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Case-volume, quality of care, and care efficiency in coronary artery bypass surgery

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Abstract

Background—How case volume and quality of care relate to hospital costs or length of stay are important questions as we seek to improve the value of healthcare.

Methods—Observational study of patients 18 or older who underwent coronary artery bypass grafting surgery in a network of US hospitals. Case volumes were estimated using our dataset. Quality was assessed by whether recommended medications and services were not received in ideal patients, as well as the overall number of measures missed. We used multivariable hierarchical models to estimate the effects of case volume and quality on hospital cost and length of stay.

Results—The majority of hospitals (51%) and physicians (78%) were lowest volume providers and only 18% of patients received all quality of care measures. Median length of stay was 7 days (interquartile range [IQR] 6 to 11 days), and median costs were $25140 (IQR $19677, $33121). In analyses adjusted for patient and site characteristics, lowest volume hospitals had 19.8% higher costs (95% CI 3.9% to 38% higher); adjusting for care quality did not eliminate differences in costs. Low surgeon volume was also associated with higher costs, though less strongly (3.1% higher costs, 95% CI 0.6% to 5.6% higher). Individual quality measures had inconsistent associations with costs or length of stay, but patients who had no quality measures missed had much lower length of stay and costs than those who missed even one.

Conclusions—Avoiding lowest volume hospitals and maximizing quality are separate approaches to improving healthcare efficiency through reducing costs of coronary bypass surgery.

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Introduction

Improving quality and reducing costs of care are crucial goals for US healthcare. One approach to improving outcomes is to promote care at higher volume sites[1–3], while other efforts have focused on improving adherence to quality of care measures[4].

Few data exist to describe the interaction between quality, case volume, and costs or length of stay, even as we seek to constrain costs and increase the efficiency – and value – of healthcare[5]. We have recently published findings suggesting that overall quality of care markedly influences patient outcomes following cardiac surgery[6], but higher volume has a weaker association with outcomes. These findings suggest that care quality may be a more important potential driver for value improvement based on outcome improvement regardless of case volume. However, care value is improved if outcomes are unchanged but use of resources falls.

Understanding whether case volume or quality reduce costs or length of stay has implications for health systems. If higher case volume was independently associated with lower costs or length of stay this would provide a rationale for investing in infrastructure required to maximize access to high volume hospitals or surgeons[3]. On the other hand, a positive relationship between higher quality and efficiency might provide justification for investments in infrastructure needed to create high-reliability systems of care[7].

To explore these issues, we analyzed data collected from adults undergoing coronary artery bypass surgery in a sample of United States hospitals. Using these data, we first examined the relationship between surgeon and hospital volume, and costs and length of stay. We then examined the relationships between case volume and costs and length of stay after adjusting for individual measures of care quality, as well as overall care quality.

Methods

Sites and subjects

Our data were collected on 81,289 patients cared for by 1,451 physicians at 164 hospitals participating in Perspective (Premier Inc., Charlotte, North Carolina), a voluntary, fee-supported database developed for measuring quality and health care utilization and which we have used in previous research[6, 8–10].

In addition to standard hospital discharge file data, Perspective contains a date-stamped log of all materials (e.g. serial compression devices used to prevent venous thromboembolism), and medications (e.g. beta-blockers) charged for during hospitalization. Perspective charge data are collected electronically from participating sites and audited regularly to ensure data validity. Perspective sites are representative of the US hospital population and perform similarly on publicly reported quality measures[11].

Patients in our analysis were admitted between 10/1/2003 and 9/1/2005, were 18 years of age or older, and had coronary bypass grafting (CABG) as their principal procedure as defined by International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM) code. The institutional review board at UCSF approved our study.

Data

In addition to patient age, sex, race or ethnicity, martial status, insurance information, and principal diagnosis, we classified comorbidities using the method of Elixhauser[12]. Data regarding length of stay and hospital costs were obtained from the Perspective discharge file. Three-quarters of hospitals that participate in Perspective report costs derived from their cost accounting systems, while others provide costs using Medicare cost to charge ratios. In addition, the database contains information about hospital size, teaching status, and location.

