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ORIGINAL RESEARCH

Trends in Characteristics and Outcomes of Hospitalized Young Patients Undergoing Coronary Artery Bypass Grafting in the United States, 2004 to 2018

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BACKGROUND: Data are limited about young adults' characteristics and outcomes undergoing coronary artery bypass grafting (CABG).

METHODS AND RESULTS: We used the National Inpatient Sample database to identify adults aged 18 to 45 years who underwent CABG between 2004 and 2018. The data were weighted to generate national estimates of the entire US hospitalized population. We identified 110 463 CABG cases, equivalent to 62.2 per 1 000 000 person-years; 27.1% were women, and 70.2% were White adults. Overall, annual CABG volume per 1 000 000 significantly decreased from 87.3 in 2004 to 45.7 in 2018. The prevalence of obesity, diabetes mellitus, hypertension, drug abuse, and chronic medical conditions increased over time. Overall, inpatient mortality was 1.76%; ST-segment–elevation myocardial infarction, non–ST-segment–elevation myocardial infarction, heart failure, peripheral vascular disease, renal failure, and valvular surgery were associated with higher inpatient mortality. Women had higher inpatient mortality than men (2.29% versus 1.57%), and Black patients had higher deaths than White patients (2.86% versus 1.58%). Inpatient mortality remained stable overall, according to sex, race, or clinical indication of CABG. However, the mean length of stay (8.4 days in 2004 to 9.5 days in 2018) and inflation-adjusted cost of care ($40 522.8 in 2004 to $52 434.2 in 2018) significantly increased during the study period.

CONCLUSIONS: Despite the increased burden of cardiometabolic risk factors, the inpatient mortality in young adults undergoing CABG remained stable during the last 15 years. However, CABG volumes have decreased, but length of stay and inflation-adjusted costs have increased over time.

Key Words: coronary artery bypass grafting ■ cost of care ■ mortality ■ young adults

Coronary artery disease (CAD) is the leading cause of mortality, morbidity, and economic loss worldwide.[1] Premature CAD (aged ≤45 years) may lead to loss of lifetime productivity, increase lifetime health-care usage, and poor prognosis.[2,3] Consequently, recent evidence suggests that an overall improvement in cardiac mortality has stalled in young adults (aged ≤45 years) in the United States since 2011.[4]

Surgical revascularization is a durable therapeutic strategy that lowers the rates of adverse cardiovascular events, improves the quality of life, and reduces the need for repeat revascularization.[5–7] However,

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CLINICAL PERSPECTIVE

What Is New?

- Between 2004 and 2018, young adults hospitalized for coronary artery bypass grafting have noted a substantial increase in cardiometabolic comorbidities.
- Coronary artery bypass grafting surgery volume has decreased, inpatient mortality has remained stable, but the length of stay and inflation-adjusted care costs have increased over time.

What Are the Clinical Implications?

- Strenuous efforts are needed to attenuate the comorbidity burden in young adults.
- Public health strategies should focus on providing cost-effective management in young adults requiring coronary artery bypass grafting.

Nonstandard Abbreviations and Acronyms

NIS	National Inpatient Sample

most coronary artery bypass graft (CABG) surgery data have primarily focused on elderly patients, and a limited number of studies have explored outcomes in younger adults.[8,9] Furthermore, prior studies of CABG in young patients have been mostly single-center analyses, without providing a perspective on the clinical risk profile, mortality, and healthcare resource usage at the national scale.[8–10] Therefore, analyzing the most recent CABG trends becomes relevant to public health interventions to assess clinical and economic burden in young adults undergoing surgical revascularization. Consequently, we analyzed data from the large US administrative claims-based database and examined trends in clinical characteristics, CABG volume, mortality, health care resource utilization, and expenditure in young adults.

METHODS

Data Sharing Statement

The National Inpatient Sample (NIS) data sets used in this project are publicly available and are easily replicable from the methods described in the article.

Setting

We used the NIS, an all-payer database that approximates a 20% stratified sample of discharges from US community hospitals participating in the Healthcare Cost Utilization Project—sponsored by the Agency for Healthcare and Research and Quality.[11] The database contains the clinical and resource utilization information abstracted from discharges from 47 US states covering >97% of the US population. The annual sample encompasses ≈8 million hospital discharges across different geographic regions and hospital types. This study was exempt from the institutional review board approval, given the NIS database's de-identified nature and public availability.

Study Design

We conducted an observational analysis using data from January 2004 to December 2018 to identify all hospitalizations in young patients[3,12] requiring CABG using an *International Classification of Diseases, Ninth Revision, Clinical Modification* (*ICD-9-CM*) procedure code of 36.1x and *International Classification of Diseases, Tenth Revision, Clinical Modification (ICD-10-CM)* procedure codes: "0210083" to "02134ZF".[13,14] Since premature CAD refers to the onset of disease in adults aged ≤45 years,[2,3] we defined young adults as those aged 18 to 45 years.[3,12] Several relevant clinical and socioeconomic features were described, including demographics, comorbidities, clinical presentation (ST-segment–elevation myocardial infarction [STEMI], non–ST-segment–elevation myocardial infarction [NSTEMI], and non-myocardial infarction [unstable angina and stable ischemic heart disease]), insurance status, household income, and discharge disposition. Tables S1 and S2 list the diagnosis codes used in this analysis.

We classified discharge disposition as (1) home; (2) short-term care facility (short-term rehabilitation or inpatient rehabilitation); (3) long-term care facility (skilled nursing and intermediate care facility); and (4) against medical advice.

Outcomes

The outcomes of interest were trends in clinical characteristics, inpatient mortality, length of stay (LOS), and inflation-adjusted care costs for hospitalization in young adults undergoing CABG.

Statistical Analysis

The national estimates of the entire US hospitalized population were calculated using the Agency for Healthcare and Research and Quality sampling and weighting method.[15] We divided the study population into 3 groups of 5-year intervals (2004–2008, 2009–2013, and 2014–2018). We described continuous variables as mean and SE and categorical variables as numbers and percentages. We used the Rao-Scott Chi-square test for between-group comparisons for categorical variables. We performed weighted logistic regression to estimate odds ratios (ORs) and 95% CIs to determine inpatient mortality predictors. We constructed a multivariable logistic regression model using variables identified as significant predictors ($P \leq 0.05$) of mortality in the univariate models (Table S3).

Hospital total charges were converted to cost estimates using hospital-specific *cost-to-charge ratios* provided by Healthcare Cost Utilization Project. Total costs were inflated to 2019 US dollars using the Consumer Price Index inflation calculator published by the US Bureau of Labor Statistics.[16] We performed a multivariate linear regression model to examine the correlation of clinical complications and components of hospital resource usage with the inflation-adjusted cost of care.

