

Defining value in cardiac surgery: A contemporary analysis of cost variation across the United States



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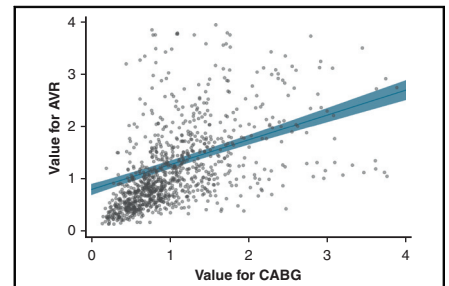
ABSTRACT

Objective: Isolated coronary artery bypass grafting and aortic valve replacement are common cardiac operations performed in the United States and serve as platforms for benchmarking. The present national study characterized hospital-level variation in costs and value for coronary artery bypass grafting and aortic valve replacement.

Methods: Adults undergoing elective, isolated coronary artery bypass grafting or aortic valve replacement were identified in the 2016-2018 Nationwide Readmissions Database. Center quality was defined by the proportion of patients without an adverse outcome (death, stroke, respiratory failure, pneumonia, sepsis, acute kidney injury, and reoperation). High-value hospitals were defined as those with observed-to-expected ratios less than 1 for costs and greater than 1 for quality, whereas the converse defined low-value centers.

Results: Of 318,194 patients meeting study criteria, 71.9% underwent isolated coronary artery bypass grafting and 28.1% underwent aortic valve replacement. Variation in hospital-level costs was evident, with median center-level cost of \$36,400 (interquartile range, 29,500-46,700) for isolated coronary artery bypass grafting and \$38,400 (interquartile range, 32,300-47,700) for aortic valve replacement. Observed-to-expected ratios for quality ranged from 0.2 to 10.9 for isolated coronary artery bypass grafting and 0.1 to 11.7 for isolated aortic valve replacement. Hospital factors, including volume and quality, contributed to approximately 9.9% and 11.2% of initial cost variation for isolated coronary artery bypass grafting and aortic valve replacement. High-value centers had greater cardiac surgery operative volume and were more commonly teaching hospitals compared to low-value centers, but had similar patient risk profiles.

Conclusions: Significant variation in hospital costs, quality, and value exists for 2 common cardiac operations. Center volume was associated with value and partly accounts for variation in costs. Our findings suggest the need for value-based care paradigms to reduce expenditures and optimize outcomes. (JTCVS Open 2022;10:266-81)



Correlation of value for CABG and AVR.

CENTRAL MESSAGE

Significant hospital-level variation persists in costs, quality, and value for isolated CABG and AVR in the United States from 2016 to 2018.

PERSPECTIVE

Isolated CABG and AVR are commonly used to benchmark cardiac surgical care. We found substantial hospital-level variation in outcomes, costs, and value, identifying a minority of hospitals as high value for either operation. High- and low-value centers treated similar patient populations, but high-value hospitals had greater cardiac surgery volume.

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Video clip is available online.

With the sustained and dramatic increase in US healthcare expenditures, several national initiatives have attempted to modify current episodic payment paradigms. Models such as accountable care organizations and quality-based or bundled-payments place emphasis on clinical outcomes while reducing costs.¹⁻³ Despite these measures, healthcare costs have continued to increase, with the Medicare budget projected to increase more than 7% per year.⁴ Interestingly, although surgical-related care accounts

Abbreviations and Acronyms

AVR	= aortic valve replacement
CABG	= coronary artery bypass grafting
ICC	= intraclass correlation coefficient
ICD-10	= International Classification of Diseases, 10th Revision
IQR	= interquartile range
LITA	= left internal thoracic artery
NRD	= Nationwide Readmissions Database
O/E	= observed-to-expected ratio

for more than 30% of total health expenditures in the United States, drivers of value, conceptually defined as the ratio of quality to costs of care, in this area remain controversial.^{5,6}

Nearly 2 decades after Birkmeyer and colleagues^{5,7} reported a positive volume-outcome relationship, minimum volume requirements continue to garner concerns for reduced access and increased costs. In the case of cardiac surgery, rigorous data collection, mandatory public reporting in some states, coupled with financial insights have allowed for exploratory analysis of cost variation. Several groups have identified complications such as acute kidney injury and respiratory failure as substantial contributors to the costs of cardiac operations.^{8,9} Given the observed center-level variability in rates of complications, their avoidance may substantially reduce costs of care. Nonetheless, the concept of value and its variation across hospitals have not been systemically examined at the national level.

The primary aim of the current study was to evaluate for the presence of center-level variation in costs, quality, and value for isolated coronary artery bypass grafting (CABG) and aortic valve replacement (AVR). We subsequently quantified the relative contribution of patient and hospital factors, including quality, to the degree of interhospital variation in cost. We hypothesized that care at high-value centers differed from low-value centers with regard to hospital volume and that hospital quality and volume strongly influenced value.

MATERIALS AND METHODS

Data Source and Study Population

This was a retrospective cohort study using the Nationwide Readmission Database (NRD). The NRD is maintained as part of the Healthcare Cost and Utilization Project, a national cost and quality improvement initiative administered by the Agency for Healthcare Research and Quality.¹⁰ The NRD samples discharges from 28 geographically diverse states, providing estimates for approximately 59% of hospitalizations in the United States. Linkage identifiers allow patients to be tracked across hospitals within the same calendar year.¹⁰

All adults (age ≥ 18 years) who underwent elective CABG or AVR from 2016 to 2018 were identified using International Classification of Diseases, 10th Revision (ICD-10) codes (Table E1). Patients undergoing concomitant valve surgery and CABG, multi-valve surgery, or ventricular assist device

placement were excluded from further study. Patients undergoing cardiac surgery at hospitals performing less than 20 CABG or valve cases annually were excluded from study. These cases were selected because they represent the scope of practice of adult cardiac surgery across a variety of hospital types in the United States.^{11,12} Those with missing data regarding in-hospital mortality, age, sex, or costs were excluded (1321, 0.4%).

Definitions of Study Variables

Patient and hospital variables were defined as reported by the Agency for Healthcare Quality and Research, including age, sex, household income quartile, insurance coverage, and teaching status.¹⁰ We used the Van Walraven modification of the Elixhauser Comorbidity Index to assess the burden of chronic conditions in the cohort. This validated tool calculates a weighted summary score based on 30 chronic conditions and adequately correlates with risk of in-hospital mortality in administrative datasets.¹³ Annual institutional caseload of all CABG and valve operations was tabulated to generate hospital volume. Safety-net hospitals were defined as those within the top quartile of Medicaid or uninsured admissions relative to all admissions.¹⁴

Because of the low mortality rates for elective CABG and AVR cases in the cohort, we developed a composite measure of hospital quality. This composite end point encompassed major adverse outcomes, including stroke, respiratory failure, prolonged mechanical ventilation, pneumonia, sepsis, acute kidney injury, reoperation, and death (Table E2). These specific complications were chosen because of their relevance to the Society of Thoracic Surgeons performance measures or patient safety indicators considered by the Centers for Medicare and Medicaid Services.^{15,16} At the hospital level, we then calculated hospital quality as the proportion of patients who did not experience a major adverse outcome (range, 0-1). Hospitalization costs were calculated from charges using cost-to-charge ratios reported by Healthcare Quality and Utilization Project and adjusted for inflation to the year 2018 using the Personal Health Care Price Index.¹⁷ We subsequently aggregated median costs at the center-level to study hospital-level costs.

Statistical Analysis

Patient and hospital-level characteristics are presented as count (percentage) for categorical variables and as mean (standard deviation) or median (interquartile range) for continuous variables. The adjusted Wald test, Mann-Whitney *U* test, and chi-square test were used for unadjusted comparisons. To assess the degree of variation in observed costs, we evaluated median, interquartile, and interdecile range of hospital-level costs for isolated CABG and isolated AVR. A similar methodology was applied to adverse outcomes at the hospital-level.

