


ORIGINAL RESEARCH

Temporal Trends in Percutaneous Coronary Intervention and Coronary Artery Bypass Grafting: Insights From the Washington Cardiac Care Outcomes Assessment Program

Akash Kataruka , MD; Charles C. Maynard, PhD; Kathleen E. Kearney, MD; Ahmed Mahmoud, MD; Sean Bell, MD; Jacob A. Doll, MD; James M. McCabe, MD; Christopher Bryson, MD; Hitinder S. Gurm, MBBS; Hani Jneid, MD; Salim S. Virani, MD, PhD; Eric Lehr, MD; Michael E. Ring, MD; Ravi S. Hira, MD

BACKGROUND: Patient selection and outcomes for percutaneous coronary intervention (PCI) and coronary artery bypass grafting (CABG) have changed over the past decade. However, there is limited information on outcomes for both revascularization strategies in the same population. The study evaluated temporal changes in risk profile, procedural characteristics, and clinical outcomes for PCI- and CABG-treated patients.

METHODS AND RESULTS: We analyzed all PCI and isolated CABG between 2005 and 2017 in nonfederal hospitals in Washington State. Descriptive analysis was performed to evaluate temporal changes in risk profile and, risk-adjusted in-hospital mortality. Over the study period, 178 474 PCI and 36 592 CABG procedures were performed. PCI and CABG volume decreased by 2.9% and 22.6%, respectively. Compared with 2005–2009, patients receiving either form of revascularization between 2014 and 2017 had a higher prevalence of comorbidities including diabetes mellitus and hypertension and dialysis. Presentation with ST-segment–elevation myocardial infarction (17% versus 20%) and cardiogenic shock (2.4% versus 3.4%) increased for patients with PCI compared with CABG. Conversely, clinical acuity decreased for patients receiving CABG over the study period. From 2005 to 2017, mean National Cardiovascular Data Registry CathPCI mortality score increased for patients treated with PCI (20.1 versus 22.4, $P<0.0001$) and decreased for patients treated with CABG (18.8 versus 17.8, $P<0.0001$). Adjusted observed/expected in-hospital mortality ratio increased for PCI (0.98 versus 1.19, $P<0.0001$) but decreased for CABG (1.21 versus 0.74, $P<0.0001$) over the study period.

CONCLUSIONS: Clinical acuity increased for patients treated with PCI rather than CABG. This resulted in an increase in adjusted observed/expected mortality ratio for patients undergoing PCI and a decrease for CABG. These shifts may reflect an increased use of PCI instead of CABG for patients considered to be at high surgical risk.

Key Words: bypass surgery ■ outcomes ■ percutaneous coronary intervention

See Editorial by Lahoud and Dauerman

Correspondence to: Akash Kataruka, MD, 1959 NE Pacific Street, Box 356422. Email: kataruka@uw.edu

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CLINICAL PERSPECTIVE

What Is New?

- In an analysis from the Cardiac Care Outcomes Assessment Program from Washington State, 178 474 patients undergoing percutaneous coronary intervention and 36 592 patients undergoing coronary artery bypass grafting between 2005 to 2017 were evaluated.
- While medical comorbidities increased for both groups, the percutaneous coronary intervention cohort demonstrated an increase in both clinical acuity (ST-segment–elevation myocardial infarction, cardiogenic shock) and procedural complexity (left main, atherectomy, chronic total occlusion).
- Risk-adjusted in-hospital mortality increased for percutaneous coronary intervention and decreased for coronary artery bypass grafting.

What Are the Clinical Implications?

- Patient selection for coronary revascularization has shifted over the past decade with higher risk patients undergoing percutaneous coronary intervention with an accompanying increase in risk-adjusted mortality.

Nonstandard Abbreviations and Acronyms

CABG	coronary artery bypass grafting
COAP	Cardiac Care Outcomes Assessment Program
CTO	chronic total occlusion
LM	left main
MI	myocardial infarction
NCDR	National Cardiovascular Data Registry
NSTEMI	non–ST-segment–elevation myocardial infarction
NYHA	New York Heart Association
O/E	observed to expected
PCI	percutaneous coronary intervention
PAD	peripheral artery disease
STEMI	ST-segment–elevation myocardial infarction
STROBE	Strengthening the Reporting of Observational Studies in Epidemiology
STS	Society of Thoracic Surgery

As a result of improved risk factor control, declining rates of acute myocardial infarction, and similar clinical outcomes between initial medical and invasive management for stable coronary disease, rates of

coronary revascularization have decreased.^{1–3} In addition, the proportion of elderly patients and prevalence of medical comorbidities among patients treated with coronary revascularization have increased in the contemporary era.^{4,5}

Concurrent innovation in percutaneous coronary intervention (PCI) has enabled treatment of complex coronary lesions in high-risk patients.⁶ High-risk PCI has increased as a result of trials demonstrating the safety of unprotected left main (LM) stenting, atherectomy devices for treatment of calcified lesions, percutaneous techniques for chronic total occlusion (CTO) PCI, and use of temporary mechanical circulatory support.^{7–11} The influence of these shifts on the risk profiles and clinical outcomes of patients undergoing PCI or coronary artery bypass grafting (CABG) are not well understood. Previous studies have either evaluated revascularization trends for PCI or CABG in isolation^{5,12,13} or studied an older cohort of patients.^{3,14–17}

The objective of our study was to evaluate temporal trends in the risk profiles and clinical outcomes for a contemporary cohort of patients undergoing PCI or CABG in nonfederal hospitals in Washington State. The COAP (Cardiac Care Outcomes Assessment Program) registry captures all PCI and cardiac surgery procedures performed in nonfederal hospitals in Washington State, providing a unique opportunity to examine shifts in revascularization strategies in the same population. We hypothesized that the risk profile and in-hospital mortality will increase for both PCI and CABG. Furthermore, procedural complexity was expected to increase for PCI.

METHODS

Data Source

Deidentified data can be made available for other investigators by reasonable request. We used the COAP database, which captures all PCI and cardiac surgery procedures performed in nonfederal hospitals in Washington State. The database has been previously described.¹⁸ Briefly, COAP is a physician-lead initiative with universal participation from all nonfederal hospitals in Washington State. Participating sites provide clinical information on consecutive PCI and cardiac surgeries for the purposes of quality improvement. Deidentified hospital-level quality metrics are discussed at monthly meetings to minimize care variation, initiate quality improvement initiatives, and share best practices. All nonfederal PCI-capable hospitals (33) and CABG hospitals (17) are currently compliant with data submission. The quality of the data is maintained through routine audits.

