Influence of Hospital Procedural Volume on Care Process and Mortality for Patients Undergoing Elective Surgery for Mitral Regurgitation

James S. Gammie, MD; Sean M. O’Brien, PhD; Bartley P. Griffith, MD; T. Bruce Ferguson, MD; Eric D. Peterson, MD

Background—Few studies have examined the procedural volume–outcome relationship for heart valve surgery. None have examined process of care factors that may be mediators of this association.

Methods and Results—This was a retrospective review of outcomes for 13,614 patients having elective surgery for mitral regurgitation between 2000 and 2003 in 575 North American centers participating in the Society of Thoracic Surgeons National Cardiac Database. Hospital annual mitral valve volume varied widely from 22 cases per year in the lowest-volume quartile to 394 in the highest. Unadjusted mortality rates decreased from 3.08% in the lowest-volume category to 1.11% in the highest-volume category. The risk-adjusted odds ratio for mortality in the highest-volume category compared with the lowest was 0.48 (95% confidence interval 0.28 to 0.82). The rates of mitral valve repair increased from 47.7% in the lowest-volume quartile to 77.4% in high-volume hospitals (P<0.0001). Similarly, the rates of bioprosthetic valve use for patients aged >65 years rose from 59% in the lowest-volume quartile to 75% in the highest-volume quartile (P=0.0002). The association between volume and mortality was still significant but attenuated when the risk adjustment was modified to adjust for mitral valve repair versus replacement.

Conclusions—Hospital procedural volume was associated with higher frequency of valve repair, higher frequency of prosthetic valve usage in elderly patients, and lower adjusted operative mortality. Differences in care process may contribute to improved outcomes in higher-volume centers. (Circulation. 2007;115:881-887.)

Key Words: mitral valve • valves • database • outcomes • surgery

The association between hospital procedural volume and outcomes for a variety of surgical procedures has been studied extensively, with most reports demonstrating improved clinical outcomes in high-volume centers. The volume–outcome effect is most pronounced for high-complexity, less commonly performed procedures. Despite this interest in procedural volume as a quality metric, volume–outcomes studies in heart valve surgery to date have been based on administrative data, have largely focused on aortic valve surgery, and have not examined care processes that might explain the volume–outcome association. In the United States, >42,000 patients per year require mitral valve surgery. We used clinical data from the Society of Thoracic Surgeons National Cardiac Database (STS NCD) to assess the relationship of hospital mitral valve procedural volume with 2 care processes and 5 outcomes for patients undergoing elective surgery for isolated mitral regurgitation. Care processes were (1) use of mitral valve repair instead of replacement and (2) use of bioprosthetic instead of mechanical prostheses for valve replacement in the elderly. A detailed risk-adjustment model was used to assess the association between hospital volume and each outcome while adjusting for differences in patient case mix across participating hospitals.

Clinical Perspective p 887

Methods

The STS NCD is a voluntary cardiac surgery database established in 1989 to support national quality improvement efforts. The database currently collects 300 variables on each patient undergoing cardiac surgery at 600 centers performing cardiac surgery in North America. Clinical sites enter data using uniform definitions and certified software systems. Core data elements can be accessed at http://www.sts.org/doc/8428. Data are warehoused and analyzed at the Duke Clinical Research Institute. The validity of the STS NCD has been confirmed by comparisons of STS data with regional data and by a recent independent comparison with Medicare data.

Patient Population

Patients undergoing an elective mitral valve operation at an STS-participating institution between January 2000 and December 2003 were included in the present analysis if they met the following inclusion criteria: at least moderate mitral regurgitation, absence of mitral stenosis, no previous cardiac surgery, no cardiogenic shock preoperatively or...
myocardial infarction within 6 hours, and no concomitant surgery other than tricuspid valve procedures. These criteria were intended to identify a population of patients amenable to mitral valve repair.

**Outcomes**

The primary outcome was operative mortality, defined as in-hospital or 30-day mortality, whichever was greater. Additional outcomes included 4 in-hospital complications (stroke, reoperation for any reason, renal failure, and mechanical ventilation for >24 hours), and a composite end point that consisted of operative mortality and the 4 complications listed above. We also examined the frequency of mitral valve repair instead of replacement and the frequency of bioprosthetic valve use in older patients (>65 years of age).

