.[9] In addition, the NIS has been externally validated by comparing estimates from the NIS with the American Hospital Association Annual Survey Database, the National Hospital Discharge Survey from the National Center for Health Statistics, and the Med-PAR inpatient database from Centers for Medicare and Medicaid Services.[10] Data from the NIS have been used previously to track outcomes and trends of coronary artery disease.[11,12] The NIS reports data using the *International Classification of Diseases, Ninth Edition (ICD-9)* until September 2015, and data from October 2015 through 2016 are reported using *ICD-10* codes. Because the data in this study are de-identified and available publicly, this study was exempt from institutional review board evaluation at the University of Texas Medical Branch.

Study Population and Outcomes

The NIS database was sampled from 2002 to 2016 to identify hospitalizations with *ICD-9* and *ICD-10* primary procedural codes for isolated CABG. We selected hospitalizations with prior CABG procedure using *ICD-9* and *ICD-10* diagnostic codes V45.81 and Z95.1, respectively. We excluded hospitalizations with patient age ≤18 years, history of valvular replacement, concomitant valve replacement surgery during the same admission, as well as those with missing data on baseline characteristics or in-hospital mortality. We reported the temporal trends of hospitalizations and in-hospital mortality for reoperative isolated CABG versus primary isolated CABG procedures. For outcomes assessment, we examined the contemporary cohort from 2012 to 2016 to compare the outcomes of hospitalizations for reoperative CABG versus primary CABG procedures. The main study outcome was in-hospital mortality. By excluding cases with missing data on discharge status, all mortalities were accounted for in this analysis. Other study outcomes included cardiac arrest, cardiogenic shock, acute kidney injury, hemodialysis for acute kidney injury, acute stroke, postoperative bleeding, requirements of blood transfusion, cardiac tamponade (ie, hemodynamic instability in setting of fluid collection in the pericardial sac), hemopericardium (ie, presence of blood in the pericardial sac), respiratory complications, vascular complications, complete heart block, permanent pacemaker implantation, discharge to nursing facility, and length of hospital stay. Procedures, clinical characteristics, and inpatient outcomes were reported using *ICD-9* and *ICD-10* codes, Clinical Classifications Software codes and Elixhauser comorbidities as provided by the Healthcare Cost and Utilization Project (Table S1).

Statistical Analysis

Trend analyses were conducted using linear or curvilinear regression analyses (quadratic or cubical) depending on the curve-shapes. We conducted multivariable regression analyses to adjust for in-hospital outcomes in patients with reoperative versus primary CABG. The model included 26 clinical and hospital related variables: age, sex, race, diabetes mellitus, fluid/electrolytes abnormalities, hypertension, liver disease, hypothyroidism, history of heart failure, carotid artery disease, tobacco abuse, chronic kidney disease, chronic lung disease, peripheral artery disease, chronic anemia, valvular heart disease, obesity, long-term use of oral anticoagulants, prior percutaneous coronary intervention, prior implantable cardiac defibrillator, prior cardiac pacemaker, prior stroke, prior myocardial infarction, hospital bed size, hospital location/teaching status, and hospital region. A multivariable regression analysis was also conducted to identify factors associated with in-hospital mortality among hospitalizations for reoperative CABG. In that model, we included variables which were statistically significant on univariate analyses, and we also forced variables that are clinically relevant and known to affect the outcomes based on previous research. For all multivariable regression models, we assessed the collinearity by evaluating variance inflation factors.

All outcomes were analyzed using the complex samples facility of SPSS to account for hospital strata, clustering, and weights.[13] All analyses were conducted using the appropriate weighting samples in accordance with Health Care Cost and Utilization Project regulations.[13] Categorical variables were compared using the chi-square test, and continuous variables were compared using Student's *t* test if normally distributed and Mann–Whitney *U* test if nonnormally distributed. Categorical values were expressed as numbers and percentages, and continuous variables were reported as mean±SD or median and range depending on being normally distributed or not. Effect sizes were expressed using odds ratios (OR) and 95% CI. In the regression model for factors associated with in-hospital mortality, we used a significance level of $P<0.15$ to stay in the model. In all other analyses, associations were considered significant if the $P<0.05$. We used the SPSS software (IBM SPSS Statistics for Windows, Version 24.0. IBM Corp., Armonk, NY; Released 2016) and R software for all statistical analysis.[14]

RESULTS

Temporal Trends of CABG Procedures

From 2002 to 2016, our initial analysis identified 3 763 823 hospitalizations for isolated CABG. After excluding cases with age <18 years (n=741), prior valve replacement (n=9776), concomitant valvular surgeries (n=498 408), missing baseline characteristics (n=51 401), and missing data on mortality (n=505), the final analysis included 3 212 768 hospitalizations for isolated CABG (Figure 1). Among all hospitalizations for CABG, 46 820 (1.5%) underwent reoperative CABG.

Over the 15-year study period, the number of primary CABG procedures significantly decreased (295 597 in 2002 versus 169 385 in 2016, $P_{trend}<0.001$), as well as the number of reoperative CABG (5506 in 2002 versus 3835 in 2016, $P_{trend}<0.001$). Over the 15-year period, there was no change in the proportion of reoperative CABG (1.8% in 2002 versus 2.2% in 2016, linear $P_{trend}=0.08$, quadratic $P_{trend=}0.32$, and cubic $P_{trend}=0.96$). However, starting 2010 there was a steady increase in the proportion of reoperative CABG procedures (1.2% in 2010 versus 2.2% in 2016, $P_{trend}=0.01$). The overall in-hospital mortality for reoperative CABG was 3.1% and did not change significantly over time (3.7% in 2002 versus 2.7% in 2016, linear $P_{trend}=0.97$, quadratic $P_{trend}=0.47$ and cubic $P_{trend}=0.19$) (Figure 2).

