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CME

The Impact of Anesthesiologists on Coronary Artery Bypass Graft Surgery Outcomes

Laurent G. Glance, MD,*† Arthur L. Kellermann, MD, MPH,‡ Edward L. Hannan, PhD, MS,§ Lee A. Fleisher, MD,‖ Michael P. Eaton, MD,* Richard P. Dutton, MD, MBA,¶ Stewart J. Lustik, MD, MBA,* Yue Li, PhD,# and Andrew W. Dick, PhD†

BACKGROUND: One of every 150 hospitalized patients experiences a lethal adverse event; nearly half of these events involves surgical patients. Although variations in surgeon performance and quality have been reported in the literature, less is known about the influence of anesthesiologists on outcomes after major surgery. Our goal of this study was to determine whether there is significant variation in outcomes between anesthesiologists after controlling for patient case mix and hospital quality.

METHODS: Using clinical data from the New York State Cardiac Surgery Reporting System, we conducted a retrospective observational study of 7920 patients undergoing isolated coronary artery bypass graft surgery. Multivariable logistic regression modeling was used to examine the variation in death or major complications (Q-wave myocardial infarction, renal failure, stroke) across anesthesiologists, controlling for patient demographics, severity of disease, comorbidities, and hospital quality.

RESULTS: Anesthesiologist performance was quantified using fixed-effects modeling. The variability across anesthesiologists was highly significant ($P < 0.001$). Patients managed by low-performance anesthesiologists (corresponding to the 25th percentile of the distribution of anesthesiologist risk-adjusted outcomes) experienced nearly twice the rate of death or serious complications (adjusted rate 3.33%; 95% confidence interval [CI], 3.09%–3.58%) as patients managed by high-performance anesthesiologists (corresponding to the 75th percentile) (adjusted rate 1.82%; 95% CI, 1.58%–2.10%). This performance gap was observed across all patient risk groups.

CONCLUSIONS: The rate of death or major complications among patients undergoing coronary artery bypass graft surgery varies markedly across anesthesiologists. These findings suggest that there may be opportunities to improve perioperative management to improve outcomes among high-risk surgical patients. (Anesth Analg 2015;120:526–33)

It is widely believed that anesthesia-related mortality has decreased dramatically during the past 25 to 50 years.[1] In a seminal study from the 1950s based on nearly 600,000 anesthetics, Beecher and Todd[2] estimated that anesthesia was the primary cause of death in 1 of 2680 cases. In its report, *To Err Is Human: Building a Safer Health Care System*, the Institute of Medicine (IOM) reports that anesthesia mortality rates have decreased from 1 in 10,000 to 1 in 200,000 to 300,000.[3] The accuracy of the low mortality estimate cited in the IOM report has been strongly challenged. Lagasse[4] estimates that the anesthesia mortality rate is 20 times higher than the IOM estimate: 1 death per 10,000 anesthetics, rather than 1 in 200,000.

Using a narrow definition of anesthesia-related outcomes, which includes only very rare complications such as esophageal intubation or cardiac arrest on induction, creates the impression that anesthesiology is safer than it actually is. If, in fact, the commonly cited statistic of 1 death in 200,000 to 300,000 anesthetics[3] is accurate, then the practical limits of what is achievable for anesthesia patient safety may already have been attained. However, if more common but still major complications, such as acute kidney injury, postoperative myocardial infarction (MI), respiratory failure, and stroke, are caused as much by anesthesia as by surgical management,[5] then surgery can be made safer by further improving anesthesia care. One of every 150 hospitalized patients experiences a lethal adverse event, and nearly half of these events involves surgical patients.[6] More than 50% of surgical adverse events may be preventable.[7] If surgical outcomes vary across anesthesiologists, then further improvements in

From the Departments of *Anesthesiology and #Public Health Sciences, University of Rochester School of Medicine, Rochester, New York; †RAND Health, RAND, Boston, Massachusetts; ‡F. Edward Hebert School of Medicine, Uniformed Services University of the Health Sciences, Bethesda, Maryland; §School of Public Health, University at Albany, State University of New York, Albany, New York; ‖Department of Anesthesiology and Critical Care, University of Pennsylvania Health System, Philadelphia, Pennsylvania; and ¶Anesthesia Quality Institute, Park Ridge, Illinois.

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Address correspondence to Laurent G. Glance, MD, Department of Anesthesiology, University of Rochester Medical Center, 601 Elmwood Ave., Box 604, Rochester, NY 14642. Address e-mail to laurent_glance@urmc.rochester.edu.

