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Shop for Quality or Volume? Volume, Quality, and Outcomes of Coronary Artery Bypass Surgery

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Background: Care from high-volume centers or surgeons has been associated with lower mortality rates in coronary artery bypass surgery, but how volume and quality of care relate to each other is not well understood.

Objective: To determine how volume and differences in quality of care influence outcomes after coronary artery bypass surgery.

Design: Observational cohort.

Setting: 164 hospitals in the United States.

Patients: 81 289 patients 18 years or older who had coronary artery bypass grafting from 1 October 2003 to 1 September 2005.

Measurements: Hospital and surgeon case volumes were estimated by using a data set. Quality measures were defined by whether patients received specific medications and by counting the number of measures missed. Hierarchical models were used to estimate effects of volume and quality on death and readmission up to 30 days.

Results: After adjustment for clinical factors, lowest surgeon volume and highest hospital volume were associated with higher mortality rates and lower readmission risk, respectively. Patients who did not receive aspirin (odds ratio, 1.89 [95% CI, 1.65 to 2.16) or β-blockers (odds ratio, 1.29 [CI, 1.12 to 1.49]) had higher odds for death, after adjustment for clinical risk factors and case volume. Adjustment for individual quality measures did not alter associations between volume and readmission or death. However, if no quality measures were missed, mortality rates at the lowest-volume centers (adjusted mortality rate, 1.05% [CI, 0.81% to 1.29%]) and highest-volume centers (adjusted mortality rate, 0.98% [CI, 0.72% to 1.25%]) were similar.

Limitation: Because administrative data were used, the quality measures may not replicate measures collected through chart abstraction.

Conclusion: Maximizing adherence to quality measures is associated with improved mortality rates, independent of hospital or surgeon volume.

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The volume–outcome relationship—the association between improved surgical outcomes at sites that (or from surgeons who) frequently perform a procedure—has become the focus of payer-driven proposals to regionalize care (1). At the same time, many national efforts are focusing on improving surgical care by maximizing adherence to quality-of-care measures (2).

Focus on quality measures and volume benchmarks have important implications for patients. If quality of care is the most important factor to be weighed when choosing a hospital for surgery, patients can choose a high- or low-volume center as long as these centers have equivalent quality scores. However, if high-volume centers maintain an outcome advantage regardless of quality-of-care measures, patients should travel to a regional referral center (3). Limited previous research suggests that once volume is accounted for, quality may have little effect on outcome (4).

See also:

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However, these studies did not use measures of quality that replicated national recommendations.

To explore whether the "volume effect" is explained by quality of care and which (volume or quality) is more powerfully associated with patient outcomes, we analyzed data collected from a sample of U.S. hospitals for adults undergoing coronary artery bypass surgery. Using these data, we first examined the relationship among patient outcomes, hospital case volume, surgeon case volume, and individual quality measures after accounting for clinical risk factors. We then tested how quality and volume affect each other. Finally, we examined whether meeting all or just some quality measures influenced death and calculated estimated mortality rates.

METHODS

Setting and Patients

We collected data on 81 289 patients cared for by 1451 surgeons at 164 hospitals participating in Perspective (Premier, Charlotte, North Carolina), a voluntary, fee-supported database developed to measure quality and health care utilization, which we have used in previous research (5–7).

In addition to standard hospital discharge file data, Perspective contains a date-stamped log of all materials (for example, serial compression devices used to prevent venous thromboembolism) and medications (for example, β-blockers) charged for during hospitalization. Perspective charge data are collected electronically from participating sites and audited regularly as part of Premier efforts to ensure data validity.

Perspective sites generally represent the U.S. hospital population because they are predominantly small to midsize, nonteaching facilities that serve a largely urban patient population. Perspective sites also have similar performance on publicly reported quality measures.

Patients in our analysis were admitted from 1 October 2003 to 1 September 2005, were 18 years or older, and had coronary artery bypass grafting as their principal procedure (defined by International Classification of Diseases, Ninth Revision, Clinical Modification code). The institutional review board at the University of California, San Francisco, approved our study.

Data

In addition to patient age, sex, race or ethnicity, insurance information, and principal diagnosis, we classified comorbid conditions by using the Elixhauser method (8). We obtained data about inhospital deaths and readmission at the index hospital 30 days from the Perspective discharge file. In addition, the database contained information about hospital size, teaching status, and location.