**Mitrail Surgery Case Volumes**

Hospital average annual mitral surgery volumes were assigned to hospitals by counting the total number of mitral operations submitted to the STS between January 2000 and December 2003 and dividing by the number of calendar years for which the hospital submitted any data during the same time period. This definition of mitral surgery volume counts all mitral surgery operations submitted to the STS and is not limited to patients who met the eligibility criteria described above (ie, not limited to first-time elective surgery for mitral regurgitation). For display purposes, average annual mitral volumes were categorized into 4 quartiles (1 to 35, 36 to 70, 71 to 140, and >140 mitral operations per year). These cut points were chosen to achieve an approximately equal number of patients in each category.

**Statistical Analysis**

Patient preoperative characteristics, care processes, and outcomes were compared across categories of hospital volume by calculating means and interquartile ranges of continuous variables and frequencies of categorical variables. Within each category, a summary measure of patient case mix was obtained by calculating the average predicted probability of mortality based on the STS aortic/mitral valve replacement model. This model was reestimated specifically for use in the present study population, which excludes aortic valve operations and includes both mitral valve repairs and replacements. Trend tests across categories were conducted by assigning equally spaced integer scores to the volume categories and then entering these scores into a regression model (linear regression for continuous outcomes; logistic regression for binary outcomes). Generalized estimating equations methodology was used to account for the clustering of observations within hospitals.

The association between category of hospital average mitral surgery volume and each end point was assessed in a manner that adjusts for case mix by fitting random effects logistic regression models. Patient variables were selected on the basis of previous STS analyses and consisted of the following: age, gender, race, body mass index, smoking, renal failure, hypertension, endocarditis, chronic lung disease, cerebrovascular accident, cerebrovascular disease, peripheral vascular disease, recent myocardial infarction, congestive heart failure, angina, arrhythmia, New York Heart Association class, and ejection fraction. These models included 1 or more terms for hospital volume, plus random effects for hospitals. Random hospital effects allow for between-hospital variation in mortality rates due to factors other than volume. The random effects represent the unmeasured factors that might systematically increase or decrease the mortality of all patients within a hospital. The amount of residual variation in mortality not explained by volume was quantified by examining the variance of these random effects. Trend tests were conducted by assigning equally spaced integer scores to the volume categories and entering these into the model as a single linear term. Categorical analyses were also performed by including a set of category indicator variables for the volume categories.

In addition to assessing the association between mitral volume and outcomes, we also used hierarchical logistic regression to assess the association between mitral volume and the frequency of valve repair (rather than replacement) and the frequency of bioprosthetic (rather than mechanical) valve usage among patients aged ≥65 years. In these analyses, the dependent (outcome) variable was a binary indicator of the type of operation (eg, 1=repair, 0=replacement). The association between hospital volume and each dependent variable (mortality; type of operation) was summarized by the presentation of odds ratios that compare a hypothetical average hospital in each volume category to an average hospital in the lowest-volume category.

In addition to categorizing hospital volume, we also performed analyses in which volume was treated as a continuous explanatory variable. A smooth estimate of the relationship between volume and each dependent variable was obtained by fitting semiparametric logistic regression models with the SAS PROC GAM procedure. In these models, the effect of hospital volume was estimated nonparametrically via smoothing splines with 2 degrees of freedom. Each of the other explanatory variables was modeled parametrically.

The results of the semiparametric regression analyses were displayed graphically by plotting risk-adjusted mortality and repair rates across categories of hospital volume. For these analyses, risk-adjusted mortality was defined as the estimated probability of mortality for a hypothetical patient having risk factors that loosely corresponded to “average risk.” The risk-adjusted repair rate was defined analogously with use of the model that predicts repair as a function of patient characteristics and hospital volume. In the plots depicting the semiparametric regression results, we also superimposed results from a logistic regression analysis in which hospital volume was categorized into 15 volume categories that contained an approximately equal number of hospitals.

Finally, our analysis also quantified residual variation in care processes and risk-adjusted mortality rates (ie, the amount of between-hospital variation in valve repair and risk-adjusted mortality rates not explained by hospital volume). To estimate the proportion of variation explained by hospital volume, we estimated the variance of the random effects distribution in the hierarchical model described above and in similar models that excluded hospital volume from the set of predictor variables. We also estimated the proportion of hospitals in the lowest-volume category that had lower risk-adjusted mortality rates than an average hospital in the highest-volume category.