We estimated CABG per 1 000 000 young US adults; the denominator for the young population was extracted from the Census Bureau estimates of US resident populations for each study year.[17] We estimated inpatient mortality as the proportion of deaths in young adults undergoing CABG over a total number of young CABG admissions. We adjusted mortality for the following variables: age, sex, Charlson comorbidity index, valve surgery, insurance status, hospital location/teaching status, hospital region, and hospital bed size.

Trends in CABG per 1 000 000, LOS, and cost of care, were examined using weighted linear regression, and binary logistic regression was used for inpatient mortality, with year as the sole predictor. Accordingly, *P* values for trends were determined based on these models.[18]

We further stratified inpatient mortality analyses by sex, race, and clinical indication for CABG. Additionally, we performed sensitivity analyses for young adults comparing clinical and economic outcomes among adults who underwent isolated CABG versus CABG plus concomitant valve surgery. We used Stata 16.0 (StataCorp, College Station, TX)[19] for all analyses, which were survey-specific, using Stata's "svy" functions.[19] Statistical significance was set at ≤5%.

RESULTS

Between 2004 and 2018, a total of 110 463 weighted cases of CABG were identified in young adults, equivalent to 62.2 (95% CI, 62.1–62.3) per 1 000 000 person-years. The mean (SE) age of the population was 40.9 (0.03) years, 27.1% were women, and 70.2% were White adults (Table 1). Most procedures were performed in hospitals in the South region (48.5%; Figure 1A), large bed-sized hospitals (72.5%), and urban teaching hospitals (65.3%). The volume of CABG procedures was lowest in rural hospitals (3.8%). Medicare or Medicaid beneficiaries had lower proportions of procedures (29.2%) than those with private insurance (53.6%). A minority of patients had prior percutaneous coronary intervention (14.8%), prior CABG (1.4%), prior myocardial infarction (17.1%), and prior stroke (2.7%). A total of 5.1% participants underwent concurrent percutaneous coronary intervention and 7.5% concomitant valve surgery. Approximately a third of the patients (31.9%) lived in ZIP codes with the lowest quartile of income.

Overall CABG per 1 000 000 in young adults significantly decreased from 87.3 (95% CI, 87.2–87.4) in 2004 to 45.7 (95% CI, 45.6–45.8) in 2018 (*P*-trend <0.01; Figure 1B).

Trends in Demographics and Comorbidities

The proportion of women, Black and Hispanic adults undergoing CABG increased, while the number of White patients receiving CABG decreased ($P<0.001$; Table 1). The proportion of patients who lived in ZIP codes with the lowest quartile of income increased significantly during the study duration (29.8–34.1%; $P<0.001$). There was also a significant increase in the proportion of Medicare/Medicaid beneficiaries from 24.5% to 35.8% over time. Hypertension (64.5%) and smoking (51.9%) were the leading risk factors; the prevalence of diabetes mellitus, hypertension, obesity, peripheral vascular disease, smoking, drug abuse, chronic renal failure, hypothyroidism, and neurological disorders significantly increased over the study duration. Between 2004 and 2018, the primary clinical presentation shifted from STEMI to NSTEMI ($P<0.001$), consistent with similar national trends in older adults.[20]

Inpatient Mortality and Clinical Outcomes

Overall, inpatient mortality in young adults undergoing CABG was 1.76%; mortality was significantly higher in patients admitted with STEMI than those with NSTEMI (3.37% versus 1.58%). Women had higher mortality (2.3% versus 1.6%) than men, and Black patients had higher mortality than White patients (2.8% versus 1.6%). Inpatient mortality remained stable over time; this trend was consistent for sex and race (Table S4), as well as for clinical indication (Figure 2). Multivariate logistic regression showed that STEMI, NSTEMI, heart failure, peripheral vascular disease, renal failure, and valvular surgery were associated with a higher likelihood of inpatient mortality (Figure S1).

During the study period, clinical complications (cardiogenic shock, acute kidney injury, stroke) and resource utilization (vasopressors, invasive ventilation) increased significantly (Table S5).

Length of Stay and Inflation-Adjusted Cost of Care

Overall mean LOS was 8.7 (0.05) days; the mean inflation-adjusted cost was $45 842.3 (345.7) (Table 2).

Table 1. Baseline Characteristics and Trends in Young Adults Undergoing CABG in the United States, 2004 to 2018

Variable, n (%)	2004–2008 (n=46 273)	2009–2013 (n=34 820)	2014–2018 (n=29 370)
Age, mean (SE), y	41.09 (0.04)	40.85 (0.05)	40.80 (0.06)
Women	11 871 (25.66)	9270 (27.92)	8315 (28.32)
Race			
White adults	23 461 (73.07)	21 707 (70.08)	18 630 (67.12)
Black adults	3352 (10.44)	3880 (12.53)	3475 (12.52)
Hispanic adults	2738 (8.53)	2934 (9.47)	2380 (10.62)
Others[†]	2558 (7.97)	2456 (7.93)	2715 (9.78)
Comorbidities			
Chronic pulmonary disease*	7462 (16.13)	5530 (15.88)	4615 (15.71)
Atrial fibrillation	2577 (5.57)	2343 (6.73)	2110 (8.85)
Diabetes mellitus	14 972 (32.36)	13 855 (39.79)	13 080 (44.54)
Hypertension	27 682 (59.82)	24 277 (69.72)	19 335 (65.83)
Obesity	8680 (18.76)	10 109 (29.03)	11 440 (38.95)
Heart failure	275 (0.59)	371 (1.07)	380 (1.29)
Peripheral vascular disease	2466 (5.33)	2277 (6.54)	2195 (7.47)
Renal failure	2930 (6.33)	3513 (10.09)	3705 (12.61)
Liver disease	508 (1.1)	449 (1.29)	680 (2.32)
Neurological disorders	1115 (2.41)	1040 (2.99)	1200 (4.09)
Deficiency anemias	5690 (12.3)	6174 (17.73)	4620 (15.73)
Hypothyroidism	1889 (4.08)	2213 (6.36)	1760 (5.99)
Valvular disease	139 (0.3)	176 (0.51)	235 (0.8)
Smoking	21 934 (47.4)	18 295 (52.54)	17 155 (58.41)
Alcohol abuse	1892 (4.09)	1440 (4.13)	1250 (4.26)
Drug abuse	2309 (4.99)	2094 (6.01)	1900 (7.68)
Previous myocardial infarction	6607 (14.28)	6025 (17.3)	4765 (20)
Previous CABG	464 (1)	404 (1.16)	685 (2.33)
Previous PCI	5885 (12.72)	5779 (16.6)	4685 (15.95)
Prior stroke	445 (0.96)	1208 (3.47)	1325 (4.51)
Concomitant PCI	2387 (5.16)	1931 (5.54)	1335 (4.55)
Concomitant valve surgery	3109 (6.72)	2885 (8.28)	2345 (7.98)
Hospital location			
Rural	1716 (3.71)	1544 (4.50)	980 (3.34)
Urban non-teaching	16 646 (35.97)	12 109 (35.27)	5175 (17.62)
Urban teaching	27 910.43 (60.32)	20 679 (60.23)	23 215 (79.04)
Bed size of the hospital			
Small	2396 (5.18)	1925 (5.61)	2785 (9.48)
Medium	9355 (20.22)	5975 (17.4)	5175 (17.62)
Large	34 522 (74.6)	26 431 (76.99)	18 795 (63.99)
Region*			
Northeast	6465 (13.97)	4936 (14.18)	3730 (12.7)
Midwest	11 269 (24.35)	8256 (23.71)	6905 (23.51)
South	22 587 (48.81)	16 654 (47.83)	14 370 (48.93)
West	5952 (12.86)	4974 (14.29)	4365 (14.86)
Median income			
0–25th	13 439 (29.82)	11 108 (32.85)	9870 (34.11)
26–50th	12 622 (28.01)	9463 (27.99)	8130 (28.1)
50–75th	10 693 (23.73)	7912 (23.4)	6510 (22.5)