Definition of volume measures

Because some hospitals did not contribute data for the entire study period, we estimated the annual case volume by dividing each hospital's or physician's observed patient count by the total number of months that the hospital or physician contributed patients to the dataset, and then multiplying this number by twelve. These "annualized" volumes were then divided into quartiles as has been done in previous work[1, 13–15].

Definition of missed quality measures

Because diagnosis codes cannot reliably distinguish between complications and preexisting conditions, we measured the proportion of ideal candidates for each care process who failed to receive them – a missed quality measure. We developed these measures by translating recommendations from the Surgical Care Improvement Project (SCIP)[4] and American Heart Association/American College of Cardiologists Guidelines[16] into a series of dichotomous quality measures[6]. These measures, many of which are also included in recently published recommendations[17], included whether antimicrobials were used to prevent surgical site infection on the operative day, whether that antimicrobial was discontinued in 48 hours, whether serial compression devices were used to prevent venous thromboembolism in the 2 days following surgery, and whether aspirin, beta-blockers, or statin lipid-lowering drugs were administered in the two days following surgery. Other measures (such as those related glucose control) cannot be detected in Perspective data and were not targeted.

In order to provide a more sensitive measure of system-level ability to provide reliable care[18], we also counted the total number of individual quality measures missed during hospitalization.

Analysis

We first described study patients and hospitals using univariable methods. Mixed effect models were used to account for clustering of patients within physicians and within hospitals. Length of stay and costs were log-transformed to account for skew and to stabilize variance of residuals in multivariable models. Beta estimates and 95% confidence intervals were converted to percent differences using the formula 100*(EXP(estimate)−1).

Models were constructed using manual variable selection methods; volume and quality measures were entered manually, while additional covariaates (confounding factors) were selected for inclusion if they were associated with the outcome at $p<0.01$, if including them changed estimates for the primary predictors by more than 10%, or for face validity. Models of length of stay were adjusted for age, gender, race, insurance type, DRG severity of illness score, admission status, geographic area, comorbid illnesses (CHF, valvular disease, hypertension, paralysis, neurological disorders, COPD, diabetes with complications, renal failure, obesity, weight loss, electrolyte disorder, blood loss, deficiency anemia, alcohol or drug abuse, psychoses, depression) and whether or not an internal mammary graft was used during the procedure. Models of costs included age, gender, race, insurance type, admission status, number of beds, severity score, comorbid illnesses (CHF, valvular disease, hypertension, paralysis, neurological disorders, diabetes, diabetes with complications, renal failure, coagulopathy, weight loss, electrolyte disorder, blood loss, deficiency anemia, psychoses, alcohol abuse), whether or not an internal mammary graft was used during the procedure, source of costs (actual costs or cost-to-charge ratio).

Multivariable models first assessed the associations between hospital volume, physician volume, individual (or overall) quality measures as single predictors in individual models for each predictor, after adjusting only for patient and hospital confounding factors. In order to determine the degree to which volume effects and missed quality effects were related, our next models included our volume and individual quality measures in one fully adjusted model; a separate fully-adjusted model include volume and overall quality measures.

To assess potential collinearity between our key predictors (hospital volume, physician volume, and quality measures) we examined Pearson correlations between them. In view of the large number of observations, these analyses gave no evidence for collinearity (all correlations <0.3). In addition, we examined models including only subsets of these variables, and found no evidence for instability. All analyses were carried out using SAS version 9.1 (SAS Institute, Inc. Cary, NC).

