Do Hospitals and Surgeons With Higher Coronary Artery Bypass Graft Surgery Volumes Still Have Lower Risk-Adjusted Mortality Rates?
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Background—Studies that are the basis of recommended volume thresholds for CABG surgery are outdated and not reflective of recent advances in the field. This study examines both hospital and surgeon volume-mortality relations for CABG surgery through the use of a population-based clinical data set.

Methods and Results—Data from New York’s clinical CABG surgery registry from 1997 to 1999 (total number of procedures, 57,150) were used to examine the individual and combined impact of annual hospital volume and annual surgeon volume on in-hospital mortality rates after adjusting for differences in severity of illness. Significantly lower risk-adjusted mortality rates occurred above all annual hospital volume thresholds between 200 and 800 and above all surgeon volume thresholds between 50 and 200. The number needed to treat (NNT) at higher-volume providers to avoid a death was minimized for a hospital threshold volume of 100 (NNT = 50) and a surgeon threshold volume of 50 (NNT = 118). The risk-adjusted mortality rate (RAMR) for patients undergoing surgery performed by surgeons with volumes of ≥ 125 in hospitals with volumes of ≥ 600 was 1.89%. The RAMR was significantly higher (2.67%) for patients undergoing surgery performed by surgeons with volumes of < 125 in hospitals with volumes of < 600.

Conclusions—Higher-volume surgeons and hospitals continue to have lower risk-adjusted mortality rates, and patients undergoing surgery performed by higher-volume surgeons in higher-volume hospitals have the lowest mortality rates. (Circulation. 2003;108:795-801.)

Key Words: bypass ■ mortality ■ risk factors

There have been numerous studies in the past two decades that have documented that hospitals and surgeons that perform higher volumes of specific surgical procedures have better patient outcomes. CABG surgery is one of the most commonly performed and frequently studied procedures in the medical literature, as well as one of the procedures for which volume-mortality relations have been studied and identified.1–15 Some of these studies have been conducted in New York State,6–8 and one of the New York studies is the basis for the Leapfrog Group’s recent recommendation that payers contract with hospitals that have an annual volume of isolated CABG surgery procedures (CABG surgery without any other major open heart procedures in the same admission) of at least 500.7 However, the American College of Cardiology recommends that hospitals with annual volumes of < 100 be closely monitored.16

This is a good time to revisit the volume-mortality relation for CABG surgery because the data in the study on which the Leapfrog recommendations are based are now old, and many advances in the quality of CABG surgery have occurred in the interim. For example, the in-hospital mortality rate for patients undergoing isolated CABG surgery in New York has fallen from 3.52% in 1989 to 2.24% in 1999.17,18 It is possible that these advances have eliminated the need to perform high volumes of CABG surgery to obtain optimal outcomes. The purpose of this study was to examine the volume-mortality relation for hospitals and surgeons in New York State from 1997 to 1999, using clinical data from New York’s Cardiac Surgery Reporting System (CSRS). As part of the study, we will also examine the interaction effect of hospital volume and surgeon volume on risk-adjusted mortality rates for CABG surgery.
Methods

Database and Patients
The database used for the study is New York State’s CSRS, which consists of detailed clinical information about every patient undergoing CABG surgery in New York State since January 1, 1989. CSRS contains numerous demographic variables; patients’ clinical risk factors and complications; dates of admission, surgery, and discharge; and discharge status. Patients included in the study were all 57,150 patients who underwent isolated CABG surgery in New York State and were discharged between January 1, 1997, and December 31, 1999.

Analysis
The bivariate relation between in-hospital CABG surgery mortality rates and each of the patient risk factors contained in the registry was examined by means of χ² tests after creating categories for the continuous variables of age and ejection fraction. Risk factors that were significantly related to death were used as candidate independent variables in a stepwise logistic regression model, with a level of significance of 0.05. The binary dependent variable was hospital discharge status.