Baseline Characteristics of the Study Population

The baseline characteristics of patients undergoing primary and reoperative CABG are described in Table 1. Patients undergoing reoperative CABG were older, less likely to be women, and had a higher prevalence of hypertension, diabetes mellitus, chronic kidney disease, chronic lung disease, peripheral vascular disease, coagulopathy, tobacco abuse, long-term use of oral anticoagulants, prior implantable cardiac defibrillator, prior permanent pacemaker implantation, prior myocardial infarction, prior percutaneous coronary intervention, and prior stroke compared with those undergoing primary CABG. There were significant regional differences in the performance of reoperative CABG procedures; we observed that hospitals in the South region had the highest rates of reoperative CABG procedures.

The prevalence of risk factors and comorbidities among patients undergoing reoperative CABG increased significantly during the 15-year study period. Reoperative CABG was also increasingly performed in small- and medium-sized hospitals (Table 2).

Clinical Outcomes of Reoperative CABG Versus Primary CABG

Reoperative CABG was associated with higher in-hospital mortality compared with primary CABG (3.2% versus 1.9%, adjusted OR, 1.86; 95% CI, 1.48–2.34, $P<0.001$), as well as higher incidence of cardiac arrest (3.9% versus 3.4%, $P=0.03$), cardiogenic shock (6.2%

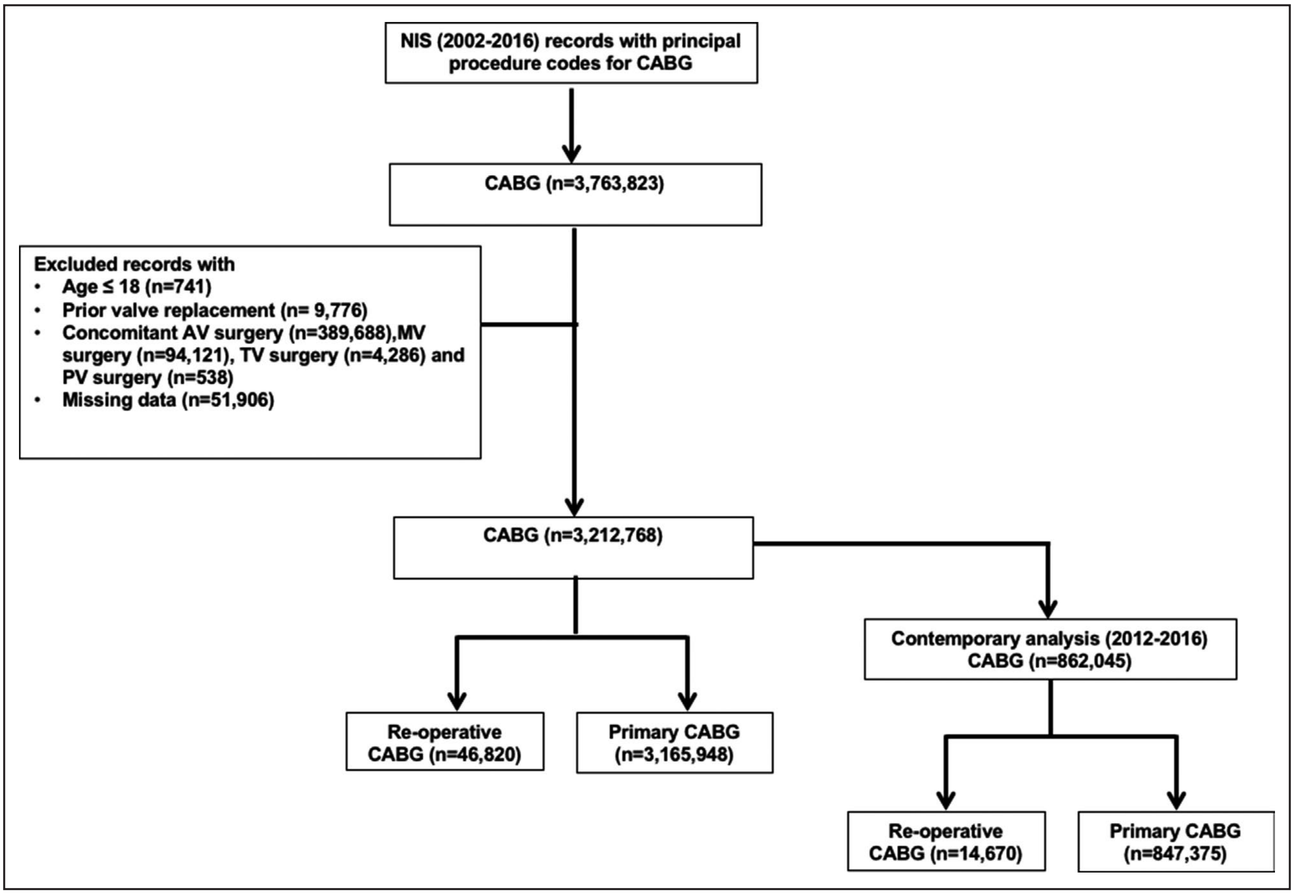

Figure 1. Study flow sheet.
AV indicates aortic valve; CABG, coronary artery bypass grafting; MV, mitral valve; PV, pulmonary valve; and TV, tricuspid valve.

versus 5.5%, P=0.01), vascular complications (1.1% versus 0.6%, P=0.01), and respiratory complications (5.7% versus 4.8%, P=0.04) (Table 3). Reoperative CABG was also associated with fewer discharges to skilled nursing facilities (18.8% versus 20.3%, P=0.01), and shorter median length of hospital stay (8 [range 0–173] versus 8 [range 0–347] days, P=0.01. There was no difference between both groups as regards acute kidney injury (17.6% versus 17.2%, P=0.37), hemodialysis (1.2% versus 1.2%, P=0.46), postoperative bleeding (41.4% versus 40.6%, P=0.54), blood transfusions (28.1% versus 26.7%, P=0.28), acute stroke

