Prevalence and Variability of Internal Mammary Artery Graft Use in Contemporary Multivessel Coronary Artery Bypass Graft Surgery

Analysis of the Society of Thoracic Surgeons National Cardiac Database

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Background—Use of an internal mammary artery (IMA) is a well-recognized, nationally endorsed quality indicator for evaluating the process of operative care for coronary artery bypass graft surgery. An objective assessment of the current status of IMA use has not been systematically performed.

Methods and Results—This cross-sectional observational study analyzed data on 541 368 coronary artery bypass graft surgery procedures reported by 745 hospitals in the Society of Thoracic Surgeons National Cardiac Database from 2002 through 2005. We assessed the current status of IMA use, the association of hospital volume and IMA use, and disparities in IMA use by patient gender and race and by region of hospital location. Rates of using at least 1 IMA and bilateral IMA were 92.4% and 4.0%, with increasing trends over the years. Hospital volume was not significantly associated with IMA use. IMAs were used less frequently in women than men (for at least 1 IMA: odds ratio, 0.62; 95% confidence interval, 0.61 to 0.63; for bilateral IMA: odds ratio, 0.65; 95% confidence interval, 0.63 to 0.68) and less frequently in nonwhite patients than white patients (for at least 1 IMA: odds ratio, 0.84; 95% confidence interval, 0.81 to 0.87; for bilateral IMA: odds ratio, 0.79; 95% confidence interval, 0.75 to 0.83). There were significant differences in frequency of IMA use by hospital region.

Conclusions—Frequency of IMA use in coronary artery bypass graft surgery is increasing; however, many patients still do not receive the benefits of IMA grafts, and some hospitals have a very low IMA use rate. Hospital volume is not associated with IMA use in coronary artery bypass graft surgery. Analysis of this critical performance measure reveals significant gender and race disparities. (Circulation. 2009;120:935–940.)

Key Words: coronary disease • grafting • surgery • quality of health care

The internal mammary artery (IMA) is considered the gold-standard conduit in coronary artery bypass graft (CABG) surgery. There is universal agreement that the IMA graft is associated with significantly improved long-term and short-term survival in CABG.1–3 Use of the IMA is nationally recognized as a key performance measure that has been endorsed by the National Quality Forum4 and approved by the Ambulatory Care Quality Alliance.5 In the recently developed Society of Thoracic Surgeons (STS) composite measure for CABG, use of an IMA was found to be the single intraoperative performance measure associated with quality of care.6 Furthermore, several studies have shown that bilateral IMA (BIMA) use improves long-term outcome compared with single IMA use.7–11 The objective assessment of surgical quality is essential to improve surgical outcomes. The first aim of this study was to assess the current status of IMA use in CABG patients in the United States.

Clinical Perspective on p 940

Hospital volume has been shown to be associated with operative mortality in CABG patients.12–14 However, the association between hospital volume and long-term outcomes or its surrogate remains unknown. Following long-term outcomes for millions of patients is time-consuming, costly, and unrealistic. Because IMA use is well recognized to correlate with long-term survival in CABG patients, we initially evaluated the current status of IMA use in CABG patients by analyzing the data from the STS National Cardiac Database. Then, we examined the association between hospital volume and IMA use in CABG patients. The second aim of this study was to investigate...
whether hospital volume is associated with IMA use, a well-recognized process quality measure of CABG.

The disparity of health care in the United States has been documented in various fields. In the field of cardiac surgery, several studies have shown disparities both in access to surgical care and in risk-adjusted operative outcomes by gender and race/ethnicity.\textsuperscript{15–19} However, there also appears to be a disparity in process quality of cardiac surgery, although it also remains poorly defined. Thus, we examined the disparity in IMA use in CABG procedures by gender, race, and hospital region through an analysis of the STS database. The third aim of this study was to assess the disparities in operative care process of cardiac surgery.

**Methods**

This study was approved by the Institutional Review Board of Brigham and Women’s Hospital, and a waiver of the informed consent was obtained. We reviewed 541 368 adult CABG patients reported in the STS National Cardiac Database from 2002 through 2005 by 745 hospitals in the United States. The STS National Cardiac Database is a voluntary, unaudited outcomes registry of cardiac surgical procedures performed in the United States. The data submitted by 17 hospitals that reported <30 average CABGs per year, which accounts for 2.2% of hospitals participating the STS National Cardiac Database between 2002 and 2005.

Two different data versions were used in the STS database during the study period: version 2.41 from 2002 through 2004 and version 2.52 from 2004 through 2005. All variables used for this study had similar or identical definitions in the 2 versions.