From 2005 to 2007, COAP collected data for CABG using its own case report form. Beginning in 2008,

the Society of Thoracic Surgery (STS) data collection form was used for CABG. Between 2005 and 2008, COAP used its own data collection form for PCI and subsequently transitioned to the American College of Cardiology NCDR (National Cardiovascular Data Registry) CathPCI data collection form in 2009. In addition to demographic information, clinical variables, procedural characteristics, and outcomes were captured.

Patient Population

We included all patients older than 18 years who were treated with PCI or isolated CABG between May 9, 2005, and December 31, 2017. Patients who received concurrent CABG at the time of valve surgery or had missing clinical variables (5.6% for PCI and 4.1% for CABG) were excluded from the analysis.

Statistical Analysis

We evaluated baseline demographics and clinical presentation over 3 time periods: (1) 2005–2009, (2) 2010–2013, and (3) 2014–2017. Three time periods of approximately equal length were selected to compare baseline variables to evaluate secular trends; the remainder of the analysis evaluated annual trends. Because of the large sample size, we calculated the standardized mean difference between the first and last time period for baseline variables. Standardized mean difference estimates the effect size and is calculated as the difference between groups divided by the standard deviation.

Annual volumes for PCI and CABG were analyzed from 2005 to 2017. Linear trend statistics were utilized to analyze significance. The analysis further stratified the indication for the invasive procedure as ST-segment–elevation myocardial infarction (STEMI), non-STEMI (NSTEMI), and elective. Temporal trends were evaluated for a subpopulation of patients with diabetes mellitus who had multivessel coronary artery disease undergoing elective revascularization.

We calculated the NCDR CathPCI mortality score for PCI- and CABG-treated patients. The model was derived from 181 775 PCI procedures and subsequently validated with prospective cohorts with excellent discriminatory function (c-statistic 0.926) for 30-day mortality.¹⁹ Variables included in the model were age, presence of cardiogenic shock, prior congestive heart failure, peripheral artery disease, chronic lung disease, glomerular filtration rate, New York Heart Association class IV symptoms, presence of STEMI, and PCI status. We used all variables in the risk score calculation except New York Heart Association class IV, which was not collected for the years 2005 through 2007 for CABG and 2005 through 2008 for PCI. We stratified the NCDR CathPCI mortality score into tertiles of low risk (<20), intermediate risk (20–40), and high risk (>40).

These tertiles reflect the distribution of the risk score in our population. In addition, the difference in the mean NCDR CathPCI mortality score from 2005 to 2017 was calculated for the CABG and PCI groups. The absolute difference was then compared with a 95% CI.

Linear trends in PCI procedural characteristics were evaluated with a focus on atherectomy use, LM interventions, and treatment of CTOs. The data collection only captured CTO PCIs following 2010.

Finally, linear trends for in-hospital mortality were analyzed for the CABG and PCI groups and expressed as an observed to expected (O/E) ratio. Statistical analyses were performed with the chi-square test for linear trend. The expected number of deaths was calculated from the logistic function adjusting for NCDR CathPCI mortality risk score for the PCI and CABG groups. For the PCI group, we performed additional adjustment for LM intervention and atherectomy use. A sensitivity analysis was performed by calculating the O/E mortality for patients with CABG using the STS risk score between 2008 and 2016. The STS risk score was not reliably available for other time periods and, therefore, not utilized for the primary analysis. We examined the association between year and the ratio of O/E deaths with linear regression and used the Durbin-Watson statistic to check for autocorrelation. SPSS version 19.0 (IBM) was used for data analysis.

All data are reported in accordance with STROBE Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines. The study was exempt from institutional review board approval because the analysis was conducted for quality improvement and did not involve human participants.

RESULTS

Our study evaluated patients treated with PCI and CABG between 2005 and 2017. In total, 178 474 patients treated with PCI and 36 592 treated with CABG were included in the analysis. PCI volume decreased by 2.9% over the entire study period, with a 19.1% decrease from 2005 to 2014 followed by a subsequent increase (Figure 1A). Annual CABG volume decreased consistently by 22.6% from 2005 to 2017 (Figure 1B), with a relative 39.0% reduction in elective and 60.7% reduction in STEMI indications. For a subpopulation of patients with diabetes mellitus and multivessel coronary artery disease undergoing elective revascularization, utilization of CABG (n=9429) and PCI (n=14 031) was evaluated over the study period. Total revascularization volume decreased from 2005 to 2017 for both strategies (2433 to 1581, $P<0.0001$), driven by