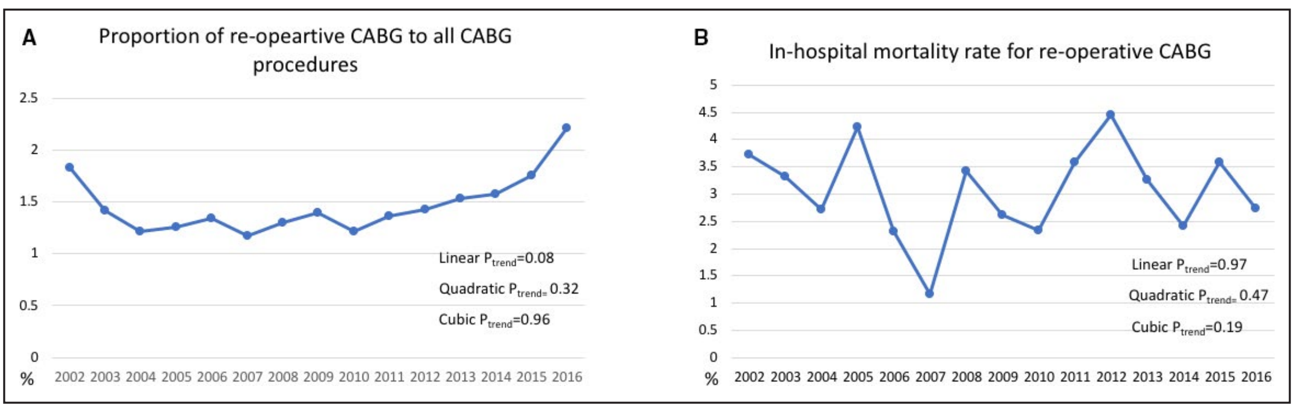

Figure 2. Temporal trends in reoperative CABG procedures and their in-hospital mortality rates.
A, Temporal trends in proportion of reoperative CABG procedures. **B**, Temporal trends in-hospital mortality rates of reoperative CABG procedures. CABG indicates coronary artery bypass grafting.

Table 1. Baseline Characteristics for Hospitalizations With Primary and Reoperative CABG

Characteristic	Reoperative CABG (n=14 670)N (%)	Primary CABG (n=847 375)N (%)	*P* Value
Age, y (mean±SD)	66.05±10.04	65.25±10.36	<0.001
Female sex	3424 (23.3)	217 009 (25.6)	0.006
Race			
White	10 869 (74.1)	623 870 (73.6)	0.113
Black	1115 (7.6)	57 445 (6.8)	
Hispanic	1000 (6.8)	58 745 (6.9)	
Asian/Pacific Islander	340 (2.3)	23 830 (2.8)	
Other races	389 (2.7)	27 194 (3.2)	
Coagulopathy	3190 (21.7)	162 175 (19.1)	<0.001
Obesity	3509 (23.9)	211 195 (24.9)	0.219
Fluid and electrolyte disorders	4579 (31.2)	278 025 (32.8)	0.75
Hypertension	12 335 (84.1)	683 175 (80.6)	<0.001
Hypothyroidism	1569 (10.7)	87 065 (10.3)	0.459
History of heart failure	150 (0.01)	9320 (0.01)	0.686
Valvular heart disease	50 (0.3)	3250 (0.4)	0.786
Chronic kidney disease	2604 (17.8)	137 855 (16.3)	0.033
Chronic liver disease	240 (1.6)	15 129 (1.8)	0.537
Chronic lung disease	3529 (24.1)	188 615 (22.3)	0.018
Diabetes mellitus	7055 (48.1)	387 725 (45.8)	0.010
Chronic anemia	2755 (18.8)	154 635 (18.2)	0.460
Carotid artery disease	680 (4.6)	42 955 (5.1)	0.282
Pulmonary circulation disease	35 (0.2)	1650 (0.2)	0.593
Peripheral vascular disease	2695 (18.4)	129 845 (15.3)	<0.001
Long-term use of OAC	1010 (6.9)	29 125 (3.4)	<0.001
Prior pulmonary embolism	75 (0.5)	2145 (0.3)	0.006
Prior other thromboembolic disease	3985 (0.5)	160 (1.1)	<0.001
Prior ICD	360 (2.5)	6664 (0.8	<0.001
Prior cardiac pacemaker	430 (2.9)	12 910 (1.5)	<0.001
Prior PCI	3670 (25.0)	136 800 (16.1)	<0.001
Prior MI	3900 (26.6)	138 175 (16.3)	<0.001
Prior stroke	1254 (8.6)	53 910 (6.4)	<0.001
Tobacco abuse	3785 (25.8)	201 460 (23.8)	0.011
Hospital bed size			
Small sized	1490 (10.2)	77 840 (9.2)	0.167
Medium sized	3694 (25.2)	204 440 (24.1)	
Large sized	9484 (64.7)	565 095 (66.7)	
Hospital region			
Northeast	2005 (13.7)	135 575 (16.0)	0.001
Midwest or North Central	3540 (24.1)	198 180 (23.4)	
South	6995 (47.7)	376 025 (44.4)	
West	2129 (14.5)	137 595 (16.2)	
Hospital teaching status			
Rural	430 (2.9)	28 460 (3.4)	0.136
Urban nonteaching	3665 (25.0)	222 730 (26.3)	
Urban teaching	10 574 (72.1)	596 185 (70.4)	

CABG indicates coronary artery bypass grafting; ICD, implantable cardiac defibrillators; OAC, oral anticoagulants; PCI, percutaneous coronary intervention; and MI, myocardial infarction.