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anesthesia management could improve surgical outcomes. Quantifying the variability in performance across anesthesiologists will provide us with an estimate of the potential improvements in surgical outcomes that might be attainable by improving anesthesia care.

The goal of this study was to determine whether there is significant variation in mortality and major complication outcomes among anesthesiologists in patients undergoing isolated coronary artery bypass graft (CABG) surgery using clinical data from the New York State Department of Health. Our goal is to help fill a critical gap in our understanding of the impact of anesthesiologists on surgical outcomes in patients undergoing high-risk surgery.

METHODS

Data Source

This study was based on population-based data from the New York State Cardiac Surgery Reporting System for patients undergoing isolated CABG surgery in New York State between 2009 and 2010. (Anesthesiologist identifiers were first available for the secondnhalf of 2009 and all of 2010).[a] The database includes comprehensive clinical information on patient demographics; encrypted[b] anesthesiologist, surgeon, and hospital identifiers; preoperative risk factors; and in-hospital mortality and major postoperative complications (stroke, Q-wave MI,[c] deep sternal wound infection, bleeding requiring reoperation, sepsis or endocarditis, gastrointestinal bleeding, perforation, or infarction; renal failure; respiratory failure; unplanned cardiac reoperation or interventional procedure).[8] This database does not include any information on physician (e.g., board certification, fellowship training) or hospital structural variables (teaching status, nurse staffing) and cannot be linked to outside datasets to obtain such information. These clinical data were collected prospectively by clinical data collectors and were submitted to the New York State Department of Health.[9] Comprehensive audit mechanisms are in place to ensure the accuracy and validity of the data.[9] Hospitals with a high reported prevalence of cardiac risk factors compared with the state average (e.g., a hospital reporting a high percentage of patients requiring emergency surgery) were subject to auditing.[9] Our study was approved by the IRB at the University of Rochester and by the New York State Department of Health. The requirement for informed consent was waived by the IRB at the University of Rochester.

Study Sample

We identified 14,390 patients who underwent isolated CABG. We excluded 63 cases with missing information on left ventricular ejection fraction and 19 with missing hematocrit values. We excluded 188 anesthesiologists with case volumes <50 (4817 cases). Because fixed-effects logistic regression is conditional on each panel member (anesthesiologist) having at least 1 success and 1 failure, we also excluded 21 anesthesiologists (1308 cases) with observed outcome rates equal to 0; their performance cannot be estimated using a fixed-effects model. Because high-quality physicians are less likely to have failures (death or major complications), they are less likely to be included in the estimation sample, resulting in selection bias. If the performance of these anesthesiologists was in fact close to perfect, then our analysis may have led to an underestimation of the variability in performance across anesthesiologists. Finally, hospitals in the resulting sample cohort with only 1 anesthesiologist meeting the above inclusion criteria were excluded (263 cases) because the anesthesiologist and hospital effect could not be separately identified. The final study cohort consisted of 7920 CABG cases managed by 91 anesthesiologists and 97 surgeons in 23 New York State hospitals.

Analysis

For our primary analysis, we defined the occurrence of a composite outcome of in-hospital mortality or major in-hospital complication (Q-wave MI,[d] renal failure,[e] or stroke[f]). We estimated a fixed-effects logistic regression model that included both anesthesiologist and hospital fixed-effects specified as intercept shifts. We assumed that anesthesiologists were nested within hospitals and then parameterized the anesthesiologist fixed effect so that each anesthesiologist was compared with the overall weighted average of the anesthesiologists working in the same hospital.[10] By specifying anesthesiologist fixed effects in this manner, we also controlled for hospital fixed effects. The adjusted odds ratio (AOR) for each anesthesiologist represents the odds of mortality or major complication attributable to a specific anesthesiologist relative to the average anesthesiologist working within the same hospital adjusted for patient risk conditional on hospital effects. We also assumed that anesthesiologists were randomly assigned to work with surgeons within their hospital so that the correlation between surgeon quality and anesthesiologist quality is small. We justified this assumption based on the widespread practice that cardiac anesthesiologists are assigned cases without consideration of surgeon quality. Our approach for estimating physician performance differs from the conventional approach for calculating the observed-to-expected mortality ratio of individual surgeons because the latter does not control for hospital quality[11] and therefore assumes that surgeon performance is the principal determinant of patient outcomes (other than severity of disease).

A priori, we included patient risk factors that are thought to be associated with death or major complications to include in our baseline prognostic model. To minimize omitted-variable bias, we created a nonparsimonious model for the composite outcome and retained some risk factors that did not achieve statistical significance but were judged to be clinically important. The predictor variables we included were age, sex, obesity (body mass index [BMI] ≥30), underweight (BMI ≤18.5), severity-of-disease (ejection fraction, emergency, unstable [requires pharmacologic or mechanical support to maintain arterial blood pressure or cardiac index], congestive heart failure, previous MI, calcified aorta, or previous open-heart surgery), and comorbidities (valvular disease, renal failure, cerebrovascular

[a]2010 data were the most recent data available.