To evaluate risk-adjusted hospital-level variation in costs and quality (lack of adverse outcomes), generalized linear models were used to generate expected costs and expected probabilities of not experiencing an adverse outcome at the patient level. Variable selection was guided by the least absolute shrinkage and selection operator, which reduces model overfitting, and models optimized to reduce the mean squared error term.¹⁸ Models were further evaluated with Bayesian information criteria, and tested for collinearity using the variance inflation factor. Final patient-level models included adjustment for age, sex, Elixhauser Comorbidity Index, income quartile, primary insurer, number of bypass grafts (CABG), bioprosthetic or mechanical valve (AVR), congestive heart failure, arrhythmias, chronic lung disease, diabetes, end-stage renal disease, chronic liver disease, coagulopathy, electrolyte disturbances, and malnutrition. We subsequently aggregated patient-level expected costs and rates of adverse outcomes for each hospital. Each hospital's O/E for costs and quality was then calculated from the estimates aggregated at the hospital-level, and 95% confidence intervals were generated from 1000 bootstrap iterations.^{19,20}

To quantify the variation attributable to hospital factors, we created 2 multilevel mixed effects models. We quantified the variation in costs and adverse outcomes across hospitals using the intraclass correlation

TABLE 1. Patient-level demographics, hospital, and operative characteristics of patients undergoing isolated coronary artery bypass grafting or isolated aortic valve replacement in 2016-2018

	Isolated CABG (n = 228,899)	Isolated AVR (n = 89,295)
Age (y)	66.0 (9.5)	65.0 (12.3)
Female	50,198 (21.9)	31,995 (35.8)
Primary payer		
Medicare	131,887 (57.7)	49,823 (55.9)
Medicaid	13,116 (5.7)	4343 (4.9)
Other Payer*	8635 (3.8)	2663 (3.0)
Private	74,975 (32.8)	32,384 (36.3)
Income quartile		
First (lowest)	60,552 (26.9)	18,166 (20.6)
Second	65,218 (28.9)	24,568 (27.9)
Third	58,795 (26.1)	24,792 (28.2)
Fourth (highest)	40,853 (18.1)	20,499 (23.3)
Urban hospital	222,542 (97.2)	87,717 (98.2)
Hospital teaching status	181,720 (79.4)	75,429 (84.5)
Operative characteristics		
Grafts		
1	22,296 (9.7)	–
2	48,600 (21.2)	–
3	87,716 (38.3)	–
≥4	70,286 (30.7)	–
LITA use	209,920 (91.7)	–
Bioprosthetic valve	–	73,437 (82.2)
Mechanical valve	–	15,858 (17.8)
Elixhauser		
Comorbidity Index		
0-4	147,352 (64.4)	39,502 (44.2)
5-8	77,298 (33.8)	46,061 (51.6)
≥9	4249 (1.9)	3732 (4.2)
Comorbidities		
Cardiac arrhythmia	100,661 (44.0)	48,593 (54.4)
Congestive heart failure	59,849 (26.2)	27,955 (31.3)
Chronic liver disease	5709 (2.5)	2579 (2.9)
Chronic lung disease	47,480 (20.7)	16,825 (18.8)
Coagulopathy	44,822 (19.6)	29,028 (32.5)
Diabetes	106,694 (46.6)	22,742 (25.5)
End-stage renal disease	7824 (3.4)	1439 (1.6)
Hypertension	201,165 (87.9)	69,167 (77.5)
Hypothyroidism	24,612 (10.8)	11,378 (12.7)
Malnutrition	3473 (1.5)	1328 (1.5)
Peripheral vascular disease	34,170 (14.9)	26,298 (29.5)
Pulmonary circulatory disorder	8360 (3.7)	7599 (8.5)
Rheumatologic disorder	5307 (2.3)	2562 (2.9)

Continuous variables reported as mean (standard deviation), and categorical as count (percentage). CABG, Coronary artery bypass grafting; AVR, aortic valve replacement; LITA, left internal thoracic artery. *Other payer includes uninsured and self-pay.

coefficient (ICC), comparing the ICC for each of the models.^{21,22} Models differed by inclusion only patient factors (Model 1) and patient and hospital factors including hospital quality (Model 2). This allowed for quantification of the degree of variation was explained by known hospital factors.

Given the relevance of operative experience in cardiac surgery, we used restricted cubic spline regression to confirm a relationship between adult cardiac surgery volume and risk-adjusted median hospital costs. Finally, we evaluated value as the quotient of hospital quality and costs, and correlated value for AVR and CABG using Pearson’s correlation coefficient. We then compared high-value with low-value centers with regard to patient risk profiles, hospital characteristics, and outcomes. For each operation, high-value centers were those with an O/E greater than 1 for quality and O/E less than 1 for costs, whereas the converse defined low-value centers.

The Institutional Review Board at the University of California, Los Angeles, deemed the study exempt from full review (IRB# 12-000805). Patient consent was waived because data were from a deidentified database. Statistical analysis was performed using Stata version 16.0 (StataCorp LLC).

RESULTS

Characteristics of Patients Undergoing Isolated Coronary Artery Bypass Grafting or Isolated Aortic Valve Replacement

Of 318,194 patients meeting study criteria, 71.9% underwent isolated CABG and 28.1% underwent isolated AVR. Patient, hospital, and operative characteristics are shown in Table 1. The mean age of those of those undergoing CABG was 66.0 years and of those undergoing isolated AVR was 65.0 years. The majority of patients undergoing CABG received 3 bypass grafts (38.3%) or 4 or more grafts (30.7%), and 91.7% received a left internal thoracic artery (LITA) graft. For isolated AVR, the majority (82.2%) of patients underwent replacement with a bioprosthetic valve, whereas a minority received a mechanical valve. Medicare was the predominant insurer for both study groups (57.7% for isolated CABG and 55.9% for isolated AVR), and the majority of cases occurred in nonrural regions (97.2% and 98.2%).

Observed Variation in Outcomes and Costs for Isolated Coronary Artery Bypass Grafting and Isolated Aortic Valve Replacement

Among institutions performing at least 20 cases annually, a mean of 554 hospitals performed a median of 95 (interquartile range [IQR], 52-177) CABGs per year, whereas 366 hospitals performed a median of 51 (IQR, 33-93) isolated AVRs per year (Table E3). Variation in observed hospital-level costs was evident, with a median center cost of \$36,400 for isolated CABG (interdecile range 24,900-57,300) and \$38,400 (interdecile range 27,500-57,800) for isolated AVR (Figures 1 and E1). From 2016 to 2018, the mean hospital mortality rate was 1.37% for isolated CABG and 1.60% for isolated AVR. Variation in adverse outcomes was evident for those undergoing isolated CABG, with a median hospital rate of 22.1%, with an interdecile range of 15.0% to 31.4%. A similar degree of variation was noted for isolated AVR, with a median adverse outcome rate of 20.0% (interdecile range, 11.8%-41.4%).