Definition of Volume Measures

Because some hospitals in our cohort did not contribute data for the entire study period, we estimated the annual case volume by dividing the observed patient count for each hospital or surgeon by the total number of months that the hospital or surgeon contributed patients to the data set. We then divided these "annualized" volumes into quartiles, as done in previous work (4, 9–11).

Context

High-volume surgeons and hospitals tend to have better outcomes of coronary artery bypass surgery. The role of quality of care in this relationship is not known.

Contribution

The authors studied 81 289 patients with coronary artery bypass surgery in 164 hospitals. Low-volume surgeons, but not hospitals, had higher 30-day adjusted mortality rates. Individual measures of quality were inconsistently related to outcomes, but regardless of hospital or surgeon volume, more missed quality measures were associated with worse mortality rates. Mortality rates were the same when no quality measures were missed.

Caution

Reliance on administrative data limits the ability to adjust for confounders.

Implication

Consistent performance on measures of quality seems more important than volume of surgery.

—The Editors

Definition of Missed Quality Measures

Using charge data, we translated recommendations from the Surgical Care Improvement Project (2) and the American Heart Association/American College of Cardiologists guidelines for secondary prevention of coronary artery disease among patients undergoing coronary artery bypass surgery (12) into a series of dichotomous quality measures (**Table 1**). These measures, many of which were also discussed in recently published recommendations (13),

Table 1. **Definitions and Descriptive Statistics for Quality Measures**

Quality Measure	Definition	Exclusion Criteria	Total Patients, *n (%)*
No use of serial compression devices in the first 2 days	No charges for serial compression devices 2 days after surgery	None	62 231 (77)
No statins in the first 2 days after surgery	No charge for "statin" lipid-lowering drug 2 days after surgery (e.g., lovastatin, pravastatin, atorvastatin)	Principal or secondary diagnosis code for liver disease, cirrhosis, myopathy	45 579 (56)
Inappropriate choice of prophylactic antimicrobials	Use of antimicrobial not on approved list	Principal or secondary diagnosis code for preexisting infection, as defined by SCIP	29 486 (36)
No prophylactic antimicrobials	No charges for antimicrobials on approved list	Principal or secondary diagnosis code for preexisting infection, as defined by SCIP	5167 (6)
No aspirin in the first 2 days after surgery	No charge for aspirin 2 days after surgery	Principal or secondary diagnosis code for cerebrovascular hemorrhage, gastrointestinal bleeding, factor deficiencies, platelet disorders	28 183 (35)
No β-blockers in the first 2 days after surgery	No charges for adrenergic blocking agents 2 days after surgery	Principal or secondary diagnosis code for conduction system disorder, hypotension, sepsis, congestive heart failure, or bradycardia	15 998 (20)

SCIP = Surgical Care Improvement Project.

included whether antimicrobials were used to prevent surgical site infection on the operative day; whether that antimicrobial was appropriate; whether serial compression devices were used to prevent venous thromboembolism on the operative day; and whether aspirin, β-blockers, or statin lipid-lowering drugs were administered in the 2 days after surgery. We did not target other Surgical Care Improvement Project measures (such as those related to hair removal, glucose level control, and discontinuing antimicrobials at 48 hours) because they could not be detected in Perspective data.

Because inpatient diagnosis codes cannot reliably distinguish between complications and preexisting conditions (14–16), we measured the proportion of ideal candidates for each care process who did not receive them—a missed quality measure. For example, we considered β-blocker use "missed" if a patient did not receive the drug and did not have an International Classification of Diseases, Ninth Revision, code for principal or secondary diagnosis of hypotension, heart block, or congestive heart failure noted in the patient's record. To provide a more sensitive measure of system-level ability for providing reliable care (17), we also counted the number of quality measures missed during hospitalization.

Statistical Analysis

We first described study patients and hospitals by using univariable methods. We then used multivariable alternating logistic models (SAS PROC GENMOD, SAS Institute, Cary, North Carolina) (15) to account for clustering of effects attributable to surgeons and hospitals who had more than 1 patient in our data set; results are reported as odds ratios with 95% CIs. We constructed models by using a combination of automated and manual variable selection methods. We entered volume and quality measures manually, whereas we selected additional covariates (confounding factors) for inclusion if they were associated with the outcome ($P < 0.01$), if including them changed estimates for the primary predictors by more than 10%, or for face validity.