[b]Anesthesiologists, surgeons, and hospitals are identified in the CABG database.

[c]Non--Q-wave MI is not included in the registry.

[d]New Q waves occurring within 48 hours after surgery.

[e]The need for temporary or permanent dialysis.

[f]Permanent new neurologic deficit.

Table 1. Characteristics of Patients Undergoing Isolated Coronary Artery Bypass Graft Surgery According to Anesthesiologist Performance

Patient characteristics	All patients (91 anesthesiologists, 7920 patients)	Anesthesiologist performance: High performance (23 anesthesiologists, 1889 patients)	Anesthesiologist performance: Low performance (23 anesthesiologists, 1884 patients)	*P* value
Patient demographics				
Age, mean (y)	66.5	66.6	66.7	0.269
Female (%)	25.8	26.1	25.7	0.832
Body mass index (%)				
Underweight	0.76	0.64	0.69	0.84
Overweight	39.2	38.9	39.1	0.92
Obese	39.9	40.9	39.8	0.49
Severity of disease (%)				
Left ventricular ejection fraction (%)	48.9	48.9	48.7	0.73
Unstable	0.66	0.58	1.22	0.038
Emergency	3.91	4.24	3.61	0.32
Congestive heart failure	12.1	13.6	14.3	0.52
Previous MI <1 d	2.42	2.22	2.07	0.75
Previous MI 1–7 d	18.6	18.3	20.2	0.15
Previous MI 8–20 d	5.03	4.39	6.05	0.022
Previous MI 21 d or more	23.0	24.3	23.4	0.55
Calcified aorta	4.77	5.24	5.04	0.78
Open heart surgery (prior)	3.31	3.07	2.60	0.39
Comorbidities (%)				
Aortic stenosis, moderate or severe	0.77	1.01	0.96	0.88
Tricuspid insufficiency, moderate or severe	1.83	1.64	1.65	0.99
Renal failure, creatinine >1.5 mg/dL	9.32	9.95	9.13	0.39
Renal failure, requiring dialysis	2.23	2.91	1.91	0.045
Cerebrovascular disease	19.4	19.8	18.6	0.34
Peripheral vascular disease	12.5	13.2	11.8	0.18
COPD	26.9	26.6	26.8	0.90
Hematocrit	37.0	36.8	36.7	0.44
Composite risk (%)				
Low risk	50.0	48.5	48.7	0.692
Intermediate risk	25.0	25.3	24.2	
High risk	25.0	26.2	27.1	
Outcomes (%)				
Death or major complication	2.89	2.22	4.46	<0.001
Death	1.45	1.22	2.12	0.030
Q-wave myocardial infarction	0.19	0.16	0.32	0.32
Renal failure	0.82	0.37	1.27	0.002
Stroke (within 24 h of CABG)	0.45	0.32	0.58	0.22
Stroke (over 24 h)	1.01	0.79	1.22	0.19

Low-performance anesthesiologists were defined as those whose adjusted performance corresponded to the lower 25th percentile, and high-performance anesthesiologists were defined as those whose adjusted performance corresponded to the top 75th percentile.

Underweight = body mass index (BMI) ≤18.5; overweight = BMI ≥25 and BMI <30; obese = BMI ≥30.

COPD = chronic obstructive pulmonary disease; MI = myocardial infarction.

disease, peripheral vascular disease, chronic obstructive pulmonary disease, and hematocrit). The discrimination of the prognostic model was assessed using the C statistic. Model calibration was assessed using the Hosmer-Lemeshow statistic. Fractional polynomials were used to determine the optimal specification of continuous predictor variables to ensure that the model was linear in the logit for continuous variables.[12]

To quantify the independent contribution of very-low–performance (90th percentile), low-performance (75th percentile), average-performance (50th percentile), high-performance (25th percentile), and very-high–performance (10th percentile) anesthesiologists on the risk of death or major complications after CABG, we performed a simulation in which we calculated the predicted probability of death for all the patients in the sample cohort based on the estimated distribution of the anesthesiologist fixed-effects within hospitals. This approach simulates the hypothetical outcomes for the sample cohort, assuming that all patients receive care from anesthesiologists with the same level of performance leaving the hospital site unchanged. To further illustrate the importance of the anesthesiologist on clinical outcomes, we also estimated the impact of very-low–, low–, average–, high–, and very-high–performance anesthesiologists on groups of low- (risk ≤1.85%), intermediate- (1.85 < risk ≤3.37), and high-risk patients (>3.37%): corresponding to the 50th, 51st to 75th, and >75th percentile of risk. Individual risk (probability of death or major complications) was calculated after re-estimating the baseline model without including anesthesiologist and hospital fixed effects.