Table 2. Temporal Changes in Baseline Characteristics for Hospitalizations With Reoperative CABG

Characteristics	2002–2006 (n=19 178)N (%)	2007–2011 (n=12 964)N (%)	2012–2016 (n=14 670)N (%)	*P* Value
Age, y (mean±SD)	65.65±10.339	66.17±10.112	66.05±10.040	<0.001
Female sex	4270 (22.3)	3226 (24.9)	3425 (23.3)	<0.001
Race				
White	11 234 (58.6)	8950 (69.0)	10 870 (74.1)	<0.001
Black	703 (3.7)	795 (6.1)	1115 (7.6)	
Hispanic	739 (3.9)	619 (4.8)	1000 (6.8)	
Asian/Pacific Islander	220 (1.1)	199 (1.5)	340 (2.3)	
Other races	382 (2.0)	402 (3.1)	390 (2.7)	
Coagulopathy	1084 (5.7)	1662 (12.8)	3190 (21.7)	
Obesity	1800 (9.4)	2103 (16.2)	3510 (23.9)	<0.001
Fluid and electrolyte disorders	1933 (10.1)	2726 (21.0)	4580 (31.2)	<0.001
Hypertension	13 371 (69.7)	10 211 (78.7)	12 335 (84.1)	<0.001
Hypothyroidism	1045 (5.4)	1215 (9.4)	1570 (10.7)	<0.001
History of heart failure	101 (0.50)	81 (0.60)	150 (1.00)	<0.001
Valvular heart disease	42 (0.20)	48 (0.40)	50 (0.30)	0.028
Chronic kidney disease	774 (4.0)	1671 (12.9)	2605 (17.8)	<0.001
Chronic liver disease	59 (0.3)	105 (0.8)	240 (1.6)	<0.001
Chronic lung disease	3198 (16.7)	2635 (20.3)	3530 (24.1)	<0.001
Diabetes mellitus	6488 (33.8)	5354 (41.3)	7055 (48.1)	<0.001
Anemia	1924 (10.0)	2620 (20.2)	2755 (18.8)	<0.001
Carotid artery disease	575 (3.0)	629 (4.9)	680 (4.6)	<0.001
Pulmonary circulation disease	NR	20 (0.2)	35 (0.2)	<0.001
Peripheral vascular disease	2340 (12.2)	2143 (16.5)	2695 (18.4)	<0.001
Long term use of OAC	257 (1.30)	508 (3.90)	1010 (6.9)	<0.001
Prior MI	4460 (23.20)	3299 (25.40)	3900 (26.60)	<0.001
Prior ICD	271 (1.4)	346 (2.7)	360 (2.5)	<0.001
Prior cardiac pacemaker	490 (2.6)	386 (3.0)	430 (2.9)	0.036
Prior PCI	3843 (20.0)	2956 (22.8)	3670 (25.0)	<0.001
Prior stroke	21 (0.1)	694 (5.4)	1255 (8.6)	<0.001
Smoking	2462 (12.8)	2122 (16.4)	3785 (25.8)	<0.001
Hospital bed size				
Small sized	971 (5.1)	840 (6.6)	1490 (10.2)	<0.001
Medium sized	3246 (16.9)	2017 (15.8)	3695 (25.2)	
Large sized	14 966 (78.0)	9876 (77.6)	9485 (64.7)	
Hospital region				
Northeast	3291 (17.2)	1748 (13.5)	2005 (13.7)	<0.001
Midwest or North Central	4032 (21.0)	3131 (24.1)	3540 (24.1)	
South	8901 (46.4)	5904 (45.5)	6995 (47.7)	
West	2960 (15.4)	2185 (16.8)	2130 (14.5)	
Hospital teaching status				
Rural	730 (3.8)	587 (4.6)	430 (2.9)	<0.001
Urban nonteaching	7309 (38.1)	5001 (39.3)	3665 (25.0)	
Urban teaching	11 144 (58.1)	7146 (56.1)	10 575 (72.1)	

CABG indicates coronary artery bypass grafting; ICD, implantable cardiac defibrillators; MI, myocardial infarction; OAC, oral anticoagulants; and PCI, percutaneous coronary intervention; NR, not reportable, per HCUP recommendations frequencies fewer than 11 should not be reported.

(1.5% versus 1.8%, *P*<0.001), hemopericardium (0.1% versus 0.1%, *P*=0.98), cardiac tamponade (0.3% versus 0.5%, *P*=0.38), complete heart block (0.7% versus 1.0%, *P*=0.09), and insertions of permanent pacemaker implantation (1.1% versus 1.0%, *P*=0.95) (Figure 3).

Table 3. Comparative Outcomes Between Reoperative Versus Primary CABG

Outcome	Reoperative CABG (n=14 670)N (%)	Primary CABG (n=847 375)N (%)	Adjusted OR*	Lower CI	Upper CI	*P* Value
In-hospital mortality	475 (3.20)	16 335 (1.90)	1.862	1.481	2.342	<0.0001
Cardiac arrest	570 (3.90)	28 560 (3.40)	1.251	1.024	1.528	0.028
Cardiogenic shock	905 (6.20)	46 930 (5.50)	1.250	1.065	1.466	0.006
Acute kidney injury	2575 (17.60)	145 760 (17.20)	1.054	0.941	1.180	0.367
Hemodialysis	170 (1.20)	10 415 (1.20)	1.138	0.806	1.608	0.463
Post-operative bleeding	6070 (41.40)	344 230 (40.60)	1.027	0.943	1.120	0.537
Blood transfusions	4125 (28.10)	226 605 (26.70)	1.051	0.960	1.151	0.281
Ischemic stroke	215 (1.50)	15 660 (1.80)	0.851	0.621	1.166	0.315
Vascular complciations	155 (1.10)	5290 (0.60)	1.794	1.262	2.551	0.001
Hemopericardium	15 (0.10)	1000 (0.10)	1.010	0.321	3.179	0.986
Cardiac tamponade	50 (0.30)	3950 (0.50)	0.745	0.387	1.436	0.380
Respiratory complications	840 (5.70)	40 755 (4.80)	1.195	1.011	1.413	0.036
Complete heart block	110 (0.70)	8510 (1.00)	0.665	0.417	1.061	0.087
Permanentpacemaker placement	165 (1.10)	8525 (1.00)	1.011	0.699	1.463	0.952
Facility discharge	2765 (18.80)	172 310 (20.30)	0.864	0.774	0.964	0.009
Length of stay, median (range)	8 (0–173)	8 (0–347)				0.001

