Variation in Use of Blood Transfusion in Coronary Artery Bypass Graft Surgery

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PATIENTS WHO UNDERGO CARDIAC SURGERY receive a significant proportion of the 14 million units of allogeneic red blood cells (RBCs) transfused annually in the United States.1 Numerous observational studies in patients who underwent cardiac surgery have shown an association between RBC transfusion and adverse outcome, including morbidity, mortality, resource utilization, and quality of life.2-9 To date, no large randomized trials of transfusion thresholds have been conducted in cardiac surgery to our knowledge to address this issue.

Almost 20 years ago, the study by Goodnough et al10 demonstrated that there was significant practice variability in transfusion practices at 18 US centers. However, this study and subsequent studies11-14 were limited in size and did not adjust for hospital or patient factors. Since these earlier studies, the Society of Thoracic Surgeons (STS) and Society of Cardiovascular Anesthesiologists published transfusion recommendations in 2007.15 However, the degree to which guidelines have resulted in consensus in community transfusion practice is unknown. Therefore, the primary goal of our study was to assess use of RBC, fresh-frozen plasma, and platelet transfusions in coronary artery bypass graft (CABG) surgery in contemporary practice. Our analyses specifically addressed the degree to which transfusion practices varied among US hospitals, after adjusting for patient characteristics.

METHODS

Data Source

The STS Adult Cardiac Surgery Database (ACSD) was established in 1989 to report outcomes following cardiothoracic surgical procedures.16-20 The database captures clinical information from the majority of US cardiac surgical procedures. A recent analysis demonstrated that more than 80% of patients undergoing CABG operations in the United States in 2007 were represented in the STS database.21 Sites enter patient data using uniform definitions (available at http://www.sts.org) and cer...
ified software systems. This information is sent semiannually to the STS Data Warehouse and Analysis Center at the Duke Clinical Research Institute, Durham, North Carolina. A series of data quality checks are performed before a site's data are aggregated into the national sample. Although participation in the STS database is voluntary, data completeness is high, with overall preoperative risk factors missing in fewer than 5% of submitted cases.22

Because the data used in analyses of the STS ACSD represent a limited data set (no direct patient identifiers) that was originally collected for nonresearch purposes, and the investigators do not know the identity of individual patients, the analysis of these data was declared by the Duke University Health System Institutional Review Board to be research not involving human subjects and is therefore considered exempt (Duke University Health System Protocol 00005876).

Patient Population
Hospital variation in the frequency of blood product administration was analyzed in a contemporary sample of isolated primary CABG operations using cardiopulmonary bypass (CPB) performed at hospitals participating in the STS ACSD between January 1, 2008, and December 31, 2008. The time frame for this analysis was chosen to represent the most contemporary data available and to minimize the effect of potential changes over time. Hospitals (n=798) contributing at least 1 adult cardiac case per month during 2008 were included. Unless stated otherwise, all analyses included all 798 sites (102 470 cases). To increase the homogeneity of the study population, we only included patients undergoing primary cardiac surgery and excluded patients who previously underwent median sternotomy. Additional exclusion criteria included (1) combination of CABG surgery with valve or other major surgical interventions; (2) off-pump CABG surgery; (3) age younger than 18 years; (4) emergent status, elective and urgent status were allowed; (5) preoperative cardiogenic shock or need for cardiopulmonary resuscitation within 1 hour before surgery; and (6) presence of infective endocarditis preoperatively. In addition, we excluded 122 patients with incomplete data for perioperative blood usage.

Variable Definitions
Blood and Blood Products. The STS database collects the number of units of packed RBCs, platelets, or fresh-frozen plasma administered to the patient intraoperatively and postoperatively during hospitalization. The measurement of packed RBCs does not include preoperatively donated or intra- and postoperatively cell-savaged autologous blood. All blood and blood product values reported herein reflect the sum of each of the products administered intraoperatively and postoperatively.

Academic vs Nonacademic Hospitals. Academic status was defined as hospitals that have residency programs, according to the STS participant information database.