We performed additional analyses to examine the assumption that surgeon and anesthesiologist performance was not correlated. We used the same approach described in the Analysis section to estimate the risk-adjusted performance for individual surgeons using a fixed-effects logistic regression model that included a separate surgeon identifier for each surgeon. The AOR for each surgeon represents the odds of mortality or major complications relative to the average surgeon working in the same hospital adjusted for patient risk and hospital effects. We then estimated the correlation coefficient for anesthesiologist and surgeon performance.

Data management and statistical analyses were performed using STATA SE/MP Version 13.0 (STATA Corp., College Station, TX). Robust variance estimators were used to account for the clustering of observations within anesthesiologists.[13] All statistical tests were 2 tailed, and P values <0.05 were considered significant.

RESULTS

There were no clinically significant differences in age, gender, BMI, severity of disease, or comorbidities between patients treated by high-performance and low-performance anesthesiologists (Table 1). Table 2 displays the AORs and 95% confidence intervals (CIs) for the composite outcome models. The fixed-effects model exhibited good discrimination, with a C statistic of 0.78 and acceptable calibration ($P >$ 0.05) (Table 2). A caterpillar plot displaying the variability in anesthesiologist performance is shown in Figure 1.

After adjusting for patient characteristics and hospital effects, we found that the variability across anesthesiologists was highly significant ($P < 0.001$). In our simulation, we found that patients managed by low-performance anesthesiologists (adjusted rate 3.33%; 95% CI, 3.09%–3.58%) had a 1.8-fold higher risk of death or serious complications than patients managed by high-performance anesthesiologists (adjusted rate, 1.82%; 95% CI, 1.58%–2.10%) conditional on hospital effects (Table 3 and Fig. 2).

When patients were stratified by their baseline preoperative risk (low risk, bottom 50th percentile of risk; intermediate risk, 51st to 75th percentile; and high risk, >75th percentile), we still found an approximately 2-fold higher rate of death or major complications in patients treated by low-performance anesthesiologists compared with high-performance anesthesiologists across all risk categories (Table 3 and Fig. 3).

In our additional analysis to examine the assumption that surgeon and anesthesiology quality is uncorrelated, we found that the correlation between anesthesiologist and surgeon risk-adjusted performance was poor (correlation coefficient = 0.14).

DISCUSSION

To date, no large-scale study has analyzed the effects of different anesthesiologists on patient outcomes. In this population-based study of patients undergoing isolated CABG surgery in New York State, we found evidence of substantial variability in death or major complications across anesthesiologists. After adjusting for patient risk and hospital quality, we found that patients cared for by low-performance anesthesiologists had approximately a 2-fold higher risk of in-hospital death or major complications relative to patients cared for by high-performance anesthesiologists. Patients in our sample experienced an absolute risk of death or major complications that was approximately 1.5 percentage points higher if they were managed by a low-performance anesthesiologist compared with a high-performance anesthesiologist. The performance gap was observed across multiple hospitals and all patient risk groups. This

Table 2. Baseline Model Parameters

Risk factors	Patient risk factors		Patient risk factors + anesthesiologist fixed effects	
	AOR	P	AOR	P
Patient demographics				
Age	1.04 (1.02–1.05)	<0.001	1.04 (1.02–1.06)	<0.001
Body mass index				
Obese	1.32 (0.97–1.78)	0.073	1.34 (0.98–1.84)	0.066
Severity of disease				
Ejection fraction	0.99 (0.98–1.00)	0.11	0.99 (0.98–1.00)	0.13
Unstable	2.95 (1.33–6.52)	0.008	2.55 (1.10–5.93)	0.030
Emergency	1.60 (0.80–3.18)	0.18	1.69 (0.88–3.25)	0.11
Congestive heart failure	1.80 (1.24–2.61)	0.002	1.85 (1.25–2.74)	0.002
Previous MI <1 d	2.34 (1.10–4.97)	0.027	2.22 (1.02–4.83)	0.044
Previous MI 1–7 d	1.54 (1.00–2.38)	0.051	1.52 (0.96–2.40)	0.071
Previous MI 8–20 d	1.59 (0.99–2.54)	0.055	1.48 (0.91–2.40)	0.11
Previous MI 21 d or more	1.45 (1.00–2.13)	0.053	1.45 (0.99–2.15)	0.059
Calcified aorta	1.18 (0.78–1.78)	0.45	1.17 (0.75–1.82)	0.49
Open heart surgery	1.39 (0.75–2.56)	0.29	1.40 (0.75–2.58)	0.29
Comorbidities				
Renal failure, creatinine >1.5 mg/dL	0.98 (0.66–1.45)	0.90	0.97 (0.64–1.47)	0.89
Renal failure, requiring dialysis	1.82 (0.91–3.63)	0.088	2.02 (1.01–4.02)	0.045
Cerebrovascular disease	1.54 (1.15–2.06)	0.004	1.58 (1.17–2.15)	0.003
Peripheral vascular disease	1.75 (1.22–2.52)	0.003	1.81 (1.25–2.61)	0.002
COPD	1.44 (1.09–1.91)	0.010	1.45 (1.07–1.97)	0.015
Hematocrit	0.97 0.94–0.99)	0.009	0.97 (0.94-0.99)	0.006
Model performance				
C statistic	0.75		0.78	
Hosmer-Lemeshow statistic	6.18 (P = 0.63)		12.02 (P = 0.15)	