CABG indicates coronary artery bypass grafting; and OR, odds ratio.
*Adjusted for age, sex, race, diabetes mellitus, fluid/electrolytes abnormalities, hypertension, liver disease, hypothyroidism, history of heart failure, carotid artery disease, tobacco abuse, chronic kidney disease, chronic lung disease, peripheral artery disease, chronic anemia, valvular heart disease, obesity, long term use of oral anticoagulants, prior percutaneous coronary intervention, prior implantable cardiac defibrillator, prior cardiac pacemaker, prior stroke, prior myocardial infarction, hospital bed size, hospital location/teaching status, and hospital region.

Factors Associated With In-Hospital Mortality for Reoperative CABG

Factors significantly associated with in-hospital mortality after reoperative CABG on multivariable regression analyses included history of heart failure (OR, 6.17; 95% CI, 1.55–24.61, *P*=0.01), chronic kidney disease (OR, 2.39; 95% CI, 1.51–3.77, *P*<0.001), and fluids/electrolytes disturbances (OR, 2.76; 95% CI, 1.80–4.23, *P*<0.001) (Table 4).

DISCUSSION

In this 15-year observational nationwide cohort analysis of ≈3.7 million hospitalizations for isolated CABG, we found that (1) despite an overall reduction in the number of hospitalizations for any isolated CABG procedure, there was no change over time in the proportion of hospitalizations for reoperative CABG; (2) patients undergoing reoperative CABG procedure had a rising burden of comorbidities; however, the in-hospital mortality rate did not change during the study period; (3) reoperative CABG was associated with higher in-hospital mortality, cardiac arrest, cardiogenic shock, vascular complications, and respiratory complications; and (4) factors associated with higher in-hospital mortality after reoperative CABG were history of heart failure, chronic kidney disease, and fluids/electrolytes disorders (Figure 4).

Historically, outcomes of reoperative CABG were much worse than those of primary CABG.[15] The higher associated mortality and morbidities of reoperative CABG procedures compared with primary CABG procedures have been traditionally attributed to the technical hazards of a redo sternotomy, as well as the high-risk anatomy and higher risk patient profile.[15] Adequate exposure of the surgical field can be difficult due to the presence of adhesions. There is a risk of injury to critical structures that lie directly behind the sternum including the right ventricle and brachiocephalic vein. Manipulation of bypass grafts carries a potential risk for embolization, ischemia, or injury to a patent graft.[16] Moreover, there is a higher likelihood for postoperative low cardiac output state and myocardial ischemia-reperfusion injury associated with intraoperative cardioplegia in patients with prior cardiac surgery.[17] However, there have been advances in minimal invasive surgical techniques in the past decade. The value of those sternotomy-sparing techniques are more important in patients with prior CABG procedure.[18] Off-pump CABG techniques in patients with prior CABG have been evaluated in multiple studies with promising results.[19,20] Minimal access incisions and arterial conduits (radial artery and internal mammary grafts) has also been demonstrated to be safe and effective during reoperative CABG procedures.[19,21,22]. Hence, we sought