To evaluate risk-adjusted variation in costs and adverse outcomes, we generated O/E ratios for these variables

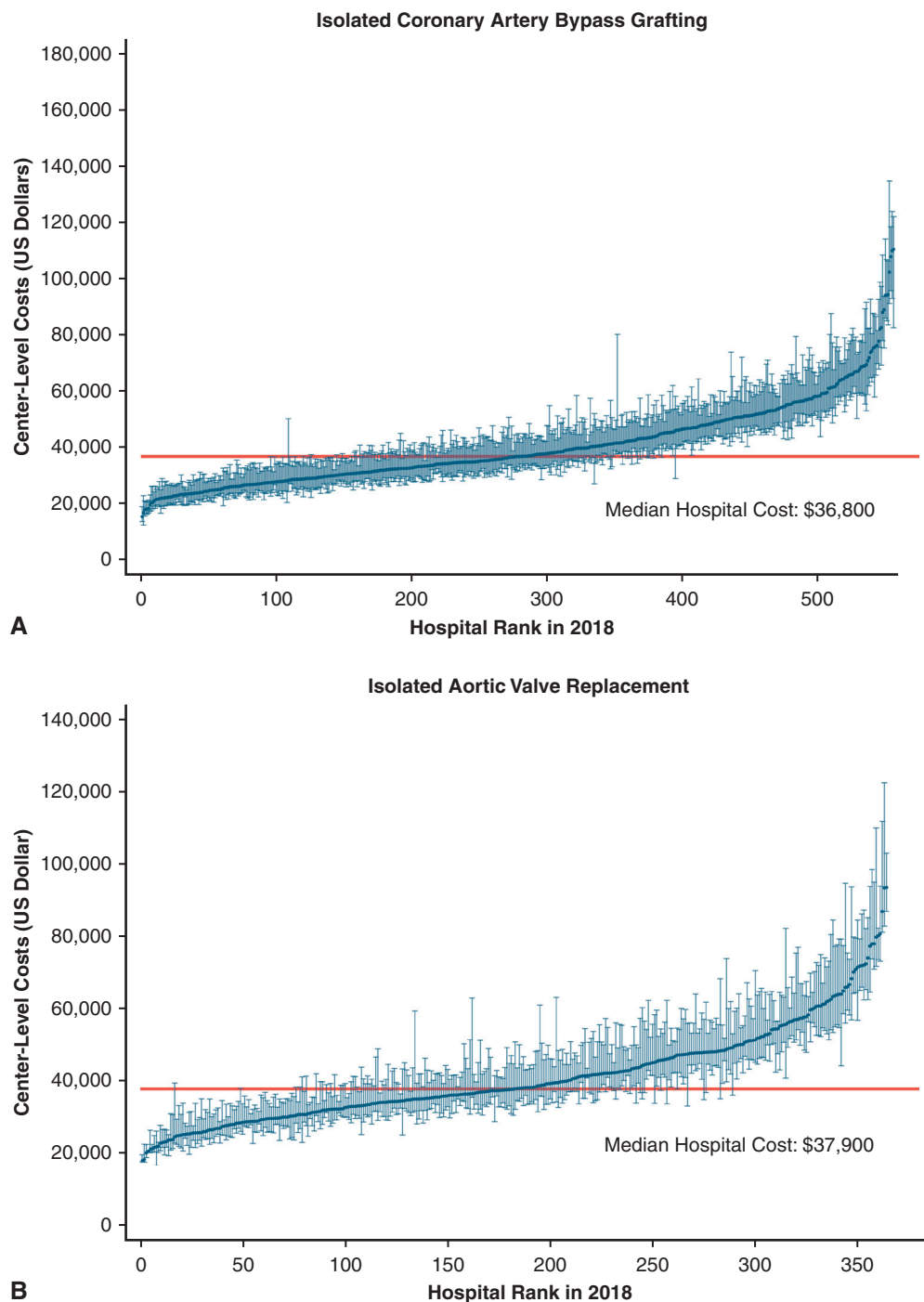


FIGURE 1. Observed variation in unadjusted center-level costs for isolated CABG (A) and AVR (B) in 2018. Costs reported as median and IQR for each center. AVR, Aortic valve replacement; CABG, coronary artery bypass grafting.

(Figure 2). Substantial variation in O/E ratios were evident for quality for isolated CABG, with an interdecile range of 0.4 to 1.7 (range, 0.2-10.9) as well as for isolated AVR, with an interdecile range of 0.4 to 2.1 (range, 0.1-11.7). A similar degree of variation in risk-adjusted costs was present for both operations (Figure 2). For isolated CABG, interdecile

range for O/E of costs was 0.7 to 1.5 (range, 0.4-3.1), with a median hospital-level risk-adjusted costs of \$33,800 (interdecile range, 23,600-52,100). Likewise, interdecile range for O/E of costs was 0.6 to 1.3 (range, 0.3-2.2) for isolated AVR, corresponding to median hospital risk-adjusted costs of \$34,600 (interdecile range, 24,700-50,300).

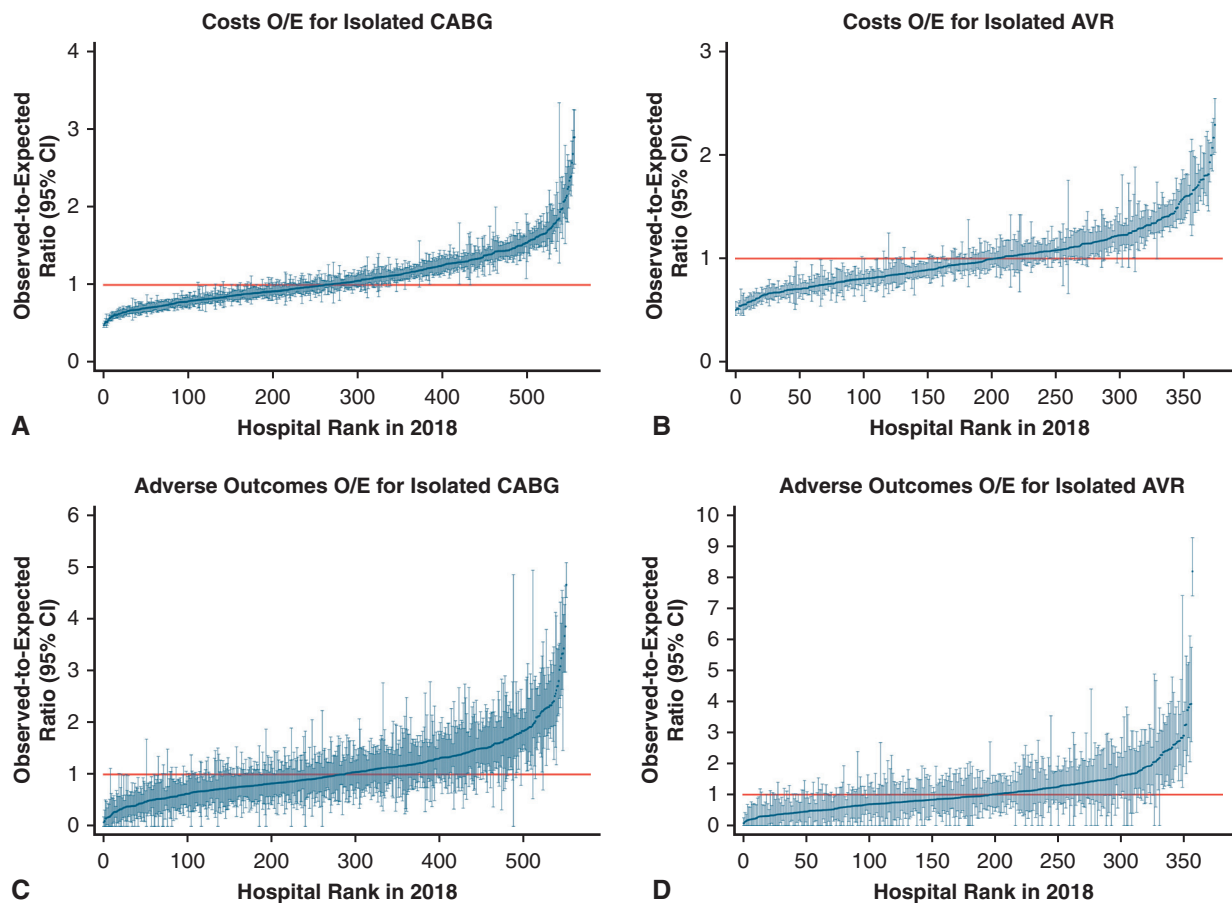


FIGURE 2. Hospital O/E for costs (A, B) and adverse outcomes (C, D) following isolated CABG and AVR for operations performed in 2018. Center estimate with 95% confidence interval reported. *O/E*, Observed-to-expected ratio; *AVR*, aortic valve replacement; *CABG*, coronary artery bypass grafting.