The anesthesiologist fixed-effects are not presented in the table.
AOR = adjusted odds ratio; MI = myocardial infarction; COPD = chronic obstructive pulmonary disease.

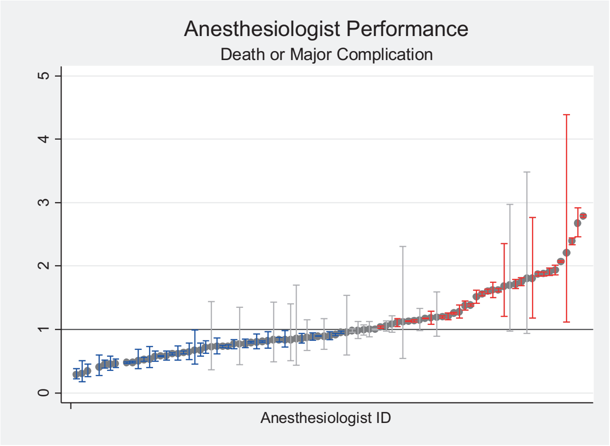

Figure 1. Plot of adjusted odds ratios (AORs) with 95% confidence interval (error bar) for individual anesthesiologists enrolled in the New York State cardiac surgery registry. Anesthesiologists with AORs significantly >1 are considered low-performance outliers, whereas anesthesiologists with AORs significantly <1 are considered high-performance outliers. This figure illustrates the variability of anesthesiologist performance and does not adjust for multiple comparisons.

performance gap is similar to the absolute difference in mortality between high- and low-volume surgeons performing CABG surgery.[14] To the best of our knowledge, this is the first large-scale study to systematically examine the impact of anesthesiologist performance on a patient's risk of experiencing death or a serious complication.

The variability of outcomes across anesthesiologists may not be surprising to experienced anesthesiologists and surgeons but is likely to be overlooked by most patients and many clinicians. General anesthesia is the induction of a reversible drug-induced coma accompanied by the loss of brainstem function, resulting in apnea and atonia in addition to cardiovascular depression.[15] The practice of anesthesia is complex and includes controlling the airway, respiratory care, hemodynamic monitoring and management, fluid and blood administration, pharmacologic manipulation, preoperative evaluation and optimization, and postoperative care, all while ensuring adequate pain control and unconsciousness. There is increasing evidence that anesthetic management may impact short-, intermediate-, and long-term outcomes.[16,17] Most major complications, such as acute kidney injury, postoperative MI, respiratory failure, and stroke, are likely to be affected by both anesthesia and surgical management.[5] The need for large clinical studies to develop a more robust evidence base for perioperative medicine is clear.[18] By highlighting the variability in outcomes across anesthesiologists, our findings reinforce the need to better understand the factors in the management of surgical patients that drive perioperative outcomes, including factors such as teamwork between anesthesiologists and surgeons.

Twenty years ago, DeAnda and Gaba[19] reported that the level of performance of anesthesiologists responding to simulated intraoperative critical incidents was highly variable. Nonetheless, there are little published data examining variability in surgical outcomes attributable to anesthesiologists. One early study, examining the association between perioperative myocardial ischemia and postoperative MI, reported that of 9 anesthesiologists, 1 was an outlier with respect to the incidence of postoperative MIs.[20] A second single-center study, based on 1300 CABG surgery patients, examined the impact of anesthesiologists on aspartate aminotransferase levels, a biomarker for MI. That study found that different anesthesiologists were associated with higher levels of aspartate aminotransferase than others.[21] However, that study used only very limited risk adjustment. Two studies have examined the impact of anesthesiologist board certification on mortality.[22,23] Silber et al.[23] documented that death and failure-to-rescue (death after a major complication) in patients undergoing general surgical or orthopedic procedures were higher in patients cared for by anesthesiologists who were not board certified.

