Impact of Patient Risk on the Hospital Volume–Outcome Relationship in Coronary Artery Bypass Grafting

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Background: The impact of surgical risk on the relationship between hospital volume and outcomes in coronary artery bypass grafting (CABG) is uncertain. We assessed (1) whether in-hospital mortality rates differ across lower- and higher-volume hospitals by expected surgical risk and (2) whether high-risk patients are more likely to undergo CABG at low-volume centers.

Methods: We used clinical data on 27,355 adults who underwent CABG at 68 hospitals in California between 1997 and 1998. Hospitals were divided into low-volume (n=44), medium-volume (n=19), and high-volume (n=5) categories on the basis of tertiles of annual CABG volume. Using hierarchical logistic regression and log-binomial regression models, we assessed for differences in in-hospital mortality rates across hospital volume categories and the likelihood of CABG being performed in each hospital volume category after adjusting for expected surgical risk.

Results: Differences in adjusted in-hospital mortality rates between low- and high-volume centers rose as the expected risk of in-hospital death increased: 0.8% vs 0.4% at the 20th risk percentile and 3.8% vs 2.5% at the 80th risk percentile (P<.001 for all comparisons). While a similar trend was seen between medium- and high-volume centers, absolute differences were substantially smaller. The likelihood of patients having surgery at a low-volume center also rose significantly with expected surgical risk (relative risk of undergoing CABG at a low-volume center for patients at 80th vs 20th risk percentile, 1.29 [95% confidence interval, 1.14-1.51; P<.001]).

Conclusion: High-risk patients are more likely to undergo CABG at low-volume facilities where their risk of dying is higher.

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Numerous studies have reported that hospitals performing a small number of coronary artery bypass graft (CABG) surgical procedures have higher in-hospital mortality rates than facilities with greater surgical volumes.2-7 As a result, the Leapfrog group—a prominent coalition of more than 130 public and private organizations responsible for providing health care benefits—has identified “evidence-based hospital referral” of patients undergoing complicated surgical procedures (including CABG) as a core patient safety objective.8 It is estimated that in 1997 such a referral strategy would have prevented 258 CABG-related deaths in California alone.9 Yet the relationship between hospital volume and surgical outcomes in CABG is complex and, importantly, may be modified by an individual patient’s expected surgical risk. In 1987, Showstack et al10 demonstrated that differences in in-hospital mortality rates between low- and high-volume centers are accentuated in higher-risk, nonscheduled (ie, emergent) cases of CABG. While we and others have reported similar results,11,12 this finding was not seen in a recent analysis of Medicare data.13 Curiously, 3 of these studies also noted that low-volume centers operated on a greater percentage of patients with high-risk characteristics than high-volume hospitals did,10-12 paradoxically suggesting that low-volume centers are more likely to perform such procedures in difficult cases despite their poorer outcomes.14

In 1995, the California CABG Mortality Report Program (CCMRP)—a public-private venture between the state government, health care purchasers, and hospitals of California—was established to collect clinical data on CABG-related outcomes for the purpose of comparative statewide reporting and assessment.15 Despite its voluntary nature, CCMRP represents the single largest public CABG reporting program in the United States and includes a large number of hospitals with wide variability in surgical volume. This last feature, in fact, makes CCMRP data ideal for exploring the com-
plex relationship between hospital volume and surgical outcome, and the potential interaction of these factors with an individual's baseline level of surgical risk.

Accordingly, we used data from CCMRP to test 2 hypotheses: (1) Do in-hospital mortality rates differ substantially across lower- and higher-volume facilities in patients at high surgical risk, but only minimally in low-risk patients? (2) Are high-risk patients more likely to undergo CABG at lower-volume centers?

**METHODS**

**CCMRP DATA AND STUDY POPULATION**

The CCMRP database contains information voluntarily collected from 82 California hospitals on 30814 patients 18 years or older who underwent isolated CABG (ie, concomitant valve or aortic surgery were excluded) between January 1, 1997, and December 31, 1998. Trained abstractors performed a comprehensive and detailed clinical data extraction. Accuracy of the CCMRP data was assured through an independent, external audit of 1006 medical records at 26 of the participating hospitals including all facilities identified as outliers on the basis of in-hospital mortality rates.