The authors had full access to and take full responsibility for the integrity of the data. All authors have read and agree to the manuscript as written.

**Results**

Between January 2000 and December 2003, 84,497 mitral valve operations were performed at 575 STS NCD-participating hospitals. Hospitals in the lowest-volume category performed an average of 22 mitral operations per year, whereas those in the highest-volume category performed 394 operations per year. The present analysis focused on 13,614 patients who had elective isolated mitral valve surgery for mitral regurgitation (Figure 1). Table 1 displays hospital and patient characteristics as a function of hospital procedural...
volume. Patients undergoing mitral valve surgery in low-volume hospitals (ie, those performing 1 to 35 mitral valve operations per year) were somewhat more likely to have diabetes mellitus and hypertension and to be female than those operated on in high-volume hospitals (>140 mitral operations per year). Fewer asymptomatic (New York Heart Association class I) patients were operated on in low-volume compared with high-volume hospitals, although there was no evidence of a trend across categories of hospital volume. No difference existed among volume categories in the incidence of infective endocarditis, renal failure, or cerebrovascular disease or in ejection fraction. Predicted mortality was slightly higher in the low-volume category.

Mortality and Hospital Procedural Volume
The overall observed mortality rate for all patients having elective mitral valve surgery for mitral regurgitation was 2.12% (289 deaths). Unadjusted mortality rate decreased from 3.08% in the lowest-volume category to 1.11% in the highest-volume category (Table 2). Rates of renal failure, prolonged mechanical ventilation, and the composite end point (mortality and major morbidity) decreased significantly with increasing hospital volume.

After adjustment for preoperative clinical risk, rates of operative mortality decreased across categories of increasing mitral surgery volume (Figure 2). The adjusted odds ratio for mortality in the highest-volume category compared with the lowest-volume category was 0.48 (95% confidence interval 0.28 to 0.82; \( P = 0.0043 \) for test of trend). A smooth estimate of the relationship between hospital volume and risk-adjusted operative mortality is illustrated in Figure 3. Also depicted are the results of a categorical analysis in which hospitals were grouped into 15 volume categories. Risk adjustment resulted in no significant differences in measures of morbidity across the volume categories, except for prolonged ventilation, which was marginally significant (Table 3).

In our hierarchical models, hospital annual volume accounted for \( \approx 14\% \) of the between-hospital variation in estimated risk-adjusted mortality rates, whereas 86% of the variation in risk-adjusted mortality rates was not explained by volume. When hospital volume was excluded from the model, 26% (95/361) of the hospitals in the lowest-volume category (1–35 procedures/yr) had a higher mortality rate compared with high-volume hospitals, and 33% (120/361) had a higher rate compared with medium-volume hospitals. These differences were not statistically significant (Figure 3). The results of the analysis of hospital death rates are presented in Table 3. The mean number of deaths per hospital was significantly higher in low-volume hospitals (1.23 deaths/hospital) than in high-volume hospitals (0.58 deaths/hospital; \( P = 0.0001 \)).