Our findings indicate a clinically important gap in quality between low-performing and high-performing anesthesiologists. This observation has important implications for patient safety and quality of care. This performance gap is a previously unrecognized opportunity to improve surgical outcomes in the highest-risk patients. Widespread generation of massive amounts of digital data in electronic health records, including data on intraoperative events and processes of care, could be harnessed to provide the "Big Data" platform for comparative effectiveness research in surgical outcomes.[24] This will only be possible through data sharing in an environment of "open science."[25] Big data could be used to discover differences in decision making among anesthesiologists that result in such substantial differences in patient outcomes. Large national outcomes registries, such as the National Anesthesia Clinical Outcomes Registry,[5] American College of Surgeons National Surgical Quality Improvement Program,[26] and Society of Thoracic Surgeons (STS) registry,[27] should be merged with intraoperative data from anesthesia information management systems to create vast digital learning laboratories for discovering best practices in perioperative medicine. The partnership between STS and the Society of Cardiovascular Anesthesiologists, in which a cardiac anesthesia module was added to the STS registry, is a model for other collaborations between anesthesiologists and surgeons to create comprehensive outcome registries. Efforts to improve perioperative outcomes are most likely to succeed when surgeons and anesthesiologists join forces, such as in the FOCUS (Flawless Operative Cardiovascular Unified Systems) initiative,[28] to improve patient outcomes.

Our study has several potential limitations. First, we were not able to examine whether anesthesiologists identified as low performance remained low performance over time. The sample size available for this study was not sufficient to assess whether patients treated by anesthesiologists identified as performance outliers using data from previous years were as likely to experience adverse outcomes as those managed by nonoutlier anesthesiologists. The consistency of hospital or physician quality over time is a new approach for judging the validity of quality metrics. In theory, if performance measures capture hospital quality, then contemporary patients treated at hospitals identified as low performance using historical data should have worse outcomes than patients treated in average- or high-performance hospitals.[29,30] The ability of quality measures to predict future performance has been examined recently for noncardiac surgery[31] and common medical conditions[32] but is not yet a standard approach for evaluating the

Table 3. Coronary Artery Bypass Graft Surgery Outcomes Versus Anesthesiologist Performance Stratified by Patient Risk of Death or Major Complications					
	Very-high performance 10th percentile (*n* =9)	High performance 25th percentile (*n* = 14)	Average performance 50th percentile (*n* = 45)	Low performance 75th percentile (*n* = 13)	Very-low performance 90th percentile (*n* = 10)
	Adjusted rate (95% CI)	Adjusted rate (95% CI)	Adjusted rate (95% CI)	Adjusted rate (95% CI)	Adjusted rate (95% CI)
Patient risk					
All patients	1.31 (1.28–1.34)	1.82 (1.58–2.10)	2.55 (2.5–2.55)	3.33 (3.09–3.58)	4.57 (3.10–6.66)
Low risk	0.49 (0.47–0.50)	0.68 (0.59–0.79)	0.91 (0.85–0.97)	1.29 (1.19–1.39)	1.81 (1.19–2.74)
Intermediate risk	1.09 (1.06–1.12)	1.53 (1.32–1.77)	2.03 (1.91–2.17)	2.86 (2.65–3.09)	4.01 (2.66–6.00)
High risk	3.18 (3.10–3.25)	4.39 (3.81–5.04)	5.73 (5.40–6.09)	7.86 (7.32–8.44)	10.7 (7.34–15.2)

The risk of major complications or death (%) of patients treated by very-low–, low-, average-, high-, and very-high–performance anesthesiologists, conditional on patient risk and hospital quality.
n = refers to the number of anesthesiologists in each group.

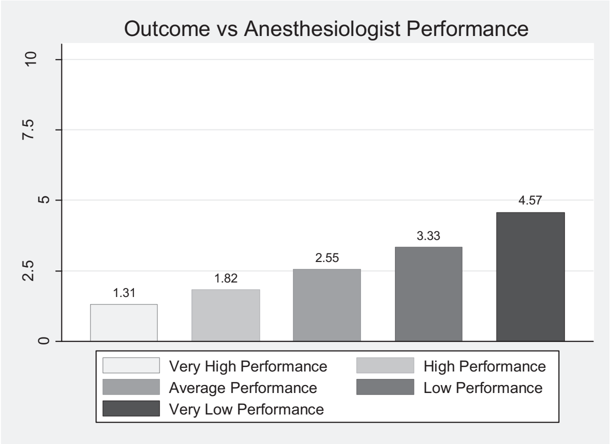

Figure 2. Estimated rate of death or major complications in sample cohort if all patients were treated by very-high–, high-, average-, low-, or very-low–performance anesthesiologists.