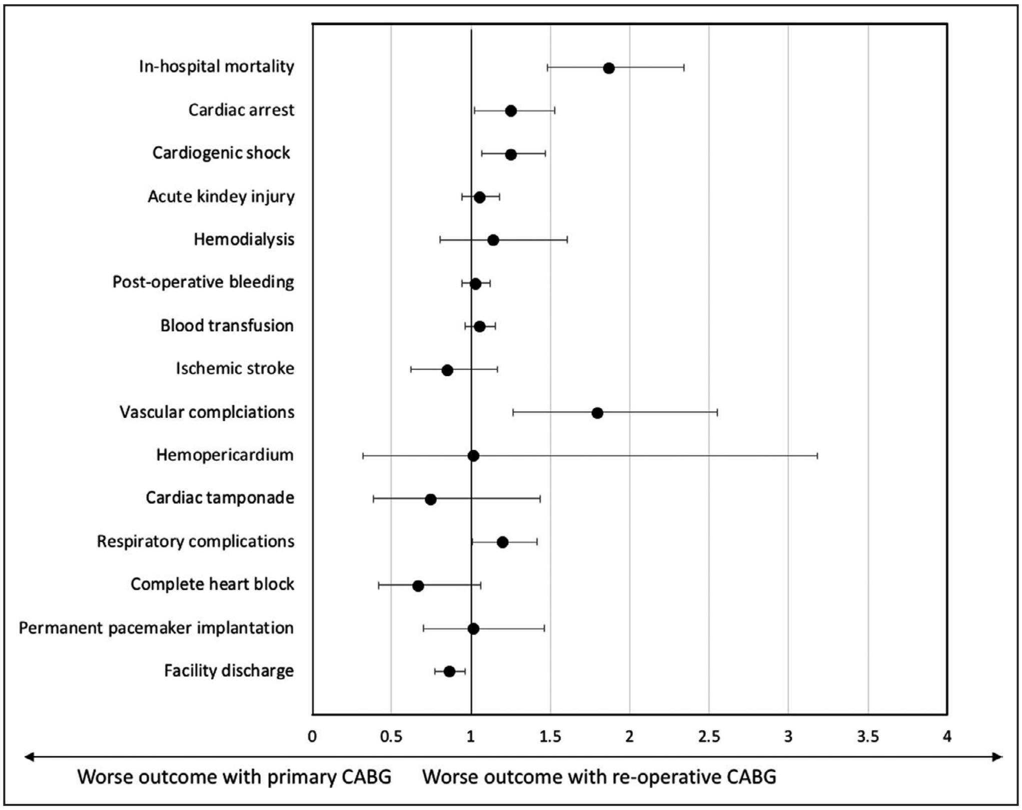

Figure 3. Forest plot for adjusted outcomes of primary vs reoperative CABG. CABG indicates coronary artery bypass grafting.

to conduct a more contemporary analysis to evaluate the outcomes of reoperative CABG in the United States.

In an analysis of the Society of Thoracic Surgeons database, Ghanta et al[5] reported a reduction in the number of reoperative CABG procedures from 2000 to 2009 and the proportion of reoperative CABG. In a single-center retrospective analysis, Spiliotopoulos et al[23] evaluated the outcomes of reoperative CABG from 1990 to 2009 among 25 347 patients undergoing isolated CABG. They found a significant decrease in the proportion of reoperative CABG during the examined period.[23] However, in our more contemporary and generalizable nationwide analysis, the proportion of reoperative CABG procedures has not changed over a 15-year period and even showed a steady rise since 2010.

Studies from the 1990s showed high operative mortality for reoperative CABG (7%–10%),[24–26] whereas studies from the early 2000s showed improved operative mortality rates (4%–6%).[5,6,27,28] In the analysis of the Society of Thoracic Surgeons database, Ghanta et al showed a significant decrease in 30-day operative mortality from 6.1% in 2000 to 4.6% in 2009. Our more contemporary analysis showed lower absolute rates of operative mortality (3.1%) in comparison to that reported by earlier studies for reoperative CABG (Table 5). That difference in absolute mortality rates is probably related to advances in the surgical techniques as well as the operators' experiences but also might be partially related to the differences in examined durations, in-hospital versus 30-day operative mortality.

In our analysis, patients undergoing reoperative CABG had a rising burden of comorbidities over time. However, the operative mortality rate did not significantly change during the study period. Similar results were noted by Spiliotopoulos et al[23], who found an increasing prevalence of comorbidities and no change in in-hospital mortality (4.7% in the 1990s and 3.8% in the 2000s). Our results suggest that in the past decade, the risk profile for patients undergoing reoperative CABG has continued to evolve to include relatively sicker patients with a higher burden of comorbidities. However, mortality rates for reoperative CABG have plateaued and are lower than those observed in earlier studies.

Our analysis showed that reoperative CABG was associated with higher in-hospital mortality (3.2% versus 1.9%) and complications compared with primary CABG. In the analysis of the Society of Thoracic Surgeons database, Ghanta et al[5] reported similar findings with worse 30-day mortality among

Table 4. Multivariable Analysis for Factors Associated With Mortality Among Reoperative CABG

Variable	OR	95% CI		*P* Value
Age >65 y	1.564	0.966	2.533	0.069
Hypertension	0.688	0.412	1.150	0.154
Diabetes mellites	1.007	0.658	1.539	0.976
Heart failure	6.171	1.548	24.607	0.010
Valvular disease	1.876	0.125	28.207	0.649
Pulmonary circulation disease	1.443	0.864	2.408	0.161
Peripheral vascular disease	3.834	0.321	45.836	0.288
Chronic kidney disease	2.386	1.510	3.772	<0.0001
Chronic liver disease	0.425	0.039	4.636	0.483
Coagulopathy	1.455	0.932	2.272	0.099
Obesity	1.107	0.693	1.766	0.671
Fluids/electrolytes disorders	2.759	1.795	4.239	<0.0001
Chronic anemia	0.975	0.596	1.594	0.919
Prior stroke	0.738	0.310	1.758	0.493
Prior myocardial infarction	0.883	0.567	1.375	0.581
Tobacco abuse	0.916	0.552	1.521	0.736
Small sized hospitals*	1.026	0.537	1.961	0.371
Medium sized hospitals*	1.483	0.855	2.573	
Northeast region†	1.934	0.829	4.514	0.289
Midwest region†	1.035	0.524	2.044	
South region†	1.386	0.757	2.537	

CABG indicates coronary artery bypass grafting; and OR, odds ratio.
*Reference category large-sized hospitals.
†Reference category West region.

reoperative CABG compared with primary CABG (4.6% versus 1.9% in 2009). In another study, reoperative CABG was evaluated using the Australasian Society of Cardiac and Thoracic Surgeons Cardiac Surgery Database from 2001 to 2008. In that study, they reported higher operative mortality with reoperative CABG (4.8%) compared with primary CABG procedures (1.8%).[27]

In our analysis, there was no difference between primary CABG and reoperative CABG in the incidence of acute stroke, renal complications, and bleeding events.In contrast, the 2000–2009 data analysis by Ghanta et al[5] found a higher risk of acute stroke, acute kidney injury, and reoperation for bleeding events among reoperative CABG compared with primary CABG. This suggests some improvement in the safety profile among reoperative CABG procedures. In our analysis reoperative CABG was associated with lower discharges to nursing facilities compared with primary CABG; however, the difference was minimal (18.8% versus 20.3%, ie, 1.5% difference). There is no clear explanation behind such a finding, but we hypothesize that patients undergoing reoperative CABG might be more carefully selected and less likely to be frail. Despite statistical significance, the difference in the length of stay among primary and reoperative CABG was not clinically meaningful.