Known Hospital Factors, Including Volume, Explain a Proportion of Cost Variation and Contribute Significantly to Costs

We subsequently studied differences in ICC between mixed effects models to quantify the degree of cost variation due to specific hospital factors (Table 2). For isolated CABG, the ICC of the base model, containing patient-level factors alone, decreased by 9.9% after accounting for known hospital-level factors, including teaching status, safety-net status, volume, and O/E for adverse outcomes. This implies that 9.9% of the hospital random-effect variation was due to these factors. Similar findings were evident for isolated AVR, with 11.2% due to known hospital factors. Factors directly associated with costs included hospital volume (\$9000 reduction per decile for CABG and AVR), hospital adverse outcome O/E (\$1400 increase per unit for isolated CABG and \$1500 increase per unit for AVR), and safety-net status (Tables E4 and E5).

To further examine the impact of volume on costs, we studied relationships between institutional cardiac surgery volume and risk-adjusted hospital costs of isolated CABG and AVR. For both operations, we observed a qualitative

reduction in variation as volume increased to a nadir and, using restricted cubic spline regression, found an association between volume and costs (Figure 3).

Hospital Value for Isolated Coronary Artery Bypass Grafting and Isolated Aortic Valve Replacement

Using O/E ratios for quality and costs, we considered high-value hospitals as those who outperformed their peers in both quality (O/E > 1) and costs (O/E < 1). Low-value hospitals performed inferiorly for both measures, and the remaining hospitals with mixed performance were considered intermediate (Table E6). Among hospitals performing CABG, 22.0% were high value and 30.9% were low value, whereas 30.6% and 20.5% of hospitals were high and low value for isolated AVR, respectively (Figure 4). Value for CABG correlated with value for AVR, with Pearson correlation coefficient $r = 0.43$ (Figure 5). Among high-value CABG centers, 68.5% were also high value for AVR, and 2.5% were low value for AVR.

We subsequently tested for differences between patient and hospital characteristics between high- and low-value

TABLE 2. Variance component analysis for patient and hospital factors associated with costs for isolated coronary artery bypass grafting and isolated aortic valve replacement

Model	Variables	Isolated CABG		Isolated AVR	
		ICC (SE)	Change in ICC	ICC (SE)	Change in ICC
Model 1	Patient factors: age, sex, payer, income, number of bypass grafts (CABG), valve type (AVR), comorbidities	0.373 (0.009)	–	0.267 (0.009)	–
Model 2	Patient and hospital factors: model 1 plus urban/rural designation, teaching status, safety-net status, volume, performance	0.336 (0.008)	0.037 (9.9%)	0.237 (0.009)	0.030 (11.2%)

CABG, Coronary artery bypass grafting; AVR, aortic valve replacement; ICC, intraclass correlation coefficient; SE, standard error.

centers (Table E6). Notably, age and comorbidity burden for both CABG and AVR did not differ at high-versus low-value centers. For isolated CABG, the number bypass grafts did not differ between high- and low-value centers, nor did use of the LITA (91.6% vs 92.4%, $P = .28$). For both operations, high-value centers had significantly greater annual cardiac surgery volume compared with low-value centers. Relative to low-value hospitals, high-value centers were more commonly teaching hospitals for both CABG and AVR, and less commonly were safety-net hospitals, suggesting that hospital structural factors influence value. Intermediate-value (neither high nor low) hospitals were comparable to high-value centers with regard to volume and teaching status, but were more commonly safety-net centers relative to high value (18.1% vs 13.7% for CABG, 16.0% vs 10.7% for AVR).

As expected, compared with low-value, high-value centers operated with reduced mortality for CABG (0.8% vs 1.5%, $P < .001$) and AVR (1.1% vs 1.8%, $P < .001$), as well as reduced rates of adverse outcomes and at lower costs

(Table E6). Notably, hospital length of stay was significantly shorter at high-value centers (6 days, IQR, 4-7) compared with low-value centers (6 days, IQR 5-8, $P < .001$) for CABG, as well as for AVR (5 days, IQR 4-7 vs 6 days, IQR 5-8, $P < .001$). Among patients surviving to discharge, nonelective readmissions at 30 days were slightly lower at high-value centers relative to low-value centers for CABG (8.2% vs 8.9%, $P = .02$) but similar for AVR (9.7% vs 9.8%, $P = .87$). These findings suggest that high-value centers may mitigate index costs partly by reducing length of stay, and, to a minor degree, by reducing readmission.

DISCUSSION

High-quality care that efficiently uses resources to yield positive clinical outcomes is the fundamental tenet of value-based healthcare delivery. In adult cardiac surgery, isolated CABG and AVR are common operations used for benchmarking of quality and costs. In the present study, we found evidence of variation in hospitalization costs and adverse

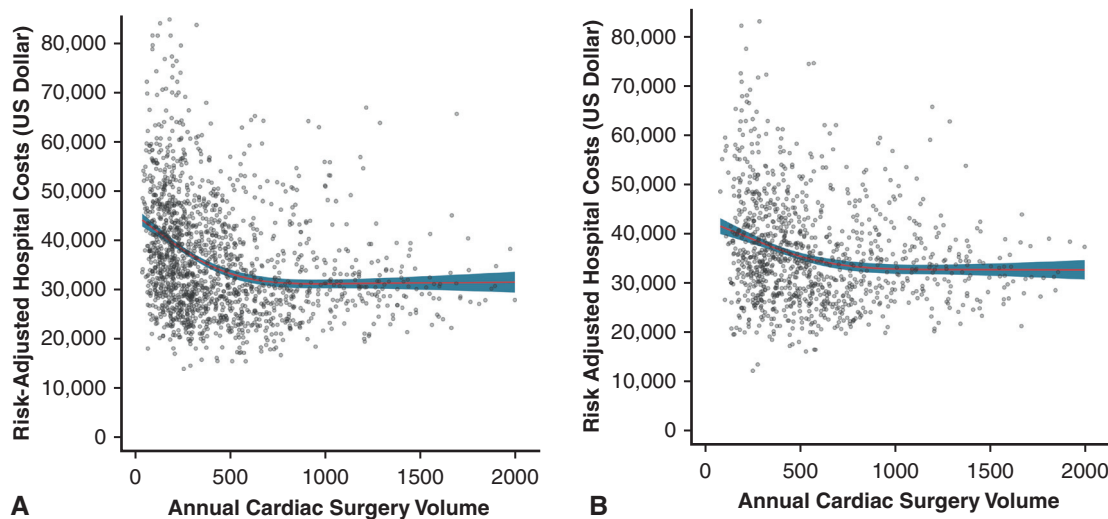


FIGURE 3. Relationship between institutional cardiac surgery volume and risk-adjusted median hospital costs for isolated CABG (A) and AVR (B). Institutional cardiac surgery volume represents all adult CABG and valve surgery caseload. Axes truncated for display at volume less than 2000 and costs less than 80,000. AVR, Aortic valve replacement; CABG, coronary artery bypass grafting.