TABLE 1. Patient and Hospital Characteristics

<table>
<thead>
<tr>
<th>Hospital Mitral Volume (Procedures/Year)</th>
<th>1–35</th>
<th>36–70</th>
<th>71–140</th>
<th>&gt;140</th>
<th>( P^\dagger )</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of patients</td>
<td>3479</td>
<td>3294</td>
<td>3322</td>
<td>3519</td>
<td></td>
</tr>
<tr>
<td>No. of hospitals</td>
<td>361</td>
<td>120</td>
<td>69</td>
<td>27</td>
<td></td>
</tr>
<tr>
<td>Age, mean (IQR), y</td>
<td>61.2 (51–72)</td>
<td>61.1 (51–72)</td>
<td>59.5 (49–71)</td>
<td>58.6 (49–70)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Male</td>
<td>49.4</td>
<td>51.6</td>
<td>54.4</td>
<td>56.3</td>
<td>0.0003</td>
</tr>
<tr>
<td>Diabetes mellitus</td>
<td>9.1</td>
<td>8.7</td>
<td>8.2</td>
<td>6.5</td>
<td>0.0306</td>
</tr>
<tr>
<td>Renal failure</td>
<td>3.7</td>
<td>3.9</td>
<td>3.9</td>
<td>3.0</td>
<td>0.6782</td>
</tr>
<tr>
<td>Hypertension</td>
<td>51.7</td>
<td>50.8</td>
<td>48.6</td>
<td>42.8</td>
<td>0.0003</td>
</tr>
<tr>
<td>Infective endocarditis</td>
<td>6.5</td>
<td>6.8</td>
<td>6.8</td>
<td>6.2</td>
<td>0.6190</td>
</tr>
<tr>
<td>CVD</td>
<td>6.1</td>
<td>6.2</td>
<td>6.3</td>
<td>7.3</td>
<td>0.4949</td>
</tr>
<tr>
<td>CVA</td>
<td>4.6</td>
<td>5.2</td>
<td>4.2</td>
<td>4.2</td>
<td>0.5561</td>
</tr>
<tr>
<td>NYHA I (asymptomatic)</td>
<td>19.4</td>
<td>15.8</td>
<td>19.0</td>
<td>24.4</td>
<td>0.9385</td>
</tr>
<tr>
<td>Ejection fraction, mean (IQR), %</td>
<td>55.6 (50–65)</td>
<td>54.5 (50–63)</td>
<td>54.7 (50–60)</td>
<td>56.1 (50–64)</td>
<td>0.4408</td>
</tr>
<tr>
<td>Predicted risk %, mean (IQR)</td>
<td>2.3 (0.6–2.6)</td>
<td>2.2 (0.6–2.5)</td>
<td>2.1 (0.5–2.3)</td>
<td>1.8 (0.5–1.9)</td>
<td>0.0002</td>
</tr>
</tbody>
</table>

IQR indicates interquartile range; CVD, cerebrovascular disease; CVA, cerebrovascular accident; and NYHA, New York Heart Association.

All values are percentages unless otherwise indicated.

\( \dagger \) Test of trend.

TABLE 2. Frequency of Adverse Outcomes by Category of Hospital Volume

<table>
<thead>
<tr>
<th>Hospital Mitral Volume (Procedures/Year)</th>
<th>1–35</th>
<th>36–70</th>
<th>71–140</th>
<th>&gt;140</th>
<th>( P^* )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operative mortality</td>
<td>3.08</td>
<td>2.31</td>
<td>2.02</td>
<td>1.11</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Reoperation</td>
<td>8.19</td>
<td>8.65</td>
<td>8.85</td>
<td>6.59</td>
<td>0.8894</td>
</tr>
<tr>
<td>Renal failure</td>
<td>2.85</td>
<td>2.82</td>
<td>1.96</td>
<td>1.90</td>
<td>0.0264</td>
</tr>
<tr>
<td>Prolonged mechanical ventilation (&gt;24 h)</td>
<td>7.19</td>
<td>5.98</td>
<td>6.05</td>
<td>4.01</td>
<td>0.0026</td>
</tr>
<tr>
<td>Stroke</td>
<td>1.12</td>
<td>1.55</td>
<td>1.41</td>
<td>1.22</td>
<td>0.7434</td>
</tr>
<tr>
<td>Mortality plus major morbidity</td>
<td>15.61</td>
<td>15.12</td>
<td>14.30</td>
<td>11.31</td>
<td>0.0364</td>
</tr>
</tbody>
</table>

\( ^* \) Test of trend.

All values are percentages unless otherwise indicated.
category were estimated to have a lower risk-adjusted mortality rate than the median hospital in the highest-volume category. In addition, 37% (10/27) of hospitals in the highest-volume category were estimated to have higher risk-adjusted mortality than the median hospital in the lowest-volume category.

Hospital Procedural Volume and Operative Care Processes

The frequency of mitral valve repair differed markedly with mitral valve procedural volume, increasing from 47.7% in low-volume hospitals to 77.4% in high-volume hospitals ($P<0.0001$; Figure 4). The association between volume and repair rates was still significant after adjustment for differences in patient characteristics (Figure 5). The rate of bioprosthetic valve use (compared with mechanical valve use) for mitral valve replacement in patients >65 years of age increased across increasing categories of hospital volume (Figure 6).