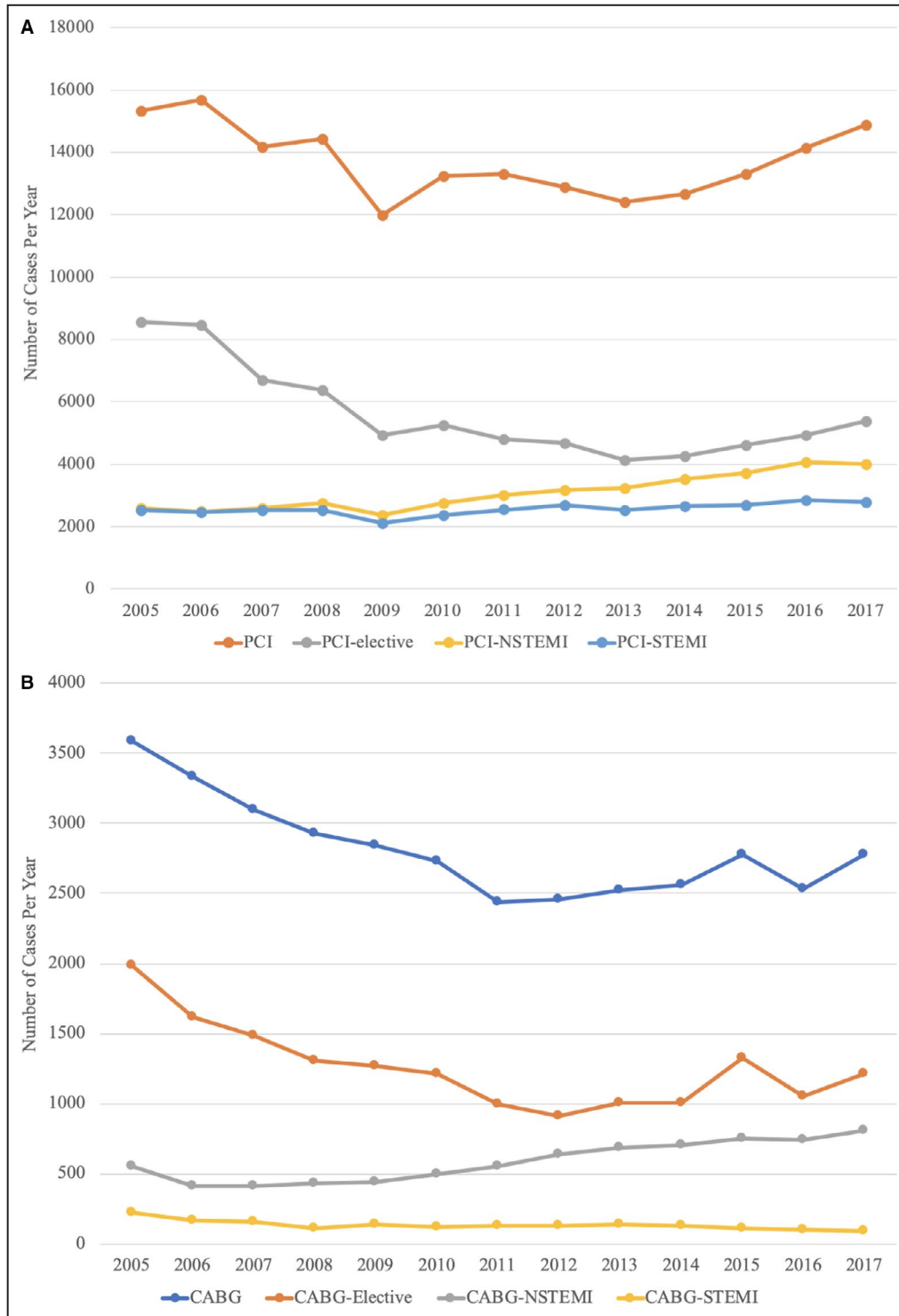


Figure 1. Annual percutaneous coronary intervention (PCI) volume (A) and annual coronary artery bypass grafting (CABG) volume (B). NSTEMI indicates non-ST-segment-elevation myocardial infarction; STEMI, ST-segment-elevation myocardial infarction.

reduction in PCI volume (decrease from 1624 to 856, $P=0.0003$). CABG volume did not change substantially over the study period. Proportional utilization of PCI decreased from 66.7% to 54.1% ($P<0.0001$) and CABG

increased from 33.3% to 45.9% ($P<0.0001$) over the study period.

Table 1 summarizes the clinical characteristics for PCI over 3 time periods 2005–2009, 2010–2013, and

Table 1. Demographic and Clinical Characteristics for PCI

Variable	Time Periods				Mean Standardized Difference (95% CI)
	All Years	June 9, 2005, to October 12, 2009	October 13, 2009, to December 31, 2013	January 1, 2014, to December 31, 2017	
PCI, No.	178 474	71 590	51 880	55 004	
Demographic variables and risk factors					
Age, mean±SD, y	66±12	65±12	66±12	66±12	-0.109 (-0.120 to -0.098)
Age ≥80 y	23 381 (13)	8911 (12)	6960 (13)	7510 (14)	-0.036 (-0.047 to -0.025)
Women	50 965 (29)	20 924 (29)	14 711 (28)	15 330 (28)	0.030 (0.019-0.041)
Race	50 965 (29)				
White	157 609 (88)	62 119 (87)	46 613 (90)	48 877 (89)	-0.064 (-0.075 to -0.053)
Nonwhite	16 637 (10)	7316 (10)	4162 (8)	5159 (9)	0.028 (0.017-0.039)
Unknown	4228 (2.4)	2155 (3.0)	1105 (2.1)	968 (1.8)	0.081 (0.070-0.092)
Hypertension	135 119 (76)	52 644 (74)	39 822 (77)	42 653 (78)	-0.092 (-0.104 to -0.081)
Diabetes mellitus	57 747 (32)	21 365 (30)	16 960 (33)	19 422 (35)	-0.117 (-0.128 to -0.106)
Dialysis	3371 (1.9)	977 (1.4)	955 (1.8)	1439 (2.6)	-0.091 (-0.102 to -0.080)
Cerebrovascular disease	21 234 (12)	8051 (11)	6095 (12)	7088 (13)	-0.050 (-0.061 to -0.039)
COPD	23 573 (13)	10 058 (14)	6389 (12)	7306 (13)	0.022 (0.011-0.034)
PAD	18 859 (11)	7411 (10)	5278 (10)	6170 (11)	-0.028 (-0.039 to -0.017)
CABG	29 723 (17)	12 580 (18)	8656 (17)	8487 (15)	0.058 (0.046-0.069)
Valve surgery	2904 (1.6)	795 (1.1)	907 (1.7)	1202 (2.2)	-0.086 (-0.097 to -0.075)
PCI	65 691 (37)	25 674 (36)	19 696 (38)	20 321 (37)	-0.022 (-0.033 to -0.011)
CHF	20 522 (12)	7061 (10)	5307 (10)	8154 (15)	-0.153 (-0.164 to -0.142)
NYHA class IV	3085 (2.8)	80 (2.2)	1142 (2.2)	1864 (3.4)	-0.064 (-0.098 to -0.030)
Creatinine >2.0 mg/dL	7138 (4.2)	2548 (3.7)	1962 (4.2)	2628 (5.0)	-0.064 (-0.075 to -0.052)
Clinical presentation					
Cardiogenic shock	4883 (2.7)	1700 (2.4)	1339 (2.6)	1844 (3.4)	-0.059 (-0.070 to -0.048)
Cardiac arrest	5170 (3.2)	1812 (3.2)	1635 (3.2)	1723 (3.1)	0.005 (-0.007 to 0.017)
Balloon pump	3177 (1.8)	678 (0.9)	1186 (2.3)	1313 (2.4)	-0.023 (-0.057 to 0.011)
Cardiac presentation					
No angina	11 524 (6)	6589 (9)	3048 (6)	1887 (3)	0.233 (0.222-0.244)
Atypical CP	5196 (2.9)	3578 (5)	857 (1.7)	761 (1.4)	0.200 (0.189-0.211)
Stable angina	30 443 (17)	13 710 (19)	7902 (15)	8831 (16)	0.081 (0.070-0.092)
Unstable angina	57 333 (32)	22 444 (31)	17 728 (34)	17 161 (31)	0.004 (-0.007, 0.015)
NSTEMI	40 307 (23)	12 802 (18)	12 185 (24)	15 320 (28)	-0.241 (-0.252 to -0.230)
STEMI	12 189 (17)	12 189 (17)	10 148 (20)	10 993 (20)	-0.076 (-0.087 to -0.065)

(Continued)