Hospital volume thresholds for CABG surgery (in units of 100, between 100 and 800) were created, and the percentage of patients and number of hospitals with annual volumes on either side of each threshold were calculated along with the 3-year observed mortality rate for hospitals on either side of each threshold. Also, the 3-year predicted mortality rate was calculated for each hospital volume group by summing the predicted probabilities of death of all of its patients obtained from the logistic regression model and then averaging over the number of patients. Risk-adjusted mortality rates were calculated for volume groups on either side of the threshold by dividing the observed mortality rates for the group by its predicted mortality rate and then multiplying the quotient by the overall 3-year mortality rate for all patients (2.20%). For each volume threshold, the number of additional patients needed to treat (from hospitals with volumes below the threshold) by hospitals with volumes in excess of the threshold to save one life was calculated along with the number of deaths avoidable (if all patients were treated in hospitals with volumes above the threshold) and the percentage of all deaths that were avoidable. The same exercise was then repeated for surgeon volume thresholds.

To test the interaction effects of hospital volume and surgeon volume, annual surgeon volume and annual hospital volume were each separated into 2 groups, and the resulting 4 hospital volume/surgeon volume groups were then compared by calculating the risk-adjusted mortality rate for each group. In another set of analyses, the group with the highest hospital and surgeon volumes was used as a reference in multivariable analyses, with the other 3 groups as indicator variables. These multivariable analyses were conducted by using 3 methods—logistic regression analysis, generalized estimating equations (GEE), and hierarchical logistic regression analysis. The last two methods were used to account for clustering of the observations within hospitals. All analyses except the hierarchical model were conducted with the use of SAS Version 8.2 (SAS Institute). The software package HLM5 (Scientific Software International) was used for the hierarchical model.

Results
Table 1 indicates that significant predictors of death for patients with isolated CABG surgery in New York in 1997 to 1999 include increasing age, female gender, lower ejection fractions, a recent myocardial infarction, left main artery disease, compromised hemodynamic state (shock, hemodynamic instability, cardiopulmonary resuscitation), a large group of comorbidities, and previous open heart operations.

Table 2 presents, for various annual volume thresholds, the percentage of New York State patients undergoing CABG surgery in hospitals below the threshold, the number of hospitals above and below the threshold, and the observed and predicted mortality rates for hospitals with volumes above and below the threshold. Three-year observed mortality rates were 2.91% for hospitals with volumes <100, compared with 2.13% for hospitals with volumes >800.

Table 3 indicates that the risk-adjusted mortality rate was significantly higher for hospitals below the volume threshold than for hospitals above the threshold for all thresholds except 100. The differential in risk-adjusted mortality rates between “high-volume” and “low-volume” hospitals decreased as the volume threshold increased, as evidenced by the rising number of patients needed to treat (NNT). The NNT increased from 50, with a volume threshold of 100 to 361, with a volume threshold of 800. The number of deaths avoidable was a maximum (n=110) for a threshold of 600. The percentage of deaths avoidable was highest for the lower thresholds, with a maximum of 48% at a volume threshold of 100 and a minimum of 12% at a volume threshold of 800.

Table 4 presents the same information for surgeon volumes as was presented in Table 2 for hospital volumes. For the most part, the observed mortality rate decreased with increasing surgeon volume, with a mortality rate of 2.92% for patients undergoing surgery performed by surgeons having annual volumes <25, compared with a mortality rate of 1.93% for patients undergoing surgery performed by surgeons with annual volumes >200.

Table 5 indicates that the risk-adjusted mortality rate was significantly higher for surgeons with volumes below the threshold than for surgeons with volumes above the threshold for all thresholds except 25. The differential in risk-adjusted mortality rate remained relatively constant for all thresholds, and the number of patients who would have to be shifted from hospitals below the volume threshold to hospitals above the threshold varied from a low of 118 for a threshold of 50 to a high of 303, for a threshold of 25. The number of deaths avoidable if patients treated by surgeons with volumes below the threshold were treated by surgeons with volumes above the threshold increased steadily with higher thresholds. Except for the lowest threshold, the percentage of deaths avoidable remained fairly constant, ranging from 20% to 28%.