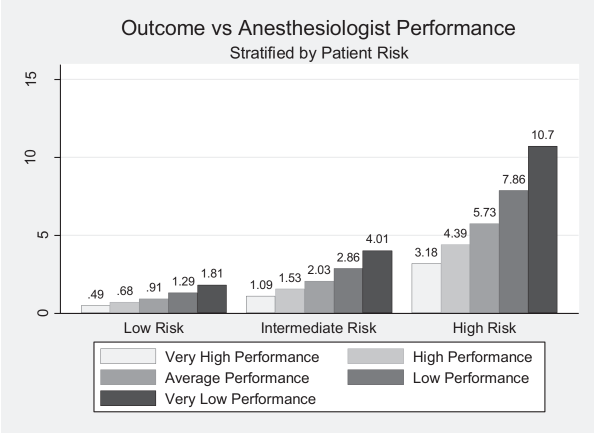

Figure 3. Estimated rate of mortality or major complications in sample cohort if all patients were treated by very-high–, high-, average-, low-, or very-low–performance anesthesiologists, stratified by patient risk.

performance of report cards. We have shown previously that past hospital performance predicts future performance for CABG surgery in New York State.[33] Although risk adjustment is an inexact science, the finding that the past performance of a hospital predicts the outcomes of future patients suggests that performance metrics have face validity. The recent finding by Birkemeyer et al.[34] that the independent assessment of surgeon technical skill is associated with risk-adjusted complication rates also suggests that quantifying the variability in physician performance has face validity.

Second, we excluded anesthesiologists with either low case volumes or no deaths or major complications. The adjusted outcomes for anesthesiologists with no bad outcomes cannot be estimated using fixed-effects modeling, whereas the adjusted outcomes for low-volume anesthesiologists would have been very imprecise and unlikely to reflect physician quality. Third, because it was not possible to simultaneously control for both surgeon and hospital effects within a fixed-effects model, we assumed that surgeon and anesthesiologist quality were not correlated, and that our estimate of anesthesiologist performance was independent of surgeon quality. We justified this assumption based on the widespread practice that cardiac anesthesiologists are assigned cases without consideration of surgeon quality, and the finding that surgeon and anesthesiologist performance were poorly correlated in our sample.

Fourth, it is possible that some of the variability in outcomes among anesthesiologists was caused by unobserved differences in severity of disease that were not adequately controlled by risk adjustment. The comprehensiveness of the New York State database and the good statistical performance of our multivariable model in our analyses mitigate, but do not eliminate, this limitation. Fifth, attending anesthesiologists frequently supervise anesthesiology residents, fellows, and certified registered nurse anesthetists, and these personnel were not included in our analytic model. To the degree that other anesthesiology personnel influence the management of CABG patients, this may bias the attending anesthesiologist's impact on mortality toward the null, leading us to underestimate the variability in anesthesiologist performance. Furthermore, the anesthesiologist of record may transfer his/her case to another attending anesthesiologist at the end of the day. By omitting other anesthesia personnel, our study may underestimate the overall impact of anesthesia management on CABG mortality. Sixth, the accuracy of the complication data in the New York State registry may not be as accurate as that of other data elements. We cannot exclude the possibility that some of the variation in outcomes across anesthesiologists may be attributable to systematic differences in coding accuracy of complications at the hospital level. Seventh, because our data did not include information on anesthetic processes of care, we could not explore possible clinical explanations for this observed variation. In the future, it may be possible to link the New York State data with intraoperative information (e.g., drug, fluid, and blood product administration) to identify best practices in intraoperative management.