(*Continued*)

Table 1. (Continued)

Variable, n (%)	2004–2008 (n=46 273)	2009–2013 (n=34 820)	2014–2018 (n=29 370)
75–100th	8310 (18.44)	5326 (15.75)	4425 (15.29)
Insurance status			
Medicare or Medicaid	11 291 (24.46)	10 350 (29.81)	10 500 (35.83)
Private insurance	26 881 (58.24)	17 296 (49.82)	14 940 (50.98)
Self-pay, no charge, or other	7982 (17.29)	7072 (20.37)	3865 (13.19)
Clinical presentation			
STEMI	31 098 (67.2)	21 877 (62.83)	16 625 (56.61)
NSTEMI	8036 (17.37)	8885 (25.52)	9715 (33.08)
Non-myocardial infarction	7139 (15.43)	4058 (11.65)	3030 (10.32)

Non-myocardial infarction: unstable angina and stable ischemic heart disease. CABG indicates coronary artery bypass graft; NSTEMI, non–ST-segment–elevation myocardial infarction; PCI, percutaneous coronary intervention; and STEMI, ST-segment–elevation myocardial infarction.

*P>0.05.

†Other includes Asian/Pacific Islander, and Native American.

The mean LOS increased from 8.4 in 2004 to 9.5 in 2018 (P-trend <0.01; Figure 1C). The inflation-adjusted cost of care also increased from $40 523 in 2004 to $52 434 in 2018 ($P$-trend <0.01; Figure 1D). Clinical complications (acute kidney injury, cardiogenic shock, stroke, cardiac tamponade) and hospital resource usage (invasive mechanical ventilation, permanent pacemaker implantation, dialysis, tracheostomy) were significantly correlated with the LOS and inflation-adjusted cost of care (Tables S6 and S7, respectively). The discharge disposition to home decreased (from 94.5% to 91.4%) and to long-term care facility increased (from 3.2% to 5.6%) (P<0.001).

Sensitivity Analyses

Overall, larger number of patients underwent isolated CABG (n=102 124) compared with CABG plus concomitant valve surgery (n=8339). Patients undergoing isolated CABG were slightly older, predominantly White, and had a higher proportion of smoking, diabetes mellitus, hypertension, and obesity. Whereas patients undergoing CABG plus concomitant valve surgery had higher proportions of women, Black patients, and other comorbidities (atrial fibrillation, heart failure, peripheral vascular disease, anemias, neurological disorders) (Table S8). Inpatient mortality was significantly higher in patients undergoing CABG plus concomitant valve surgery than those receiving isolated CABG (10% versus 1.1%, P<0.05). Similarly, use of resources (vasopressors, invasive ventilation, Intra-aortic balloon pump, dialysis, tracheostomy, gastrostomy) and complications (cardiogenic shock, acute kidney injury, stroke, permanent pacemaker implantation, and cardiac tamponade) were higher with CABG plus concomitant valve surgery versus isolated CABG (Table S9). The mean LOS (13.5 versus 8.3, P<0.05) and inflation-adjusted cost of care ($80 283 versus $43 027, P<0.05) were significantly higher with CABG plus concomitant valve surgery than isolated CABG.

DISCUSSION

We document the following key trends in young adults undergoing CABG over the last 15 years in the United States. While the comorbidity profile has become increasingly complex, the inpatient mortality remained stable overall and according to demographic characteristics and clinical indications. CABG use has significantly decreased, whereas the LOS and inflation-adjusted care costs have increased, mainly because of extended LOS, higher usage of hospital resources, and medical complications. Inpatient mortality, LOS, inflation-adjusted care cost, and complications were significantly higher in adults undergoing CABG plus concomitant valve surgery than those receiving isolated CABG. Finally, a higher proportion of individuals were discharged to long-term care facilities instead of home, further influencing the CABG's total cost burden.

We found temporal changes in demographic, socioeconomic, and clinical profiles in young adults hospitalized for CABG. A significant number of patients belonging to the lowest income quartile and Medicaid/Medicare insurance have increased, suggesting a higher proportion of economically underserved young adults can afford CABG, likely attributable to the Affordable Care Act and Medicaid expansion efforts.[21] In contrast, we noted a considerable rise in cardiovascular and non-cardiovascular comorbidities in young patients. These trends are in line with a rising prevalence of cardiometabolic risk factors, smoking, and drug abuse in the young population in the United States.[22,23] While the prevalence of the cardiovascular disease has reduced in most age groups,[24,25] recent NIS analyses have shown an increase in cardiovascular comorbidities, including stroke and acute myocardial infarction in the young population.[4,26]