The goal of our analysis was to determine whether our key predictors—hospital volume, surgeon volume, individual quality measures, or overall quality of care (the total number of individual measures missed)—were associated with our key outcomes (death and readmission) after adjustment for confounding patient- or site-related factors (such as patient comorbid condition or hospital teaching status). To achieve this goal, we did our analyses in stages. First, we tested individual predictors in models singly and adjusted only for confounding patient and site factors. In our next modeling stage, we assessed whether quality measures mediated effects of hospital or surgeon volume by constructing models that adjusted for hospital volume, surgeon volume, quality measures, and confounding factors. We then compared our first and second set of models for attenuation of the adjusted odds ratios toward 1.0 to determine mediation of effects related to volume or quality of care (individual quality measures or the overall quality measure). Finally, to better display the absolute differences in deaths attributable to volume and overall quality, we calculated adjusted mortality rates.

To assess for collinearity among our key predictors (hospital volume, surgeon volume, and quality measures), we examined Pearson correlations among them. These analyses gave little evidence for collinearity (all correlations <0.3). In addition, we examined models including only subsets of these variables and found no evidence for instability. Finally, we checked for interactions between volume and quality measures and found no statistically significant modification of effects. We used SAS, version 9.1 (SAS Institute), for all analyses.

Role of the Funding Source

The study was funded by California HealthCare Foundation. The funding source had no role in the design, conduct, execution of the study, preparation of the manuscript, or decision to submit this article for publication.

RESULTS

Table 2 shows patient characteristics: 81 289 patients had coronary artery bypass grafting at 1 of the study sites from 1 October 2003 to 1 September 2005. The mean age of patients was 65.0 years (SD, 10.9), and 72% were men. Most were white, were married, and had Medicare insurance. The most common comorbid conditions in our cohort were hypertension (72%), diabetes without chronic complications (31%), and chronic obstructive pulmonary disease (23%). Most patients received care at nonteaching hospitals in the southern United States. Two percent (1825 of 81 289) of patients died, and 11% were readmitted in 30 days.

Quality Measures

Table 1 shows the definition of individual quality measures. The proportion of patients for whom individual quality measures were missed varied widely. Most (77%) did not have charges for serial compression devices, but few (20%) did not receive a β-blocker, and few (6%) had no antimicrobial charges on the operative day. Few (12%) patients had no missed quality measures, and 44% missed 3 or more. Among patients with 1 to 2 missed care measures, 70% received no serial compression device, 33% received no statins, 8% received no aspirin, 29% received inappropriate antibiotics, and 14% received no β-blocker.

Table 3 shows hospital and surgeon volume and rates of missed quality measures. Most hospitals (85 of 164 [51%]) and surgeons (1143 of 1451 [78%]) were lowest-volume providers. Hospital volume ranged from 142 patients per year (interquartile range [IQR], 104 to 175) in the lowest-volume quartile to 744 (IQR, 548 to 1166) in the highest-volume quartile. Surgeon volume ranged from

Table 2. **Patient Characteristics**

Characteristic	Total Patients (n = 81 289)
Mean age (SD), *y*	65.0 (10.9)
Men, *n (%)*	58 398 (72)
Race, *n (%)*	
White	61 621 (76)
Other	11 434 (14)
Black	5500 (7)
Hispanic	2734 (3)
Marital status, *n (%)*	
Married	51 094 (63)
Single	8646 (11)
Widowed	8439 (10)
Other	6899 (8)
Divorced	6211 (8)
Primary payer, *n (%)*	
Medicare	43 164 (53)
Managed care	21 987 (27)
Indemnity	8177 (10)
Medicaid	3614 (4)
Uninsured	2575 (3)
Other	1057 (1)
Capitated	715 (1)
Discharge status, *n (%)*	
To home	43 588 (54)
Home health care	24 444 (30)
Skilled nursing facility	8028 (10)
Rehabilitation	2574 (3)
Death in the hospital	1738 (2)
Transferred	399 (0.5)
Other	443 (0.5)
Hospice	75 (0.1)
Any intensive care unit charges, *n (%)*	60 392 (74)
APR-DRG risk for death, *n (%)*	
1	8702 (11)
2	40 789 (50)
3	23 747 (29)
4	8051 (10)
APR-DRG severity score, *n (%)*	
1	27 388 (34)
2	32 065 (39)
3	15 883 (20)
4	5953 (7)
Comorbid condition, *n (%)*	
Hypertension	58 492 (72)
Diabetes without chronic complications	25 423 (31)
Chronic obstructive pulmonary disease	18 974 (23)
Fluid and electrolyte disorders	12 815 (16)
Deficiency anemia	11 981 (15)
Obesity	11 636 (14)
Peripheral vascular disease	11 034 (14)
Coagulopathy	6335 (8)
Hypothyroidism	6038 (7)
Diabetes with chronic complications	4623 (6)
Renal failure	4308 (5)
Depression	3781 (5)
Other neurologic disorders	1882 (2)
Alcohol abuse	1663 (2)
Rheumatoid arthritis or collagen vascular disease	1191 (1)
Psychosis	1006 (1)
Paralysis	949 (1)
Solid tumor without metastasis	918 (1)
Congestive heart failure	443 (0.5)
Internal mammary graft not used, *n (%)*	9938 (12)
Characteristic of care site, *n (%)*	
Teaching hospital	30 295 (37)
Urban hospital	76 079 (94)
Rural hospital	5210 (6)
Region	
South	46 768 (58)
Midwest	14 082 (17)
Northeast	11 201 (14)
West	9237 (11)
Beds	
100–199	2952 (4)
200–299	7469 (9)
300–399	16 678 (21)
400–499	13 373 (16)
≥500	40 817 (50)
Outcomes, *n (%)*	
Death ≤30 d	1825 (2)
Readmission ≤30 d	8653 (11)