Table 1. Continued

Variable	Time Periods				Mean Standardized Difference (95% CI)
	All Years	June 9, 2005, to October 12, 2009	October 13, 2009, to December 31, 2013	January 1, 2014, to December 31, 2017	
Diseased vessels, No.					
0	4384 (2.5)	2568 (3.6)	850 (1.6)	966 (1.8)	0.111 (0.100–0.122)
1	88 983 (50)	36 348 (51)	25 715 (50)	26 920 (49)	0.037 (0.026–0.048)
2	49 195 (28)	18 955 (26)	14 567 (28)	15 673 (28)	–0.045 (–0.056 to –0.034)
3	35 912 (20)	13 719 (19)	10 748 (21)	11 445 (21)	–0.041 (–0.052 to –0.030)
Ejection fraction	54±13	55±13	54±13	52±13	0.165 (0.151–0.179)
Procedure priority					
Elective	68 410 (42)	30 106 (50)	15 852 (39)	22 452 (35)	0.286 (0.275–0.297)
Urgent	64 805 (36)	20 865 (29)	20 989 (40)	22 951 (42)	–0.267 (–0.279 to –0.256)
Emergent	39 275 (22)	15 319 (21)	11 649 (22)	12 307 (22)	–0.024 (–0.035 to –0.013)
Salvage	1093 (0.6)	314 (0.4)	318 (0.6)	461 (0.8)	–0.051 (–0.062 to –0.040)

Values are expressed as number (percentage) unless otherwise indicated.

CABG indicates coronary artery bypass grafting; CHF, congestive heart failure; COPD, chronic obstructive pulmonary disease; CP, chest pain; NSTEMI, non-ST-segment-elevation myocardial infarction; NYHA, New York Heart Association; PCI, percutaneous coronary intervention; PAD, peripheral artery disease; and STEMI, ST-segment-elevation myocardial infarction.

2014–2017. Compared with 2005–2009, a higher proportion of patients undergoing PCI between 2014 and 2017 were elderly patients older than 80 years (12% versus 14%) and had increased medical comorbidities such as diabetes mellitus (30% versus 35%), hypertension (74% versus 78%), requirement of dialysis (1.4% versus 2.6%), cerebrovascular disease (11% versus 13%), congestive heart failure (10% versus 15%), and chronic kidney disease, defined as preprocedure creatinine >2.0 mg/dL (3.7% versus 5.0%). History of previous CABG decreased over the study period (18% versus 16%). Clinical acuity for patients undergoing PCI also increased over the study period, with higher prevalence of STEMI (17% versus 20%), NSTEMI (18% versus 28%), cardiogenic shock (2.4% versus 3.4%), emergent or urgent procedures (50% versus 64%), and use of intra-aortic balloon pump (0.9% versus 2.4%).

Compared with 2005–2009, CABG-treated patients between 2014 and 2017 also demonstrated higher prevalence of diabetes mellitus (37% versus 45%), hypertension (80% versus 85%), requirement of dialysis (1.6% versus 2.5%), cerebrovascular disease (14% versus 21%), and previous PCI (23% versus 29%) (Table 2). However, there was a decrease in the proportion of elderly patients older than 80 years (9% versus 7%), prevalence of chronic kidney disease (4.7–4.1%), presentation with cardiogenic shock (2.4% versus 1.3%), and STEMI (5.0% versus 4.3%). Re-do CABG also decreased (4.0% versus 1.5%).

Annual risk profiles of patients treated with PCI and CABG stratified by tertiles of NCDR CathPCI mortality score are displayed in Figure 2A and 2B. Low risk was defined as an NCDR CathPCI score <20, medium risk was defined as a score of 20 to 40, and high risk was defined as a score >40. Over the study period, the proportion of patients undergoing PCI who were considered at low risk decreased from 54.4% to 46.0%, while those considered at high risk increased from 4.8% to 6.2% (Figure 2). Conversely, the proportion of patients undergoing CABG who were considered at low risk increased from 62.3% to 63.3%, while those considered at high risk decreased from 3.0% to 1.6% (Table S1). The mean NCDR CathPCI mortality score increased for PCI by 2.3 points (95% CI, 2.0–2.6) from 2005 to 2017 and decreased for CABG by –1.0 points (95% CI, –1.5 to –0.5), with an absolute difference between the groups of 3.3 points (95% CI, 2.7–3.9) (Table S2 and S3).

For patients treated with PCI, high-risk interventions such as atherectomy use (1.3–3.0%, *P*<0.0001) and LM intervention (1.6–4.3%, *P*<0.0001) (Figure 3) increased from 2005 to 2017. PCI for CTOs also increased from 2010 to 2017 (4.4% versus 7.6%, *P*<0.0001).

Over the study period, unadjusted in-hospital mortality increased for PCI (1.5–2.3%, *P*<0.0001) and decreased for CABG (2.3–1.2%, *P*<0.0001). After adjustment for baseline NCDR CathPCI mortality score

Table 2. Demographic and Clinical Characteristics for CABG

Variable	Time Periods			Mean Standardized Difference (95% CI)
	All Years	June 9, 2005, to October 12, 2009	October 13, 2009, to December 31, 2013	
CABG volume	36 592	15 793	10 151	10 648
Demographic variables and risk factors				
Age, mean±SD, y	66±11	66±11	65±10	66±10
Age ≥80 y	2981 (8)	1350 (9)	856 (8)	775 (7)
Women	8198 (22)	3649 (23)	2357 (23)	2192 (21)
Race				
White	32 294 (88)	14 210 (90)	9045 (89)	9078 (85)
Nonwhite	3775 (11)	1428 (9)	1055 (10)	1292 (12)
Unknown	523 (1.4)	155 (1.0)	51 (0.5)	375 (3.0)
Hypertension	30 299 (83)	12 570 (80)	8651 (85)	9078 (85)
Diabetes mellitus	14 739 (40)	5812 (37)	4156 (41)	4771 (45)
Dialysis	742 (2.0)	256 (1.6)	220 (2.2)	266 (2.5)
Cerebrovascular disease	5822 (16)	2153 (14)	1451 (14)	2218 (21)
COPD	6740 (18)	2801 (18)	2132 (21)	1537 (14)
PAD	4886 (13)	22 358 (15)	1283 (13)	1245 (12)
CABG	1039 (2.8)	632 (4.0)	244 (2.4)	163 (1.5)
Valve surgery	115 (0.3)	54 (0.3)	26 (0.3)	35 (0.3)
PCI	9399 (26)	3602 (23)	2754 (27)	3043 (29)
MI	17 855 (49)	6402 (41)	5473 (54)	5980 (56)
CHF	5845 (16)	2051 (13)	1709 (17)	2085 (20)
NYHA class IV	896 (3.4)	189 (3.3)	357 (3.5)	350 (3.3)
Creatinine >2.0 mg/dL	1614 (4.4)	741 (4.7)	437 (4.3)	436 (4.1)
Clinical presentation				
Cardiogenic shock	764 (2.1)	379 (2.4)	244 (2.5)	141 (1.3)
Balloon pump	2392 (6.5)	1014 (6.4)	745 (7.3)	633 (6.2)
Cardiac presentation				
No angina	2418 (7)	1791 (11)	253 (2.5)	374 (4)
Atypical CP	1109 (3)	438 (2.8)	229 (2.3)	442 (4)
Stable angina	9162 (25)	4602 (29)	2376 (24)	2184 (21)
Unstable angina	13 850 (38)	5733 (36)	4376 (43)	3741 (37)
NSTEMI	7638 (21)	2253 (14)	2378 (24)	3007 (30)
STEMI	1759 (5)	806 (5)	515 (5)	438 (4.3)
Missing MI type	110 (0.3)	110 (0.7)	0 (0.0)	0 (0.0)