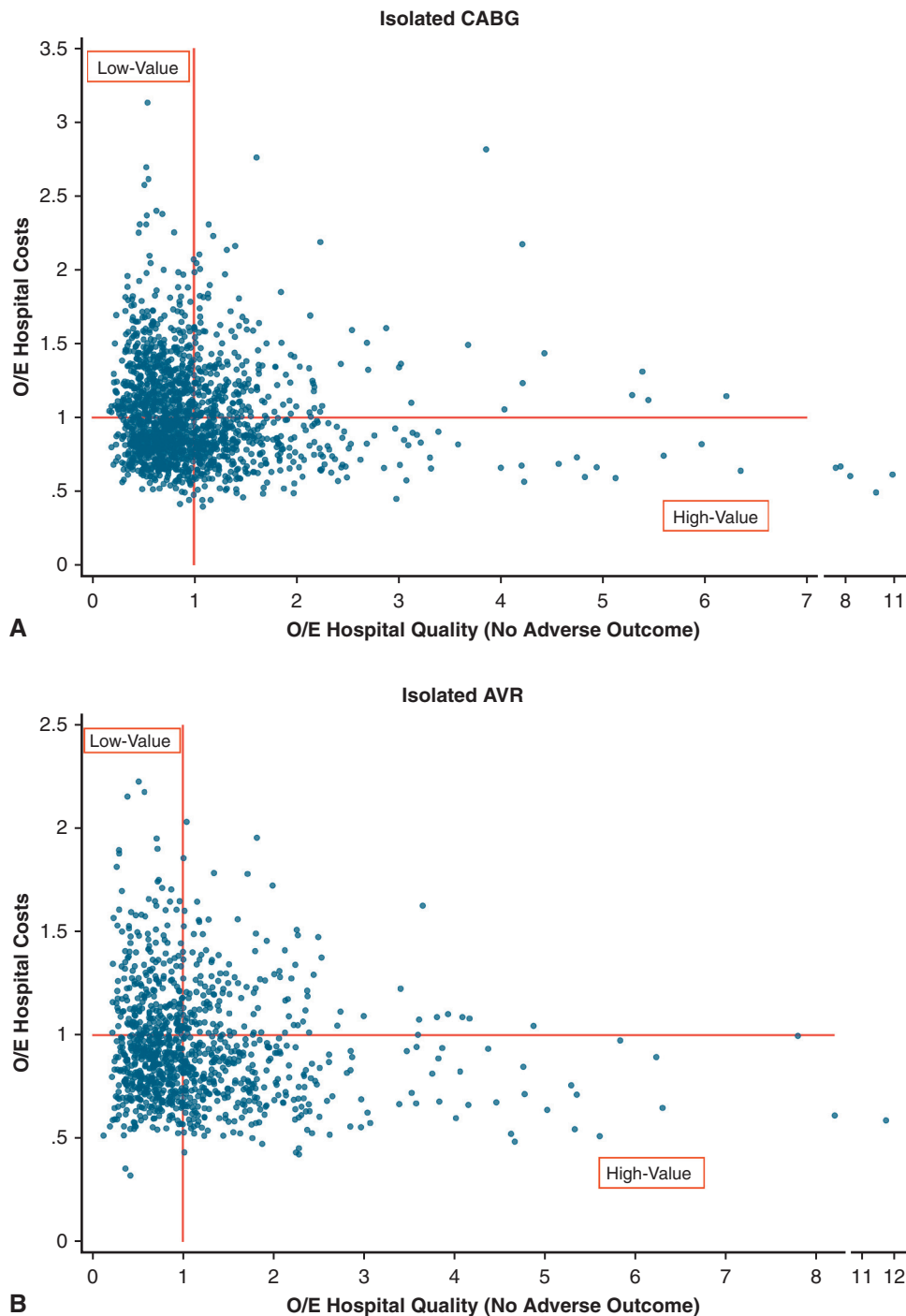


FIGURE 4. Value in isolated CABG (A) and AVR (B) defined by O/E ratios for hospital quality and costs. High-value centers were those with O/E greater than 1 for quality and O/E less than 1 for costs, and low-value had O/E less than 1 for quality and O/E greater than 1 for costs. *O/E*, Observed-to-expected ratio; *AVR*, aortic valve replacement; *CABG*, coronary artery bypass grafting.

outcomes after isolated CABG and AVR (Figure 6). We identified that cost variation is partly due to known hospital factors such as hospital volume and quality; however, other factors, not captured by the NRD, influence center-level costs.

Hospital value for CABG correlated with AVR, supporting the presence of hospital-specific effects that influence value. Finally, high-value hospitals for both CABG and AVR treated comparable patient populations, had similar rates of estab-

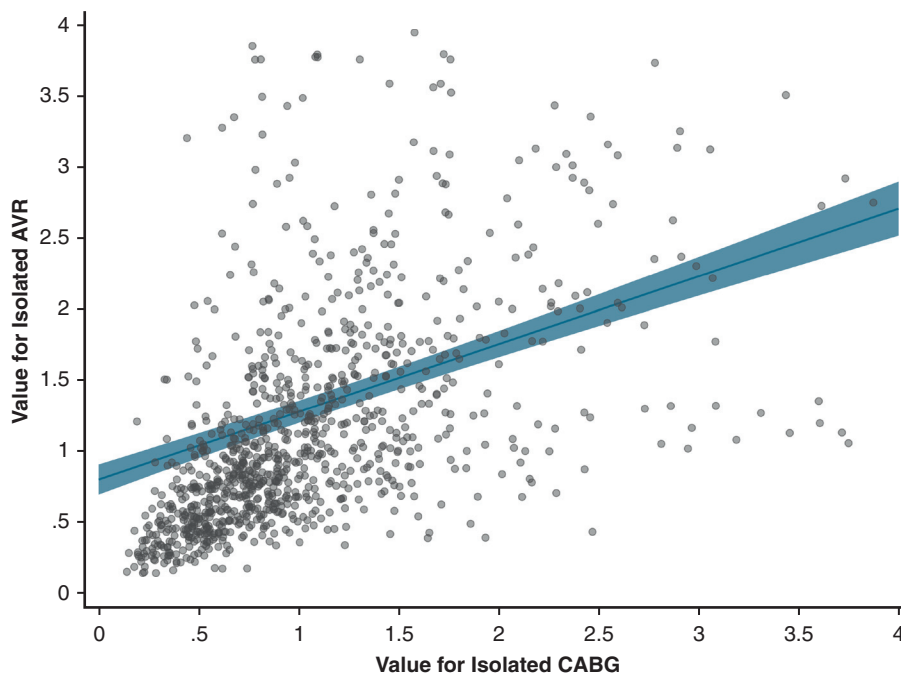


FIGURE 5. Correlation between value for isolated CABG and AVR. Value represents quotient of quality *O/E* to cost *O/E*, such that value increases as the quotient increases. Axes truncated for display at value greater than 4, but all data points contribute to best fit linear regression and 95% CI. AVR, Aortic valve replacement; CABG, coronary artery bypass grafting; CI, confidence interval; *O/E*, observed-to-expected ratio.

lished quality metrics such as LITA use, but high-value hospitals had greater cardiac surgery case volume and were more commonly teaching hospitals (Video 1).

Among the most striking findings of the present analysis is the degree of observed variation in the costs of elective isolated CABG and AVR. The median center cost for isolated CABG was \$36,800, with 25% of hospitals costing more than \$10,000 above the median, including 10% that were \$20,000 over the median. A similar degree of variation existed for isolated AVR, with a median cost of \$38,400, with 25% costing approximately \$9000 greater than the median and 10% costing approximately \$20,000 over the median. Using the National Inpatient Sample, Kilic and colleagues²³ examined the cost of isolated CABG from 2005 to 2008 and found a similar degree of hospital-level variation, with mean CABG costs of approximately \$40,000 and standard deviation of \$12,000. Our cohort represented data from operations performed over a decade later whereby similar variation in costs persists despite extensive quality improvement and cost-containment efforts. Several studies have identified in-hospital complications as a key component of exponential increases in costs.^{8,9,24,25} After identification of prolonged ventilation and acute kidney injury as key drivers of cost, the Virginia Cardiac Services Quality Initiative instituted quarterly quality meetings and developed shared perioperative practices across 14 cardiac surgical practices and 18 hospitals. Compared with the preimplementation period, the incidence of prolonged ventilation

and acute kidney injury significantly decreased postimplementation, despite a greater predicted risk of mortality/morbidity in the later era. In this cohort of approximately 28,000 patients undergoing isolated CABG from 2008 to 2015, reduction of these 2 specific complications decreased estimated costs by \$18.7 million.²⁶ Adoption of similar practices across hospital systems or consortia, rather than solely at the individual hospital level, may significantly reduce costs of the delivery of cardiac surgical care.