Continued on following column

APR-DRG = all-patient refined–diagnosis-related group.

40 patients per year (IQR, 24 to 53) in the lowest-volume quartile, to 158 (IQR, 142 to 193) in the highest-volume quartile. Mortality and readmission rates were similar across quartiles of hospital and surgeon volume. Although univariable tests for linear trend were statistically significant, very small absolute differences in rates of missed quality measures across hospital or surgeon volume quartiles were observed. In fact, higher-volume hospitals or surgeons tended to have more missed quality measures than smaller ones.

Table 4 shows the effects of volume on outcomes. In unadjusted analyses, no consistent associations between surgeon or hospital volume and death or readmission were observed. After adjustment for confounding patient and hospital factors, there continued to be little consistent gradient in association between hospital volume and odds for death, although hospital volume remained associated with lower odds for readmission. Compared with patients who received care from highest-volume surgeons, patients who had an operation by a low-volume surgeon had higher odds for death. After adjustment for individual quality measures, no significant changes in these findings were noted, suggesting that the effect of surgeon volume on patient outcomes was independent of hospital factors, quality of care, or confounding factors.

Table 5 shows the effects of individual and overall quality on outcomes. Individual quality measures had varied associations with risk for death and readmission. Patients who did not receive aspirin (odds ratio, 1.89 [95% CI, 1.65 to 2.16]) or β-blockers (odds ratio, 1.29 [CI, 1.12 to 1.49]) had higher odds for death after adjustment for clinical risk factors and case volume; only inappropriate antimicrobial use was associated with differences in readmission risk. For either outcome, adjustment for individual

Table 3. **Hospital and Surgeon Volume and Missed Quality Measures, by Quartile of Patient Volume**

Annual Hospital or Surgeon Volume, by Quartile of Patient Volume	Patients, *n*	Hospitals or Surgeons, *n*	Median Volume (Interquartile Range), *patients/y*	Deaths, *n (%)*	Readmissions, *n (%)*	Mean Missed Quality Measures (SD), *n**
Hospital						
1 (lowest volume)	20 358	85	142 (104–175)	489 (2.4)	2311 (11.4)	2.29 (1.40)
2	20 089	40	244 (217–266)	392 (2.0)	2179 (10.9)	2.21 (1.35)
3	20 491	26	373 (340–423)	487 (2.4)	2307 (11.3)	2.11 (1.27)
4 (highest volume)	20 351	13	744 (548–1166)	457 (2.3)	1856 (9.1)	2.56 (1.53)
Surgeon						
1 (lowest volume)	20 331	1143	40 (24–53)	534 (2.6)	2208 (10.9)	2.24 (1.41)
2	20 350	150	77 (71–86)	457 (2.3	2193 (10.8)	2.18 (1.42)
3	20 402	96	108 (101–117)	414 (2.0)	2180 (10.7)	2.37 (1.36)
4 (highest volume)	20 206	62	158 (142–193)	420 (2.1)	2072 (10.3)	2.40 (1.40)

* $P < 0.001$ for trend in number of missed quality measures for both annual hospital and surgeon volume.

quality measures did not alter any associations with surgeon or hospital case volume.