Finally, it could be argued that we should have used hierarchical as opposed to a fixed-effect modeling to quantify the variability in anesthesiologist performance. However, the use of hierarchical modeling and shrinkage estimators to assess provider quality is controversial. Proponents of hierarchical modeling argue that hierarchical modeling is better able to accommodate providers with low case volume. Although it is true that nonhierarchical models are likely to lead to more extreme values of the point estimates for low-volume providers, the wider CIs surrounding the point estimates for low-volume providers with "extreme" performance make it easy to differentiate between true outliers and providers with "average" performance when using nonhierarchical modeling. The other argument favoring the use of hierarchical modeling is that it properly adjusts for clustering of observations by providers.[35] However, robust variance estimators can be used to adjust for clustering of observations in nonhierarchical modeling.[13]

Hierarchical models have important disadvantages. The most important is that low-volume providers are "shrunk" to average performers and grouped with high-volume providers whose performance is truly average. The rationale for shrinkage is that, a priori, we know very little about the true performance of low-volume providers, and hence, we should "assume" that in the absence of sufficient provider case volume, low-volume providers have average performance. Some dispute this approach, arguing that because in many cases, low provider volumes are associated with worse outcomes, shrinkage toward the mean leads to biased estimates of performance. This approach is particularly problematic for public reporting, in which the goal is to promote transparency and accountability because low-volume providers who may be actually providing low-quality care tend to be classified as average performers because of the use of shrinkage estimators in hierarchical modeling.[36] On a practical level, because virtually all of the anesthesiologists are low-volume providers, their performance will be shrunk to the mean if we were to use hierarchical modeling in our analysis. Thus, the use of shrinkage estimators will present a biased estimate of the variation of anesthesiologist quality. Shrinkage estimators are a very conservative approach for assessing provider quality and will typically lead to very few providers being identified as quality outliers, even among a group of hospitals with high case volumes. Finally, hierarchical models require the assumption that there is no correlation between the patient characteristics and the quality of the anesthesiologists (or surgeons or hospitals), a set of assumptions not required with fixed-effects models. Thus, the assumptions of hierarchical modeling are frequently violated when used to estimate provider quality because hierarchical modeling assumes that the random effect (provider effect) is not correlated with patient risk. If, in fact, some anesthesiologists take care of sicker patients than others, then hierarchical modeling may lead to biased estimates of provider effects.

CONCLUSIONS

We report important and clinically significant variation in performance across anesthesiologists, thus demonstrating that the perioperative outcomes of patients undergoing CABG surgery might be improved by changes in management by anesthesiologists. We found that low-performance anesthesiologists had a nearly 2-fold higher rate of deaths or major complications compared with average-performance anesthesiologists. This observation should encourage anesthesiologists and surgeons to increase their efforts to develop evidence-based strategies for improving perioperative care. With the rapid adoption of intraoperative electronic medical records that capture granular information on all aspects of intraoperative management and patient physiology, it should be feasible to create and analyze vast digital libraries of clinical information and use these data to identify best practices in perioperative medicine. Overcoming the myth that anesthesiology is a "six sigma specialty"[37] that has minimal room for improvement should encourage anesthesiologists and surgeons to work collaboratively to further develop the science behind perioperative medicine and to successfully bridge the quality chasm in surgery.

DISCLOSURES

Name: Laurent G. Glance, MD.
Contribution: This author helped design the study, conduct the study, analyze the data, and write the manuscript.
Attestation: Laurent G. Glance has seen the original study data, reviewed the analysis of the data, approved the final manuscript, and is the author responsible for archiving the study files.
Name: Arthur L. Kellermann, MD, MPH.
Contribution: This author helped conduct the study and write the manuscript.
Attestation: Arthur L. Kellermann reviewed the analysis of the data and approved the final manuscript.
Name: Edward L. Hannan, PhD, MS.
Contribution: This author helped conduct the study and write the manuscript.
Attestation: Edward L. Hannan reviewed the analysis of the data and approved the final manuscript.
Name: Lee A. Fleisher, MD.
Contribution: This author helped conduct the study and write the manuscript.
Attestation: Lee A. Fleisher reviewed the analysis of the data and approved the final manuscript.
Name: Michael P. Eaton, MD.
Contribution: This author helped conduct the study and write the manuscript.
Attestation: Michael P. Eaton reviewed the analysis of the data and approved the final manuscript.
Name: Richard P. Dutton, MD, MBA.
Contribution: This author helped conduct the study and write the manuscript.
Attestation: Richard P. Dutton reviewed the analysis of the data and approved the final manuscript.
Name: Stewart J. Lustik, MD, MBA.
Contribution: This author helped conduct the study and write the manuscript.
Attestation: Stewart J. Lustik reviewed the analysis of the data and approved the final manuscript.

Name: Yue Li, PhD.
Contribution: This author helped conduct the study and write the manuscript.
Attestation: Yue Li reviewed the analysis of the data and approved the final manuscript.
Name: Andrew W. Dick, PhD.
Contribution: This author helped design the study, conduct the study, analyze the data, and write the manuscript.
Attestation: Andrew W. Dick has seen the original study data, reviewed the analysis of the data, and approved the final manuscript.
This manuscript was handled by: Charles W. Hogue, Jr, MD.

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