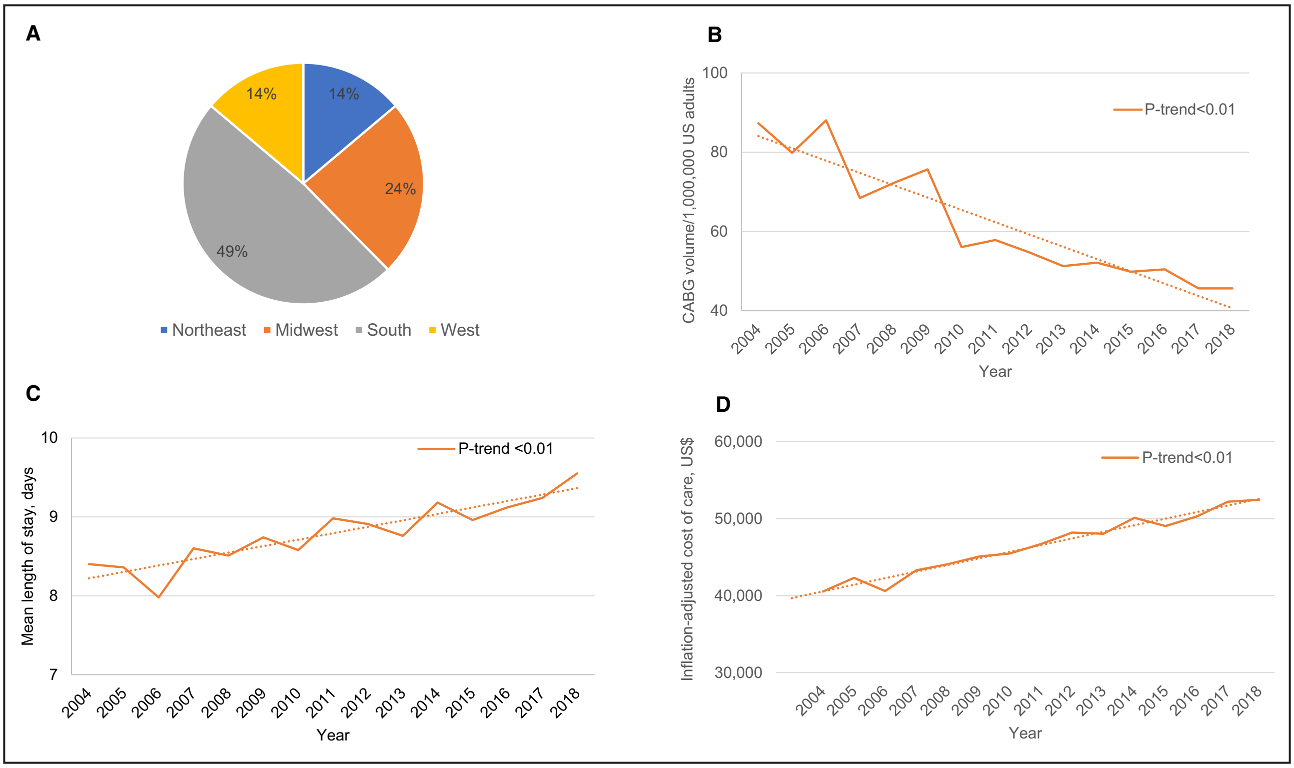

Figure 1. Trends of characteristics and outcomes in hospitalized young adults (≤45 years) undergoing CABG in the United States, 2004 to 2018.
A, Regional distribution of hospitals performing inpatient CABG; (**B**) Trends of CABG volumes per 1 000 000 US young adults; (**C**) Trends of mean length of stay in days; (**D**) Trends of inflation-adjusted cost of care in US $. CABG indicates coronary artery bypass grafting.

Sex and racial disparities exist among patients undergoing coronary revascularization.[27–30] We noted that women constituted a minor proportion of CABG recipients but had higher mortality than men. These observations are consistent with prior evidence showing higher in-hospital mortality in young women than men,[31] and that a minority of women underwent CABG compared with men.[32,33] A recent American Heart Association Survey reported that awareness of heart disease as the leading cause of death has declined in women by 21% between 2009 and 2019,[34] mainly in women aged 25 to 34 years and ethnic/racial minorities (Non-Hispanic Black and Hispanic women). Similarly, young women admitted with acute myocardial infarction were more likely to have hypertension, diabetes mellitus, chronic kidney insufficiency, and prior stroke than men in a US-based community surveillance study.[35] Furthermore, hypertension, diabetes mellitus, smoking, and obesity had a higher risk for acute myocardial infarction in women than men.[36] A recent report suggested that women aged <50 years were less likely to receive coronary revascularization or guideline-directed medical therapies and had higher all-cause mortality than men over a median follow-up of 11.2 years.[37] Women are also known to have a smaller body surface area and correspondingly smaller coronary arteries, accounting for some of the excess risks they may have when undergoing CABG.[38] Finally, sex bias in identifying and managing acute myocardial infarction has been shown to influence survival rates in women.[39]

Similarly, Black adults are disproportionally affected by cardiovascular risk factors than White adults. Black adults tend to develop premature CAD because of the early onset of traditional cardiovascular risk factors (eg, hypertension, diabetes mellitus, and obesity).[40,41] Black patients also have a greater prevalence of adverse health behaviors such as suboptimal diet, physical activity, and medication adherence. Significant socioeconomic gradients increase this racial minority's vulnerability for premature CAD.[42] In a recent study of Medicare beneficiaries, Black patients exhibited higher in-hospital mortality than White patients, despite an overall decline in Blacks' CABG usage.[43] Our study highlights concerning healthcare inequalities rooted in structural racism in young adults.[44]

We found that crude and risk-adjusted mortality remained stable over the last 15 years. The mortality statistics reflect improved surgical techniques,