Table 6 demonstrates that more than half of all patients (52%) underwent surgery performed by surgeons with annual volumes of ≥125 in hospitals with annual volumes ≥600. The other 3 groups contained between 12% and 18% of all patients. Risk-adjusted mortality rates for hospital volume/surgeon volume ranges were similar to the observed rates, with a low of 1.89% for patients with the highest volume surgeons and hospitals and a high of 2.67% for patients with the lowest-volume surgeons and lowest-volume hospitals. Patients undergoing surgery performed by higher-volume surgeons in higher-volume hospitals had significantly lower risk-adjusted mortality rates than patients in any of the other 3 volume groups, as evidenced by confidence intervals that did not overlap.

The odds of death in the 3 groups of patients with either low-volume surgeons, low-volume hospitals, or both ranged from 1.31 to 1.47 times the odds of patients treated by
higher-volume surgeons in higher-volume hospitals, and the maximum ratio of 1.47 occurred for patients undergoing surgery performed by lower-volume surgeons in lower-volume hospitals. All of these odds ratios were significantly greater than 1. When the results were adjusted for clustering by using GEE, the confidence intervals widened, but all odds ratios remained significant. Use of the hierarchical model yielded similar odds ratios (two were larger than their counterparts in the other two methods), but the OR for higher volume surgeons in lower-volume hospitals (1.30) was no longer significant.

**Discussion**

No recent volume-mortality studies for CABG surgery have had access to population-based data, used entirely clinical data, and tested the impact of both hospital and surgeon volume on mortality rates as well as the impact of the interaction of these two volume measures on mortality rates. The findings of our study, based on all 57,150 patients who underwent isolated CABG surgery in New York State between 1997 and 1999, were that both higher hospital volume and higher surgeon volume are still associated with lower risk-adjusted mortality rates and that there is an added benefit to undergoing surgery performed by a high-volume surgeon in a high-volume hospital.

The differential in risk-adjusted mortality rates between “low-volume” and “high-volume” hospitals was highest for lower hospital volume thresholds, so the number needed to treat to avoid a single death was lower for lower-volume thresholds. However, because fewer patients were treated in “low-volume” hospitals when a low volume threshold was used, the number of deaths avoidable was lowest for low-volume thresholds. Thus, there is a clear tradeoff between number needed to treat and deaths avoidable.

With regard to surgeon volume thresholds, there was also a strong increase in number of deaths avoidable with increasing threshold volume. However, the number needed to treat...
remained more constant across different volume thresholds. For example, for a surgeon volume threshold of 75, an additional 151 people need to be treated by “high-volume” surgeons to avoid a death, and 38 deaths are avoided, whereas a surgeon volume threshold of 150 results in needing to treat 198 additional people in “high-volume” hospitals to avoid a death, and 125 deaths are avoided.

Other analyses were conducted to test the impact of interactions between hospital volume and surgeon volume on risk-adjusted mortality rates. When annual hospital volume was split at 600 and annual surgeon volume was split at 125 to obtain 4 hospital volume/surgeon volume groups, we found that the lowest risk-adjusted mortality rate (1.89%) was for patients undergoing CABG surgery performed by surgeons with annual volumes of at least 125 in hospitals with annual volumes of at least 600. Also, patients undergoing surgery performed by the lower-volume surgeon group in the lower-volume hospital group had the highest mortality rates (2.67%, or an increase of 41% compared with 1.89%).

It should also be mentioned that when “volume” was defined as annual open heart surgery volume (including valve procedures and other open heart surgery, as well as CABG surgery in conjunction with valve surgery), the volume-mortality results were equally as strong, undoubtedly as a result of the fact that the correlations between isolated CABG surgery annual volume and annual open heart surgery volume were very high (0.96 for hospitals and 0.95 for surgeons). However, this raises the question of whether any effort to restrict credentialing should be based on total isolated CABG surgery volume or total volume of open-heart procedures (or CABG procedures done with or without concomitant valve surgery). The findings mentioned above would seem to suggest that total open heart procedures would be preferable.