Results

Patient characteristics (Table1)

81,289 patients underwent coronary artery bypass grafting at one of our study sites between 10/1/2003 and 9/30/2005. Mean age of patients was 65.0 years (standard deviation 10.9 years), and 72% were men. Most were white, married, and had Medicare insurance. The most common comorbidities in our cohort were hypertension (72%), diabetes without chronic complications (31%), and chronic obstructive pulmonary disease (23%). Most received care at nonteaching hospitals in the South. Median length of stay was 7 days (interquartile range [IQR] 6 to 11 days), and median costs were $25140 (IQR $19677, $33121).

Quality and volume measures (Technical Appendix 2)

We have published details of our quality measures and their characteristics in our study population previously[6]. Most patients (77%) did not have charges for serial compression devices, but few did not receive a beta-blocker (22%), or had no antimicrobial charges on the operative day (6%). Very few patients (12%) had no missed quality measures and 44% missed 3 or more. The majority of hospitals and physicians in our cohort were lowest-volume providers (Technical Appendix 3). Hospital volume ranged from 112 per year (IQR 80, 154) in the lowest quartile of volume to 644 (IQR 536, 754) in the highest quartile.

Physician volume ranged from 12 per year (IQR 11, 18) in the lowest quartile to 155 (IQR 141, 173) in the highest quartile. The proportion of patients with 1 or more missed quality measure was slightly higher as volume rose.

Associations between volume, individual quality measures, and care efficiency (Table 2)

Lowest volume hospitals had substantially higher costs but similar length of stay compared to other hospitals; these differences persisted whether or not volume measures were adjusted for patient factors alone or for individual care quality measures. Physician volume was not associated with length of stay in individual models adjusting for clinical factors alone or clinical factors and quality measures. However, lowest volume physicians had higher unadjusted costs, differences which were not eliminated after adjusting for clinical factors, or clinical factors and individual quality measures.

Of individual quality measures, a number were associated with unadjusted differences in length of stay, many of which were altered substantially by adjusting for clinical risk factors. Addition of volume as an additional adjuster in our models did not appreciably alter the adjusted associations between individual quality measures and length of stay or costs, suggesting that the associations between volume and resource use, and quality and resource use were independent of each other. In both individual and fully-adjusted models, receiving antimicrobial prophylaxis was associated with longer length of stay but not costs, and receipt of an antimicrobial after the first 48 hours, and no use of serial compression devices for prevention of venous thromboembolism were associated with substantially longer length of stay in individual or fully-adjusted models.

Associations between volume, overall care quality, and care efficiency (Table 3)

Associations between hospital and physician volume and costs or length of stay adjusting for overall care quality were essentially identical to those adjusting for individual quality measures, suggesting independence of the association between overall quality's and volume measures' associations with length of stay or costs. However, missing any quality measures was strongly associated with higher adjusted costs and length of stay, whether or not volume measures were included.

Secondary analyses

In preplanned analyses, we tested for statistical interactions between case volume measures and overall quality. In these analyses, we noted statistically significant interactions between hospital volume, overall quality and length of stay and costs, suggesting small incremental benefits of having higher quality care at a higher volume hospital or from a busier surgeon.

Discussion

In this large cohort of patients undergoing coronary artery bypass surgery, hospitals with the lowest operative volumes tended to have higher costs but similar length of stay compared to high volume hospitals; a weak association between low-volume surgeons and higher costs was also observed. These findings persisted even after adjusting for observable patient characteristics, and after adjustment for whether recommended care processes were missed.

In contrast, missing one or more quality measures was strongly associated with higher costs and longer length of stay essentially independent of the volume of the surgeon or hospital. These findings suggest that efficiency can be improved in coronary bypass surgery by advising patients to avoid low volume providers, while encouraging investment in improving the reliability of hospital care.