After the removal of unique patient and hospital identifiers, the California Office of Statewide Health Planning and Development provided limited CCMRP data for this study after institutional review board approval. Before release, that agency removed 2217 cases from 3 hospitals that had withdrawn from CCMRP after the study period was concluded. We excluded an additional 1209 cases from 11 hospitals that failed to report complete quarterly data for at least 1 calendar year and 33 cases due to insufficient data elements. Thus, the final study population consisted of 27355 patients at 68 hospitals.

**RISK PREDICTION MODEL**

The risk prediction model was constructed by using 22 clinical variables identified a priori by an expert panel: age, sex, race, surgical priority (ie, elective, urgent, emergent, or salvage), previous heart surgery, left ventricular ejection fraction, extent of left main coronary artery disease, extent of overall coronary artery disease, recent myocardial infarction, percutaneous coronary intervention on the same admission, ventricular arrhythmia, congestive heart failure (ie, New York Heart Association classification), history of angina, severity of angina (ie, Canadian Cardiovascular Society classification), mitral regurgitation, serum creatinine level, hypertension, diabetes mellitus, cerebrovascular disease, peripheral vascular disease, chronic obstructive pulmonary disease, and renal failure. The model was fitted by means of multivariate logistic regression. Initially, the entire data set was divided randomly into 2 sets: a "training set" for model development and a "test set" for assessment of model fit and discrimination. The Hosmer-Lemeshow goodness-of-fit test for the model was nonsignificant ($P = .10$), and the C-index for the model was 0.80, suggesting that the model had good overall predictive discrimination. A full description of the risk prediction model has been published and is available online at http://www.oshpd.cahwnet.gov/HQAD/Outcomes/Clinical.html#CCMRP.

**DATA ANALYSIS**

We used the CCMRP risk prediction model to calculate the expected surgical risk of in-hospital death after CABG—or, specifically, the $logit$ (in-hospital death)—for each patient within the data set. Next, facilities were classified into tertiles of low-, medium-, and high-volume hospitals on the basis of their annual number of isolated CABG surgical procedures in 1997 or 1998. For hospitals with data from 1997 and 1998, a mean annual CABG volume was calculated. We divided hospitals into tertiles for 2 reasons: (1) it allows for easier interpretation of our results and (2) there is a lack of consensus as to the definition of low-, medium-, and high-volume hospitals. Thresholds for identifying low-volume hospitals, for example, have been set at anywhere from 200 to 500 annual cases. To determine whether our results were sensitive to the choice of tertiles as a specific threshold, we repeated our analysis with hospital volume as a continuous variable and found no substantial impact on our overall results.

Analysis of variance tests were used to assess for differences in continuous variables, while $\chi^2$ tests were used to assess for differences in categorical variables across the categories of hospital volume. We used logistic regression to model the relationship between in-hospital mortality and hospital volume, adjusting for the expected surgical risk of in-hospital death. An interaction term was included to assess the independent effect of a patient's expected risk in each category of hospital volume. A 2-level hierarchical model was used to adjust for potential effects of clustering at the facility level. In addition, this model allowed us to determine the specific amount of facility-level variance independently explained by expected risk and hospital volume.

We used log-binomial regression models with robust variance estimators to assess the likelihood of having CABG at a low-volume hospital (compared with a medium- or high-volume hospital) on the basis of the patient's expected risk. This last analysis was performed both with and without emergent and salvage CABG cases. Log-binomial models were used, given the high incidence of this outcome (ie, surgery at a low-, medium-, or high-volume hospital), to directly determine relative risk ratios and their 95% confidence intervals. We specifically chose not to present odds ratios, which could be obtained through logistic regression, since they correlate poorly with relative risk ratios when the outcomes being assessed are common and they may overestimate the association.

Estimating relative risk ratios avoids errors in interpreting the magnitude of association between the likelihood of having CABG at a low-volume hospital and expected surgical risk. (Details on differences between odds ratios and relative risks for these analyses are available on request to the first author.) All analyses were performed with Stata, Version 8 (Stata Corp, College Station, Tex).