A caveat of the study is that it is based in a region with Certificate of Need regulations that have led to higher average volumes than are present in most areas of the country. Thus, the number of patients undergoing surgery in hospitals with very low volumes is limited despite the very large number of patients in the study.
TABLE 4. Observed and Predicted In-Hospital Mortality Rates by Annual Surgeon Volume Among Patients Who Underwent Isolated CABG Procedures in New York State, 1997 to 1999 (n=57,150)

<table>
<thead>
<tr>
<th>Definition of LVS: Annual Volume Less Than:</th>
<th>% of Patients Treated by LVS</th>
<th>No. of Surges per Year</th>
<th>3-Year No. of Deaths (Observed Mortality Rate, %)</th>
<th>Predicted Mortality Rate, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LVS</td>
<td>HVS</td>
<td>LVS</td>
<td>HVS</td>
</tr>
<tr>
<td>25</td>
<td>1.08</td>
<td>13–25</td>
<td>137–148</td>
<td>18 (2.92)</td>
</tr>
<tr>
<td></td>
<td>5.36</td>
<td>38–46</td>
<td>116–125</td>
<td>96 (3.14)</td>
</tr>
<tr>
<td>75</td>
<td>9.96</td>
<td>49–61</td>
<td>102–112</td>
<td>166 (2.92)</td>
</tr>
<tr>
<td>100</td>
<td>17.94</td>
<td>66–78</td>
<td>86–93</td>
<td>293 (2.86)</td>
</tr>
<tr>
<td>125</td>
<td>29.86</td>
<td>85–101</td>
<td>65–76</td>
<td>468 (2.74)</td>
</tr>
<tr>
<td>150</td>
<td>43.33</td>
<td>105–119</td>
<td>47–56</td>
<td>620 (2.50)</td>
</tr>
<tr>
<td>175</td>
<td>55.79</td>
<td>121–134</td>
<td>34–40</td>
<td>768 (2.41)</td>
</tr>
<tr>
<td>200</td>
<td>65.95</td>
<td>130–145</td>
<td>23–31</td>
<td>884 (2.35)</td>
</tr>
</tbody>
</table>

LVS indicates low-volume surgeon; HVS, high-volume surgeon; statewide mortality rate was 2.20% from 1997 to 1999.

Also, New York has a very active Cardiac Advisory Committee that oversees the quality of cardiac care in the State and the Department of Health has reported CABG surgery outcomes to hospitals, surgeons, and the public for more than a decade, and this practice has arguably contributed to overall quality of care.\(^23^–^28\) It is also conceivable that it has affected the volume-mortality relation in a manner that is different from other states. However, if this is true, it seems more likely that the relation is weaker in New York than elsewhere because quality improvement efforts should benefit lower volume providers because they have the most room for improvement.

Third, as discussed in numerous other studies of surgical volume-mortality relations, the demonstrated association between volume and mortality does not guarantee that there is a causal relation whereby if patients in lower-volume hospitals instead underwent surgery at higher-volume hospitals, their outcomes would be similar to those in the higher-volume hospitals. A competing hypothesis is the “selective referral hypothesis,” whereby high-volume hospitals have high volumes because they attract more patients who are aware of their high quality.\(^29\)

Fourth, we used in-hospital mortality rate as the outcome measure. We were unable to obtain timely data on deaths outside of the hospital within a short period (eg, 30 days) of discharge, but if these data had been available it would have been preferable to use an outcome of in-hospital mortality or death within 30 days of discharge because hospital admissions are decreasing in length and deaths shortly after discharge after CABG surgery are frequently related to complications of the recent surgery. It would also have been desirable to include other risk-adjusted adverse outcome measures such as surgical complications. Although complications are reported in the registry, it is much more difficult to confirm their reporting accuracy than it is for in-hospital mortality rates. However, there is some evidence of lower complication rates for higher-volume providers. For example, the prevalence of sternal wound infection in the 1997 to 1999 New York registry for patients undergoing CABG surgery performed by surgeons with annual volumes of ≥125 in hospitals with annual volumes of ≥600 was 0.84%, compared with a prevalence of 1.35% for patients undergoing CABG surgery performed by surgeons with annual volumes of <125 in hospitals with annual volumes of <600

TABLE 5. Deaths Potentially Avoidable if Applying Selective Referral to High-Volume Surgeons for Isolated CABG Procedures in New York State, 1997 to 1999 (n=57,150)

