Understanding the Volume-Outcome Effect in Cardiovascular Surgery
The Role of Failure to Rescue

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importance
To effectively guide interventions aimed at reducing mortality in low-volume hospitals, the underlying mechanisms of the volume-outcome relationship must be further explored. Reducing mortality after major postoperative complications may represent one point along the continuum of patient care that could significantly affect overall hospital mortality.

objective
To determine whether increased mortality at low-volume hospitals performing cardiovascular surgery is a function of higher postoperative complication rates or of less successful rescue from complications.

design, setting, and participants
We used patient-level data from 119,434 Medicare fee-for-service beneficiaries aged 65 to 99 years undergoing coronary artery bypass grafting, aortic valve repair, or abdominal aortic aneurysm repair between January 1, 2005, and December 31, 2006. For each operation, we first divided hospitals into quintiles of procedural volume. We then assessed hospital risk-adjusted rates of mortality, major complications, and failure to rescue (ie, case fatality among patients with complications) within each volume quintile.

exposure
Hospital procedural volume.

main outcomes and measures
Hospital rates of risk-adjusted mortality, major complications, and failure to rescue.

results
For each operation, hospital volume was more strongly related to failure-to-rescue rates than to complication rates. For example, patients undergoing aortic valve replacement at very low-volume hospitals (lowest quintile) were 12% more likely to have a major complication than those at very high-volume hospitals (highest quintile) but were 57% more likely to die if a complication occurred.

conclusions and relevance
High-volume and low-volume hospitals performing cardiovascular surgery have similar complication rates but disparate failure-to-rescue rates. While preventing complications is important, hospitals should also consider interventions aimed at quickly recognizing and managing complications once they occur.

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Although the volume-outcome relationship is well recognized in cardiovascular surgery, minimal progress has been made at reducing the mortality disparity between high- and low-volume centers. However, cardiovascular disease is distinguished from many other clinical entities by a long history of standardization in processes of care. For instance, in 1987 the Northern New England Cardiovascular Disease Study Group created a patient registry with the aim to “develop and exchange information concerning the treatment of cardiovascular disease.” The group harnessed benchmarking and continuous quality improvement initiatives to disseminate gains in clinical care. Furthermore, their data have been used by accreditation bodies such as The Joint Commission and the American Heart Association to create practice guidelines. For example, the latter has recommended hospitals use volume thresholds to reduce morbidity and mortality. Although increased surgeon and hospital volumes significantly improve outcomes in cardiovascular surgery, the benefit is substantially less pronounced than in other specialties. This may suggest that for cardiovascular surgery, standardization of perioperative care has left less room for improvement.

However, differences in mortality may not be solely a function of volume. Recent research has identified failure to rescue (FTR; mortality after a major complication) as one system-level factor influencing postoperative mortality. Prior studies of gastrectomy, pancreatectomy, and esophagectomy demonstrate little variation in hospital postoperative complication rates but striking variation in FTR rates. The latter measure reflects a hospital’s capacity to expeditiously diagnose and appropriately manage complications. In turn, this capacity is largely dictated by the ability of teams to work cohesively during times of crisis. Thus, poorly performing hospitals may have the opportunity to improve outcomes through better teamwork.

In this context, we sought to examine the effect of FTR on mortality. We hypothesize that FTR will account for excess mortality at low-volume hospitals. We used 2 years of data from the US Medicare population for 3 high-risk cardiovascular procedures.

**Methods**

**Data Source and Patient Population**

We used the Centers for Medicare and Medicaid Services’ Medicare Provider Analysis and Review files for 2005 and 2006 to obtain patient-level data. The Medicare Provider Analysis and Review database includes all claims submitted by hospitals for inpatient services provided to Medicare beneficiaries. It catalogs age, sex, admission and discharge dates, 30-day mortality, and the International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM) codes for both primary and secondary diagnoses.

We included all patients between the ages of 65 and 99 years with ICD-9-CM codes for coronary artery bypass grafting (CABG), aortic valve repair (AVR), or abdominal aortic aneurysm repair (AAA). These operations were chosen as each has previously exhibited a volume-outcome relationship and all are associated with significant morbidity and mortality.

**Hospital Volume**

First, we tabulated individual hospital volume for each of the 3 procedures. Second, we divided the hospitals into quintiles of procedure volume.