Geographic Region. Hospitals were grouped into 9 regions using categories defined by the US Census Bureau as follows: New England (Maine, Massachusetts, Vermont, New Hampshire, Rhode Island, and Connecticut), Mid-Atlantic (New Jersey, New York, and Pennsylvania), South Atlantic (Delaware, District of Columbia, West Virginia, Virginia, Maryland, North Carolina, South Carolina, Georgia, and Florida), Great Lakes (Illinois, Indiana, Michigan, Ohio, and Wisconsin), Pacific (Alaska, Hawaii, Oregon, Washington, and California), Mountain (Arizona, Colorado, Idaho, Montana, Nevada, New Mexico, Utah, and Wyoming), Plains (North Dakota, South Dakota, Nebraska, Kansas, Minnesota, Iowa, and Missouri), West South Central (Oklahoma, Louisiana, Arkansas, and Texas), and East South Central (Mississippi, Alabama, Tennessee, and Kentucky).

Hospital CABG Surgery Volumes in 2008. The annual hospital volume for primary isolated CABG surgery during 2008 was categorized into 4 groups (quartiles), with an approximately equal number of patients in each group. The categories were quartile 1 (<115 cases), quartile 2 (115-183 cases), quartile 3 (184-299 cases), and quartile 4 (≥300 cases).

Statistical Analyses. Baseline characteristics were summarized as percentage or median (interquartile range) as appropriate and compared for patients receiving vs not receiving any RBCs in the intraoperative or postoperative period. To quantify between-hospital variation in blood usage, we calculated the percentage of patients undergoing primary isolated CABG surgery at each hospital who received any RBCs, any fresh-frozen plasma, and any platelets in the intraoperative or postoperative period. To display the results graphically, we plotted hospital-specific percentages of patients receiving blood products against hospital-specific numbers of eligible cases. We superimposed lines representing 99.9% binomial prediction limits23 (Figure 1). The binomial prediction limits indicate the range of results that would normally occur as a result of random statistical variation for a hospital whose true frequency of using blood products is equal to the mean for all hospitals.

Additional analyses focused on determining the amount of hospital-level variation in blood product usage that is due to true signal variation, as opposed to random statistical variation (ie, noise), and exploring factors that might explain the signal variation. Separate analyses were performed for RBCs, fresh-frozen plasma, and platelets. A series of 2-level hierarchical logistic regression models with hospital-specific random intercepts were fit to the patient-level data. In each model, the end point was a patient-level binary variable coded as 1 if the patient received the blood product and as 0 otherwise. Model 1 contained only hospital-specific random intercepts and no covariates. This model was used for estimating the distribution of true hospital usage rates of blood products af-
ter subtracting out the effect of random sampling variation. Results were summarized in tabular form by presenting selected percentiles of the hospital distribution. These percentiles were calculated from the estimated mean and variance of the random effects parameters (assumed to be normally distributed on the log-odds scale) and were transformed from the scale of log-odds to the scale of probabilities to facilitate interpretation. The same estimates were used to construct a histogram depicting the estimated distribution of true hospital-specific usage rates (Figure 2).

Model 2 contained hospital-specific random intercepts plus patient-level covariates, which included age, female sex, race, left ventricular ejection fraction, body surface area, serum creatinine, date of surgery (dichotomized into first vs second 6-month period), procedure, need for dialysis, atrial fibrillation, hypertension, immunosuppressive treatment, percutaneous coronary intervention less than 6 hours before surgery, presence of intra-aortic balloon pump or administration of inotropes, peripheral vascular disease, unstable angina (no myocardial infarction <7 days), left main disease, aortic stenosis, aortic insufficiency, mitral insufficiency, tricuspid insufficiency, chronic lung disease, cerebrovascular disease or cerebrovascular accident, diabetes, number of diseased coronary vessels, myocardial infarction, acuity status, congestive heart failure, New York Heart Association class, preoperative hematocrit, and use of medications, including warfarin, aspirin, adenosine diphosphate inhibitor within 5 days, or glycoprotein IIb/IIIa inhibitor. Model 2 was used for quantifying between-hospital signal variation after subtracting out differences due to patient-level risk factors. A hospital’s risk-adjusted RBC usage rate was calculated as $1/(1 + \exp[-(\alpha + \beta_j)])$, where the constant $\alpha$ was chosen to reflect the baseline probability of receiving RBCs for an “average” patient and $\beta_j$ denotes the j-th hospital’s random intercept parameter. Percentiles were based on the estimated mean and variance of the $\beta_j$’s. This method was also used for fresh-frozen plasma and platelets.