Management decisions regarding repeat revascularization in patients with prior CABG require careful risk-benefit assessment after engaging the patient in a process of shared-decision making in order to decide between complex percutaneous coronary intervention versus reoperative CABG. Hence, it is important to identify the high-risk clinical variables that correlate with worse outcomes among patients undergoing reoperative CABG for better patient selection. Previous studies have shown that traditional risk scores such as Euro SCORE, Society of Thoracic Surgeons score, and Sino SCORE have poor predictive value for early postoperative mortality rate in patients with redo CABG.[29] In our analysis, the predictors of higher mortality among reoperative CABG procedures included history of heart failure, chronic kidney disease, and fluids/electrolytes disorders. Similar to our study, Maltais et al[6] identified history of left ventricular systolic dysfunction and renal impairment as predictors of higher operative mortality for reoperative CABG. In the analysis by Spiliotopoulos et al[23], predictors of mortality for reoperative CABG included, history of heart failure, and preoperative shock. In another study, prior heart failure and low left ventricular systolic function were independent predictors of operative mortality for reoperative CABG.[30] Unlike our analysis, age and peripheral vascular disease correlated with higher operative mortality in other studies.[6,23]

The strength of our analysis stems from the relatively large number of patients and its national representation. However, our results are limited by the lack of operative details for CABG procedures (eg, procedural time, use of cardiopulmonary bypass, and use of arterial grafts). Being an administrative database, the NIS is subject to documentation and coding errors. Nevertheless, the NIS has been internally and externally validated. In addition, it is time discrete, with no available long-term data beyond the index hospitalization. Many useful data were not available for this analysis, including data on imaging, medications, echocardiographic, and laboratory values. In addition, our study lacks other relevant information regarding the decision to undergo redo CABG versus complex percutaneous coronary intervention, such as angiographic findings and left ventricular function. Despite these limitations, we conducted robust statistical analyses to reduce the potential risk

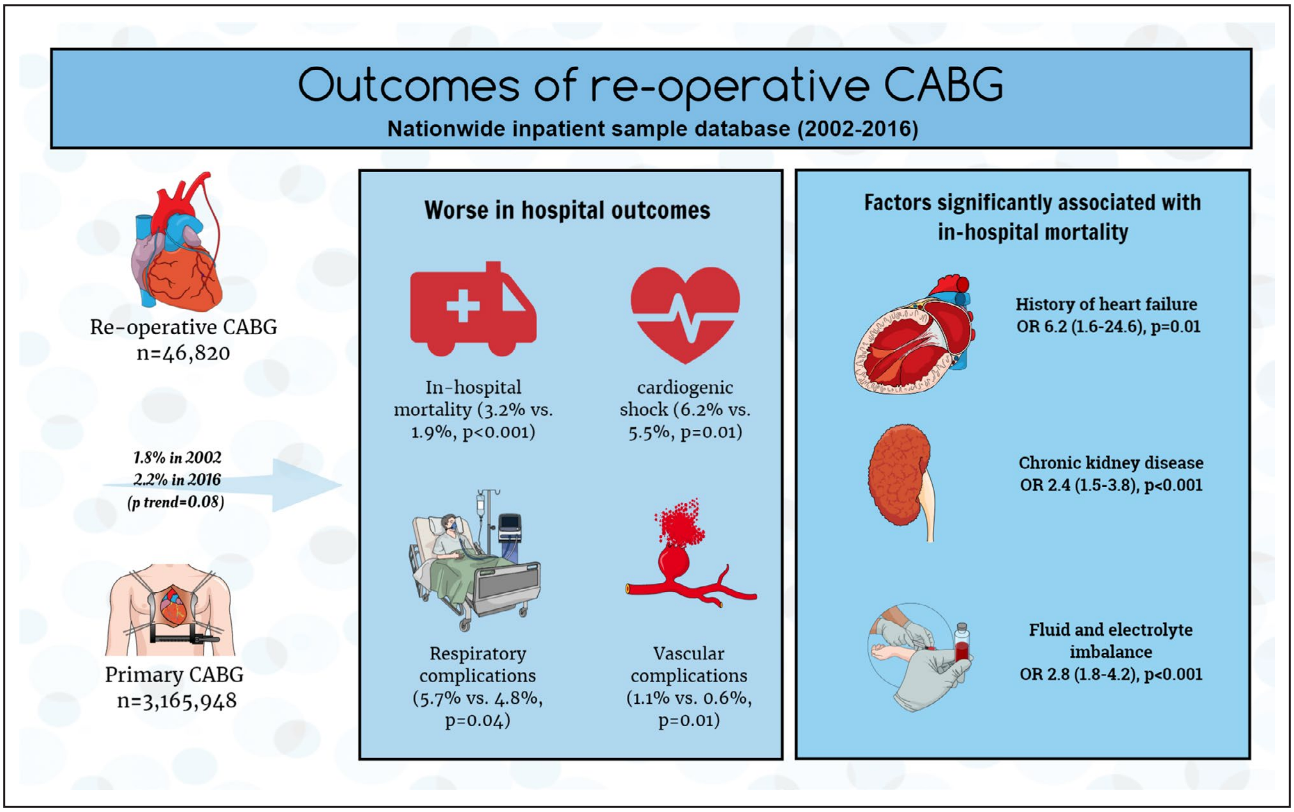

Figure 4. Trends and outcomes of reoperative CABG compared with primary CABG procedure. CABG indicates coronary artery bypass grafting.

of allocation and selection biases. Our study contributes to a current knowledge gap, regarding the contemporary short-term outcomes of reoperative CABG procedures. Further studies are still warranted to explore the long-term outcomes for reoperative CABG in the current era.