**Hospital Mortality, Complications, and FTR**

Hospital mortality was defined as 30-day or in-hospital mortality. Using methods previously validated by the Complications Screening Program, we identified 8 major postoperative complications by ICD-9-CM codes and divided them into medical and surgical groups. The medical group included pulmonary failure, pneumonia, myocardial infarction, deep venous thrombosis or pulmonary embolism, acute renal failure, and gastrointestinal bleeding. The surgical group included postoperative hemorrhage and surgical site infection (eTable in Supplement). This method of coding complications has been shown to be in good agreement with patient-level medical records as measured by physician reviewers. We excluded myocardial infarction from our analysis of patients undergoing CABG because of the inability to assess the temporal relationship between infarction and operation. The overall complication rates using these methods have strong face validity and are consistent with previously published outcomes.

**Statistical Analysis**

We began by calculating risk-adjusted mortality rates accounting for patient age, sex, race, urgency of operation, and pre-existing comorbidities. We used logistic regression to calculate the probability of death for each patient. To estimate expected hospital mortality rates, we summated the probability of death by hospital. Finally, we generated each hospital’s operation-specific risk-adjusted mortality rate by multiplying the overall mean mortality rate for each operation by the hospital’s ratio of observed to expected mortality for that operation.

Failure to rescue was defined as death in a patient after 1 or more of the listed complications. We determined hospital FTR rates by evaluating the proportion of deaths among patients who developed at least 1 postoperative complication (numerator) relative to the total number of patients who developed a postoperative complication (denominator).

We used robust standard errors to adjust for clustered effects (nonindependence of patients within hospitals). All analysis was performed using Stata version 10.0 statistical software (StataCorp LP). Our cutoff for statistical significance was P < .05.

**Results**

Overall, our final study cohort included 119,434 Medicare patients having 1 of 3 cardiovascular procedures between January 1, 2005, and December 31, 2006. With the exception of black
race, patients in the lowest- and highest-volume quintiles were similar with respect to preoperative risk factors (Table 1). We did not find evidence of a systemic racial bias across volume quintiles. This presumption is strengthened by very similar rates of expected mortality between the highest- and lowest-volume quintiles. During our study period, the median procedure volumes at the lowest-volume hospitals were 87 cases for CABG, 27 for AVR, and 14 for AAA. For the highest-volume hospitals, these volumes were 591, 274, and 169 cases, respectively.

As compared with the highest-volume hospitals, the lowest-volume hospitals had significantly increased rates of risk-adjusted mortality for all 3 operations. Differences in the odds of major postoperative complications between the highest- and lowest-volume quintiles were small but statistically significant for AAA (odds ratio [OR] = 1.18; 95% CI, 1.09-1.27) and for AVR (OR = 1.12; 95% CI, 1.06-1.18). In contrast, our results showed no statistically significant difference for CABG (OR = 1.02; 95% CI, 0.89-1.16) (Figure). When considering all 3 operations together, there were no statistically significant differences in major complications (OR = 1.01; 95% CI, 0.99-1.04). Table 2 details complication incidences for all operations combined. When evaluating the incidence of surgical complications alone (ie, hemorrhage and surgical site infection), we found no statistically significant difference between the highest- and lowest-volume quintiles. In contrast, for medical complications, we found statistically significant differences in the incidence of pneumonia (OR = 1.33; 95% CI, 1.12-1.46) and pulmonary failure (OR = 1.71; 95% CI, 1.47-1.97).

For FTR, we found significantly lower rates among the highest-volume hospitals. The OR for FTR ranged from 1.16 for CABG (95% CI, 1.02-1.33) to 1.57 for AVR (95% CI, 1.38-1.79) (Figure). When considering FTR stratified by individual complications, we found statistically significant differences for both surgical complications. However, for medical complications, differences were driven largely by myocardial infarction and acute renal failure (Table 2).

### Discussion
To our knowledge, this is the first study to investigate the association between the volume-outcome relationship and FTR in cardiovascular surgery. Echoing prior research, our study found that the highest-volume hospitals have dramatically lower risk-adjusted mortality rates but only modestly lower complication rates.6,9 This difference in overall mortality may be explained by the substantially higher mortality after serious complications (ie, FTR) observed at the lowest-volume hospitals. These findings suggest that FTR is a potential mechanism for the higher mortality rates at low-volume hospitals.

In cardiovascular surgery, there is little research toward explaining the mechanisms driving the volume-outcome effect. Many prior studies of this effect in cardiovascular surgery have focused on parsing out the relative contributions of hospital and surgeon volumes.5,13 For instance, Birkmeyer et al5 found that surgeon volume explained 100% of the survival benefit seen at high-volume hospitals for AVR, 57% for

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### Abbreviations
- AAA, abdominal aortic aneurysm repair
- AVR, aortic valve repair
- CABG, coronary artery bypass grafting