The relationship between higher volume of care and better outcomes of cardiac surgery is well established[14, 19–21]. Because cost savings attributable to volume-based referrals has generally been modest (less than 5%)[22], the volume-based referrals have been thought to improve value largely based on improved clinical outcomes[22–24]. Our data suggest the bulk of savings would result if patients avoided low volume hospitals (as high as 16% savings if quality is not taken into account), and that little savings would result from a shift of patients from second highest to highest-volume centers (or third highest to highest). In our study, patients living near a lowest volume hospital (about ½ of our hospitals) could choose from any of the 79 higher volume hospitals rather than just the 19 in the highest quartile, saving between $85 and 171 million dollars per year.

Our results also suggest promotion of adherence to process measures is a separate approach for improving care efficiency in cardiac surgery, but that maximizing overall rather than individual measure performance is critical. While worse performance on individual measures in our study was inconsistently associated with costs or length of stay, and had minimal impact on the association between volume and outcomes, the number of care processes missed was a strong and consistent predictor of longer length of stay and costs. Differences in the associations between costs and length of stay between individual and overall quality measures are important because overall quality and all-or-none measurement are thought to be a more valid measure of a systems' ability to deliver all aspects of care reliably to individual patients[18]. Our data suggests that overall system performance in quality may have a direct effect on patient care efficiency, and provide another rationale for 'all or none' quality measurement as a method to compel widespread improvements in care[25], or at the least efforts to standardize care.[26] Importantly, our overall quality measure was strongly associated with cost reductions even though it included individual measures with weak (or reversed) associations with resource use. Refining this listing to just those measures or reweighting them (another proposed method for maximizing impact of quality reporting) is likely to only magnify the importance of overall quality in identifying optimal systems

Our study has a number of limitations. First, because we used administrative data from the inpatient stay only, we cannot easily distinguish complications from preexisting disease. However, we constructed our quality measures to focus on patients who had no documented contraindications, and we did not use comorbidities to define outcomes. Our quality measures focus primarily on inpatient medications, and cannot not distinguish continuation of home medications and initiation of medications in hospital. This factor may be influencing the associations between resource use and aspirin, beta-blockers, and statins, but is less likely to affect antimicrobial or serial compression device use. In addition, our quality measures were collected from electronic billing systems rather than chart abstraction, and have not been validated in a scientific study. However, because Premier's business model focuses on provision of accurate benchmarking data to their members, all charge and diagnosis data are regularly audited for accuracy. Our cost data include those incurred during hospitalization, and may miss costs of post-hospital care. Because we did not have these data available, our cost models did not adjust for differences in local wage index or share of low income patients. As an observational study, the results are subject to biases related to nonrandom assignment of patients to receive medications or devices, as well as documentation biases described. However, our results were robust even after adjusting for all available patient-level and hospital-level data associated with our measures of resource use. Although Premier hospitals are similar to other US centers in terms of size, teaching status, and location, it is possible that they differ from non-Premier sites in subtle ways not captured in our data. Having said this, previous research in Premier sites has produced results useful to policymakers. Additionally, while we constructed our volume measures to be consistent with those employed in previous work, it is possible that they do not adequately represent expertise accrued if low volume surgeons were performing other complex cardiovascular surgeries frequently, or performed surgeries outside of our Premier hospitals. Finally, it is likely that some surgeries in our dataset were at least partially performed by fellows or residents. To address this potential concern, we did adjust for whether the surgery was performed at a teaching hospital.

Our results add to the literature by suggesting that one strategy to enhance the value of CABG is to direct patients away from lower volume surgeons and hospitals to institution and providers who perform the procedure regularly. However, our findings also suggest that quality improvement efforts focused on improving adherence to process measures as an all-or-none metric will also have beneficial effects on the value of care through reductions in cost and length of stay. Healthcare reform efforts aimed at improving the value of care in the United States should examine whether strategies which incentivize systems to provide maximal care quality would be useful in this effort.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Dr Auerbach had full access to all of the data in the study

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Technical Appendix 1: Variables included in multivariable models

As described in Methods, we built multivariable hierarchical models (permitting clustering at the physician and hospital level) by selecting covariates which demonstrated an association with length of stay or costs at $p<0.05$, or to maintain face validity of the model.