(Continued)

Table 2. Continued

Variable	Time Periods				Mean Standardized Difference (95% CI)
	All Years	June 9, 2005, to October 12, 2009	October 13, 2009, to December 31, 2013	January 1, 2014, to December 31, 17	
Diseased vessels, No.					
0	482 (1.3)	435 (2.8)	39 (0.4)	8 (0.1)	0.201 (0.186–0.235)
1	2967 (8.1)	2157 (13.7)	404 (4.0)	402 (3.8)	0.340 (0.316–0.365)
2	8148 (22.3)	3780 (24.1)	2173 (21.4)	2195 (20.5)	0.081 (0.056–0.105)
3	24 884 (68.2)	9329 (59.4)	7533 (74.2)	8002 (75.4)	–0.343 (–0.368 to –0.318)
Ejection fraction	53±13	53±14	53±13	53±12	–0.113 (–0.036 to –0.014)
Procedure priority					
Elective	16 401 (45)	7691 (49)	4131 (41)	4599 (43)	0.111 (0.087–0.136)
Urgent	18 539 (51)	7311 (46)	5533 (54)	5696 (54)	–0.141 (–0.166 to –0.116)
Emergent	1518 (4)	704 (4)	472 (5)	342 (3)	0.065 (0.040–0.089)
Salvage	77 (0.2)	51 (0.3)	15 (0.1)	11 (0.1)	0.046 (0.021–0.070)

Values are expressed as number (percentage) unless otherwise indicated.

CABG indicates coronary artery bypass grafting; CHF, congestive heart failure; COPD, chronic obstructive pulmonary disease; CP, chest pain; MI, myocardial infarction; NSTEMI, non-ST-segment-elevation myocardial infarction; NYHA, New York Heart Association; PCI, percutaneous; PAD, peripheral artery disease; and STEMI, ST-segment-elevation myocardial infarction.

and procedural characteristics unique to the PCI group, the ratio of O/E deaths decreased for CABG (1.21–0.74, $P<0.0001$) but increased for PCI (0.98–1.19, $P<0.0001$) (Figure 4). Durbin-Watson statistics for both CABG and PCI indicated that there was no autocorrelation. Additional sensitivity analysis for O/E ratio for CABG adjusting for NCDR CathPCI mortality score and STS risk score between 2008 and 2016 showed no difference in mortality (Table S4).

DISCUSSION

The present study evaluated temporal trends in the procedural volume, risk profile, PCI procedural characteristics, and clinical outcomes for a contemporary cohort of patients treated with PCI and CABG in nonfederal hospitals in Washington State between 2005 and 2017. Several important findings emerged from our analysis. First, there was an overall 6.6% decrease in all revascularization procedures, a finding primarily driven by a relative 22.6% reduction in CABG volume and a modest 2.9% reduction in PCI volume. A unique finding from our analysis was an increase in PCI in the recent era from 2013 to 2017, with a 20.0% increase in overall PCI and 30.3% increase in elective PCI. Second, the percentage of patients with moderate to high composite risk scores increased for PCI and decreased for CABG despite higher medical comorbidities in both groups, a finding driven by higher clinical acuity including cardiogenic shock and STEMI among PCI-treated patients. Third, high-risk PCI such as LM intervention, atherectomy use, and CTO PCI increased. Finally, risk adjusted O/E in-hospital mortality ratio increased for PCI and decreased for CABG over the study period.

Rates of coronary revascularization declined between 2005 and 2017, particularly for CABG. The decreasing rates of revascularization for stable coronary disease reflect cumulative forces of improved risk factor control, lack of improvement in clinical outcomes between initial medical and invasive management, adoption of appropriate use criteria for coronary revascularization, and use of physiologic hemodynamic assessment.^{18,20–26} A unique finding from our analysis was a relative 20.0% increase in PCI procedures from 2013 to 2017, with a 30.3% increase in elective PCIs. While previous studies demonstrated steady reduction in annual PCI volume, a contemporary cohort had not been evaluated.^{3,18,26} Reporting of PCI volume in California also demonstrated a 14.3% increase from 2013 to 2016,²⁷ similar to our findings. Multiple forces may influence the growth in elective PCI including increasing LM and CTO interventions, which may shift patients who