### Table 1. Patient Characteristics by Hospital Volume

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Lowest-Volume Hospitals</th>
<th>Highest-Volume Hospitals</th>
</tr>
</thead>
<tbody>
<tr>
<td>CABG (n = 17 881)</td>
<td>(n = 17 510)</td>
<td></td>
</tr>
<tr>
<td>Age, median, y</td>
<td>73.9</td>
<td>73.9</td>
</tr>
<tr>
<td>Male, %</td>
<td>68.6</td>
<td>68.1</td>
</tr>
<tr>
<td>Black, %</td>
<td>6.6</td>
<td>6.4</td>
</tr>
<tr>
<td>≥3 Comorbidities, %</td>
<td>24.9</td>
<td>23.9</td>
</tr>
<tr>
<td>AVR (n = 11 820)</td>
<td>(n = 11 533)</td>
<td></td>
</tr>
<tr>
<td>Age, median, y</td>
<td>76.0</td>
<td>76.7</td>
</tr>
<tr>
<td>Male, %</td>
<td>58.1</td>
<td>58.4</td>
</tr>
<tr>
<td>Black, %</td>
<td>4.5</td>
<td>2.7</td>
</tr>
<tr>
<td>≥3 Comorbidities, %</td>
<td>21.5</td>
<td>18.0</td>
</tr>
<tr>
<td>AAA (n = 10 541)</td>
<td>(n = 10 149)</td>
<td></td>
</tr>
<tr>
<td>Age, median, y</td>
<td>75.2</td>
<td>75.8</td>
</tr>
<tr>
<td>Male, %</td>
<td>72.1</td>
<td>75.9</td>
</tr>
<tr>
<td>Black, %</td>
<td>5.9</td>
<td>3.7</td>
</tr>
<tr>
<td>≥3 Comorbidities, %</td>
<td>27.6</td>
<td>26.3</td>
</tr>
</tbody>
</table>

*P < .05.*

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### Table 2

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Lowest-Volume Hospitals</th>
<th>Highest-Volume Hospitals</th>
</tr>
</thead>
</table>
| Survival benefit seen at high-volume hospitals for AVR, 57% for

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### Figure. Hospital Rates of Risk-Adjusted Mortality, Major Complications, and Failure to Rescue

A | B | C

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**A**: Lowest-volume quintile

**B**: Highest-volume quintile

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Risk-adjusted mortality (A), major complications (B), and failure to rescue (C). AAA indicates abdominal aortic aneurysm repair; AVR, aortic valve repair; CABG, coronary artery bypass grafting; and OR, odds ratio.
elective AAA, and 49% for CABG. In another study, Peterson et al\textsuperscript{6} found that low- and high-volume centers have similar reoperation, renal failure, prolonged ventilation, stroke, and sternal wound infection rates, but low-volume centers have mortality rates 1.5 times greater than high-volume centers. However, that study was limited only to patients undergoing CABG.

In noncardiovascular surgery, there have been significant strides toward determining the mechanism of the volume-outcome effect. Ghaferi et al\textsuperscript{8} evaluated rates of risk-adjusted mortality and complications between high- and low-volume hospitals performing gastrectomy, pancreatectomy, and esophagectomy. That study yielded 2 significant results. First, a volume-outcome effect was shown for high-risk cancer surgery. Second, despite similar rates of major complications, patients undergoing surgery at high-volume centers were 2 to 3 times more likely to survive a complication than those at low-volume centers. Those findings led to further studies examining the association between patient outcomes, hospital volume, and hospital macrosystem characteristics (eg, nurse to patient ratios, intensivist physician staffing), the presence of residency and fellowship training programs, and technology availability.\textsuperscript{8,14} Although prior studies of FTR have reported rates ranging from 15% (trauma) to more than 30% (lower extremity amputations), no authorities have posited an acceptable FTR rate.\textsuperscript{9,15} In our cohort, the FTR rates were 10.9% at high-volume hospitals, we estimate that 487 deaths would have been prevented during our 2-year study period.

Our study adds to the volume-outcome literature by identifying FTR as a clinical pathway contributing to higher mortality at low-volume cardiovascular centers. While the differences in FTR and mortality rates were sizable between high- and low-volume hospitals, the magnitude was less than the 2- to 3-fold variation previously reported for high-risk cancer operations.\textsuperscript{8} One explanation for the attenuation of the volume-mortality relationship in cardiovascular surgery, compared with oncologic operations, is the significant standardization in perioperative processes of care. For example, in patients undergoing CABG, the most recent studies have found a 3-fold increase in the use of antilipid therapy—a cost-effective and well-documented means of reducing perioperative mortality.\textsuperscript{16,17} However, the persistence of the volume-outcome effect suggests that gains made through perioperative measures may have already plateaued. In this event, further strides may be possible through applying similar standardization in postoperative care. For instance, with acute myocardial infarction, treatment delays have been shown to dramatically increase the odds of mortality.\textsuperscript{18-20} Studies of novel hospital-based strategies such as empowering emergency medicine physicians to directly activate the cardiac catheterization laboratory or transmitting triage electrocardiograms to the on-call interventional cardiologist’s smartphone have reduced door-to-balloon time by 30%.\textsuperscript{21,22} In cases of acute stroke, a joint venture between the departments of emergency medicine, neurology, and laboratory services that implemented Toyota’s “Lean” manufacturing principles reduced treatment times by 33%.\textsuperscript{23} One permissive theme in each of these interventions is synergy through interdisciplinary communication.