LOS models adjusted for age, gender, race, insurance type, DRG severity of illness score, admission status, geographic area, comorbid illnesses (CHF, valvular disease, hypertension, paralysis, neurological disorders, COPD, diabetes with complications, renal failure, obesity, weight loss, electrolyte disorder, blood loss, deficiency anemia, alcohol or drug abuse, psychoses, depression) and whether or not an internal mammary graft was used during the procedure.

COST models adjusted for age, gender, race, insurance type, admission status, number of beds, severity score, comorbid illnesses (CHF, valvular disease, hypertension, paralysis, neurological disorders, diabetes, diabetes with complications, renal failure, coagulopathy, weight loss, electrolyte disorder, blood loss, deficiency anemia, psychoses, alcohol abuse), whether or not an internal mammary graft was used during the procedure, and source of costs (actual costs or cost-to-charge ratio).

Table 1

Characteristics of patients (n=81289)

	Value
Patient age (Mean, SD)	65.0 (10.9)
Male (n, %)	58398 (72%)
Race (n, %)	
White	61621 (76%)
Other	11434 (14%)
Black	5500 (7%)
Hispanic	2734 (3%)
Marital status (n, %)	
Married	51094 (63%)
Single	8646 (11%)
Widowed	8439 (10%)
Other	6899 (8%)
Divorced	6211 (8%)
Primary payor (n, %)	
Medicare	43164 (53%)
Managed Care	21987 (27%)
Indemnity	8177 (10%)
Medicaid	3614 (4%)
Uninsured	2575 (3%)
Other	1057 (1%)
Capitated	715 (1%)
Discharge status (n, %)	
To home	43588 (54%)
Home health care	24444 (30%)
Skilled nursing facility	8028 (10%)
Rehabilitation	2574 (3%)
Death in hospital	1738 (2%)
Transfer	399 (0.5%)
Other	443 (0.5%)
Hospice	75 (0.1%)
Any ICU charges (n, %)	60392 (74%)
APR™ DRG severity (n, %)	
1	8702 (11%)
2	40789 (50%)
3	23747 (29%)
4	8051 (10%)
APR™ DRG risk of mortality (n, %)	
1	27388 (34%)
2	32065 (39%)

	Value
3	15883 (20%)
4	5953 (7%)
Comorbidities (n, %)	
Hypertension	58492 (72%)
Diabetes w/o chronic complications	25423 (31%)
Chronic pulmonary disease	18974 (23%)
Fluid & electrolyte disorders	12815 (16%)
Deficiency anemia	11981 (15%)
Obesity	11636 (14%)
Peripheral vascular disease	11034 (14%)
Coagulopathy	6335 (8%)
Hypothyroidism	6038 (7%)
Diabetes w/chronic complications	4623 (6%)
Renal failure	4308 (5%)
Depression	3781 (5%)
Other neurological disorders	1882 (2%)
Alcohol abuse	1663 (2%)
Rheumatoid arthritis or collagen vascular disease	1191 (1%)
Psychoses	1006 (1%)
Paralysis	949 (1%)
Solid tumor w/o metastasis	918 (1%)
Congestive Heart Failure	443 (0.5%)
Internal mammary graft not used (n, %)	9938 (12%)
Site of care	
Teaching hospital (n, %)	30295 (37%)
Urban hospital	76079 (94%)
Rural hospital	5210 (6%)
Region (n, %)	
South	46768 (58%)
Midwest	14082 (17%)
Northeast	11201 (14%)
West	9237 (11%)
Number of beds (n, %)	
100–199	2952 (4%)
200–299	7469 (9%)
300–399	16678 (21%)
400–499	13373 (16%
>=500	40817 (50%)
Resource use	
Length of stay (Median, IQR)	7 days (6, 11)
Total costs (Median, IQR)	$25,140 ($19,677, $33,121)