Model 3 contained the factors in model 2, plus 3 hospital-specific factors (academic status, region, and vol-

Figure 1. Observed Variation in Hospital-Specific Transfusion Rates for Primary Isolated CABG Surgery With Cardiopulmonary Bypass During 2008 (N=798 Sites)
volume). This model was used to explore
the effect of each hospital-level factor
while adjusting for differences in pa-
tient case mix. The effect of each hos-
pital-level covariate was summarized by
reporting odds ratios (ORs) with 95% con-
fidence intervals (CIs). The ability
of hospital and patient factors to ex-
plain between-hospital variation in
transfusion rates was examined. To
quantify between-hospital variation, the
predicted log odds from model 3 was
averaged within each hospital and de-
composed as the sum of 3 compo-
nents (namely, the contributions of pa-
tient factors, hospital covariates, and
hospital random effects). The percent-
age of between-hospital variation ex-
plained by hospital covariates was cal-
culated as the squared Pearson
correlation between the hospital fac-
tor component of the average log-
ods and the sum of all 3 compo-
nents. An analogous calculation was
used to quantify the percentage of varia-
tion explained by patient factors (ie, 
case mix).

 Hierarchical logistic regression with
random intercepts was used to assess
the association between the percent-
age of patients receiving RBCs at a hos-
pital and the patient-level end point of
all-cause mortality. All-cause mortal-
ity was defined as death during the same
hospitalization as surgery or after dis-
charge but within 30 days of surgery. To
minimize misclassification error in
the hospital-specific transfusion rates,
only hospitals with at least 100 on-
pump isolated CABG operations were
included in these analyses. Hospitals
were assigned to 4 groups according to
the percentage of patients receiving RBC
transfusion intraoperatively or postop-
eratively (7.8%-43.2%, 43.3%-55.9%,
56.0%-65.6%, and 65.7%-92.8%). Rates
of mortality were compared across cat-
ergories of hospital transfusion rates
with and without adjustment for patient
factors (model 2 covariates).

 Parameters of the various models were
estimated using a penalized quasi-
likelihood approximation as imple-
mented in SAS version 9.2 PROC
GLIMMIX (SAS Institute, Cary, North
Carolina). R statistical package version
2.9.0 (R Foundation for Statistical Com-
puting, Vienna, Austria) was also used.
P<.05 was considered significant. All
tests were 2-sided and were not ad-
justed for multiple comparisons.

 RESULTS
Among the 102 592 cases of primary
isolated CABG surgery with CPB sub-
mited from 798 hospitals in 2008,
102 470 cases (99.9%) had complete in-
formation about perioperative RBC,
platelet, and fresh-frozen plasma trans-
usions. The rates of perioperative trans-
fusion were 56.1% (95% CI, 55.8%-56.4%) for packed RBCs, 19.3% (95%
CI, 19.1%-19.6%) for fresh-frozen
plasma, and 24.7% (95% CI, 24.5%-25.0%) for platelets. Patients receiv-
ing RBC transfusion (n=57 445) were
more likely to be women, were older,
had received adenosine diphosphate
inhibitors, had lower preoperative he-
matocrit, and exhibited other tradi-
tional risk factors for morbidity and
mortality compared with those pa-
tients who did not receive RBC trans-
usions (TABLE 1).

 Between-Hospital Variation
in Blood Usage
There was dramatic variability in the ob-
served hospital-specific transfusion
rates for all 3 blood products in 102 470
patients undergoing isolated primary
CABG surgery at 798 hospitals
(Figure 1). To ensure that between-
center differences would not be domi-
nated by random statistical variation,
we also analyzed the subset of hospi-
tals performing at least 100 eligible on-
pump CABG operations during the
year. At these 408 sites (n=82 446
cases), the frequency of blood transfu-
sion rates ranged from 7.8% to 92.8%
for RBCs, 0% to 97.5% for fresh-
frozen plasma, and 0.4% to 90.4% for
platelets.