Prior studies have established that hospital factors influence the costs of care in cardiac surgery.^{23,27-29} Salenger and colleagues²⁷ examined variation in charges for isolated CABG across Maryland hospitals and found significant variation in charges and operative time, preoperative length of stay, and complications such as renal failure and prolonged ventilation. Consistent with work by the Virginia Cardiac Services Quality Initiative, these measures can be targeted for quality improvement to reduce costs.²⁶ In our study, we similarly found that risk-adjusted hospital adverse outcomes as well as available hospital factors, such as volume, influence costs of care. Similar to Salenger and colleagues²⁷ and Yount and colleagues,³ we also found that individual centers remained associated with costs in mixed effects regression, suggesting the presence of additional hospital-level contributors to costs not captured in our data, such as intensive care unit length of stay and surgeon-attributable factors.⁶ For example, efforts to reduce operating room time by improving turnover or reduce

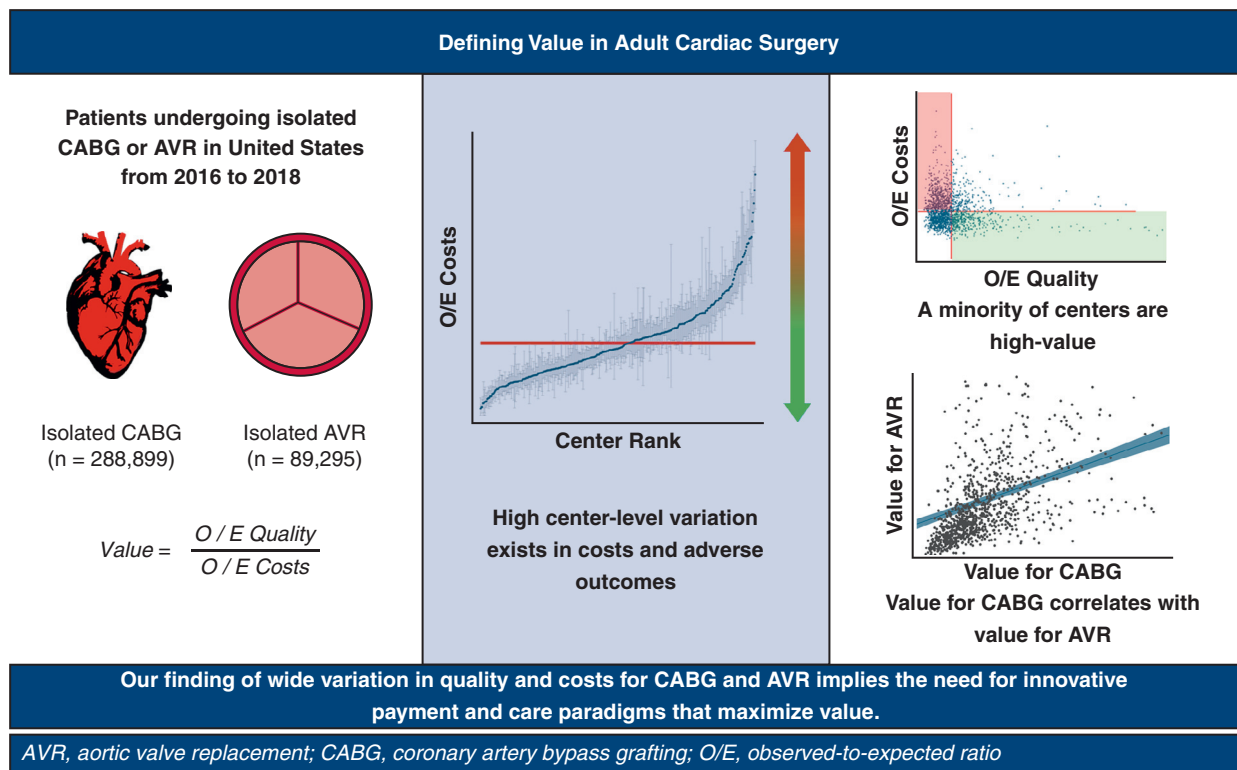


FIGURE 6. Significant variation in costs and quality exists after elective isolated CABG or AVR, with a minority of centers identified as high value. CABG, Coronary artery bypass grafting; AVR, aortic valve replacement; O/E, observed-to-expected ratio.

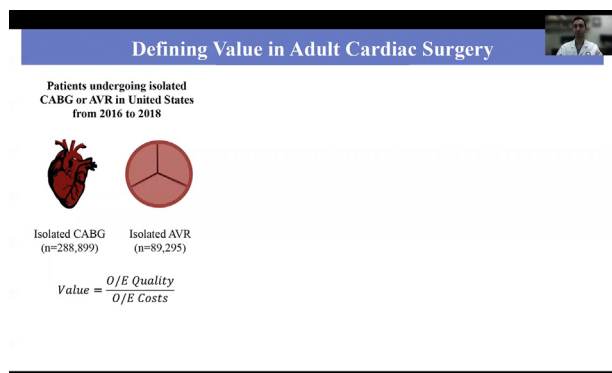
intensive care unit time by implementing protocols for timely extubation may plausibly reduce costs through hospital-level practices. Studies examining implementation of operating room team-based training or value stream mapping have reported improved room turnover time, proportion of first start cases, and reduced morbidity.^{30,31}

With increasing healthcare costs, value-based care has received significant national attention. In the present study, we found 22.0% of hospitals to be high value for CABG and 30.9% for isolated AVR, as defined by outperformance of peers for both costs and quality. Although our definition of value incorporated the absence of adverse outcomes, other measures such as adherence to care bundles, timely extubation, and discharge with appropriate medications may better capture quality and assess value.^{29,32} Approaches to promote value-based care have been developed institutionally and at the national level. For example, voluntary bundled payments were offered by the Centers for Medicare and Medicaid Services for various medical and surgical conditions, including CABG, through the Bundled Payments for Care Improvement initiative as an avenue to improve value.^{33,34} Using a pay-for-performance program within a single healthcare system, Casale and colleagues³⁵ reported a trend toward improvement in 30-day outcomes after CABG, with greater routine discharge rates and a

5% reduction in charges. In the present study, we did not identify significant differences in patient characteristics among high-versus low-value hospitals, suggesting that factors beyond patient selection contribute to value. Moreover, traditional metrics for value, such as LITA use for isolated CABG, did not discriminate centers, likely due to the high prevalence of LITA use in the United States. Interestingly, among hospital factors available in our data set, we found increasing hospital volume and teaching institutions to be associated with value, emphasizing the continued relevance of volume and experience in cardiac surgical care.

Study Limitations

The present study has several limitations inherent to its design and the descriptive nature of the work. We used a diagnosis coding–based composite end point to provide sufficient events for studying quality, which is subject to coding practices and may introduce bias compared with a clinically derived end point. To reduce miscoding of complications, we limited our study to elective, isolated CABG or AVR, because complications may be more prone to bias in nonelective cases. Costs were evaluated using cost-to-charge ratios, which may overestimate hospital-level variation compared with payments or activity-based costing; nonetheless, these approaches are not available in



VIDEO 1. Authors briefly discuss variation in quality and costs of isolated CABG and AVR. Video available at: [https://www.jtcvs.org/article/S2666-2736\(22\)00178-4/fulltext](https://www.jtcvs.org/article/S2666-2736(22)00178-4/fulltext).

national, all-payer databases. We limited our hospital-level analysis to those performing at least 20 cases, which captured 93.3% of isolated AVR and 99.3% of isolated CABG cases, because we expected greater heterogeneity in models for hospital quality and costs for hospitals performing a low number of cases or experiencing no adverse outcomes. Despite performing at least 20 cases annually, 11 and 3 hospitals had no adverse outcomes after CABG or AVR, respectively, and did not contribute to value analysis. Certain clinical parameters, such as the Society of Thoracic Surgeons risk score and left ventricular ejection fraction are not available in this data set and could not be used for risk adjustment, which may lead to overestimates of variation. More granular analysis of hospital characteristics, including intraoperative metrics and availability of intensive care and other perioperative teams, was not possible given the limitations of administrative data. Nonetheless, our study included more than 300,000 isolated CABG or AVR from a nationally representative sample and builds on our existing knowledge of cost variation and value in adult cardiac surgery.