Table 2

Association between volume, individual quality measures, and resource use

Value	Length of stay			Costs		
	Unadjusted % difference (95%CI)	Adjusted* % difference (95% CI)	Adjusted** % difference (95% CI)	Unadjusted % difference (95%CI)	Adjusted* % difference	Adjusted** % difference (95% CI)
Hospital volume						
1st quartile	−7.0 (−8.0, −6.1) P<0.0001	1.1 (−5.9, 8.7) P=0.7508	1.6 (−5.1, 8.8) P=0.6473	13.2 (12.2, 14.1) P<0.0001	19.8 (3.9, 38.0) P=0.0126	18.3 (2.0, 36.3) P=0.0196
2nd quartile	−7.6 (−8.6, −6.7) P<0.0001	0.9 (−7.2, 7.9) P=0.9758	0.2 (−6.7, 7.5) P=0.9627	−6.9 (−7.7, −6.0) P<0.0001	−0.2 (−14.1, 16.0) P=0.9764	−1.0 (−14.7, 15.0) 0.8972
3rd quartile	−7.3 (−8.2, −6.7) P<0.0001	−1.6 (−9.1, 6.6) P=0.6978	−0.7 (−7.9, 7.0) P=0.8447	−4.4 (−5.2, −3.5) P<0.0001	0.3 (−14.4, 17.5) P=0.9728	0.5 (−14.2, 17.7) P=0.9528
4th quartile	Referent	Referent	Referent	Referent	Referent	Referent
Physician volume						
1st quartile	0.4 (−0.7, 1.4) P=0.4897	1.1 (−1.1, 3.4) P=0.3082	0.9 (−1.3, 3.2) P=0.4365	10.7 (9.8, 11.7) P<0.0001	3.4 (0.9, 6.0) P=0.0086	3.1 (0.6, 5.6) 0.0148
2nd quartile	−3.9 (−4.9, −3.0) P<0.0001	−1.0 (−3.3, 1.3) P=0.3958	−1.2 (−3.5, 1.2) P=0.3285	3.5 (2.5, 4.4) P<0.0001	1.1 (−1.6, 3.9) P=0.4320	1.0 (−1.7, 3.7) P=0.4831
3rd quartile	0.9 (−0.1, 1.9) P=0.0778	0.6 (−1.7, 3.0) P=0.5790	0.9 (−1.4, 3.3) P=0.4406	−0.6 (−1.4, 0.3) P=0.2155	−0.5, −3.2, 2.2) P=0.7031	−0.3 (−2.9, 2.3) P=0.8027
4th quartile	Referent	Referent	Referent	Referent	Referent	Referent
Measure						
Serial compression devices not used	−1.3 (−2.2, −0.5) P=0.0019	12.9 (11.7, 14.1) P<0.0001	12.5 (11.3, 13.7) P<0.0001	−3.8 (−4.5, −3.1) P<0.0001	6.0 (5.1, 6.9) P<0.0001	6.0 (5.1, 6.9) P<0.0001
Statin not administered	−9.9 (−10.6, −9.2) <0.0001	−9.8 (−10.4, −9.1) P<0.0001	−9.8 (−10.5, −9.2) P<0.0001	−7.9 (−8.4, −7.3) P<0.0001	−3.6 (−4.1, −3.1) P<0.0001	−3.6 (−4.1, −3.1) P<0.0001
Antibiotics not discontinued	44.9 (43.9, 45.8) P<0.0001	23.1 (22.4,23.8) P<0.0001	23.1 (22.4, 23.9) P<0.0001	32.2 (31.4, 33.0) P<0.0001	14.7 (14.2, 15.2) P<0.0001	14.7 (14.2, 15.2) P<0.0001
Aspirin not administered	−14.7 (−15.4, −14.1) P<0.0001	−9.8 (−10.4, −9.1) P<0.0001	−9.1 (−9.7, −8.4) P<0.0001	−9.5 (−10.2, −9.0) P<0.0001	−4.5 (−5.0, −4.0) P<0.0001	−4.5 (−5.0, −4.0) P<0.0001
Beta-blocker not administered	−9.6 (−10.4, −8.8) P<0.0001	−1.1 (−1.8, −0.4) P=0.0006	−1.2 (−1.9, −0.5) P=0.0006	−5.5 (−6.2, −4.8) P<0.0001	0.4 (−0.1, 1.0) P=0.1346	0.4 (−0.1, 1.0) P=0.1363
Prophylactic antibiotics not administered	2.1 (0.6, 3.6) P=0.0060	5.2 (3.6, 6.9) P<0.0001	5.1 (3.4, 6.8) P<0.0001	3.1 (1.7, 4.4) P<0.0001	0.1 (−1.1, 1.3) P=0.9018	0.1 (−1.1, 1.3) P=0.9158