 The estimated distribution of trans-
fusion rates based on hierarchical mod-
eling is shown in TABLE 2. According
to this model, hospitals at the 99th per-
centile of the distribution were 4.6 times
more likely to use RBCs (90.6%/19.7%
=4.6), 31.2 times more likely to
use fresh-frozen plasma (71.7%/2.3%
=31.2), and 22.5 times more likely
to use platelets (76.4%/3.4%=22.5)
compared with hospitals at the 1st per-
centile of the distribution. This wide
variation was not explained by patient
risk factors. Comparing the 1st and 99th
percentiles, hospitals at the 99th per-
centile of the distribution were 7.7 times
more likely to use RBCs (94.5%/12.2%),
34.8 times more likely to use
fresh-frozen plasma (73.1%/2.1%),
and

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24.3 times more likely to use platelets (77.6%/3.2%), even after adjusting for patient risk factors (Table 2).

**Hospital Characteristics and Blood Usage**

Table 3 shows unadjusted and adjusted associations between hospital characteristics and blood usage. The frequency of perioperative RBC usage decreased across categories of increasing CABG surgery volume from 61.4% (95% CI, 59.4%-63.4%) in quartile 1 to 51.6% (95% CI, 48.0%-55.2%) in quartile 4 ($p<.001$). The adjusted ORs for RBC usage were inversely related to volume and were statistically significant for quartile 2 (OR, 0.71; 95% CI, 0.59-0.86), quartile 3 (OR, 0.61; 95% CI, 0.49-0.76), and quartile 4 (OR, 0.51; 95% CI, 0.38-0.66) compared with quartile 1.

There was also substantial geographic variation in RBC usage. In the unadjusted analysis, blood usage was significantly lower in all 8 regions compared with the West South Central region. After adjusting for patient risk factors, blood usage was found to be significantly lower in 7 of the 8 geographic regions (OR of these 7 regions ranged between 0.45 and 0.67). Blood usage was more than 2-fold lower in the Mountain (OR, 0.45; 95% CI, 0.31-0.64) and New England (OR, 0.46; 95% CI, 0.29-0.72) regions compared with the West South Central region.

A significant association (OR, 1.32; 95% CI, 1.04-1.69; $p=.03$) was observed between academic hospital status and perioperative RBC usage, after adjusting for patient-level risk factors. However, these 3 hospital characteristics combined only explained 11.1% of the variation in hospital risk-adjusted RBC usage. Case mix explained 20.1% of the variation between hospitals in RBC usage.

**Table 1. Demographic Characteristics and Outcomes of Patients Who Underwent Primary Isolated CABG Surgery With or Without Perioperative RBC Transfusion During 2008**