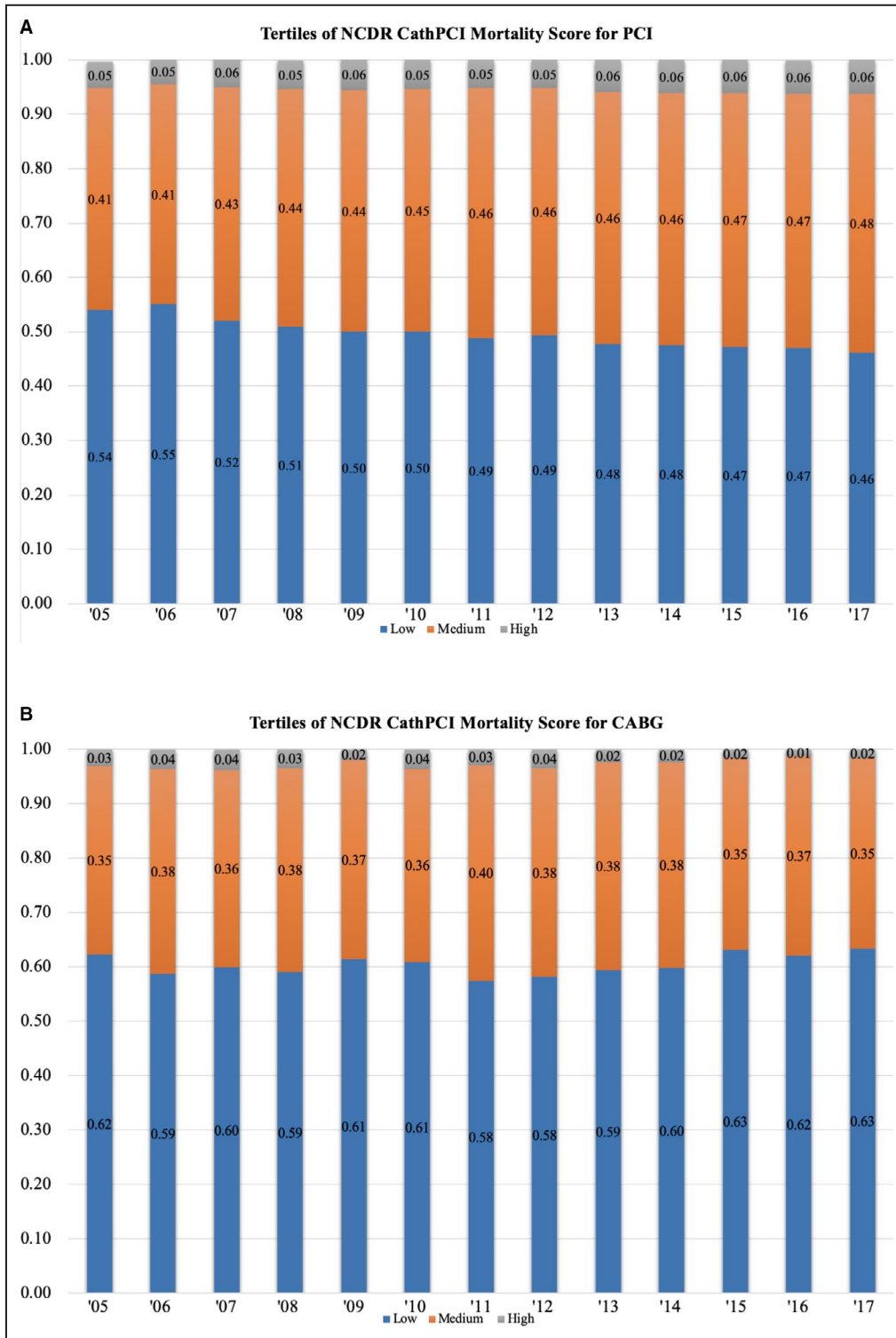


Figure 2. Annual risk profile of percutaneous coronary intervention coronary intervention (PCI) (A) and coronary artery bypass grafting (CABG) (B) by NCDR (National Cardiovascular Data Registry) CathPCI mortality score. High indicates NCDR CathPCI mortality score >40; low, NCDR CathPCI mortality score <20; and medium, NCDR CathPCI mortality score 20 to 40.

were previously treated with CABG or untreated entirely. Furthermore, Medicaid expansion with the Affordable Care Act may have influenced a rise in

elective PCI. Other states participating in Medicaid expansion have also observed increased cardiovascular procedural volumes.²⁸

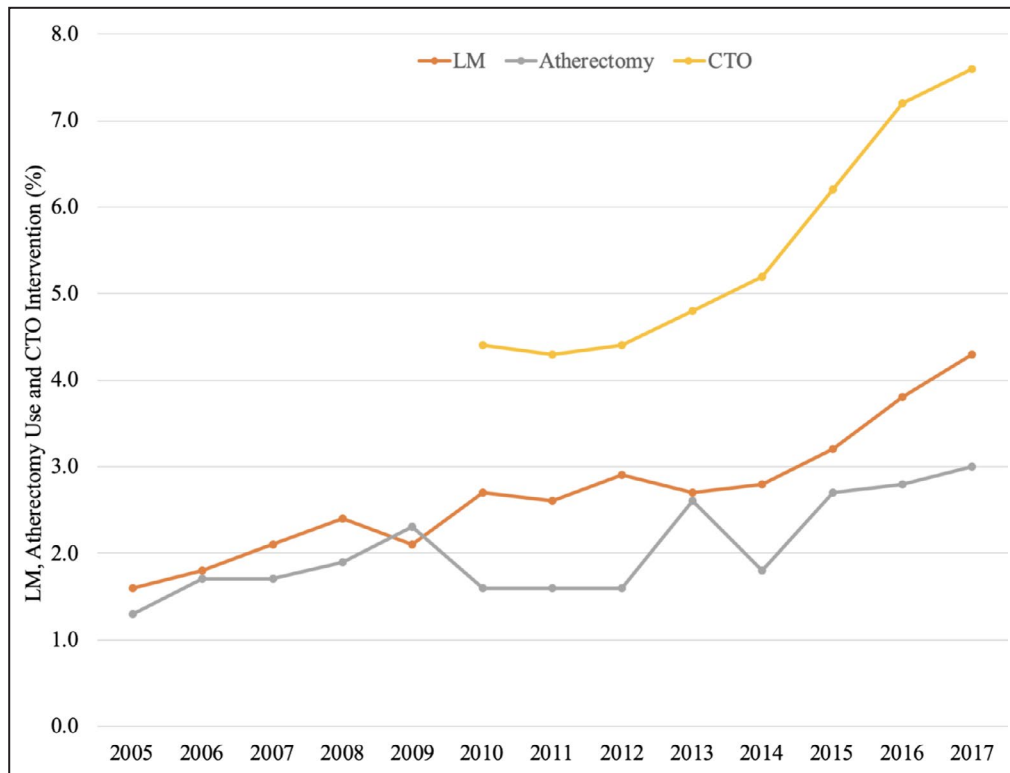


Figure 3. Temporal trend left main (LM) coronary artery intervention, atherectomy use, and chronic total occlusion (CTO) revascularization. PCI indicates percutaneous coronary intervention.