Hospital volume was defined as the average annual volume of CABGs included in this study. For each calendar year, the annual volume of a site was calculated as 12 times the total number of cases divided by the number of months during which the site submitted data. The average annual volume was then obtained by summing the annual volumes and dividing by the number of years of participation in STS. Hospital volume was categorized as follows: very low (<100), low (101 to 200), high (201 to 300), and very high (>300). There were 164, 274, 135, and 172 hospitals in each group, respectively. In the STS database, race/ethnicity is coded as white, black, Hispanic, Asian, and other. We dichotomized those into white and nonwhite (all others).

**Data Analysis**

Patient characteristics were compared between the non-IMA and at least 1 IMA groups, between the non-BIMA and BIMA groups, and among different hospital volume groups. Continuous variables are expressed as mean±SD. P values for these comparisons were highly significant because of the large sample size and are not presented.

Between-hospital variation in IMA use was assessed informally by plotting hospital-specific percentages of IMA use (at least 1 IMA or BIMA) versus hospital-specific average annual volumes. Only hospitals that participated in the STS database all 4 years of the study were included in the graphs. To illustrate the amount of variation that would be expected from chance alone, exact 99.9% binomial control limits were calculated. The control limits indicate the range of normal variation that would be expected under the null hypothesis that each hospital has the same true underlying IMA use rate (equal to the overall percentage of patients receiving IMA or BIMA at hospitals participating for all 4 calendar years).

The strength of the association between volume and hospital-specific IMA use rates was quantified by calculating the proportion of variation in these rates that is explained by a linear function of volume. The proportion of explained variation is equal to the square of the correlation coefficient (R\textsuperscript{2}).

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**Table 1. Patient and Characteristics and IMA Use in CABG**

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Non-IMA Use (n=41 395)</th>
<th>At Least 1 IMA Use (n=499 973)</th>
<th>BIMA Use (n=21 620)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y</td>
<td>68.3±11.4</td>
<td>64.8±10.8</td>
<td>58.4±10.4</td>
</tr>
<tr>
<td>Women, n (%)</td>
<td>16 536 (40.0)</td>
<td>133 198 (26.0)</td>
<td>3398 (15.7)</td>
</tr>
<tr>
<td>Race (nonwhite), n (%)</td>
<td>6050 (14.6)</td>
<td>63 640 (12.7)</td>
<td>2535 (11.7)</td>
</tr>
<tr>
<td>Body mass index, kg/m(^2)</td>
<td>28.6±6.4</td>
<td>29.3±5.7</td>
<td>28.7±4.9</td>
</tr>
<tr>
<td>Diabetes mellitus, n (%)</td>
<td>14 729 (33.5)</td>
<td>181 552 (36.3)</td>
<td>4196 (19.4)</td>
</tr>
<tr>
<td>Dialysis, n (%)</td>
<td>1202 (2.9)</td>
<td>7210 (1.4)</td>
<td>163 (0.75)</td>
</tr>
<tr>
<td>Chronic obstructive pulmonary disease (mild)</td>
<td>8506 (14.0)</td>
<td>42 258 (8.5)</td>
<td>1012 (4.7)</td>
</tr>
<tr>
<td>New York Heart Association class IV, n (%)</td>
<td>9894 (28.5)</td>
<td>102 074 (20.4)</td>
<td>3811 (17.8)</td>
</tr>
<tr>
<td>Left main disease, n (%)</td>
<td>11 664 (28.2)</td>
<td>137 871 (27.6)</td>
<td>5963 (27.6)</td>
</tr>
<tr>
<td>Ejection fraction, %</td>
<td>43.9±9.6</td>
<td>45.5±8.0</td>
<td>46.9±6.6</td>
</tr>
<tr>
<td>Nonelective surgery, n (%)</td>
<td>23 471 (56.7)</td>
<td>249 315 (49.9)</td>
<td>9659 (44.7)</td>
</tr>
<tr>
<td>Performed in very-low-volume hospitals, n (%)</td>
<td>2743 (6.6)</td>
<td>29 100 (5.8)</td>
<td>1325 (6.1)</td>
</tr>
<tr>
<td>Performed in low-volume hospitals, n (%)</td>
<td>8977 (21.7)</td>
<td>114 307 (22.9)</td>
<td>5278 (24.4)</td>
</tr>
<tr>
<td>Performed in high-volume hospitals, n (%)</td>
<td>7881 (19.0)</td>
<td>96 962 (19.4)</td>
<td>4686 (21.7)</td>
</tr>
<tr>
<td>Performed in very-high-volume hospitals, n (%)</td>
<td>21 794 (52.7)</td>
<td>259 604 (51.9)</td>
<td>10 331 (47.8)</td>
</tr>
<tr>
<td>Performed in teaching hospitals, n (%)</td>
<td>9996 (24.2)</td>
<td>141 665 (28.3)</td>
<td>7155 (33.1)</td>
</tr>
<tr>
<td>Northeast region, n (%)</td>
<td>3896 (9.4)</td>
<td>68 966 (13.8)</td>
<td>3697 (17.1)</td>
</tr>
<tr>
<td>Midwest region, n (%)</td>
<td>12 399 (30.0)</td>
<td>16 599 (33.1)</td>
<td>7012 (32.4)</td>
</tr>
<tr>
<td>West region, n (%)</td>
<td>7307 (17.7)</td>
<td>83 930 (16.8)</td>
<td>3619 (16.7)</td>
</tr>
<tr>
<td>South region, n (%)</td>
<td>17 820 (43.1)</td>
<td>181 478 (36.3)</td>
<td>7292 (33.7)</td>
</tr>
</tbody>
</table>
of the Pearson correlation coefficient between hospital volumes and IMA use rates. Furthermore, we used hierarchical logistic regression with random intercepts to assess the associations of hospital volume with IMA use while adjusting for covariates. We performed identical analyses for at least 1 IMA and BIMA. In each model, the very-low-volume category served as the primary reference group. Each model included categorized hospital volume, hospital location (Northeast, Midwest, West, and South as a referent variable), teaching status of the hospital, the year of the procedure, and patient age, gender (female versus male), race (nonwhite versus white), body mass index, diabetes mellitus, dialysis, chronic obstructive pulmonary disease (moderate/severe versus non/mild), New York Heart Association class IV, triple-vessel disease, left main disease, ejection fraction, and urgency of surgery (nonelective versus elective surgery). We included variables that could reasonably explain the surgeon’s decision not to use IMA mostly considering the risk of sternal infection: body mass index, diabetes mellitus, long-term dialysis, and chronic obstructive pulmonary disease. We also included hospital characteristics, general patient characteristics (age, gender, and race), and characteristics of coronary artery disease.