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Without RBC</th>
<th>With RBC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, median (IQR), y</td>
<td>62 (55-69)</td>
<td>67 (60-75)</td>
</tr>
<tr>
<td>Men</td>
<td>39 294 (87.3)</td>
<td>36 013 (62.7)</td>
</tr>
<tr>
<td>Academic hospital</td>
<td>3825 (8.5)</td>
<td>6432 (11.2)</td>
</tr>
<tr>
<td>Demographic region</td>
<td></td>
<td></td>
</tr>
<tr>
<td>West South Central</td>
<td>3226 (7.2)</td>
<td>5049 (8.8)</td>
</tr>
<tr>
<td>South Atlantic</td>
<td>10 808 (24.0)</td>
<td>12 964 (22.6)</td>
</tr>
<tr>
<td>Plains</td>
<td>3718 (8.3)</td>
<td>4365 (7.6)</td>
</tr>
<tr>
<td>Pacific</td>
<td>5300 (11.8)</td>
<td>6262 (10.9)</td>
</tr>
<tr>
<td>New England</td>
<td>1636 (3.8)</td>
<td>2296 (3.9)</td>
</tr>
<tr>
<td>Mountain</td>
<td>2306 (5.1)</td>
<td>2257 (3.9)</td>
</tr>
<tr>
<td>Mid-Atlantic</td>
<td>4806 (10.7)</td>
<td>6559 (11.4)</td>
</tr>
<tr>
<td>Great Lakes</td>
<td>8993 (20.0)</td>
<td>12 362 (21.5)</td>
</tr>
<tr>
<td>East South Central</td>
<td>4232 (9.4)</td>
<td>5361 (9.3)</td>
</tr>
<tr>
<td>Weight, median (IQR), kg</td>
<td>92 (81-104)</td>
<td>82 (71-96)</td>
</tr>
<tr>
<td>BMI, median (IQR)</td>
<td>29.8 (26.7-33.6)</td>
<td>28.1 (25.0-32.1)</td>
</tr>
<tr>
<td>Diabetes</td>
<td>16 171 (35.9)</td>
<td>24 939 (43.4)</td>
</tr>
<tr>
<td>Hypertension</td>
<td>36 665 (81.4)</td>
<td>49 634 (86.4)</td>
</tr>
<tr>
<td>Current or recent smoker</td>
<td>14 384 (32.0)</td>
<td>14 775 (25.7)</td>
</tr>
<tr>
<td>Peripheral vascular disease</td>
<td>4677 (10.4)</td>
<td>9709 (16.9)</td>
</tr>
<tr>
<td>ADP inhibitor (thienopyridine)</td>
<td>4235 (9.4)</td>
<td>8668 (15.1)</td>
</tr>
<tr>
<td>Glycoprotein IIb/IIIa inhibitor</td>
<td>1822 (4.1)</td>
<td>2690 (4.7)</td>
</tr>
<tr>
<td>Preoperative creatinine, median (IQR), mg/dL</td>
<td>1.0 (0.9-1.1)</td>
<td>1.0 (0.9-1.3)</td>
</tr>
<tr>
<td>Dialysis for renal failure</td>
<td>376 (0.84)</td>
<td>1966 (3.42)</td>
</tr>
<tr>
<td>History of myocardial infarction</td>
<td>18 382 (40.8)</td>
<td>26 835 (46.7)</td>
</tr>
<tr>
<td>Ejection fraction, median (IQR), %</td>
<td>55 (45-60)</td>
<td>55 (43-60)</td>
</tr>
<tr>
<td>Duration, median (IQR), min</td>
<td>85 (66-108)</td>
<td>93 (72-117)</td>
</tr>
<tr>
<td>Cardiopulmonary bypass</td>
<td>60 (45-79)</td>
<td>64 (48-85)</td>
</tr>
<tr>
<td>No. of distal bypass grafts, median (IQR)</td>
<td>3.0 (3.0-4.0)</td>
<td>3.0 (3.0-4.0)</td>
</tr>
<tr>
<td>Reoperation for bleeding</td>
<td>66 (0.2)</td>
<td>2318 (4.0)</td>
</tr>
<tr>
<td>Postoperative length of stay, median (IQR), d</td>
<td>5.0 (4.0-6.0)</td>
<td>6.0 (5.0-8.0)</td>
</tr>
<tr>
<td>Readmission within 30 d</td>
<td>3150 (7.0)</td>
<td>6342 (11.0)</td>
</tr>
<tr>
<td>All-cause mortality*</td>
<td>196 (0.4)</td>
<td>1330 (2.3)</td>
</tr>
</tbody>
</table>

Abbreviations: ADP, adenosine diphosphate; BMI, body mass index, calculated as weight in kilograms divided by height in meters squared; CABG, coronary artery bypass graft; IQR, interquartile range; RBC, red blood cell.

*SI conversion: To convert creatinine to µmol/L, multiply by 88.4.*

*a Defined as death during the same hospitalization as surgery or after discharge but within 30 days of surgery.

COMMENT

Our large observational study shows that there is enormous variability in the rates of transfusion of RBCs, fresh-frozen plasma, and platelets in patients undergoing isolated primary CABG surgery across a large number of US hospitals, even after adjusting for patient- and hospital-level risk factors. Our analysis of blood transfusion practices represents patients who have undergone surgery at 798 US hospitals. Because the STS database includes the majority of US patients who underwent cardiac surgery,21 our findings present a comprehensive picture of transfusion practices in patients undergoing CABG surgery.