Among patients who underwent any form of coronary revascularization, the prevalence of older age and medical comorbidities increased in our study and national registries.^{5,13,29} The risk profile as assessed by the NCDR CathPCI mortality score for patients with CABG and PCI, however, diverged despite the increased medical comorbidities in both groups. The mean NCDR CathPCI mortality score increased for PCI (from 20.1 to 22.2) and decreased for CABG (from 18.8 to 17.8) from 2005 to 2017. In particular, the proportion of high and moderate NCDR CathPCI mortality score increased for PCI and decreased for CABG. An analysis from the Department of Veterans Affairs demonstrated a similar increase in the median NCDR CathPCI mortality score from 2009 to 2015 (14–15, $P=0.005$).¹³ Conversely, an analysis of 65 097 patients treated with CABG between 1997 and 2011 demonstrated a lower predicted operative mortality (3.1–1.7%) despite an increase in medical comorbidities.⁵ In our study, the discordance between medical comorbidities and risk profile resulted from both higher-risk patients, such as octogenarians and those with chronic kidney disease, and acute clinical presentations, such as STEMI and cardiogenic, for patients treated with PCI. The higher prevalence of cardiogenic shock in the PCI group is particularly important as 30-day mortality from cardiogenic shock complicating acute

MI has remained unchanged at $\approx 45\%$ over the past decade despite the use of various percutaneous left ventricular assist devices.^{30–32} Together, our findings highlight an important clinical and therapeutic shift in coronary revascularization with increasing utilization of PCI rather than CABG among moderate- and high-risk patients, especially those with cardiogenic shock or STEMI.

In addition to higher-risk patient profiles, procedural complexity of PCI increased over the study period. We discovered a consistent uptrend in LM intervention, CTO PCI, and atherectomy use over the study period. Current guidelines favor CABG over PCI in the presence of LM or multivessel disease in the context of complex coronary anatomy, diabetes mellitus, and cardiomyopathy.³³ Despite the guidelines, studies from national registries demonstrate increased utilization of PCI in patients with complex coronary anatomy, including those with a class I indication for CABG.^{34,35} Our study demonstrated a reduction in combined revascularization volume for patients with diabetes mellitus and multivessel coronary artery disease, consistent with overall findings. However, PCI remained the most common revascularization strategy in this patient population. Similarly, from an NCDR analysis, PCI was the most common form of revascularization for patients with diabetes

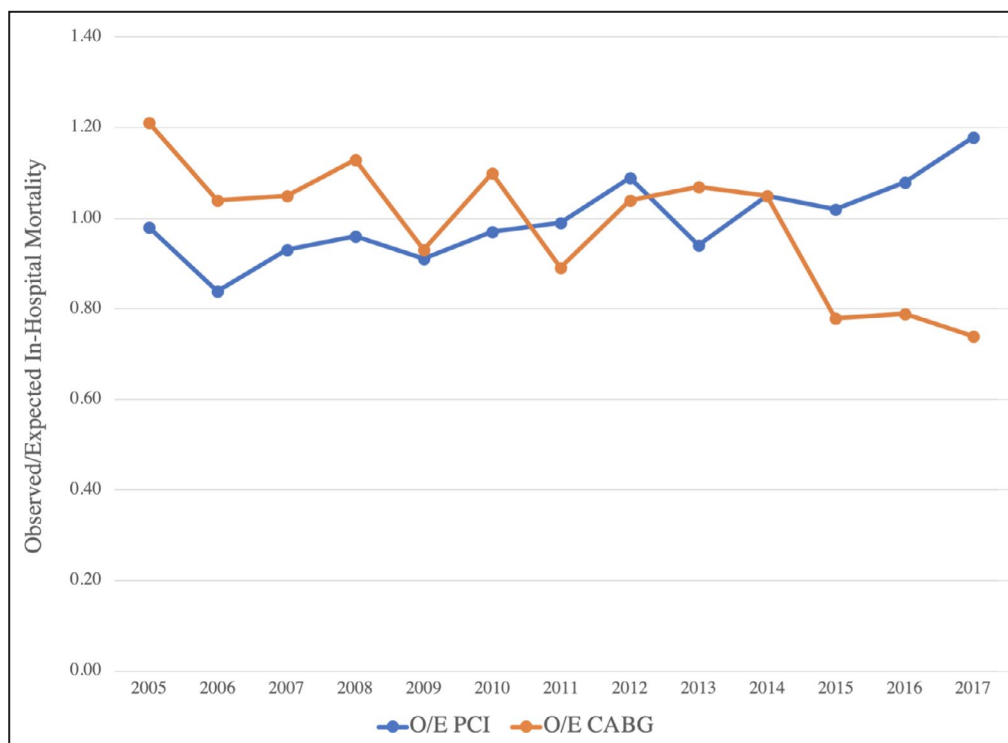


Figure 4. Risk-adjusted observed to expected ratio for in-hospital mortality for percutaneous coronary intervention (PCI) and coronary artery bypass grafting (CABG).

*Outcomes adjusted for NCDR (National Cardiovascular Data Registry) CathPCI score and procedural characteristic for PCI group (left main and atherectomy use).

mellitus and multivessel coronary artery disease hospitalized with NSTEMI.³⁵ Increase in LM intervention may be related to numerous factors. With the increased prevalence of octogenarians and medical comorbidities, patients may be deemed surgically ineligible for CABG. Alternatively, increased operator comfort and patient preference for PCI may drive shared decision-making towards a percutaneous procedure.

The adjusted O/E ratio for in-hospital mortality decreased for CABG and increased for PCI in our analysis. Similar results were seen in a large study of Medicare beneficiaries, which showed increased in-hospital mortality for PCI and decreased in-hospital mortality for CABG between 2008 and 2012.¹⁶ In our study, adjusted O/E ratio for PCI initially remained stable between 2005 and 2013 (O/E ratio, 0.94–0.95) followed by an increase from 2014 to 2017 (O/E ratio, 1.0–1.17). This temporally correlates with an uptrend in high-risk PCI. However, higher mortality persisted despite adjusting for LM intervention and atherectomy device utilization, factors known to be associated with increased procedural risk.^{36,37} While previous studies have demonstrated improved short- and long-term mortality for PCI, a contemporary cohort had not been evaluated.^{4,29} In an analysis of US veterans treated with PCI, Waldo et al¹³ demonstrated a trend towards

decreased mortality from 2009 to 2015 (hazard ratio, 0.98; 95% CI, 0.96–1.00). However, the population had lower clinical acuity with a minor increase in STEMI (2–4%) and unchanged rates of LM intervention (2%) and intra-aortic balloon pump use (1%). Therefore, the increased clinical acuity with STEMI and cardiogenic shock along with the rise in PCI for high-risk lesions may explain the increase in in-hospital mortality in our cohort.

Finally, the adjusted O/E ratio for in-hospital mortality decreased for patients with CABG over the study period from 1.21 to 0.74 ($P < 0.0001$). Analysis of the VA and Medicare population undergoing CABG also demonstrated similar improvement in clinical outcomes.^{5,38} The national and regional shifts in CABG outcomes may reflect changes in patient selection owing to increased scrutiny on outcomes of cardiac surgery, proposed changes for financial reimbursement leading to risk avoidance in patients at high or extreme risk, and increasing percutaneous options for complex lesions.³⁹ These factors may prompt the transition to PCI of patients who were previously thought to only be amenable to surgical revascularization. As the selection of the optimal revascularization strategy continues to evolve, a heart-team approach will be needed to determine the optimal revascularization strategy.