<table>
<thead>
<tr>
<th>Definition of LVS: Annual Volume Less Than:</th>
<th>Risk-Adjusted Mortality Rate, %</th>
<th>NNT (95% CI)</th>
<th>No. of Deaths Avoidable in NYS (95% CI)</th>
<th>% of Deaths Avoidable</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LVS</td>
<td>HVS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>2.53</td>
<td>2.20</td>
<td>303 (66, 128)</td>
<td>2 (9, 9)</td>
</tr>
<tr>
<td></td>
<td>3.01*</td>
<td>2.16</td>
<td>118 (68, 242)</td>
<td>26 (7, 45)</td>
</tr>
<tr>
<td>75</td>
<td>2.80*</td>
<td>2.14</td>
<td>151 (90, 460)</td>
<td>38 (12, 63)</td>
</tr>
<tr>
<td></td>
<td>2.69†</td>
<td>2.09</td>
<td>167 (107, 379)</td>
<td>61 (27, 96)</td>
</tr>
<tr>
<td>100</td>
<td>2.63†</td>
<td>2.01</td>
<td>161 (111, 289)</td>
<td>106 (51, 153)</td>
</tr>
<tr>
<td></td>
<td>2.49†</td>
<td>1.98</td>
<td>198 (133, 392)</td>
<td>125 (63, 187)</td>
</tr>
<tr>
<td>125</td>
<td>2.46†</td>
<td>1.89</td>
<td>175 (123, 303)</td>
<td>182 (105, 259)</td>
</tr>
<tr>
<td>150</td>
<td>2.39†</td>
<td>1.86</td>
<td>190 (130, 356)</td>
<td>198 (106, 291)</td>
</tr>
</tbody>
</table>

LVS indicates low-volume surgeon; HVS, high-volume surgeon; NYS, New York State; and NNT, No. needed to treat by high-volume surgeons to avoid 1 death. Statewide mortality rate was 2.20% from 1997 to 1999.

*Risk-adjusted mortality rate of patients treated by LVS was significantly higher than that of patients treated by HVS, P<0.01. †P<0.001.
related to the structure of the setting or the processes used in outcomes than others, and to the extent that these reasons are to find out why some providers have substantially better outcomes.\textsuperscript{31}

We must regard volume as a transitional, crude, proxy while high-volume hospitals that provide relatively poor care.\textsuperscript{32,33} It is also important to note that although the present study is based on data as recent as others in the literature, it is based on 4- to 6-year-old data, and CABG surgery techniques are changing, especially with regard to the increasing use of off-pump surgery. Also, the proliferation of coronary stenting has contributed to a reduction in the total number of CABG procedures being performed. The reason why more recent data have not been used is that the time required to confirm the accuracy of New York Registry data are considerable because of medical record audits and subsequent resubmissions of data by hospitals. However, it should be noted that despite the large increase in the percentage of off-pump cases done in 1999 (from 9.6\% in 1998 to 20.4\% in 1999), the impact of volume on mortality rates was as strong in 1999 as in 1998. Also, it should be noted that although the volume of CABG surgery has decreased in the last few years, it has leveled off somewhat, with the volume in 2000 in New York being slightly higher than in 1999.

It is also important to emphasize that even if mortality rates were reduced if patients were channeled to higher-volume hospitals, there are numerous challenges in implementing such a policy, including travel time constraints, unwillingness of patients to travel to distant hospitals, the loss of continuity with the primary physician, and the potential detrimental effects of further reducing volumes at low-volume hospitals so that their performance with emergency patients who cannot be transported to a distant hospital deteriorates.\textsuperscript{2,12,30,31}

Thus, although it may be wise to judiciously channel some patients to higher-volume hospitals, we must realize that there are low-volume hospitals that provide excellent care and high-volume hospitals that provide relatively poor care.\textsuperscript{32,33} We must regard volume as a transitional, crude, proxy while we attempt to develop clinical databases that will enable us to obtain risk-adjusted outcome rates.\textsuperscript{31–33} Furthermore, we need to find out why some providers have substantially better outcomes than others, and to the extent that these reasons are related to the structure of the setting or the processes used in the provision of care, we must attempt to transfer this capability to all providers.\textsuperscript{31–33}

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