Almost 20 years ago, the study by Goodnough et al10 showed significant variability in transfusion practice in 540 patients who underwent cardiac surgery across 18 institutions and drew at-
tention to this problem. Several subsequent studies provided additional data on this topic, but these are no longer contemporary, had no or limited risk-adjustment, and were limited in size.11,13,14 Despite nearly 2 decades of awareness of inconsistent transfusion practices and the publication of clinical practice guidelines, there has been no improvement in disparate transfusion practices. For example, Goodnough et al10 found that the transfusion rates for RBCs, fresh-frozen plasma, and platelets ranged from 17% to 100%, 0% to 90%, and 0% to 80%, respectively. In our analysis, transfusion rates were similar. This variability cannot be attributed to inclusion of hospitals with small denominators. Indeed, in hospitals reporting at least 100 eligible on-pump CABG operations (82,446 cases at 408 sites), transfusion rates among patients undergoing primary isolated on-pump CABG surgery still ranged from 7.8% to 92.8% for RBCs, 0% to 97.5% for fresh-frozen plasma, and 0.4% to 90.4% for platelets. Moreover, the variation persisted after adjustment for a large number of patient and hospital factors.

We found that patients at academic hospitals and those in the lowest quartile of volume were more likely to receive RBC transfusion compared with other hospitals. We also observed variation in RBC usage based on geographic region. These differences are unexplained and warrant further study.

### Table 2. Estimated Percentiles of the Distribution of Hospital-Specific True Transfusion Rates in Patients Who Underwent Primary Isolated CABG Surgery During 2008

<table>
<thead>
<tr>
<th>Model</th>
<th>Probability of Transfusion in Percentile, %</th>
<th>1st</th>
<th>10th</th>
<th>25th</th>
<th>50th</th>
<th>75th</th>
<th>90th</th>
<th>99th</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red blood cells</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unadjusted</td>
<td>19.7</td>
<td>36.0</td>
<td>47.5</td>
<td>60.7</td>
<td>72.4</td>
<td>81.0</td>
<td>90.6</td>
<td></td>
</tr>
<tr>
<td>Adjusted</td>
<td>12.2</td>
<td>29.1</td>
<td>43.5</td>
<td>60.7</td>
<td>75.6</td>
<td>85.3</td>
<td>94.5</td>
<td></td>
</tr>
<tr>
<td>Fresh-frozen plasma</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unadjusted</td>
<td>2.3</td>
<td>6.3</td>
<td>11.0</td>
<td>19.6</td>
<td>32.5</td>
<td>47.0</td>
<td>71.7</td>
<td></td>
</tr>
<tr>
<td>Adjusted</td>
<td>2.1</td>
<td>6.1</td>
<td>10.8</td>
<td>19.6</td>
<td>33.0</td>
<td>48.0</td>
<td>73.1</td>
<td></td>
</tr>
<tr>
<td>Platelets</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unadjusted</td>
<td>3.4</td>
<td>8.9</td>
<td>15.0</td>
<td>25.3</td>
<td>39.5</td>
<td>54.0</td>
<td>76.4</td>
<td></td>
</tr>
<tr>
<td>Adjusted</td>
<td>3.2</td>
<td>8.6</td>
<td>14.7</td>
<td>25.3</td>
<td>39.9</td>
<td>55.0</td>
<td>77.6</td>
<td></td>
</tr>
</tbody>
</table>

Abbreviation: CABG, coronary artery bypass graft.

### Table 3. Association Between Perioperative RBC Transfusion and Hospital Characteristics in Patients Who Underwent Primary Isolated CABG Surgery During 2008