From the same regression model, we assessed the association of IMA use with patient gender, race, and hospital region to determine whether disparities in IMA use exist. We also compared the regions in a pairwise manner.

The rate of missing data for model covariates was <1% for all variables except New York Heart Association class and ejection fraction, which were missing 4.5% and 5.3%, respectively. We imputed continuous variables to the median and binary variables to the negative value. Although multiple imputation is generally preferred over single imputation on theoretical grounds, our decision to use single imputation is consistent with advice in a regression modeling textbook, which notes that the imputation method has little impact when the proportion of missing data is <5%.22 In other analyses of STS data, nearly identical regression coefficients and SE estimates were obtained when multiple imputation was used compared with single imputation. Thus, our simple single imputation approach was considered acceptable.

All statistical analyses were performed with SAS version 9.1 (SAS Institute Inc, Cary, NC) and S-Plus version 6.1. A Bonferroni correction was applied to adjust for multiple comparisons. The significance level was defined as <0.002 (0.05 divided by 22, the number of comparisons in multivariable regression analyses).

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

Among 541,368 patients, 499,973 (92.4%) had at least 1 IMA graft, and only 21,620 patients (4.0%) had BIMA grafts. In the subgroups of young patients, those rates were 94.2% and 6.3% (<65 years of age) and 94.1% and 9.6% (<50 years of age). By year, the frequencies of at least 1 IMA use and BIMA use were 91.1% and 3.6% in 2002, 92.1% and 3.6% in 2003, 92.8% and 4.3% in 2004, and 93.6% and 4.5% in 2005. Patient and hospital characteristics in the non-IMA, 1 IMA, and BIMA groups are shown in Table 1.

The frequency of using at least 1 IMA in each hospital ranged from 48.0% to 100% (median, 94%), and that of using BIMA ranged from 0% to 52.9% (median, 1.7%). Histograms of rates of using at least 1 IMA and BIMA by hospital are shown in Figure 1. One hundred seventy hospitals (22.8% of database participating hospitals during these 4 years) had a <90% rate of using at least 1 IMA, and 407 hospitals (54.6% of database participating hospitals during these 4 years) had <2% rate of using BIMA, including 85 hospitals (11.4%) that did not use BIMA at all. Scatterplots of hospital volume versus IMA use among hospitals with 4 years of data are shown in Figure 2. The large number of hospitals outside the 99.9% binomial control limits indicates that the between-hospital variation in IMA use is not explained by random statistical fluctuations.