Effect of Rate of Mitral Valve Repair on Risk-Adjusted Hospital Mortality

The relationship between repair rates and hospital volume raises the question of whether the volume–outcome association might be explained in part by differences in the frequency of mitral valve repair rates across hospitals. To address this question, we modified the hierarchical logistic regression models to adjust for surgical technique (repair versus replacement). We found that the association between volume and operative mortality was still significant ($P=0.04$ for test of trend) but was attenuated when the risk-adjustment model was adjusted for operation type (odds ratio for annual volume >140 versus ≤35 was 0.59 [95% confidence interval 0.35 to 1.01], $P=0.05$; Table 4), which suggests that increased performance of mitral valve repair partially but not completely explained improved outcomes in high-volume hospitals.

Discussion

Although many studies have examined the relationship between hospital surgical volume and outcomes, few have examined the volume–outcome relationship for heart valve surgery. Birkmeyer et al² used Medicare data from 1994 to 1999 and found an absolute mortality difference of 3.5% between the lowest and highest hospital volume quintiles for patients having mitral valve replacement. That study was limited to patients >65 years of age, was only partially risk-adjusted for patient characteristics, and did not consider patients having mitral valve repair. The present analysis is the first report to examine outcomes in mitral valve surgery based on results from a national clinical database, using a robust, validated risk-adjustment model. It is also the first report to examine the relationship between hospital procedural volume and rates of mitral valve repair (versus replacement).

### Table 3. Relationship Between Annual Volume of All Mitral Operations and Risk of Mortality and Morbidities Among Patients Undergoing First-Time Elective Surgery for Mitral Regurgitation

<table>
<thead>
<tr>
<th>Category of Annual Mitral Volume</th>
<th>Outcome</th>
<th>1–35</th>
<th>35&lt;Volume≤70</th>
<th>70&lt;Volume≤140</th>
<th>Volume&gt;140</th>
<th>$P$ for Trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operative mortality</td>
<td>1.0</td>
<td>0.71 (0.50–1.01)</td>
<td>0.74 (0.50–1.09)</td>
<td>0.48 (0.28–0.82)</td>
<td>0.0043</td>
<td></td>
</tr>
<tr>
<td>Reoperation</td>
<td>1.0</td>
<td>1.07 (0.86–1.34)</td>
<td>1.20 (0.94–1.52)</td>
<td>0.83 (0.61–1.14)</td>
<td>0.9875</td>
<td></td>
</tr>
<tr>
<td>Renal failure</td>
<td>1.0</td>
<td>0.94 (0.67–1.31)</td>
<td>0.72 (0.49–1.06)</td>
<td>0.88 (0.54–1.41)</td>
<td>0.1953</td>
<td></td>
</tr>
<tr>
<td>Prolonged ventilation</td>
<td>1.0</td>
<td>0.76 (0.59–0.99)</td>
<td>0.92 (0.69–1.24)</td>
<td>0.63 (0.42–0.94)</td>
<td>0.0472</td>
<td></td>
</tr>
<tr>
<td>Stroke</td>
<td>1.0</td>
<td>1.40 (0.92–2.12)</td>
<td>1.34 (0.85–2.11)</td>
<td>1.15 (0.66–2.02)</td>
<td>0.3731</td>
<td></td>
</tr>
<tr>
<td>Major adverse event</td>
<td>1.0</td>
<td>0.97 (0.81–1.16)</td>
<td>1.01 (0.83–1.23)</td>
<td>0.77 (0.60–1.00)</td>
<td>0.1737</td>
<td></td>
</tr>
</tbody>
</table>

Values are adjusted odds ratios (95% confidence intervals).
Although payors have suggested that hospital procedural volume may be used as a surrogate marker of provider quality, there have been few data available to support or refute this suggestion. Although hospital procedural volume has been shown to predict outcomes for a number of surgical procedures, utilization of surgical volumes alone to predict outcomes will lead to misclassification of many low-volume hospitals as underperformers and some high-volume centers as high performers. Possible reasons why high-volume hospitals enjoy better outcomes include physician and institutional experience (“practice makes perfect”), selective referral (lower-risk patients migrate to high-volume hospitals and therefore create an improved case mix), and improved process of care at higher-volume institutions. In addition to measuring outcomes in mitral valve surgery as a function of hospital volume, we examined 2 specific processes of care—the performance of mitral valve repair instead of replacement and the implantation of bioprosthetic (versus mechanical) valves in the elderly—to determine whether they contributed to better outcomes or were markers of better overall perioperative care in high-volume, high-performing centers.