In contrast, associations between the number of quality measures missed and death were strong. After adjustment, patients who missed 3 measures (adjusted odds ratio, 1.54 [CI, 1.20 to 1.98]) and those who missed 4 or more (adjusted odds ratio, 1.63 [CI, 1.24 to 2.15]) had higher odds for death than did those who missed no quality measures. The number of missed quality measures was not associated with readmission risk.

The **Figure** describes overall quality of care, case volume, and patient outcomes. When we estimated mortality rates (adjusted for age, sex, death predicted by the diagnosis-related group, congestive heart failure, hypertension, neurologic disorders, diabetes with complications, renal failure, coagulopathy, deficiency anemia, and whether an internal mammary graft was used during the procedure) death was negligibly associated with hospital volume but was strongly influenced by the number of quality measures missed (**Figure**, *top*). In the lowest-volume quartile, adjusted mortality rates increased from 1.05% (CI, 0.81% to 1.29%) if none were missed to 2.37% (CI, 1.94% to 2.79%) if 4 or more were missed. In fact, if no quality measures were missed, lowest-volume and highest-volume hospitals had similar mortality rates (adjusted mortality, 1.05% [CI, 0.81% to 1.29%]).

Similar findings were seen in analyses of death by quartile of surgeon volume and the number of missed quality measures (**Figure**, *bottom*). The association between surgeon volume and outcome was inconsistent, but deaths among patients with no missed quality measures increased from 0.83% (CI, 0.39% to 1.02%) in the lowest quartile of surgeon volume to 1.07% (CI, 0.78% to 1.36%) in the highest quartile.

Table 4. **Hospital and Surgeon Volume and Care Outcomes, by Quartile of Patient Volume**

Annual Hospital or Surgeon Volume, by Quartile of Patient Volume	30-Day Mortality Rate (*n* = 1825)			Readmission Rate (*n* = 8653)		
	Unadjusted OR (95% CI)	Adjusted OR (95% CI)*†	Adjusted OR (95% CI)†‡	Unadjusted OR (95% CI)	Adjusted OR (95% CI)*§	Adjusted OR (95% CI)†§
Hospital						
1 (lowest volume)	1.07 (0.94–1.22)	1.23 (0.98–1.55)	1.14 (0.89–1.45)	1.28 (1.20–1.36)	1.24 (1.08–1.42)	1.22 (1.06–1.41)
2	0.87 (0.76–0.99)	1.10 (0.86–1.41)	1.12 (0.87–1.44)	1.21 (1.14–1.29)	1.19 (1.03–1.36)	1.16 (1.01–1.33)
3	1.06 (0.93–1.21)	1.22 (0.97–1.53)	1.28 (1.01–1.61)	1.26 (1.19–1.35)	1.22 (1.06–1.40	1.21 (1.05–1.39)
4 (highest volume)	Reference	Reference	Reference	Reference	Reference	Reference
Surgeon						
1 (lowest volume)	1.27 (1.12–1.45)	1.26 (1.05–1.51)	1.26 (1.02–1.56)	1.07 (1.00–1.14)	1.06 (0.98–1.15)	1.02 (0.94–1.11)
2	1.08 (0.95–1.24)	1.11 (0.92–1.33)	1.11 (0.90–1.36)	1.06 (0.99–1.13)	1.09 (1.01–1.17)	1.05 (0.96–1.15)
3	0.98 (0.85–1.12)	1.04 (0.88–1.23)	1.03 (0.85–1.24)	1.05 (0.98–1.12)	1.04 (0.96–1.13)	1.03 (0.95–1.12)
4 (highest volume)	Reference	Reference	Reference	Reference	Reference	Reference

OR = odds ratio.
* Adjusted for confounders only.
† Confounders included in mortality rate models were age, sex, diagnosis-related group–predicted mortality, congestive heart failure, hypertension, neurologic disorders, diabetes with complications, renal failure, coagulopathy, deficiency anemia, and whether an internal mammary graft was used during the procedure.
‡ Adjusted for individual quality measures and confounders.
§ Confounders included in readmission models were age, sex, race, insurance type, admission status, diagnosis-related group–predicted mortality, chronic obstructive pulmonary disease, peripheral vascular disease, diabetes, diabetes with complications, renal failure, electrolyte disorders, deficiency anemia, psychoses, depression, and geographic region.