Hospital Volume and IMA Use

Median hospital rates of using at least 1 IMA and BIMA were 93.9% and 1.6% in the very-low-volume group, 94.6% and 1.9% in the low-volume group, 94.1% and 1.8% in the high-volume group, and 94.3% and 1.5% in the very-high-volume group. Hospital volume explained <1% of the variation in hospital rates of using at least 1 IMA and <1% of the variation in hospital BIMA use rates. Patient characteristics in hospital volume categories are shown in Table 2. From
the multivariable regression model, there was no significant association between hospital volume and IMA use (Table 3).

### Disparities in IMA Use

In female patients, 89.0% had at least 1 IMA (versus 93.7% of male patients) and 2.3% had BIMA (versus 4.7% of male patients). In nonwhite patients, 91.3% had at least 1 IMA (versus 93.7% of white patients), and 2.3% had BIMA (versus 4.7% of white patients). The frequencies of BIMA use in each region were as follows: Northeast, 94.7%; Midwest, 93.0%; West, 92.0%; and South, 91.1%. The frequencies of BIMA use in each region are the following: Northeast, 5.1%; Midwest, 3.9%; West, 4.0%; and South, 3.7%.

### Discussion

Compared with CABG using only venous conduits, the use of an IMA is associated with improved long-term survival. In one of the first studies based on the STS database,3 it was found that use of an IMA also significantly reduced in-hospital operative mortality. Given that there are very few contraindications to the use of an IMA, one would anticipate a uniformly high use of this unequivocally valuable conduit. Recognition of these facts led to gradual increases in IMA use across the country, but annual reports from the STS database revealed a surprising disparity among participating centers. Accordingly, it seems mandatory to explore the nature of this wide variation in care.

During this 4-year study period, 92.4% of patients had at least 1 IMA and 4.0% of patients had BIMA used in CABG procedures. The rate of using at least 1 IMA seems acceptable and has been increasing slightly over the years. The rate of BIMA use is still low, although it has been increasing over the years. Even in very young patients <50 years of age, only 10% received the long-term survival benefits of BIMA use. BIMA use may not be recommended for every patient. The long-term benefit of BIMA use is relatively low in the elderly. BIMA use may increase the risk of sternal wound infection,23,24 especially in patients with diabetes mellitus.25 However, other studies have shown that the skeletonization technique reduces the risk of wound infection after BIMA use in diabetic patients26 and that BIMA grafts provide some benefits even in diabetic patients.26 The indications and contraindications are controversial. However, considering the benefits on long-term outcomes,7–11 BIMA grafts seem underused in the United States.

By hospital, the rate of using at least 1 IMA varied from 92.5% of white patients), and 3.6% had BIMA (versus 4.0% of male patients) and 2.3% had BIMA (versus 4.7% of male patients). In nonwhite patients, 91.3% had at least 1 IMA (versus 93.7% of white patients), and 2.3% had BIMA (versus 4.7% of white patients). The frequencies of BIMA use in each region were as follows: Northeast, 94.7%; Midwest, 93.0%; West, 92.0%; and South, 91.1%. The frequencies of BIMA use in each region are the following: Northeast, 5.1%; Midwest, 3.9%; West, 4.0%; and South, 3.7%.

### Table 3. Hospital Volume and At Least 1 IMA/BIMA Use (Multivariable Regression Analysis)

<table>
<thead>
<tr>
<th>Annual CABG Volume, n</th>
<th>Reference</th>
<th>OR</th>
<th>95% CI</th>
<th>P</th>
<th>Reference</th>
<th>OR</th>
<th>95% CI</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤100</td>
<td>(Reference)</td>
<td>1.19</td>
<td>1.00–1.42</td>
<td>0.05</td>
<td>1.05</td>
<td>0.78–1.41</td>
<td>0.76</td>
<td></td>
</tr>
<tr>
<td>101–200</td>
<td></td>
<td>1.12</td>
<td>0.92–1.38</td>
<td>0.26</td>
<td>0.9</td>
<td>0.64–1.27</td>
<td>0.55</td>
<td></td>
</tr>
<tr>
<td>201–300</td>
<td></td>
<td>1.15</td>
<td>0.94–1.39</td>
<td>0.17</td>
<td>0.84</td>
<td>0.60–1.16</td>
<td>0.28</td>
<td></td>
</tr>
</tbody>
</table>

OR indicates odds ratio; CI, confidence interval. Adjusted for age, gender, race, body mass index, diabetes, chronic dialysis, chronic obstructive pulmonary disease (moderate/severe versus non/mild), New York Heart Association class IV, triple-vessel disease, left main disease, ejection fraction, nonelective surgery, race, hospital region, teaching status of hospital, and year of procedure.
actual hospital IMA use rates and other quality measures should be made available to the public and used for quality improvement and patients' hospital selection.