**RESULTS**

Forty-four facilities were classified as low-volume centers (mean, 164 annual surgical procedures; range, 44-216), 19 as medium-volume centers (mean, 348; range, 223-561), and 5 as high-volume centers (mean, 1027; range, 625-1283). The general characteristics of the study population are summarized in Table 1. Patients undergoing CABG at low-volume centers were older; more often women; and had a higher prevalence of peripheral vascular disease, severe left-main disease, severe congestive heart failure (New York Heart Association class IV), and emergent or salvage surgical priority. These patients, however, were less likely to have severe angina (Canadian Cardiovascular Society class IV) than those at higher-volume centers. Overall in-hospital mortality rates varied significantly across low-, medium-, and high-volume facilities (3.4% vs 2.6% vs 1.5%, respectively; $P<.001$).

Table 2 summarizes the results of the logistic regression model, showing in-hospital mortality rates across low-, medium-, and high-volume centers stratified at the
Table 1. General Characteristics of Patients Undergoing CABG at Low-, Medium-, and High-Volume Hospitals

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Low-Volume Hospitals (n = 44)</th>
<th>Medium-Volume Hospitals (n = 19)</th>
<th>High-Volume Hospitals (n = 5)</th>
<th>P Value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. (%) of patients</td>
<td>9407 (34.4)</td>
<td>9307 (34.0)</td>
<td>8641 (31.6)</td>
<td>NA</td>
</tr>
<tr>
<td>Annual CABG surgeries, mean ± SD, No.</td>
<td>164 ± 41</td>
<td>348 ± 105</td>
<td>1027 ± 243</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Age, mean ± SD, y</td>
<td>66.7 ± 10.7</td>
<td>66.5 ± 10.7</td>
<td>65.0 ± 10.3</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Sex, % F</td>
<td>28.7</td>
<td>28.1</td>
<td>25.2</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Diabetes mellitus, %</td>
<td>32.7</td>
<td>34.8</td>
<td>32.9</td>
<td>.006</td>
</tr>
<tr>
<td>Cerebrovascular disease, %</td>
<td>10.7</td>
<td>12.0</td>
<td>9.3</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Peripheral vascular disease, %</td>
<td>14.6</td>
<td>14.4</td>
<td>11.2</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Serum creatinine, mean ± SD, mg/dL</td>
<td>1.16 ± 0.81</td>
<td>1.17 ± 0.75</td>
<td>1.15 ± 0.68</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>LV ejection fraction, mean ± SD, %</td>
<td>53.7 ± 14.5</td>
<td>53.2 ± 14.4</td>
<td>55.2 ± 13.9</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Severe left main disease (&gt;90%), %</td>
<td>2.9</td>
<td>2.9</td>
<td>2.2</td>
<td>.004</td>
</tr>
<tr>
<td>Triple-vessel disease, %</td>
<td>75.6</td>
<td>71.9</td>
<td>74.7</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>PCI during same admission, %</td>
<td>5.3</td>
<td>4.5</td>
<td>1.3</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>MI within 21 d, %</td>
<td>25.4</td>
<td>22.0</td>
<td>24.2</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>NYHA class IV, %</td>
<td>14.8</td>
<td>13.5</td>
<td>4.9</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>CCS angina class IV, %</td>
<td>32.8</td>
<td>35.0</td>
<td>45.7</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Severe mitral regurgitation, %</td>
<td>0.5</td>
<td>0.3</td>
<td>0.01</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Ventricular arrhythmias, %</td>
<td>6.3</td>
<td>5.4</td>
<td>4.1</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Emergent or salvage cases, %</td>
<td>9.0</td>
<td>7.5</td>
<td>3.2</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>In-hospital deaths, %</td>
<td>3.4</td>
<td>2.6</td>
<td>1.5</td>
<td>&lt;.001</td>
</tr>
</tbody>
</table>

Abbreviations: CABG, coronary artery bypass grafting; CCS, Canadian Cardiovascular Society; LV, left ventricle; MI, myocardial infarction; NA, not applicable; NYHA, New York Heart Association; PCI, percutaneous coronary intervention.