Table 5. **Quality Measures and Care Outcomes**

Variable	30-Day Mortality Rate (n = 1825)			Readmission Rate (n = 8653)		
	Unadjusted OR (95% CI)	Adjusted OR (95% CI)*†	Adjusted OR (95% CI)†‡	Unadjusted OR (95% CI)	Adjusted OR (95% CI)*§	Adjusted OR (95% CI)‡§
Individual measures						
No aspirin	1.17 (1.06–1.29)	1.90 (1.66–2.16)	1.89 (1.65–2.16)	0.91 (0.87–0.95)	1.01 (0.94–1.08)	1.00 (0.94–1.06)
No β-blocker	0.82 (0.72–0.93)	1.29 (1.12–1.48)	1.29 (1.12–1.49)	0.83 (0.78–0.88)	0.95 (0.89–1.01)	0.96 (0.90–1.02)
No statin	1.23 (1.12–1.35)	1.07 (0.95–1.20)	1.07 (0.95–1.21)	0.95 (0.91–0.99)	0.97 (0.91–1.04)	0.96 (0.91–1.02)
No prophylactic antibiotics	1.12 (0.94–1.35)	1.25 (0.77–2.00)	1.25 (0.79–2.00)	0.82 (0.74–0.91)	0.87 (0.76–1.00)	0.90 (0.80–1.01)
Inappropriate antibiotics	2.05 (1.86–2.25)	0.66 (0.58–0.74)	0.66 (0.58–0.75)	1.26 (1.20–1.32)	1.10 (1.05–1.15)	1.12 (1.08–1.17)
No serial compression device	1.22 (1.09–1.37)	1.00 (0.82–1.22)	1.00 (0.83–1.22)	1.01 (0.95–1.06)	0.99 (0.90–1.09)	1.01 (0.93–1.09)
Missed measures‖						
0	Reference	Reference	Reference	Reference	Reference	Reference
1	1.68 (1.35–2.10)	1.05 (0.79–1.37)	1.05 (0.80–1.38)	1.10 (1.01–1.20)	1.00 (0.92–1.10)	1.01 (0.92–1.10)
2	1.58 (1.28–1.95)	1.15 (0.87–1.53)	1.15 (0.87–1.53)	1.09 (1.01–1.18)	0.99 (0.91–1.08)	1.00 (0.92–1.09)
3	2.43 (1.99–2.98)	1.54 (1.20–1.98)	1.54 (1.20–1.98)	1.08 (0.99–1.17)	0.99 (0.90–1.10)	1.00 (0.91–1.10)
≥4	2.37 (1.92–2.92)	1.62 (1.23–2.14)	1.63 (1.24–2.15)	1.03 (0.95–1.13)	0.98 (0.88–1.10)	1.02 (0.93–1.13)

OR = odds ratio.
* Adjusted for confounders only.
† Confounders included in mortality rate models were age, sex, diagnosis-related group–predicted mortality, congestive heart failure, hypertension, neurologic disorders, diabetes with complications, renal failure, coagulopathy, deficiency anemia, and whether an internal mammary graft was used during the procedure.
‡ Adjusted for volume measures and confounders.
§ Confounders included in readmission models were age, sex, race, insurance type, admission status, diagnosis-related group–predicted mortality, chronic obstructive pulmonary disease, peripheral vascular disease, diabetes, diabetes with complications, renal failure, electrolyte disorders, deficiency anemia, psychoses, depression, and geographic region.
‖ 9378 (12%) patients had 0 missed measures, 14 884 (18%) had 1 missed measure, 20 534 (25%) had 2 missed measures, 21 232 (26%) had 3 missed measures, and 15 261 (18%) had ≥4 missed measures.

Secondary Analyses

To test the robustness of our results, we conducted analyses in which we fit models including covariates with P values less than 0.20, rather than less than 0.01. Results from these analyses also did not demonstrate consistent associations between volume and outcome, nor did less parsimonious models change the associations between overall quality of care and mortality rates. We then examined the influence of interactions between volume measures and factors that might represent shifting of complex cases to higher-volume hospitals or surgeons. Specifically, we checked for interactions between the volume variables and all-patient refined–diagnosis-related group risk for death and all-patient refined–diagnosis-related group severity of illness. These interaction terms were not significant, and inclusion of these terms in our models did not alter our results. We found no significant interaction between hospital or surgeon volume and missed quality measures ($P > 0.50$ for both). This finding suggests that quality and volume attributed differences to outcomes independently.