Our analysis has shown that there is no relationship between hospital volume and IMA use. High-volume hospitals do not necessarily use IMA grafts more often or perform higher-quality operations; this finding highlights that hospital volume is not necessarily associated with high process quality or probably long-term outcome. Peterson et al. have shown that the relationship between volume and operative mortality is weak and suggested that hospital volume may not be an adequate quality measure for CABG. Our findings are consistent with their conclusion.

Our analysis also has shown that women are less likely to receive IMA grafts than men (35% to 40% lower odds) and that nonwhite patients are less likely to receive IMA grafts than white patients (15% to 20% lower odds). Gender and racial disparities are seen in process of care, access to care, and outcomes. Unlike access to care or outcomes, this process of care, conduit selection, is determined by a clinician almost 100% of the time. These disparities may be caused by a difference in patient characteristics that was not included in the regression model, or they may be caused by clinician bias. To the best of our knowledge, there is no scientific evidence that women or nonwhite patients have less benefit or more complications from IMA grafts. These disparities are not fully justified on a scientific basis. Further investigation and efforts to eliminate these disparities are necessary.

Disparities in IMA use by region do not necessarily mean that hospitals in 1 region are better than those in other regions. For example, there are many hospitals with low IMA use rates in the Northeast and many hospitals with high IMA use rates in the South; there is a large variability. However, this disparity information might be useful for regional efforts of quality improvement.

Although the strengths of this study include a large sample size and rich clinical information, there are a few limitations. We did not review appropriateness of IMA use in each case.

### Table 4. Patient/Hospital Characteristics and At Least 1 IMA/BIMA Use (Multivariable Regression Analysis)

<table>
<thead>
<tr>
<th></th>
<th>At Least 1 IMA</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OR  95% CI</td>
<td>P</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>0.62</td>
<td>0.61–0.63</td>
<td>&lt;0.0001*</td>
<td></td>
<td>0.65</td>
<td>0.63–0.68</td>
<td>&lt;0.0001*</td>
</tr>
<tr>
<td>Nonwhite race</td>
<td>0.84</td>
<td>0.81–0.87</td>
<td>&lt;0.0001*</td>
<td></td>
<td>0.79</td>
<td>0.75–0.83</td>
<td>&lt;0.0001*</td>
</tr>
<tr>
<td>Region</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Northeast vs South</td>
<td>1.75</td>
<td>1.41–2.18</td>
<td>&lt;0.0001*</td>
<td></td>
<td>1.83</td>
<td>1.27–2.63</td>
<td>0.001*</td>
</tr>
<tr>
<td>Midwest vs South</td>
<td>1.33</td>
<td>1.14–1.55</td>
<td>0.0003*</td>
<td></td>
<td>1.19</td>
<td>0.92–1.55</td>
<td>0.19</td>
</tr>
<tr>
<td>West vs South</td>
<td>1.27</td>
<td>1.06–1.52</td>
<td>0.01</td>
<td></td>
<td>1.49</td>
<td>1.10–2.02</td>
<td>0.01</td>
</tr>
<tr>
<td>Northeast vs Midwest</td>
<td>1.32</td>
<td>1.06–1.64</td>
<td>0.01</td>
<td></td>
<td>1.53</td>
<td>1.07–2.19</td>
<td>0.02</td>
</tr>
<tr>
<td>West vs Midwest</td>
<td>0.96</td>
<td>0.80–1.14</td>
<td>0.62</td>
<td></td>
<td>1.25</td>
<td>0.94–1.68</td>
<td>0.13</td>
</tr>
<tr>
<td>Northeast vs West</td>
<td>1.38</td>
<td>1.09–1.75</td>
<td>0.01</td>
<td></td>
<td>1.23</td>
<td>0.83–1.81</td>
<td>0.31</td>
</tr>
</tbody>
</table>

OR indicates odds ratio; CI, confidence interval. Adjusted for age, body mass index, diabetes, chronic dialysis, chronic obstructive pulmonary disease (moderate/severe versus non/mild), New York Heart Association class IV, triple-vessel disease, left main disease, ejection fraction, nonelective status, hospital volume, teaching status of hospital, and year of procedure.

*Significant after adjustment for multiple comparisons (Bonferroni method).
quality of care. High hospital volume is not associated with high rate of IMA use, which indicates that hospital volume does not necessarily reflect quality of care in patients undergoing CABG. There are significant disparities in IMA use by gender and race, which should be addressed in the interest of expanding the benefits of IMA grafting to the maximum possible number of patients.

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All funding for this work was provided by the STS.

Disclosures
None.

References
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