Our study has some important limitations. First, it may not be widely generalizable given that the study population included only Medicare patients aged 65 years and older. This issue is somewhat lessened by the fact that patients within this age group account for a significant proportion of persons undergoing surgery for AAA, CABG, and AVR. Second, our risk-adjustment model may have been biased by unobserved differences in patient factors. This is an inherent problem of the use of administrative data. To reduce potential bias, we used standard, well-accepted risk-adjustment techniques to minimize statistically significant differences in comorbidities, sex, and race between volume quintiles. Third, as with all administrative data sets, the use of ICD-9-CM codes in determining postoperative complications is somewhat limited. To miti-

### Table 2. Hospital Rates of Complication and Failure to Rescue by Volume, With All Operations Combined

<table>
<thead>
<tr>
<th>Complications</th>
<th>Very Low Volume, %</th>
<th>Very High Volume, %</th>
<th>OR (95% CI)</th>
<th>Complication Incidence</th>
<th>Failure to Rescue</th>
<th>OR (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Medical</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Myocardial infarction\textsuperscript{a}</td>
<td>3.9</td>
<td>4.4</td>
<td>0.90 (0.82-1.00)</td>
<td></td>
<td>19.1</td>
<td>12.9</td>
</tr>
<tr>
<td>Acute renal failure</td>
<td>10.3</td>
<td>10.9</td>
<td>0.94 (0.82-1.07)</td>
<td></td>
<td>18.5</td>
<td>15.0</td>
</tr>
<tr>
<td>VTE</td>
<td>0.8</td>
<td>1.1</td>
<td>0.78 (0.63-0.96)</td>
<td></td>
<td>12.4</td>
<td>9.9</td>
</tr>
<tr>
<td>Pneumonia</td>
<td>2.3</td>
<td>1.7</td>
<td>1.13 (1.12-1.46)</td>
<td></td>
<td>19.9</td>
<td>17.5</td>
</tr>
<tr>
<td>GI tract bleed</td>
<td>1.0</td>
<td>1.0</td>
<td>1.06 (0.93-1.22)</td>
<td></td>
<td>14.2</td>
<td>11.3</td>
</tr>
<tr>
<td>Pulmonary failure</td>
<td>8.8</td>
<td>5.3</td>
<td>1.71 (1.47-1.97)</td>
<td></td>
<td>20.2</td>
<td>21.4</td>
</tr>
<tr>
<td><strong>Surgical</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Postoperative hemorrhage</td>
<td>5.4</td>
<td>6.2</td>
<td>0.87 (0.76-0.99)</td>
<td></td>
<td>11.4</td>
<td>9.0</td>
</tr>
<tr>
<td>Surgical site infection</td>
<td>1.6</td>
<td>1.8</td>
<td>0.86 (0.74-1.00)</td>
<td></td>
<td>13.7</td>
<td>7.6</td>
</tr>
</tbody>
</table>

Abbreviations: GI, gastrointestinal; OR, odds ratio; VTE, venous thromboembolism.

\textsuperscript{a}Excludes patients undergoing coronary artery bypass grafting secondary to the inability to make temporal inferences from Medicare data.
gate this issue, we used prior methods by Lezzeni et al.14,9,10 to choose a subset of complications unlikely to be caused by factors other than the operation at hand. For instance, we excluded mortality from myocardial infarction in patients undergoing CABG. The final list of complications is consistent with published work derived from prospectively collected clinical data.9

Our findings not only reaffirm the previously described volume-outcome effect for cardiovascular surgery but also demonstrate that FTR is an important component of the mechanism underlying this relationship. This suggests that developing a postoperative complication is not irreversibly fatal. Although the critical opportunity may be further along the continuum of patient care than previously thought, it still relies on quickly recognizing and treating complications. In devising quality improvement strategies for low-volume hospitals, future studies should first examine why high-volume hospitals are better able to execute such rescues.

Conclusions

Failure to rescue may be an important component in explaining the mortality differences between high-volume and low-volume hospitals. Although preventing complications is important, to make further gains toward decreasing mortality, clinical leaders should also seek to optimize the recognition and treatment of postoperative complications.

REFERENCES