CONCLUSIONS

Wide variation in costs of care and quality after CABG and AVR exist in the United States. Although hospital volume is associated with both costs and quality, it only partly explains the variation. While sharing similar patient demographics, high-value hospitals were often high volume and had reduced costs of care. Identification of this source of variation may better inform value-based purchasing and serve as a platform to optimize outcomes while limiting healthcare expenditures.

Conflict of Interest Statement

R.J.S. serves as a consultant to the Edwards Lifesciences Advisory Board and Co-Principal Investigator on

PARTNER II Trial. All other authors reported no conflicts of interest.

The *Journal* policy requires editors and reviewers to disclose conflicts of interest and to decline handling or reviewing manuscripts for which they may have a conflict of interest. The editors and reviewers of this article have no conflicts of interest.

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Key Words: aortic valve replacement, coronary artery bypass grafting, cost variation, healthcare expenditures, quality of care, value

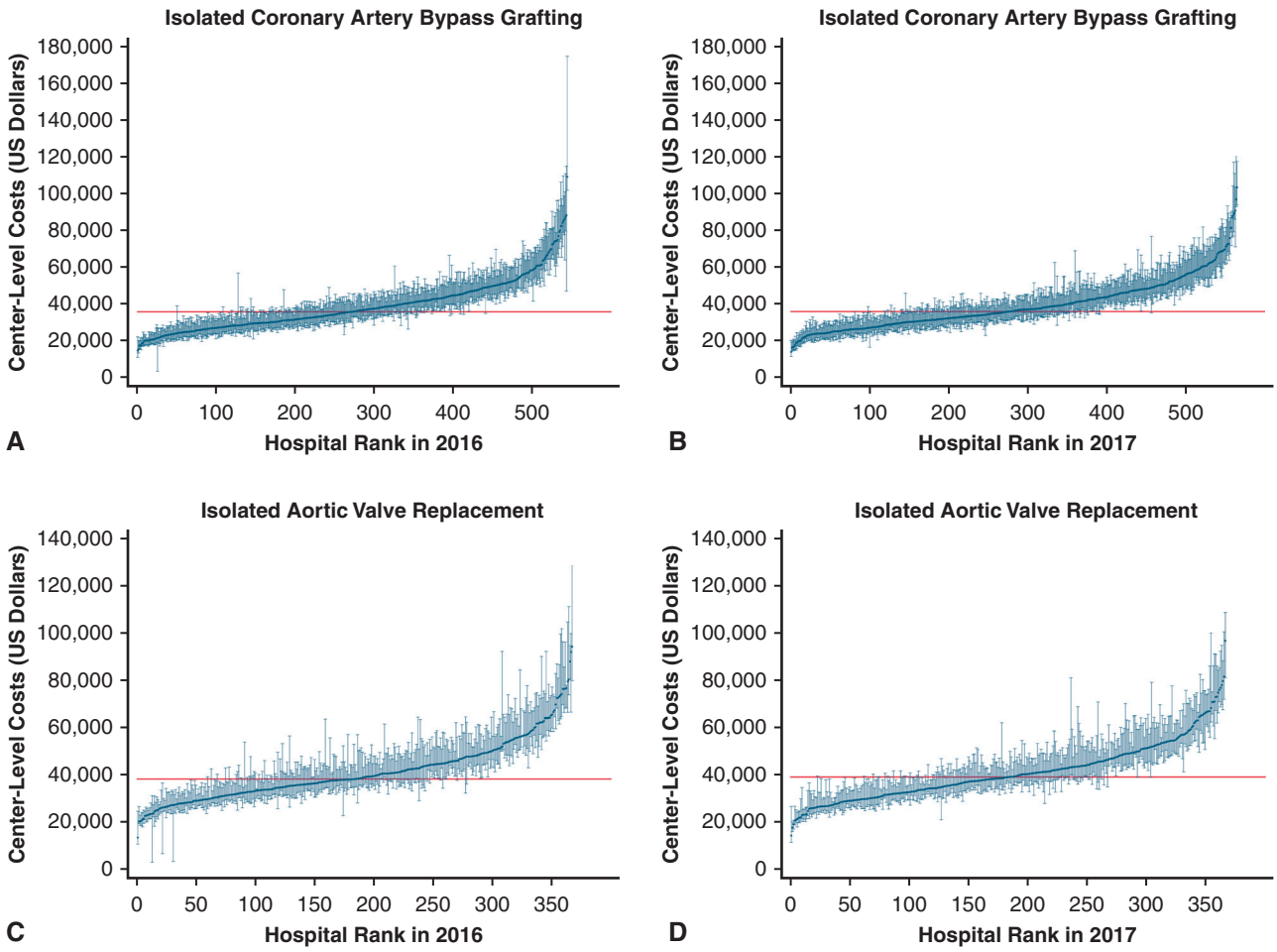


FIGURE E1. Observed variation in unadjusted center-level costs. Data presented for isolated CABG (A, B) and isolated AVR (C, D) by year. Costs reported as median and IQR for each center. *AVR*, Aortic valve replacement; *CABG*, coronary artery bypass grafting.

TABLE E1. International Classification of Diseases, 10th Revision, Procedure Coding System Codes for coronary artery bypass grafting and aortic valve replacement

Operation	ICD-10-PCS codes
CABG	021008, 021008, 02100A, 02100J, 02100K, 02100Z, 021048, 021049, 02104A, 02104J, 02104K, 02104Z, 021108, 021108, 02110A, 02110J, 02110K, 02110Z, 021148, 021149, 02114A, 02114J, 02114K, 02114Z, 021208, 021208, 02120A, 02120J, 02120K, 02120Z, 021248, 021249, 02124A, 02124J, 02124K, 02124Z, 021308, 021308, 02130A, 02130J, 02130K, 02130Z, 021348, 021349, 02134A, 02134J, 02134K, 02134Z
AVR	02RF07, 02RF08, 02RF0J, 02RF0K, 02RF47, 02RF48, 02RF4J, 02RF4K

ICD-10-PCS, International Classification of Diseases, 10th Revision, Procedure Coding System; CABG, coronary artery bypass grafting; AVR, aortic valve replacement.

TABLE E2. International Classification of Diseases, 10th Revision, Procedure Coding System or Clinical Management codes for adverse outcomes

Condition	ICD-10 codes
Mortality	Defined per Nationwide Readmissions Database Data Dictionary.
Stroke	I60, I61, I62, I63, I97.810, I97.820, G97.32, G97.52, G97.62
Respiratory failure	J80, J95.82, J96.0, J96.2
Prolonged mechanical ventilation	5A1945Z, 5A1955Z
Pneumonia	J13, J14, J15, J16, J17, J18, J95.851
Sepsis	A40, A41, T81.12, T81.44, R65.2
Acute kidney injury	N17
Reoperation	0W390ZZ, 0W3B0ZZ, 0W394ZZ, 0W3B4ZZ, 02JA0ZZ, 02JA4ZZ, 0W3D0ZZ, 0W3C0ZZ, 0W3C4ZZ, 0W380ZZ, 0W384ZZ, 02JY0ZZ, 02JY4ZZ performed on separate procedure day

ICD-10, International Classification of Diseases, 10th Revision.