Overall hospital survival was excellent (97.8%) for patients undergoing elective isolated mitral valve operation for mitral regurgitation. There was marked variability in procedural volume, with centers in the lowest-volume quartile performing on average 22 mitral valve operations per year compared with an average of 394 mitral operations per year in the highest-volume quartile. Although mortality was uncommon, there was a significant decline in both unadjusted and risk-adjusted mortality as hospital procedural volumes increased, with a risk-adjusted odds ratio for mortality in the highest-volume quartile less than half that in the lowest-volume quartile. Although volume in aggregate was a predictor of risk-adjusted mortality, great variability existed among outcomes in individual institutions, and thus, volume alone was a poor predictor of outcomes for any given center.

Wide agreement exists that mitral valve repair, when performed correctly, is preferable to mitral valve replacement. Mitral valve repair is associated with lower perioperative morbidity and mortality, better preservation of left ventricular function, avoidance of long-term anticoagulation and the associated risks of bleeding, a low rate of thromboembolic complications, a low risk of infective endocarditis, excellent freedom from reoperation, and improved long-term survival. Although individual centers with an interest in mitral valve surgery have demonstrated high repair rates, the majority of patients having mitral valve surgery in North America continue to receive a replacement rather than a repair. We observed a dramatic effect of hospital procedural volume on mitral valve repair rates, with repair rates climbing from 47.7% in the lowest-volume quartile to 77.4% in the highest-volume quartile. Importantly, we have demonstrated wide variability in repair rates, with some low-volume institutions having high repair rates and some high-volume centers having low repair rates. The present analyses demonstrate that increased application of mitral valve repair in higher-volume centers partially but not completely explains improved risk-adjusted mortality in these centers.

Current guidelines issued by both the American Heart Association and the American College of Cardiology recommend the use of bioprosthetic valves in the mitral position for patients >70 years of age because of the major reduction in the rate of structural valve deterioration after age 70 and the increased risk of bleeding in this age group. These guidelines also recognize uncertainty in the optimal valve choice for patients between the ages of 65 and 70 years. There is growing evidence to support implantation of bioprosthetic compared with mechanical valves in this patient population. In the present study, rates of bioprosthetic (versus mechanical) valve implantation increased significantly across volume quartiles, with overall tissue valve utilization substantially more common in the highest-volume institutions. Although we do not know the ideal frequency of bioprosthetic valve use for mitral valve replacement in the elderly, the fact that there is widespread variability from center to center and substantially higher rates of bioprosthetic valve use in high-volume centers suggests that there is an opportunity to improve...
quality by better defining the optimal choice of valve for specified patient characteristics and disseminating these results to all programs that perform mitral valve surgery. Increased utilization of tissue valves in the elderly in high-volume centers likely reflects overall improved perioperative care processes in those centers.

We have identified 1 specific process of care (increased application of mitral valve repair) in high-volume centers that was associated with improved outcomes. Opportunities to improve rates of mitral valve repair might include focused educational efforts at the resident/fellow level, dissemination of techniques at the attending surgeon level, subspecialization of surgeons within groups to concentrate experience with mitral valve surgery, and perhaps the adoption of new technologies to facilitate mitral valve repair.

We have observed great center-to-center variability in the frequency of application of mitral valve repair and the use of bioprosthetic valves in the elderly. Although there are likely many processes of care that differ between high- and low-volume centers, these 2 processes are currently captured in the STS NCD (and therefore measurable) and are representative of the concept that observable processes of care have a significant impact on clinical outcomes. Future work examining clinical outcomes should focus on defining other care processes that differ in high- and low-performing centers. These “discovered process measures” may then become targets for quality improvement.