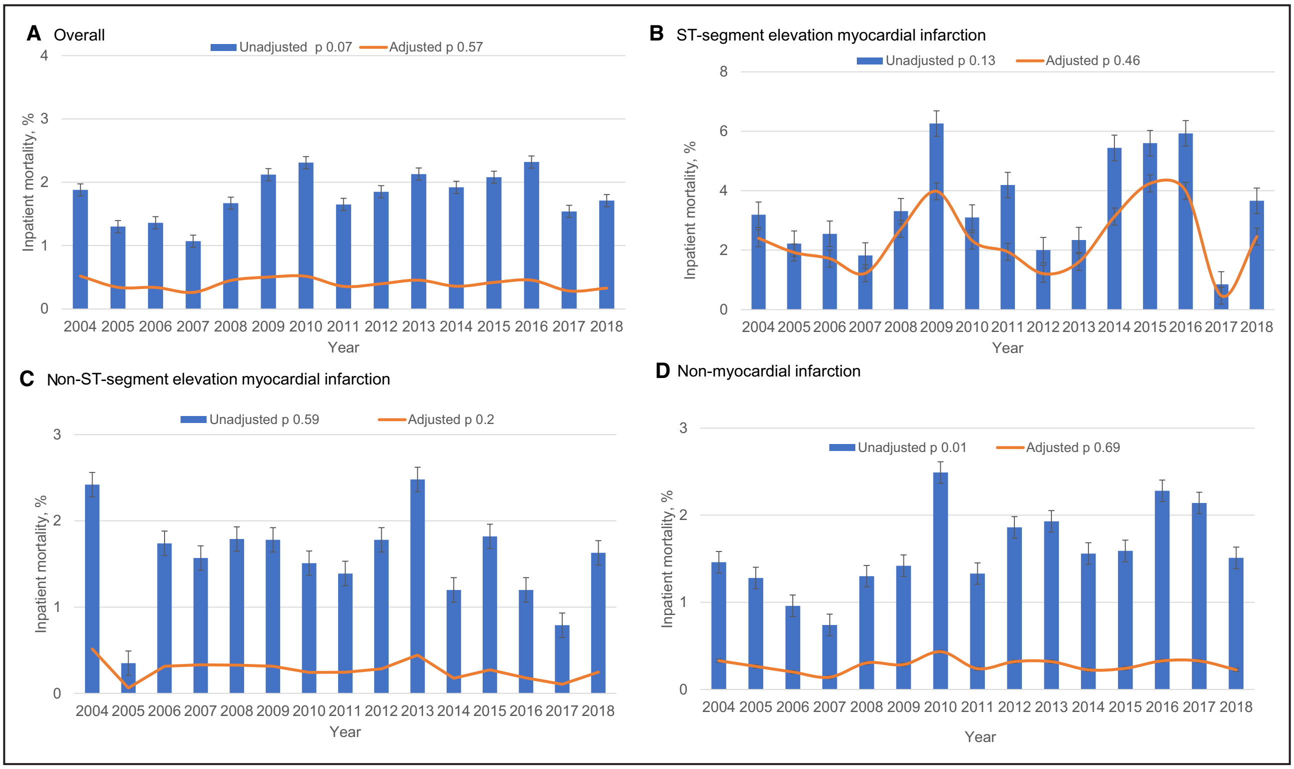

Figure 2. Trends of inpatient mortality in hospitalized young adults (≤45 years) undergoing coronary artery bypass grafting in the United States, 2004 to 2018.

A, Overall inpatient mortality; (**B**) Inpatient mortality after ST-segment–elevation myocardial infarction; (**C**) Inpatient mortality after non–ST-segment–elevation myocardial infarction; (**D**) Non-myocardial infarction. *P* values refer to *P*-trends. For adjusted inpatient mortality, estimates were adjusted for age, sex, concomitant valvular surgery, Charlson comorbidity index, insurance status, hospital location/teaching status, hospital region, and hospital bed size.

adoption of quality measures, appropriate patient selection, and concurrent medical therapy. However, our findings in the young adults do not correlate with preliminary evidence suggesting a substantial decline in CABG mortality.[14] We focused on the young study population compared with all comers, which may have masked the age-related outcome differences in prior studies.[14] Consistent with general trends,[45] we report a significant ≈47% decline in CABG volume from 2004 to 2018. These trends likely demonstrate improved dissemination of cardiovascular health-related information, the evolution of medical therapies, or selective replacement of surgical revascularization with the transcatheter approach.[46–48] Many states in the United States had adopted the policy of CABG-mortality public reporting around the year 2000. The unintended consequence of risk aversion and case selection may have played some role in the CABG decline in the study period.[49] Nevertheless, the secular decline in CABG did not decrease LOS or improve care costs. Furthermore, percutaneous coronary intervention preferential use over CABG for relatively

Table 2. Trends in Discharge Disposition and Economic Outcome in Young Adults Undergoing CABG, 2004 to 2018

Variable	2004–2008	2009–2013	2014–2018
Length of stay, mean (SE), d	8.35 (0.08)	8.79 (0.09)	9.20 (0.09)
Inflation-adjusted cost, US $, mean (SE)	42 036.6 (524.9)	46 570.8 (574.6)	50 758.2 (636.3)
Discharge disposition of surviving patients, n (%)			
Home	43 737 (94.54)	32 326 (92.89)	26 810 (91.36)
Short-term care facility	255 (0.55)	263 (0.76)	230 (0.78)
Long-term care facility	1493 (3.23)	1450 (4.17)	1665 (5.67)
Against medical advice	95 (0.2)	54 (0.15)	75 (0.26)

stable patients and diverting those with complex coronary anatomy to CABG with subsequent clinical complications might have also influenced LOS and higher costs.

CABG continues to be an expensive procedure, with annual cost estimates of about $6.5 billion to Centers for Medicare and Medicaid Services.[50,51] The in-hospital cost of CABG in the United States is 82.5% higher than in Canada.[52] We noted a 29% relative increase in inflation-adjusted costs over 15 years. Moreover, most patients were discharged to long-term care facilities, further increasing the cost burden. Historically, CABG is proven to be cost-effective compared with percutaneous coronary intervention with a drug-eluting stent for complex multivessel coronary artery disease,[53] however, the upfront costs of hospitalization and direct cost of care for postoperative complications remain a concern. Despite the emphasis on health care and price transparency, a significant cost variation for CABG exists in the United States. Reduction in direct costs and centralizing the pricing based on hospital characteristics and outcomes measurement-based "value" reimbursements may address CABG's heavy economic burden.[54] Public and health strategies should focus on providing cost-effective management in young adults requiring CABG.

Our study has several limitations. First, we used the NIS administrative database, which is subject to coding errors, mainly because of the transition from *ICD-9* to *ICD-10* coding system during the study period. Furthermore, since *ICD* codes are designed for billing purposes, issues related to the validity of the codes exist as they may not reflect the true clinical outcomes. Second, we could not perform analyses according to anatomic features such as culprit artery, number of bypassed arteries, detailed procedural information, and granular patient-level characteristics because of data limitations. Third, the NIS database does not include patients' longitudinal follow-up after discharge; thus, long-term outcomes cannot be analyzed. Our study did not address readmissions-related costs, which would have driven care costs per CABG episode higher than mentioned here. Despite these limitations, the NIS database remains the most comprehensive resource for estimating procedures, clinical outcomes, and resource usage trends.

In conclusion, this 15-year contemporary analysis of CABG hospitalization in young adults documents a decline in CABG volume without worsening inpatient mortality; however, it highlights the concerns of rising costs attributable to extended LOS and healthcare resource usage.

ARTICLE INFORMATION

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Supplementary Material

Tables S1–S9
Figure S1

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Supplemental Material

Table S1. ICD-9 codes used in the analysis.