CONCLUSIONS

In this 15-year nationwide analysis, there was no significant change in the proportion of reoperative CABG procedures. Although reoperative CABG was increasingly performed in higher risk profile patients,

Table 5. Prior Major Studies Evaluating Outcomes of Re-Operative CABG

Outcome	Year of Analysis	Re-Operative CABG Procedures Evaluated (n)	Mean Age	Centre	Operative Mortality (%)
Christenson[26]	1984–1994	594/3157	62/63	Single	9.6%/2.8%*
Spiliotopoulos[23]	1990–2009	1204	NA	Single	4.7% in (1990-1999)† 3.8% in (2000-2009)
Grinda[24]	1986–1998	240	63.6	Single	10%†
Yau[25]	1982–1997	1,230	61	Single	6.8%†
Sabik[31]	1990–2003	3,919	65.1	Single	4.4%†
Di Mauro[28]	1994–2001	274	63.3	Single	4.2%
Yap[27]	2001–2008	458	67.3	Multicenter	4.8%*
Ghanta[5]	2000–2009	8784 in 2000 5734 in 2009	67	Multicenter	6.1% in 2000* 4.6% in 2009
Maltais[6]	1993–2014	748	67.5	Single	6%*
Current study	2002–2016	46 820	66.1	Multicenter	3.1%†

CABG indicates coronary artery bypass grafting; and NA, not available.
*30-day operative mortality.
†In-hospital mortality.

in-hospital mortality related to reoperative CABG did not change during the study period. Compared with primary CABG, reoperative CABG was associated with higher in-hospital mortality and complications.

ARTICLE INFORMATION

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Supplementary Material

Table S1

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SUPPLEMENTAL MATERIAL

Table S1. List of the used ICD-9. ICD-10, and CCS codes.

	ICD 9 CODE	ICD 10 CODE
CABG	CCS-45	CCS-45
Prior myocardial infarction	412.0	I25.2
Previous percutaneous coronary intervention	V45.82	Z98.61
Previous coronary artery bypass grafting	V45.81	Z95.1
Previous CVA	V12.54	Z86.73
Carotid artery disease	433.10	I65.01 I65.02 I65.03 I65.09
Cardiogenic shock	785.51	R57.0
Cardiac arrest	CCS-107	CCS-107
Post-operative hemorrhage	998.11, 998.12, 285.1	I97611 I97618 I97620 I97411 I97418 I9742 T85838 T82837 T82838
Transfusion	99.01-99.09	30243N0 30243N1 30243P0 30243P1 30243H0 30243H1 30240N0 30240N1 30240P0 30240P1 30240H0 30240H1 30230H0 30230H1 30230N0 30230N1 30230P0 30230P1 30233N0 30233N1 30233P0 30233P1
Acute stroke	CCS-100	CCS-100
Respiratory complications	997.3, 997.31, 997.32, 997.39	J9562 J9561 J9572 J9571 J9588 J95861 J95860 J95831 J95830 J95863 J95862 J9589 J95821 J95822
Permanent pacemaker	37.80 37.83	02HK3JZ 02H63JZ 02HN0JZ 02H60JZ 02H60NZ 02H63JZ 02H63NZ 02H64JZ 02H64NZ

		02HK0JZ 02HK0NZ 02HK3JZ 02HK3NZ 02HK4JZ 02HK4NZ 02HN4JZ 0JH604Z 0JH634Z 0JH605Z 0JH607Z 0JH635Z 0JH606Z 0JH634Z 0JH635Z 0JH636Z 0JH637Z
Acute kidney injury	584	N17 N19 N990 R34 R944
Vascular complications	39.31, 39.41, 39.49, 39.52, 39.53, 39.56, 39.57, 39.58, 39.59, 39.79	04QY0ZZ 04QY3ZZ 04QY4ZZ 04QC0ZZ 04QC3ZZ 04QC4ZZ 04QD0ZZ 04QD3ZZ 04QD4ZZ 03QY0ZZ 03QY3ZZ 03QY4ZZ 03Q30ZZ 03Q33ZZ 03Q34ZZ 03Q40ZZ 03Q43ZZ 03Q44ZZ 0GQ60ZZ 0GQ63ZZ 0GQ64ZZ 0GQ70ZZ 0GQ73ZZ 0GQ74ZZ 03L23ZZ 03L33ZZ 03L43ZZ 03L50DZ 03L53DZ 03L53ZZ 03L54DZ 03L60DZ 03L63DZ 03L63ZZ 03L64DZ 03L70DZ 03L73DZ 03L73ZZ 03L74DZ 03L80DZ 03L83DZ 03L83ZZ 03L84DZ 03L90DZ 03L93DZ 03L93ZZ 03L94DZ 03LA0DZ 03LA3DZ 03LA3ZZ 03LA4DZ 03LB0DZ 03LB3DZ 03LB3ZZ 03LB4DZ 03LC0DZ 03LC3DZ 03LC3ZZ

	03LC4DZ 03LH3ZZ 03LJ3ZZ 04L03ZZ 04LC0DZ 04LC3DZ 04LC3ZZ 04LC4DZ 04LD0DZ 04LD3DZ 04LD3ZZ 04LD4DZ 04LE0DZ 04LE3DZ 04LE3ZZ 04LE4DZ 04LF0DZ 04LF3DZ 04LF3ZZ 04LF4DZ 04LH0DZ 04LH3DZ 04LH3ZZ 04LH4DZ 04LJ0DZ 04LJ3DZ 04LJ3ZZ 04LJ4DZ 04LK0DZ 04LK3DZ 04LK3ZZ 04LK4DZ 04LL0DZ 04LL3DZ 04LL3ZZ 04LL4DZ