<table>
<thead>
<tr>
<th>Outcome</th>
<th>No. of Patients</th>
<th>Transfused, % (95% CI)</th>
<th>OR (95% CI)</th>
<th>P Value</th>
<th>OR (95% CI)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Region</td>
<td></td>
<td></td>
<td>Unadjusted</td>
<td></td>
<td>Adjusted</td>
<td></td>
</tr>
<tr>
<td>West South Central</td>
<td>8275</td>
<td>61.0 (55.6-66.5)</td>
<td>1 [Reference]</td>
<td>.04</td>
<td>1 [Reference]</td>
<td>.007</td>
</tr>
<tr>
<td>East South Central</td>
<td>9593</td>
<td>55.9 (51.1-60.7)</td>
<td>0.65 (0.48-0.87)</td>
<td>.003</td>
<td>0.79 (0.54-1.15)</td>
<td>.21</td>
</tr>
<tr>
<td>Great Lakes</td>
<td>21 355</td>
<td>57.9 (55.4-60.3)</td>
<td>0.69 (0.55-0.87)</td>
<td>.001</td>
<td>0.67 (0.51-0.80)</td>
<td>.007</td>
</tr>
<tr>
<td>Mid-Atlantic</td>
<td>11 365</td>
<td>57.7 (53.7-61.8)</td>
<td>0.66 (0.51-0.85)</td>
<td>.001</td>
<td>0.53 (0.38-0.74)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Mountain</td>
<td>4563</td>
<td>49.5 (44.8-54.1)</td>
<td>0.48 (0.36-0.64)</td>
<td>&lt;.001</td>
<td>0.45 (0.31-0.64)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>New England</td>
<td>3902</td>
<td>58.1 (50.4-65.8)</td>
<td>0.62 (0.43-0.89)</td>
<td>.01</td>
<td>0.46 (0.29-0.72)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Pacific</td>
<td>11 562</td>
<td>54.2 (49.5-58.8)</td>
<td>0.74 (0.58-0.94)</td>
<td>.02</td>
<td>0.55 (0.40-0.75)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Plains</td>
<td>8083</td>
<td>54.0 (49.3-58.7)</td>
<td>0.56 (0.43-0.73)</td>
<td>&lt;.001</td>
<td>0.54 (0.39-0.76)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>South Atlantic</td>
<td>23 772</td>
<td>54.5 (51.3-57.8)</td>
<td>0.63 (0.50-0.80)</td>
<td>&lt;.001</td>
<td>0.60 (0.45-0.81)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Hospital volume, quartileb</td>
<td>102 470</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 (n = 441)</td>
<td>25 530</td>
<td>61.4 (59.4-63.4)</td>
<td>1 [Reference]</td>
<td>.04</td>
<td>1 [Reference]</td>
<td>.007</td>
</tr>
<tr>
<td>2 (n = 177)</td>
<td>25 509</td>
<td>56.9 (54.4-59.3)</td>
<td>0.74 (0.64-0.85)</td>
<td>&lt;.001</td>
<td>0.71 (0.59-0.86)</td>
<td>.001</td>
</tr>
<tr>
<td>3 (n = 116)</td>
<td>25 783</td>
<td>54.4 (51.7-57.1)</td>
<td>0.65 (0.56-0.77)</td>
<td>&lt;.001</td>
<td>0.61 (0.49-0.76)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>4 (n = 64)</td>
<td>25 648</td>
<td>51.6 (48.0-55.2)</td>
<td>0.58 (0.47-0.71)</td>
<td>&lt;.001</td>
<td>0.51 (0.38-0.66)</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Academic status</td>
<td>102 470</td>
<td></td>
<td>.008</td>
<td>.03</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nonacademic</td>
<td>92 213</td>
<td>55.3 (53.8-56.8)</td>
<td>1 [Reference]</td>
<td>.04</td>
<td>1 [Reference]</td>
<td>.007</td>
</tr>
<tr>
<td>Academic hospital</td>
<td>10 257</td>
<td>62.7 (59.0-66.4)</td>
<td>1.29 (1.07-1.56)</td>
<td>.008</td>
<td>1.32 (1.04-1.69)</td>
<td>.03</td>
</tr>
</tbody>
</table>

Abbreviations: CABG, coronary artery bypass graft; CI, confidence interval; OR, odds ratio; RBC, red blood cell.

aAdjusted models include all 3 classes of hospital characteristics variables (region, hospital volume, and academic status) and patient-level predictors as described in the Methods section.

bThe annual hospital volume for primary isolated CABG surgery during 2008 was categorized into 4 groups (quartiles) with an approximately equal number of patients in each group as described in the Methods section (quartile 1 = lowest volume, quartile 4 = highest volume).
USE OF BLOOD TRANSFUSION IN CABG SURGERY

Our study has several limitations. First, data on RBC, platelet, and fresh-frozen plasma transfusions have not undergone audit; therefore, we cannot be absolutely sure of the accuracy of data reported by sites. Some of the variability in observed transfusion rates might be due to differences in the accuracy with which programs document usage. For example, sites may rely on only one or a combination of paper or electronic medical record, blood bank records, or both. However, our analysis only included patients who had data available on blood product usage at both time points (intraoperative and postoperative).