TABLE E3. Annual center-level outcomes and costs from 2016 to 2018 for isolated coronary artery bypass grafting and isolated aortic valve replacement

Variable	Isolated CABG	Isolated AVR
Centers per y	554	366
Volume (median, IQR)	95 (52-177)	51 (33-93)
Costs		
Minimum	14,100	13,500
10th percentile	24,900	27,500
25th percentile	29,500	32,300
50th percentile	36,400	38,400
75th percentile	46,700	47,700
90th percentile	57,300	57,800
Maximum	110,400	96,600
Mortality rate (mean)	1.37	1.60
Adverse outcome rate		
Minimum	0.0	0.0
10th percentile	9.8	6.5
25th percentile	15.0	11.8
50th percentile	22.1	20.0
75th percentile	31.4	29.4
90th percentile	46.2	41.4
Maximum	100.0	100.0

Costs reported to nearest \$100. Adverse outcomes included mortality, stroke, respiratory failure, prolonged mechanical ventilation, pneumonia, sepsis, acute kidney injury, and reoperation within same admission. CABG, Coronary artery bypass grafting; AVR, aortic valve replacement; IQR, interquartile range.

TABLE E4. Mixed effect model for costs of isolated coronary artery bypass grafting

Variable	B-coefficient (95% CI)	P value
Age (per y)	60 (40-70)	<.001
Sex		
Female	1100 (800-1300)	<.001
Male	Reference	
Primary payer		
Medicare	300 (-10 to 600)	.05
Medicaid	1200 (700-1700)	<.001
Other payer*	300 (-400 to 900)	.39
Private insurer	Reference	
Income quartile		
First (lowest)	140 (-270 to 540)	.51
Second	10 (-370 to 390)	.95
Third	-80 (-430 to 280)	.68
Fourth (highest)	Reference	
Location and teaching status		
Metropolitan nonteaching	1100 (-2700 to 4800)	.58
Metropolitan teaching	-1200 (-4900 to 2400)	.51
Rural	Reference	
Safety-net status	6000 (4300-7600)	<.001
Cardiac surgery volume (per decile)	-900 (-1100 to -600)	<.001
Adverse outcomes O/E (per unit)	1400 (500-2300)	.002
Grafts		
1	Reference	
2	400 (-10 to 900)	.05
3	1000 (600-1400)	<.001
≥4	2100 (1700-2600)	<.001
Elixhauser Comorbidity Index		
0-4	Reference	
5-8	3000 (2700-3400)	<.001
≥9	11,800 (10,900-12,700)	<.001
Comorbidities		
Cardiac arrhythmia	3800 (3500-4000)	<.001
Congestive heart failure	4400 (4100-4700)	<.001
Chronic liver disease	13,300 (12,600-14,000)	<.001
Chronic lung disease	1100 (800-1400)	<.001
Coagulopathy	3000 (2700-3300)	<.001
Diabetes	-900 (-1100 to -700)	<.001
End-stage renal disease	8700 (8100-9300)	<.001
Electrolyte disorder	5700 (5400-6000)	<.001
Malnutrition	33,100 (32,200-34,000)	<.001

Costs reported to nearest \$10 if less than \$100, otherwise to nearest \$100. CI, Confidence interval; O/E, observed-to-expected ratio. *Other payer includes uninsured and self-pay.

TABLE E5. Mixed effect model for costs of isolated aortic valve replacement

Variable	B-coefficient (95% CI)	P value
Age (per y)	-20 (-50 to 10)	.09
Sex		
Female	440 (-10 to 900)	.06
Male	Reference	
Primary payer		
Medicare	700 (100-1300)	.03
Medicaid	3400 (2300-4500)	<.001
Other payer*	700 (-700 to 2000)	.32
Private Insurer	Reference	
Income quartile		
First (lowest)	200 (-600 to 900)	.69
Second	900 (200-1600)	.01
Third	500 (-100 to 1100)	.12
Fourth (highest)	Reference	
Location and teaching status		
Metropolitan nonteaching	3000 (-2800 to 8800)	.32
Metropolitan teaching	1300 (-4200 to 6900)	.64
Rural	Reference	
Safety-net status	5700 (3500-7900)	<.001
Cardiac surgery volume (per decile)	-900 (-1200 to -600)	<.001
Adverse outcomes O/E (per unit)	1500 (500-2500)	.002
Valve type		
Bioprosthetic	Reference	
Mechanical	2100 (1500-2700)	<.001
Elixhauser Comorbidity Index		
0-4	Reference	
5-8	1900 (1300-2400)	<.001
≥8	10,100 (8800-11,500)	<.001
Comorbidities		
Cardiac arrhythmia	5800 (5400-6300)	<.001
Congestive heart failure	4000 (3400-4500)	<.001
Chronic liver disease	18,000 (16,600-19,200)	<.001
Chronic lung disease	40 (-500 to 600)	.89
Coagulopathy	3800 (3300-4400)	<.001
Diabetes	-1200 (-1700 to -700)	<.001
End-stage renal disease	17,500 (15,700-19,300)	<.001
Electrolyte disorder	6500 (6000-7000)	<.001
Malnutrition	50,000 (48,200-51,800)	<.001

Costs reported to nearest \$10 if less than \$100, otherwise to nearest \$100. *CI*, Confidence interval; *O/E*, observed-to-expected ratio. *Other payer includes uninsured and self-pay.

TABLE E6. Characteristics and outcomes of hospitals by value for isolated coronary artery bypass grafting and isolated aortic valve replacement

Variable	Low value	Intermediate value	High value	P value
CABG				
Percentage of centers	30.9	47.1	22.0	
Age	66.1 (9.9)	65.9 (9.5)	66.1 (9.5)	.82
Elixhauser Comorbidity Index	4.0 (2.0)	3.9 (1.9)	3.9 (2.0)	.27
LITA use	92.5	91.5	91.6	.21
Mortality rate	1.5	1.2	0.8	<.001
Adverse outcome rate	30.7	25.6	14.2	<.001
Costs	48,000 (39,700-60,300)	32,800 (26,200-42,500)	29,600 (24,400-36,000)	<.001
Length of stay	6 (5-8)	6 (5-8)	6 (4-7)	<.001
Annual cardiac surgery volume	261 (166-490)	423 (226-828)	491 (288-815)	<.001
Safety-net status	30.9	18.1	13.7	<.001
Teaching hospital	65.0	71.4	72.6	.02
AVR				
Percentage of centers	20.5	48.9	30.6	
Age	64.9 (13.0)	65.0 (12.1)	65.0 (11.9)	.68
Elixhauser Comorbidity Index	4.9 (2.1)	4.9 (1.9)	5.0 (1.9)	.25
Mortality rate	1.8	1.6	1.1	<.001
Adverse outcome rate	28.1	24.5	13.5	<.001
Costs	53,500 (44,400-67,600)	39,200 (31,500-51,700)	34,400 (28,900-41,900)	<.001
Length of stay	6 (5-8)	6 (4-7)	5 (4-7)	<.001
Annual cardiac surgery volume	419 (262-721)	562 (343-943)	624 (399-1084)	<.001
Safety-net status	26.2	16.0	10.7	<.001
Teaching hospital	72.0	80.0	80.7	.02

Low-value hospitals were those with low quality and high costs, whereas high-value hospitals were those with high quality and low costs. Intermediate-value hospitals included both those with low quality and low costs or those with high quality and high costs. Continuous variables reported as median and IQR except age and Elixhauser Index (mean, standard deviation), and categorical variables are reported as percentage. *P* values reported for comparison of low-value versus high-value centers. *CABG*, Coronary artery bypass grafting; *LITA*, left internal thoracic artery; *AVR*, aortic valve replacement.