Variables	ICD Codes
Chronic pulmonary disease	AHRQ Elixhauser comorbidity
Diabetes mellitus	AHRQ Elixhauser comorbidity
Hypertension	AHRQ Elixhauser comorbidity
Obesity	AHRQ Elixhauser comorbidity
Heart failure	AHRQ Elixhauser comorbidity
Peripheral vascular disease	AHRQ Elixhauser comorbidity
Renal failure	AHRQ Elixhauser comorbidity
Liver disease	AHRQ Elixhauser comorbidity
Neurological disorders	AHRQ Elixhauser comorbidity
Deficiency Anemias	AHRQ Elixhauser comorbidity
Hypothyroidism	AHRQ Elixhauser comorbidity
Valvular disease	AHRQ Elixhauser comorbidity
Smoking	3051, V1582
Alcohol abuse	AHRQ Elixhauser comorbidity
Drug abuse	AHRQ Elixhauser comorbidity
Previous myocardial infarction	412, 41002, 41012, 42022, 42032, 42042, 42052, 42062, 42072, 42082, 42092
Previous coronary artery bypass grafting	V4581 , 41402, 41403, 41404, 41405, 41407
Previous percutaneous coronary intervention	V4582
Prior stroke	V1254, 438xx
ST-elevation myocardial infarction	41000 , 41001, 41010, 41011, 41020, 41021, 41030, 41031, 41040, 41041, 41050, 41051, 41060, 41061, 41080, 41081, 41090, 41091
Non-ST-elevation myocardial infarction	41070, 41071
Percutaneous coronary intervention	0066, 3601, 3602, 3605, 3606, 3607, 3609, 1755
Valvular procedures	350x,351x, 352x, 3533, 3596,3597,3599

Pressors use	0017
Invasive mechanical ventilation	9670, 9671, 9672, 9604
Cardiogenic shock	78551, 99801
Permanent pacemaker implantation	3780, 3781, 3782, 3783, 0050
Acute kidney injury	5845, 5846, 5847, 5848, 5849
Acute kidney injury requiring dialysis	5845, 5846, 5847, 5848, 5849 plus Procedure code of 3995 or diagnosis code of V560, V561, V4511 excluding Procedure code of chronic dialysis, 3927, 3942, 3943, 3993
Intra-aortic balloon pump	3761
Extracorporeal membrane oxygenation	3965
Left ventricular assist device	3766
Mechanical circulatory support	3761,3768, 3765, 3762, 3760, 3965, 3966, 3766
Stroke	4330, 43311, 43321, 43331, 43381, 43391, 43401, 43411, 43491, 436, 430, 431, 99702, 346
Gastrostomy	431, 4311, 4319, 4432
Tracheostomy	311, 3121, 3129
Cardiac tamponade	4233
Cardiopulmonary resuscitation	9960, 9963

Table S2. ICD-10 codes used in the analysis.

Chronic pulmonary disease	AHRQ Elixhauser comorbidity
Diabetes mellitus	AHRQ Elixhauser comorbidity
Hypertension	AHRQ Elixhauser comorbidity
Obesity	AHRQ Elixhauser comorbidity
Heart failure	AHRQ Elixhauser comorbidity
Peripheral vascular disease	AHRQ Elixhauser comorbidity
Renal failure	AHRQ Elixhauser comorbidity
Liver disease	AHRQ Elixhauser comorbidity
Neurological disorders	AHRQ Elixhauser comorbidity
Deficiency Anemias	AHRQ Elixhauser comorbidity
Hypothyroidism	AHRQ Elixhauser comorbidity
Valvular disease	AHRQ Elixhauser comorbidity
Smoking	F172xx, Z720, Z87891
Alcohol abuse	AHRQ Elixhauser comorbidity
Drug abuse	AHRQ Elixhauser comorbidity
Previous myocardial infarction	I252, I22xx
Previous coronary artery bypass grafting	Z951, I257xx,I25810, I25812
Previous percutaneous coronary intervention	Z9861, Z955
Prior stroke	Z8673, I69xx
ST-elevation myocardial infarction	I2101, I2102, I2109, I2111, I2119, I2121, I2129, I213, I220, I221, I228, I229
Non-ST-elevation myocardial infarction	I214,I222
Percutaneous coronary intervention	02703XX, 02704XX, 02713XX, 02714XX, 02723XX, 02724XX, 02733XX, 02734XX, 02C03XX, 02C04XX, 02C13XX, 02C14XX, 02C23XX, 02C24XX, 02C33XX, 02C34XX
Valvular procedures	024XXXX, 027FXXX, 027GXXX, 027HXXX, 027JXXX, 02CFXXX, 02CGXXX, 02CJXXX, 02CHXXX, 02LHXXX, 02NFXXX, 02NGXXX, 02NJXXX, 02NHXXX, 02QFXXX, 02QGXXX, 02QJXXX, 02QHXXX,

	02RFXXX, 02RGXXX, 02RJXXX, 02RHXXX, 02THXXX, 02UFXXX, 02UGXXX, 02UJXXX, 02UHXXX, 02WFXXX, 02WGXXX, 02WJXXX, 02WHXXX, X2RFXXX,
Pressors use	3E030XZ, 3E033XZ, 3E040XZ, 3E043XZ, 3E050XZ, 3E053XZ, 3E060XZ, 3E063XZ
Invasive mechanical ventilation	5A1935Z, 5A1945Z, 5A1955Z, 0BH17EZ, 0BH18EZ
Cardiogenic shock	R570, T8111XA
Permanent pacemaker implantation	0JH60PZ, 0JH63PZ, 0JH80PZ, 0JH83PZ, 0JH604Z, 0JH634Z, 0JH804Z, 0JH834Z, 0JH605Z, 0JH635Z, 0JH805Z, 0JH835Z, 0JH606Z, 0JH636Z, 0JH806Z,0JH836Z,02H40NZ,02H43NZ,02H44NZ,02H60NZ,02H63NZ, 02H64NZ, 02H70NZ, 02H73NZ, 02H74NZ, 02HK0NZ, 02HK3NZ, 02HK4NZ, 02HL0NZ,02HL3NZ, 02HL4NZ
Acute kidney injury	N17xx, N990
Acute kidney injury requiring dialysis	N17xx, N990 plus procedure code of 5A1D00Z or 5A1D60Z
Intra-aortic balloon pump	5A02110, 5A02210
Extracorporeal membrane oxygenation	5A15223
Left ventricular assist device	02HA0Q Z
Mechanical circulatory support	5A02xx, 02HAxx, 5A15223
Stroke	I63xx, I60xx, I61xx, G436xx, I9782xx, I9781xx
Gastrostomy	0D16074, 0D160J4, 0D160K4, 0D163J4, 0D16474, 0D164J4, 0D164K4, 0D164Z4, 0D160Z4, 0D16874, 0D168J4, 0D168K4 , 0D168Z4, 0D9600Z, 0D960ZZ, 0D9640Z, 0D964ZZ, 0DC60ZZ, 0DC63ZZ, 0DC64ZZ, 0DH603Z, 0DH60UZ, 0DH63UZ, 0DH633Z, 0DH64UZ, 0DH643Z, 0DH67UZ, 0DH68UZ, 0DH683Z, 0DH673Z, 0D9630Z, 0D963ZZ
Tracheostomy	0B110F4, 0B110Z4, 0B113F4, 0B113Z4, 0B114F4, 0B114Z4
Cardiac tamponade	I314
Cardiopulmonary resuscitation	5A12012

Table S3. Variables used in univariate analysis to identify predictors of in-patient mortality.