The results of the present study should be interpreted in the context of several weaknesses. First, as in previous volume–outcome studies, the small number of patients undergoing surgery at low-volume centers leads to wide confidence intervals when one estimates the volume–outcome association. Second, the cut points used for defining categories of hospital volume were arbitrary. Because the majority of hospitals were grouped into a single category (the lowest-volume category), we are unable to detect a volume effect that might occur at the extreme lower tail of the distribution of hospital volume. For this reason, we also estimated the volume-association nonparametrically, treating volume as a continuous variable. Third, although we used a validated statistical clinical model to perform risk adjustment for differences in patient preoperative characteristics at different hospitals, it is possible that an unrecognized referral bias yielded healthier patients at high-volume institutions. Fourth, although the STS NCD includes more than half of all patients having cardiac surgery in North America, it tends to slightly overrepresent higher-volume centers and those with better procedural outcomes. The consistency of the present findings with those of prior administrative analyses, however, supports their generalizability. Finally, although we attempted to investigate whether differences in care processes across categories of volume might help explain the volume–outcome association, the present data are observational, and we are unable to conclude that these care processes had a causal relationship with better outcomes. A rigorous assessment of the direct versus indirect effects of hospital volume and the causal effects of valve repair is challenging, because we presume that unmeasured patient factors may influence the decision to perform repair rather than replacement.

We have found that unadjusted and risk-adjusted mortality for elective mitral valve surgery in North America is associated with center volume. The ability of hospital procedural volume alone to predict outcomes at a specific center was poor, and we found great variability in mortality and several processes of care from center to center. The rates of mitral valve repair and bioprosthetic valve use in the elderly were greater in higher-volume centers. We found that the performance of mitral valve repair rather than replacement contributed to lower in-hospital mortality. The rate of mitral valve repair is a potentially important metric to assess quality of care in centers that perform heart valve surgery. Wider application of mitral valve repair is an important opportunity to effect quality improvement for patients undergoing mitral valve surgery that has the potential to improve short- and long-term outcomes for thousands of patients.

Sources of Funding
The Society of Thoracic Surgeons through the Adult National Cardiac Database and the Duke Clinical Research Institute supported this work.

Disclosures
None.

References


**CLINICAL PERSPECTIVE**

Each year in the United States, >42,000 patients require mitral valve surgery, with the vast majority having mitral regurgitation. Mitral valve repair is clearly superior to replacement, with lower in-hospital mortality and improved long-term outcomes. On the basis of contemporary data from the Society of Thoracic Surgeons National Cardiac Database, the present study found that higher hospital mitral valve case volume was associated with a greater likelihood of repair, a higher frequency of prosthetic (versus mechanical) valve implantation in elderly patients, and lower risk-adjusted operative mortality rates. Mitral valve repair rates ranged from 47% in the lowest-volume hospitals to 77% in the highest-volume hospitals. The process of increased application of mitral valve repair in part explained the lower risk-adjusted mortality rates in the high-volume hospitals. The rate of mitral valve repair is a potentially important metric to assess quality of care in centers that perform heart valve surgery. Wider application of mitral valve repair is an important opportunity to effect quality improvement for patients undergoing mitral valve surgery.
Influence of Hospital Procedural Volume on Care Process and Mortality for Patients Undergoing Elective Surgery for Mitral Regurgitation
James S. Gammie, Sean M. O'Brien, Bartley P. Griffith, T. Bruce Ferguson and Eric D. Peterson

Circulation. 2007;115:881-887; originally published online February 5, 2007;
doi: 10.1161/CIRCULATIONAHA.106.634436
Circulation is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 2007 American Heart Association, Inc. All rights reserved.
Print ISSN: 0009-7322. Online ISSN: 1524-4539

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://circ.ahajournals.org/content/115/7/881

Permissions: Requests for permissions to reproduce figures, tables, or portions of articles originally published in Circulation can be obtained via RightsLink, a service of the Copyright Clearance Center, not the Editorial Office. Once the online version of the published article for which permission is being requested is located, click Request Permissions in the middle column of the Web page under Services. Further information about this process is available in the Permissions and Rights Question and Answer document.

Reprints: Information about reprints can be found online at:
http://www.lww.com/reprints

Subscriptions: Information about subscribing to Circulation is online at:
http://circ.ahajournals.org//subscriptions/