SI conversion factor: To convert creatinine to micromoles per liter, multiply by 88.4.

*P values comparing differences across low-, medium-, and high-volume hospitals.

Table 2. In-Hospital CABG Mortality Rates at Low-, Medium-, and High-Volume Hospitals Across Risk Percentiles

<table>
<thead>
<tr>
<th>Patient Risk</th>
<th>Low-Volume Hospitals</th>
<th>Medium-Volume Hospitals</th>
<th>High-Volume Hospitals</th>
<th>P Value†</th>
</tr>
</thead>
<tbody>
<tr>
<td>20th Percentile</td>
<td>0.8</td>
<td>0.5</td>
<td>0.5</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>40th Percentile</td>
<td>1.4</td>
<td>0.9</td>
<td>0.9</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>60th Percentile</td>
<td>2.1</td>
<td>1.5</td>
<td>1.5</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>80th Percentile</td>
<td>3.8</td>
<td>3.0</td>
<td>3.0</td>
<td>&lt;.001</td>
</tr>
</tbody>
</table>

Abbreviation: CABG, coronary artery bypass grafting.

*Hospitals are categorized on the basis of tertiles of surgical volume; risk percentiles are based on expected risk of in-hospital death after coronary artery bypass grafting.

†P values comparing differences in in-hospital mortality rates for patients at low- and high-volume hospitals.

‡P values comparing differences in in-hospital mortality rates for patients at low-, medium-, and high-volume hospitals.

20th, 40th, 60th, and 80th percentiles of expected surgical risk. Across these 4 risk percentiles, significant differences in in-hospital mortality rates were seen between low- and high-volume centers, with absolute differences generally increasing at higher levels of expected risk (Figure). For patients at the 20th risk percentile, the absolute difference in in-hospital mortality rates was 0.4% between low- and high-volume centers. This difference rose to 1.3% for patients at the 80th risk percentile. While a similar trend was seen between medium- and high-volume centers, absolute differences in in-hospital mortality rates were substantially smaller.

In the hierarchical regression model, adjustment for expected surgical risk and hospital volume explained nearly all the variation in in-hospital mortality rates across different facilities. Adjusting for a patient’s expected risk alone reduced facility-level variance by 38% (hospital-level variance, or τ², was reduced from 0.14 in the empty model to 0.09), while adding hospital volume categories to the regression model reduced it by an additional 61% (τ² was reduced further from 0.09 to <0.001). Approximately 99% of the total variance in outcomes across facilities was therefore explained by these 2 factors.

The likelihood of a patient having CABG at a low-volume center rose significantly as his or her expected risk of in-hospital death increased (Table 3). The probability of patients at the 20th risk percentile undergoing surgery at a low-volume center was 29.4% compared with 32.1%, 34.7%, and 38.5% for patients at the 40th, 60th, and 80th risk percentiles, respectively. For patients at the 80th risk percentile, the relative risk of undergoing CABG at a low-volume center was 1.29 times that of patients at the 20th risk percentile (95% confidence interval, 1.14-1.51; P <.001). No substantial changes were seen in these results when the analysis was repeated after exclusion of emergent and salvage CABG cases (Table 3).
Our study has 3 important findings. First, we found that absolute differences in in-hospital mortality rates between low-, medium-, and high-volume hospitals rose with increasing levels of expected surgical risk. This occurred even though relative differences in in-hospital mortality actually declined at higher surgical risk levels (despite remaining statistically significant). This finding is consistent with several previous studies. Second, our analysis of facility-level variance in the hierarchical regression model suggests that the variation in in-hospital mortality rates across facilities is driven primarily by hospital differences in CABG volume and expected surgical risk. And third, we found that higher-risk patients were more likely than lower-risk patients to undergo their CABG at low-volume hospitals. To our knowledge, this association has not been specifically reported for CABG by means of multivariate models, although earlier data support this possibility.