* Results of 3 models examining volume and quality measures separately, and adjusting for covariates described in Methods.

** Results of single model examining volume measures and quality, and adjusting for covariates described in Methods

Table 3

Association between volume, overall quality, and care efficiency

Value	Length of stay			Costs		
	Unadjusted % difference (95%CI)	Adjusted* % difference (95% CI)	Adjusted** % difference (95% CI)	Unadjusted % difference (95%CI)	Adjusted* % difference	Adjusted** % difference (95% CI)
Hospital volume						
1st quartile	See Table 2		1.3 (−5.7, 8.8) P=0.7155	See Table 2		18.3 (2.6, 36.5) P=0.0207
2nd quartile			0.3 (−6.8, 8.0) P=0.9270			−5.4 (−14.5, 15.7) P=0.9437
3rd quartile			−1.2 (−8.6, 6.8) P=0.7685			0.4 (−14.4, 17.8) P=0.9578
4th quartile			Referent			Referent
Surgeon volume						
1st quartile	See Table 2		1.2 (−1.0, 3.4) P=0.2838	See Table 2		3.3 (0.8, 5.8) P=0.0104
2nd quartile			−0.9 (−3.1, 1.5) P=0.4665			1.2 (−1.5, 4.0) P=0.3851
3rd quartile			0.7 (−1.6, 3.0) P=0.5478			−0.5 (−3.1, 2.3) P=0.7395
4th quartile			Referent			Referent
Number of missed quality measures						
None missed	Referent	Referent	Referent	Referent	Referent	Referent
1 missed	21.5 (19.9, 23.1) P<0.0001	11.9 (10.8, 13.1) P<0.0001	11.9 (10.8, 13.1) P<0.0001	13.7 (12.4, 15.0) P<0.0001	7.8 (6.9, 8.6) P<0.0001	7.8 (6.9, 8.6) P<0.0001
2 missed	12.3 (10.9, 13.7) P<0.0001	8.1 (6.9, 9.3) P<0.0001	8.1 (6.9, 9.3) P<0.0001	5.3 (4.1, 6.4) P<0.0001	6.7 (5.8, 7.6) P<0.0001	6.7 (5.8, 7.6) P<0.0001
3 missed	8.0 (6.7, 9.4) P<0.0001	5.0 (3.8, 6.2) P<0.0001	5.0 (3.8, 6.1) P<0.0001	4.6 (3.5, 5.8) P<0.0001	6.7 (5.8, 7.6) P<0.0001	6.7 (5.8, 7.6) P<0.0001
4 or more	13.0 (11.5, 14.5) P<0.0001	9.5 (8.2, 10.8) P<0.0001	9.5 (8.2, 10.8) P<0.0001	9.6 (8.3, 10.9) P<0.0001	10.1 (9.1, 11.1) P<0.0001	10.1 (9.1, 11.1) P<0.0001

* Results of 3 models examining volume and quality measures separately, and adjusting for covariates described in Methods.

** Results of single model examining volume measures and quality, and adjusting for covariates described in Methods.