Demographics: age, sex.
Comorbidities: Chronic pulmonary disease, diabetes mellitus, hypertension, obesity, heart failure, peripheral vascular disease, renal failure, liver disease, neurological disorder, anemia, hypothyroidism, smoking, alcohol abuse, previous myocardial infarction, previous CABG, previous PCI, previous stroke.
Hospital Location: rural, urban non-teaching, urban teaching.
Bed Size of the hospital: small, medium, large.
Region: Northeast, Midwest, South, West.
Insurance status: Medicare/Medicaid, private insurance, self-pay, no charge, or other.
Clinical Presentation: ST-segment elevation myocardial infarction; Non-ST-segment elevation myocardial infarction; non-myocardial infarction (unstable angina/stable ischemic heart disease)
Procedures: Concomitant valvular surgery, percutaneous coronary intervention

Table S4. **Trends in in-patient mortality in young adults undergoing CABG, stratified by sex and race in the United States, 2004-2018.**

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	P-trend
Unadjusted estimates																
Sex																
Men	1.66	1.17	1.33	1.13	1.36	1.68	2.2	1.46	1.57	1.68	1.84	2.16	1.85	1.53	1.37	0.17
Women	2.51	1.69	1.45	0.88	2.53	3.18	2.59	2.14	2.66	3.36	2.15	1.9	3.51	1.56	2.61	0.25
Race																
White	1.9	1.09	1.39	0.98	1.5	1.58	1.43	1.56	1.42	2.5	1.24	2.13	2.18	1.29	1.45	0.32
Black	2.7	2.09	2.77	2.6	1.73	4.57	4.31	1.17	2.58	2.16	3.05	4.73	4.26	2.34	1.36	0.86
Hispanic	1.84	2.57	1.43	0.00	1.91	3.74	4.24	0.82	1.75	1.71	3.48	0.00	1.79	0.78	2.7	0.76
Other	3.9	2.09	2.57	0.00	3.83	2.48	1.22	2.61	2.91	1.05	1.79	1.85	0.00	4.12	1.64	0.48
Adjusted estimates																
Sex																
Men	0.38	0.26	0.29	0.21	0.29	0.33	0.40	0.26	0.27	0.30	0.27	0.35	0.28	0.22	0.21	0.38
Women	0.89	0.51	0.42	0.30	0.89	0.95	0.78	0.61	0.73	0.90	0.57	0.53	0.97	0.40	0.66	0.89
Race																
White	0.33	0.17	0.20	0.15	0.25	0.23	0.19	0.22	0.19	0.35	0.14	0.31	0.28	0.15	0.19	0.92
Black	2.04	1.55	2.33	1.70	1.21	4.15	2.98	0.75	1.49	1.19	1.73	2.71	2.92	1.39	0.77	0.56
Hispanic	0.91	1.12	0.53	0.00	0.93	1.53	2.38	0.29	0.89	0.90	1.25	0.00	0.63	0.26	0.88	0.71
Other	0.25	0.12	0.15	0.00	0.19	0.12	0.09	0.15	0.17	0.05	0.11	0.09	0.00	0.25	0.10	0.49

Estimates were adjusted for age, sex, concomitant valvular surgery, Charlson comorbidity index, insurance status, hospital location/teaching status, hospital region, and hospital bed-size.

Table S5. Trends in clinical outcomes in young adults undergoing CABG, 2004-2018.

Variable, n (%)	**2004-2008**	**2009-2013**	**2014-2018**
Use of vasopressors	503 (1.09)	630 (1.81)	1040 (3.54)
Invasive mechanical ventilation	2977 (6.43)	2775 (7.97)	2445(8.32)
Cardiogenic shock	1537 (3.32)	2304 (6.62)	2760 (9.4)
*Permanent pacemaker implantation	156 (0.34)	130 (0.37)	70 (0.24)
Acute kidney injury	2346 (5.07)	3321 (9.54)	4190 (14.27)
Acute kidney injury requiring dialysis	261 (0.56)	448 (1.29)	255 (0.87)
*Intra-aortic balloon pump	5274 (11.4)	4289 (12.32)	3310 (11.27)
Stroke	451 (0.98)	365 (1.05)	540 (1.84)
*Gastrostomy	135 (0.29)	63 (0.18)	125 (0.43)
*Tracheostomy	384 (0.83)	261 (0.75)	180 (0.61)
Cardiac tamponade	57 (0.12)	245 (0.7)	215 (0.73)
Cardiac pulmonary resuscitation	191 (0.41)	300 (0.86)	295 (1)

*P-value >0.05

Table S6. Linear regression model examining the correlation of clinical complications with care costs in young adults undergoing CABG, 2004-2018.

Variables		**95% Confidence Interval**	
	β coefficient	**Lower**	**Upper**
Length of stay, days	3351.18	3074.67	3627.68
Use of vasopressors	7583.01	3559.19	11606.84
Invasive mechanical ventilation	6915.65	4405.92	9425.39
Cardiogenic shock	18914.50	15848.46	21980.54
Permanent pacemaker implantation	19874.71	10378.91	29370.51
Acute kidney injury	4248.29	2274.03	6222.56
Acute kidney injury requiring dialysis	18563.28	9349.88	27776.69
Intra-aortic balloon pump	8847.62	7343.13	10352.10
Stroke	16008.15	9104.74	22911.56
Tracheostomy	38891.88	24298.98	53484.79
Cardiac tamponade	30749.13	14080.07	47418.20
*Cardiopulmonary resuscitation	3760.81	-2361.84	9883.46

*P-value >0.05

Table S7. Linear regression model examining the correlation of clinical complications with length of stay in young adults undergoing CABG, 2004-2018.

Variables		95% Confidence Interval	
	β coefficient	**Lower**	**Upper**
*Use of vasopressors	0.25	-0.52	1.02
Invasive mechanical ventilation	3.22	2.71	3.74
Cardiogenic shock	2.24	1.56	2.92
Permanent pacemaker implantation	5.06	3.21	6.92
Acute kidney injury	4.52	4.06	4.98
Acute kidney injury requiring dialysis	3.06	1.12	5.00
Intra-aortic balloon pump	0.37	0.07	0.67
Stroke	5.47	4.12	6.81
*Gastrostomy	2.03	-4.31	8.37
Tracheostomy	27.18	22.82	31.54
Cardiac tamponade	3.33	0.59	6.07

*P-value >0.05

Table S8. Demographic and clinical differences between isolated CABG and CABG with concomitant valve surgery in young adults in the United States, 2004-2018.