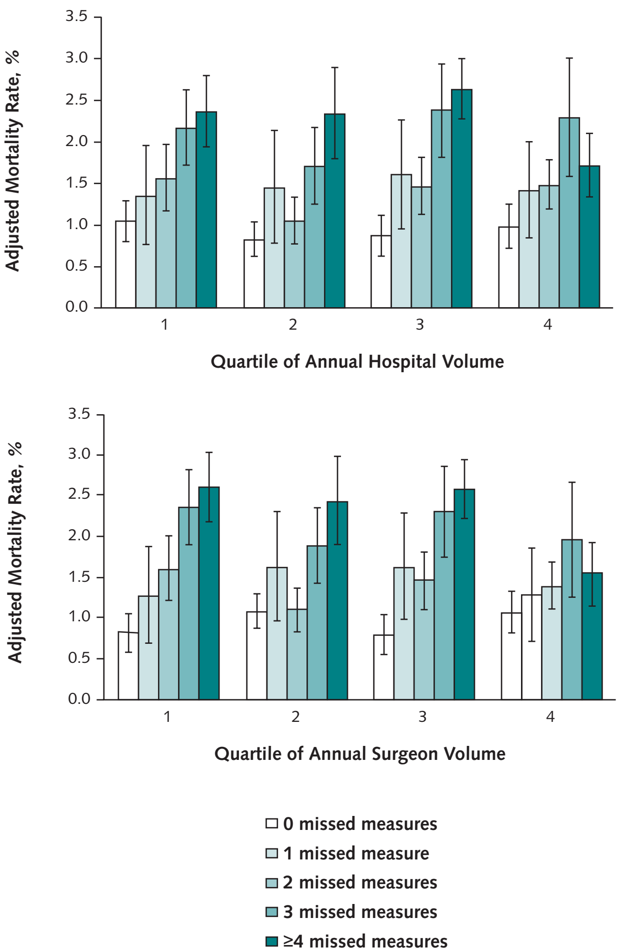
Discussion

In this large cohort of patients undergoing coronary artery bypass surgery, we found that hospital and surgeon volume had few consistent associations with death or risk for readmission after cardiac surgery. Likewise, individual quality-of-care measures had a similarly inconsistent pattern of association with clinical outcomes, and adjustment for quality-of-care differences or patient characteristics did not reveal an association between volume measures and our outcomes. However, overall adherence to quality measures was strongly associated with differences in mortality rates, regardless of hospital or surgeon volume. Because improving quality of care at hospitals is potentially more feasible than increasing case volume, these results may have substantial implications for patients undergoing coronary artery bypass surgery.

The relationship between higher volume of care and better outcomes of cardiac surgery is well recognized (11, 18–20) and has been endorsed as a way for purchasers to identify preferred sites and improve patient outcomes (1)—an approach aptly termed "follow the crowd" (21). However, regionalization of services poses practical problems for hospitals that need to try to meet volume standards and patients who need to travel for surgery and perioperative care (22, 23). In addition, the evidence for volume benchmarks' ability to accurately identify "best" sites has limitations (3, 24, 25).

We did note an association between lowest-volume surgeons and higher mortality rates and between higher-volume hospitals and lower risk for readmission. However, the strength of the volume–outcome associations we observed is weaker and less consistent than that of other studies (11, 18–20). Although it seems likely that higher case volume remains an important route to improved outcomes, many interrelated trends may be affecting the volume–outcome relationship in cardiac surgery (26). For example, emergence of improved tech-

Figure. **Adjusted mortality rates of patients undergoing coronary artery bypass surgery, by quartile of hospital volume and count of missed quality measures and by quartile of surgeon volume and count of missed quality measures.**



Models are adjusted for age, sex, diagnosis-related group–predicted mortality, congestive heart failure, hypertension, neurologic disorders, diabetes with complications, renal failure, coagulopathy, deficiency anemia, whether an internal mammary graft was used during the procedure, the volume and number of missed quality measures, and the interaction between volume and number of missed quality measures. **Top.** A strong association between the number of quality measures missed and death across all quartiles of hospital volume is observed, with mortality rates similar across quartiles of hospital volume if no quality measures are missed. **Bottom.** A strong association between the number of quality measures missed and mortality rates across all quartiles of surgeon volume is observed, with similar mortality rates even for lowest-volume surgeons if no quality measures are missed.

niques in interventional cardiology, the push to disseminate best practices across sites, and public reporting of mortality rates (27) are providing several confounding factors that may influence outcomes independent of case volume. In addition, shorter length of stay and shifting care to postdischarge settings may also limit the association between shorter-term mortality rates and volume. Recent work suggests that higher surgeon and hospital volume are associated with better longer-term outcomes of cardiac surgery (28).