Our study’s primary goal was to assess the variability between hospitals with respect to transfusion; therefore, as such it was not prospectively designed to focus on the association between hospital transfusion rate and adverse outcome. Nevertheless, our limited analysis (eTable) appears to suggest that there is no strong association between hospital transfusion rate and mortality. This does not necessarily contradict the large body of literature showing an association between transfusion and adverse outcome because those studies focused on patient-level risk.2-9 Our analysis of mortality focused on comparing groups of hospitals according to their hospital-level transfusion rates. We specifically did not compare mortality of individual patients who did vs did not receive transfusion. We can state, however, that even if higher transfusion rates at some hospitals are not deleterious they may still represent potentially unnecessary care that is costly. The acquisition costs of a unit of RBCs, fresh-frozen plasma, and platelets (apheresis) were $214, $60, and $539, respectively, in 2006.1 These costs underestimate the true direct and indirect costs of transfusion.25 For example, a recent analysis estimated the total cost of each RBC transfusion to range from $522 to $1183 (mean cost, $761 per RBC unit).26 Therefore, even if unnecessary transfusion is not deleterious, a reduction in the observed variability might result in significant cost savings.

As is the case in other areas of medicine, the degree of variability in clinical practice we observed represents a potential quality improvement opportunity. This is particularly complex in relation to transfusion practice in CABG surgery. The decision to transfuse has multiple triggers, resulting from a wide array of clinical scenarios and the consequent inability to apply standardized algorithms. The multiplicity of health care practitioners in CABG surgery care generates differences of opinion about safety and efficacy. Transfusion thresholds will change during the course of care; the threshold for a rapidly bleeding patient is different than for a stable patient postoperatively. Improvement in quality related to transfusion practice in CABG surgery is a multifactorial, complex but critically important, challenge. Studies have demonstrated that use of a blood conservation program significantly improves transfusion rates over time.27-31 This may be a more effective way of improving transfusion rates, as opposed to publishing guidelines, which may not be that helpful as our study suggests. In addition, the role of lack of data from randomized trials cannot be overstated. To our knowledge, there has never been a large randomized trial of the safety and efficacy of blood transfusion in cardiac surgery15; therefore, some of the variability we observed may be due to honest differences between clinicians in the perceived benefits and risks of transfusion.

Author Contributions: Dr Bennett-Guerrero had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis. Study concept and design: Bennett-Guerrero, O’Brien, Ferguson, Gammie, Song. Acquisition of data: Peterson, Gammie, Song. Analysis and interpretation of data: Bennett-Guerrero, Zhao, O’Brien, Gammie, Song. Drafting of the manuscript: Bennett-Guerrero, O’Brien, Gammie, Song. Critical revision of the manuscript for important intellectual content: Zhao, O’Brien, Ferguson, Peterson, Gammie, Song. Statistical analysis: Zhao, O’Brien, Song. Obtained funding: Peterson, Song.

Administrative, technical, or material support: Ferguson, Gammie, Song. Study supervision: Bennett-Guerrero, O’Brien, Ferguson, Gammie, Song.

Financial Disclosures: Dr Bennett-Guerrero is principal investigator (grant RO1 HL101382-01 from the National Institutes of Health) for a multicenter study assessing the impact of blood transfusion on peripheral and cerebral oxygenation and the microcirculation. He is also a named inventor on a patent application related to methods of washing red blood cells. No other authors have any disclosures.

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Role of the Sponsors: This study was sponsored by the STS. Specifically, the DCRI has a contract with the STS to be their National Cardiac Data Warehouse and Analysis Center. In this role, the DCRI independently harvests data from each participating STS center, creates a national analysis database, and performs statistical analyses. The proposal for this study was submitted to and approved by of the STS National Database Publications Committee. After approval, the manuscript was reviewed by the coauthors and a final version was approved by the publications committee. The STS was involved in the design and conduct of the study; in the collection, management, analysis, and interpretation of the data; and in the review and approval of the manuscript.

Disclaimer: Dr Peterson, a contributing editor for JAMA, was not involved in the editorial review of or the decision to publish this article.

Online-Only Material: An eTable is available at http://www.jama.com.

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Reality, no matter how widened and heightened our perceptions, never ceases to be anything but the effect on us of an infinite mystery.

—Laurens van der Post (1906-1996)