Variable, n (%)	**Isolated CABG** (n =102124)	**CABG + concomitant valve Surgery** (n =8339)
Age (mean [SE]), year	41.04 (0.03)	39.64 (0.13)
Female	27092 (26.53)	2814 (33.74)
Race		
Whites	59126 (70.49)	4672 (67.12)
Blacks	9652 (11.51)	1056 (15.17)
Hispanics	7906 (9.42)	701 (10.07)
Others	7197 (8.58)	532 (7.64)
Comorbidities		
*Chronic pulmonary disease	16219 (15.88)	1389 (16.65)
Atrial fibrillation	6223 (6.09)	1332 (15.97)
Diabetes mellitus	40048 (39.22)	1859 (22.29)
Hypertension	67223 (65.83)	4071 (48.82)
Obesity	28763 (28.16)	1465 (17.57)
Heart failure	685 (0.67)	341 (4.09)
Peripheral vascular disease	5489 (5.37)	1449 (17.37)
Renal failure	8929 (8.74)	1219 (14.62)
Liver disease	1391 (1.36)	246 (2.95)
Neurological disorders	2936 (2.87)	419 (5.02)
Deficiency Anemias	14844 (14.54)	1639 (19.66)
*Hypothyroidism	5375 (5.26)	487 (5.84)
Smoking	50853 (49.8)	2715 (32.56)
*Alcohol abuse	4263 (4.17)	319 (3.82)
*Drug abuse	5700 (5.58)	603 (7.23)
Previous myocardial infarction	17559 (17.19)	884 (10.6)
*Previous CABG	1273 (1.25)	140 (1.68)
Previous percutaneous coronary intervention	13224 (12.95)	441 (5.28)
Prior stroke	2640 (2.58)	338 (4.05)
Concomitant percutaneous coronary intervention	5515 (5.4)	139 (1.66)

Clinical Presentation		
ST-segment elevation myocardial infarction	62798 (61.49)	6802 (81.57)
Non-ST-segment elevation myocardial infarction	25705 (25.17)	930 (11.16)
Non-myocardial infarction	13621 (13.34)	607 (7.28)

* P-value >0.05.

Non- myocardial infarction: unstable angina/stable ischemic heart disease

CABG: Coronary Artery Bypass Graft; SE: Standard Error

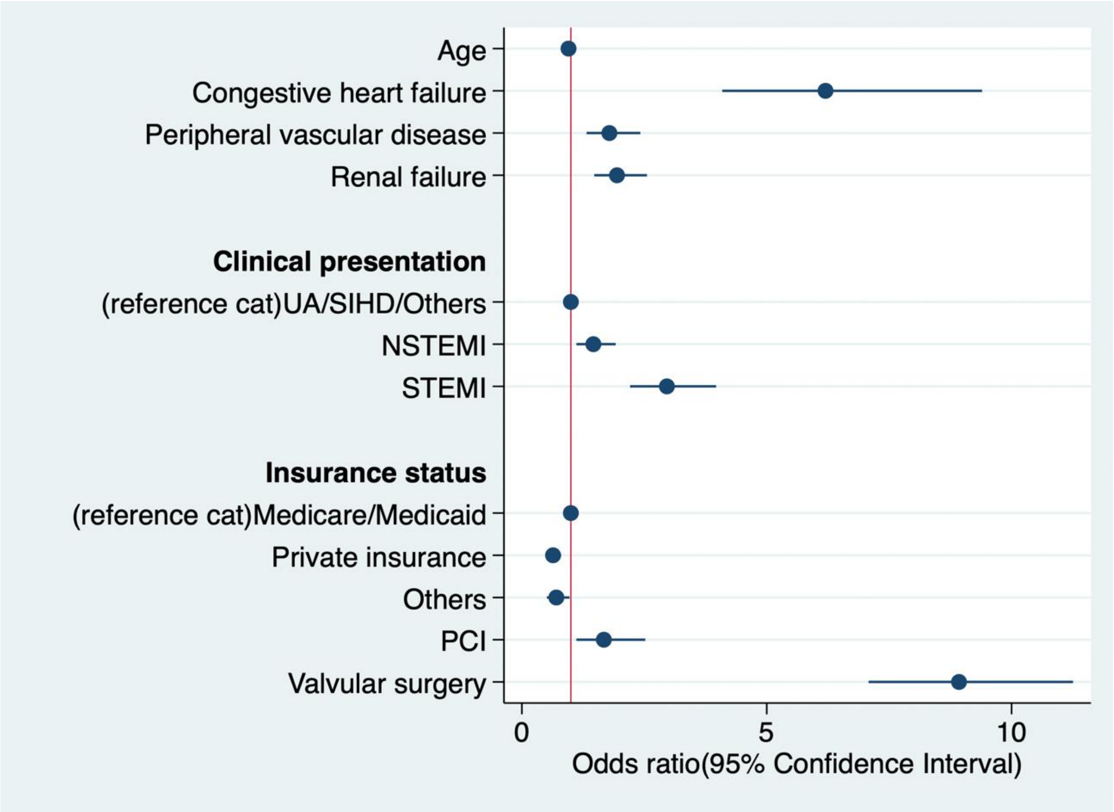
Table S9. Clinical outcomes and resource utilization between isolated CABG and CABG with concomitant valve surgery in young adults in the United States, 2004-2018.

Clinical outcomes/complications	Isolated CABG	CABG + concomitant valve Surgery
Use of vasopressors	1814 (1.78)	358 (4.29)
Invasive mechanical ventilation	6756 (6.62)	1441 (17.28)
Cardiogenic shock	5278 (5.17)	1323 (15.86)
Permanent pacemaker implantation	120 (0.12)	236 (2.83)
Acute kidney injury	8111 (7.94)	1746 (20.94)
Acute kidney injury requiring dialysis	739 (0.72)	224 (2.68)
Intra-aortic balloon pump	11444 (11.21)	1430 (17.14)
Stroke	925 (0.91)	432 (5.18)
Gastrostomy	256 (0.25)	68 (0.81)
Tracheostomy	609 (0.6)	216 (2.6)
Cardiac tamponade	354 (0.35)	163 (1.95)
Cardiac pulmonary resuscitation	626 (0.61)	160 (1.91)
Inpatient mortality	1112 (1.09)	834 (10.01)
Economic Burden		
Length of stay (mean [SE]), days	8.33 (0.05)	13.48 (0.29)
Inflation-adjusted Cost, US $ (mean [SE])	43026.85 (307.48)	80283.4 (1766.12)

* P-value >0.05.

SE: Standard Error

Figure S1. Forest plot showing predictors of in-patient mortality in young adults undergoing CABG in the United States, 2004-2018.



SIHD = stable ischemic heart disease; STEMI = ST-segment elevation myocardial infarction; NSTEMI = Non-ST-segment elevation myocardial infarction; UA = unstable angina; PCI: Percutaneous coronary intervention