What do these results suggest overall? It appears that patients who are most likely to benefit from having CABG at high-volume hospitals are the ones least likely to have surgery at such a center. That is, natural referral patterns in California during the study period generally steered high-risk patients to low-volume centers or low-risk patients to high-volume centers. This last result may suggest that the variation in in-hospital mortality rates across facilities is driven primarily by hospital differences in CABG volume and expected surgical risk. And third, we found that higher-risk patients were more likely than lower-risk patients to undergo their CABG at low-volume hospitals. To our knowledge, this association has not been specifically reported for CABG by means of multivariate models, although earlier data support this possibility.

Although merely speculative, a few potential explanations exist as to why this finding may occur in nonemergent cases. First, given a relatively lower number of cases from which to select, low-volume hospitals may be less inclined to turn down high-risk cases. This may be especially important for hospitals struggling to compete in a constrained marketplace given the lucrative nature of cardiothoracic-related services. Alternatively, high-volume centers may be operating on a large number of low-risk patients who could be treated more conservatively. To address issues of proper utilization of CABG at all hospitals, future studies attempting to correlate surgical volume and outcomes will need to adjust for surgical appropriateness in an ideal world, the measurement of surgical appropriateness would go hand in hand with assessments of hospital volume and other quality measures such as risk-adjusted mortality rates.

Second, higher surgical volumes at specialized centers may simply reflect the natural consequences of Luft and coworkers’ “selective referral” hypothesis. Although most earlier studies have assumed that higher hospital volumes are causally linked to better outcomes (ie, the “practice makes perfect” hypothesis), Luft and colleagues found that at least part of the differences in outcomes are actually due to the fact that better hospitals attract more patients by either physician referral or self-referral. Finally, Ballard et al...
demonstrated that risk-adjusted mortality rates of hospitalized Medicare patients at 7 large, tertiary-care hospitals fell in comparison with predicted mortality rates as referral distances increased. Their finding suggests that patients with the opportunity and desire to be referred may be “healthier” in general because of a variety of other factors, such as higher socioeconomic levels.

Our findings are consistent with those recently reported by Peterson and colleagues using the Society for Thoracic Surgery’s National Cardiac Database. In that study, the largest absolute differences in in-hospital mortality were in patients 65 years or older and those with higher expected surgical risks. We expanded on this finding by reporting that adjustment for expected surgical risk in addition to hospital volume explained nearly all facility-level variation in the hierarchical regression model. We also went a step further and determined the likelihood of a patient undergoing CABG at a low-volume hospital based on his or her expected surgical risk. While such a trend (i.e., higher-risk patients being operated on at lower-volume hospitals) was noted in the Peterson et al study, no specific analyses of this phenomenon were performed.

Our analysis has some important limitations. First, this was an observational study. As with other studies on hospital volume and outcome, we cannot establish definitive causal relationships between higher CABG volumes and improved in-hospital mortality rates. Second, we focused on in-hospital death as our primary outcome and could not examine 30-day or longer-term mortality rates. Third, although the majority of CABG surgical procedures performed in California between 1997 and 1998 were included in CCMRP, 39 hospitals chose not to participate and data from 14 additional hospitals were excluded from our analysis because of insufficient records. Publicly released discharge records from nonparticipating facilities suggest similar unadjusted in-hospital rates despite a lower number of annual CABG surgical procedures on average (approximately 41 fewer cases per year).

Fourth, our results may not be easily generalizable to other areas of the United States because of widespread differences in health care delivery systems. California, for example, does not have certificate of need regulation. Lack of statewide certificate of need regulation has been linked to a greater prevalence of lower-volume hospitals and higher in-hospital mortality rates in CABG. Finally, we were unable to account for the impact of other quality indicators for CABG, such as surgeon volume or hospital size and teaching status.

The relationship between hospital volume and in-hospital death is complex in CABG. It appears to be affected by a patient’s expected surgical risk, with higher-risk patients more likely to benefit from care at centers with greater surgical volumes. Nevertheless, higher-risk patients may be more likely to have surgery at low-volume centers despite worse outcomes at these facilities. Future research is needed to better understand reasons for this finding and its relationship to the appropriateness of CABG across hospital volume categories. To maximize the immediate impact of referral strategies on patient safety, supporters of regionalization policy for CABG may consider focusing initially on the transfer of high-risk patients to higher-volume facilities.

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