STUDY LIMITATIONS

Our study has several limitations that warrant discussion. First, long-term outcomes of PCI and CABG were not available. Therefore, conclusions regarding the appropriate choice for revascularization cannot be drawn from this analysis. Second, we could not evaluate for staged PCI procedures (which may underestimate the number of lesions treated) or crossover between revascularization strategies. Third, the STS risk score could not be calculated for the CABG group for all years because of lack of available data. However, the NCDR CathPCI mortality score and STS risk score for isolated CABG overlap on many variables and our sensitivity analysis demonstrated similar risk-adjusted mortality between 2008 and 2016. Fourth, we cannot exclude potential upcoding of procedural urgency by providers. The rising rates of STEMI, cardiogenic shock, and intra-aortic balloon pump use in the PCI group, however, suggest an objective increase in clinical acuity and emergent procedures. Finally, changes in the data collection form for PCI and CABG may have artificially altered variable definition. We attempted to minimize the effect of these changes by focusing on common variables between the data collection forms.

CONCLUSIONS

Rates of coronary revascularization decreased for both elective PCI and CABG from 2005 to 2017 in nonfederal hospitals in Washington State. Risk profile and procedural complexity increased for the PCI group, whereas risk profile decreased for CABG. Our findings suggest a shift in revascularization patterns, with increasing rates of PCI in higher-risk patients and acute clinical presentations. Adjusted in-hospital mortality increased for PCI and decreased for CABG, reflecting changes in patient selection for surgical procedures.

ARTICLE INFORMATION

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Affiliations

From the Division of Cardiology (A.K., K.E.K., A.M., J.A.D., J.M.M., R.S.H.), Departments of Health Services (C.C.M.), and Medicine (S.B., C.B.), University of Washington, Seattle, WA; Cardiac Care Outcomes Assessment Program, Foundation for Health Care Quality, Seattle, WA (C.C.M., R.S.H.); VA Puget South Health Care System, Seattle, WA (J.A.D.); Division of Cardiology, University of Michigan, Ann Arbor, MI (H.S.G.); Division of Cardiology, Michael E. DeBakey VA& Baylor College of Medicine, Houston, TX (H.J., S.S.V.); Department of Cardiac Surgery, Swedish Heart & Vascular Institute, Seattle, WA (E.L.); Providence Sacred Heart Medical Center, Spokane, WA (M.E.R.).

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Supplementary Materials

Tables S1–S4

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Supplemental Material

Table S1. Proportion of low, medium, and high-risk patients for PCI and CABG by tertiles of NCDR CathPCI mortality score.

Year	PCI (NCDR CathPCI Mortality Score)			CABG ((NCDR CathPCI Mortality Score)		
	Low (<20)	Medium (20-40)	High (>40)	Low (<20)	Medium (20-40)	High (>40)
2005	0.544	0.408	0.048	0.623	0.346	0.03
2006	0.548	0.405	0.048	0.587	0.376	0.037
2007	0.515	0.430	0.055	0.599	0.363	0.038
2008	0.512	0.437	0.051	0.590	0.376	0.034
2009	0.497	0.444	0.059	0.613	0.367	0.020
2010	0.500	0.446	0.054	0.609	0.355	0.036
2011	0.488	0.461	0.051	0.575	0.396	0.029
2012	0.493	0.455	0.052	0.581	0.384	0.035
2013	0.477	0.464	0.059	0.594	0.382	0.024
2014	0.476	0.463	0.061	0.597	0.380	0.023
2015	0.472	0.468	0.06	0.632	0.351	0.016
2106	0.470	0.467	0.062	0.621	0.365	0.014
2017	0.460	0.478	0.062	0.633	0.351	0.016

PCI = percutaneous coronary intervention, CABG = coronary artery bypass grafting

Table S2. Annual mean NCDR-Cath PCI mortality score for PCI and CABG.

Year	PCI (Mean, SD) (n)	CABG (Mean, SD) (n)
2005	20.1 (11.9) (n=14,462)	18.8(10.6) (n=3513)
2006	20.1 (11.9) (n=15,123)	19.5(11.0) (n=3308)
2007	21.1(12.3) (n=13,673)	19.4(11.0) (n=3078)
2008	20.9(12.0) (n=14,058)	19.4(10.7) (n=2557)
2009	21.3(12.3) (n=12,816)	18.7(9.9) (n=2400)
2010	21.2(11.9) (n=12,114)	19.0(10.8) (n=2639)
2011	21.4(11.7) (n=11,954)	19.3(10.4) (n=2439)
2012	21.3(11.9) (n=11,728)	19.3(10.7) (n=2439)
2013	21.9(12.5) (n=11,412)	19.0(10.2) (n=2512)
2014	22.0 (12.6) (n=11,849)	18.7(9.9) (n=2550)
2015	22.0(12.4) (n=12,594)	17.7(9.4) (n=2769)
2016	22.2(12.7) (n=13,649)	18.2(9.2) (n=2529)
2017	22.4 (12.3) (n=14,485)	17.8(9.0) (n=2738)
All	21.4(12.2) (n=168,431)	18.8(10.3) (n=35,469)

PCI = percutaneous coronary intervention, CABG = coronary artery bypass grafting

Table S3. Mean differences in NCDR CathPCI mortality score from 2005-2017.

Year	PCI	CABG	Absolute Difference (PCI – CABG)
2005 Mean (SD)	20.1 (11.9)	18.8(10.6)	1.3 (1.1-1.9)
2017 Mean (SD)	22.4 (12.3)	17.8(9.0)	4.6 (4.2-5.1)
Mean difference, (95% confidence interval)	2.3(2.5 - 2.1)	-1.0(0.5-1.5)	3.3(2.7-3.9)

PCI = percutaneous coronary intervention, CABG = coronary artery bypass grafting, SD = standard deviation

Table S4. Observed to Expected Deaths for CABG by NCDR CathPCI Mortality Score and STS Risk Score.

Year	O/E NCDR Adjusted	O/E STS Adjusted
2008	1.10	1.07
2009	0.99	0.99
2010	1.11	1.07
2011	0.89	0.82
2012	1.06	1.03
2013	1.11	1.06
2014	1.04	0.98
2015	0.77	0.69
2016	0.78	0.73

O/E = observed to expected mortality ratio, CABG = coronary artery bypass grafting