Guidelines such as those we used to develop our study's quality measures (2, 12) represent care practices that should be followed regardless of operative volume. Of the measures tested, not receiving β-blockers or aspirin was associated with higher mortality rates and not receiving a statin lipid-lowering drug barely missed tests of statistical significance, suggesting the rationale for these measures may be sound. However, after adjustment, receiving an incorrect antimicrobial was associated with lower mortality rates, a finding which may indicate gaps in documentation (that is, lack of documentation for why antimicrobials might have been continued appropriately). Our data are consistent with previous evidence suggesting that performance on publicly reported quality measures explains only a small portion of differences in patient outcomes (29); early experience with Surgical Care Improvement Project measures in colorectal surgery has not seen a relationship between quality measures and improved outcomes (30).

Overall quality—for the purpose of our study, not missing any quality measures—is thought to be a measure of a system's ability to deliver all aspects of care reliably (17), whereas individual practices may be divided among team members (29, 31). Our results support publications that endorse maximizing overall quality (32) as a way to ensure outcome improvement through the development of systems that are highly reliable; that is, reliable systems provide consistent care from patient to patient because the system compels consistency rather than dependence on individual team members' individual efforts. We saw strong trends in outcome, even though our overall quality measurement included individual measures with weak or reversed associations with mortality rates. Refining this listing to include only measures with a beneficial effect on mortality rates or reweighting them (another proposed method for maximizing effect of quality reporting) would probably magnify the importance of overall quality in identifying optimal systems. Maximizing quality of care at low-volume hospitals (over regionalization alone) (33) has advocates; our results would support this approach. Overall quality of care was not associated with readmission risk—a particularly striking finding when juxtaposed with the association between quality and 30-day mortality rates. Although our data do not allow us to directly test these hypotheses, readmission risk may be more influenced by care delivered at discharge, such as care planning or the presence of support during the postdischarge period, whereas in-hospital death is dependent more on decisions and care provided earlier in the hospital stay (captured in our data), such as medications.

Our study has many limitations. Because we used administrative data, we cannot easily distinguish complications from preexisting disease. However, we constructed the quality measures to focus on patients who had no documented contraindications, and we did not use comorbid conditions to define outcomes. Our quality measures focus primarily on inpatient medications and cannot distinguish continuation of home medications from initiation of medications in the hospital. This factor may be influencing the associations between death and aspirin, β-blockers, or statins, but it is less likely to affect antimicrobial or serial compression device use. 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 death and readmission outcomes focus on events occurring at only the index hospital and may have missed these events if they occurred elsewhere. We also did not include other clinical outcomes of interest in cardiac surgery, such as relief of angina or later cardiac events (28). Lack of these clinical outcomes prompted us to use readmission as a proxy for short-term adverse events. 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, secondary analyses, including adjustment for hospital-level likelihood of receiving quality measures, did not suggest that this bias was a substantial threat. We examined only 1 surgical procedure, and our results cannot be extrapolated to other high-risk surgeries, such as cancer surgery, in which volume is thought to be an important predictor of outcome. Although Premier hospitals are similar to other U.S. centers in size, teaching status, and location, they may differ from non-Premier sites in subtle ways not captured in our data. Nonetheless, previous research in Premier sites has produced results useful to policymakers (34). Although we constructed our volume measures to be consistent with those used in previous work, it is possible that they do not adequately represent expertise accrued if low-volume surgeons were doing other complex surgeries frequently. It is likely that some surgeries in our data set were at least partially done by fellows or residents. To address this potential concern, we adjusted for whether the surgery was done at a teaching hospital.

Our study represents an important view of how case volume, quality of care, and outcomes of care are related. Although efforts to encourage patients to "follow the crowd" to a higher volume site or surgeon (or at least avoid lowest volume ones) may be useful, our results suggest that volume alone may be less important in the current era. In contrast, our results suggest that efforts to increase the overall quality of care so that patients can "shop for the best" provide a higher likelihood of benefits, and represent an approach that could be implemented wherever coronary artery bypass surgery is done, regardless of surgeon or hospital volume.

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