Variation in Red Blood Cell Transfusion Practices During Cardiac Operations Among Centers in Maryland: Results From a State Quality-Improvement Collaborative

J. Trent Magruder, MD, Elena Blasco-Colmenares, MD, PhD, Todd Crawford, MD, Diane Alejo, BA, John V. Conte, MD, Rawn Salenger, MD, Clifford E. Fonner, BA, Christopher C. Kwon, MD, Jennifer Bobbitt, BSN, RN, James M. Brown, MD, Mark G. Nelson, MD, Keith A. Horvath, MD, and Glenn R. Whitman, MD

Divisions of Cardiac Surgery and Cardiology, Department of Medicine, The Johns Hopkins University School of Medicine, Baltimore; Division of Cardiac Surgery, University of Maryland School of Medicine, Baltimore; Maryland Cardiac Surgery Quality Initiative, Baltimore; Beverly & Jerome Fine Cardiac Valve Center, Sinai Hospital of Baltimore, Baltimore; Department of Cardiac Surgery, Washington Adventist Hospital, Takoma Park; The Heart Institute, Western Maryland Health System, Cumberland; and Cardiothoracic Surgery Research Program, National Heart, Lung, and Blood Institute, National Institutes of Health, Bethesda, Maryland

Background. **Variation in red blood cell (RBC) transfusion practices exists at cardiac surgery centers across the nation. We tested the hypothesis that significant variation in RBC transfusion practices between centers in our state's cardiac surgery quality collaborative remains even after risk adjustment.**

Methods. **Using a multiinstitutional statewide database created by the Maryland Cardiac Surgery Quality Initiative (MCSQI), we included patient-level data from 8,141 patients undergoing isolated coronary artery bypass (CAB) or aortic valve replacement at 1 of 10 centers. Risk-adjusted multivariable logistic regression models were constructed to predict the need for any intraoperative RBC transfusion, as well as for any postoperative RBC transfusion, with anonymized center number included as a factor variable.**

Results. **Unadjusted intraoperative RBC transfusion probabilities at the 10 centers ranged from 13% to 60%; postoperative RBC transfusion probabilities ranged from 16% to 41%. After risk adjustment with demographic, comorbidity, and operative data, significant intercenter variability was documented (intraoperative probability range, 4%–59%; postoperative probability range, 13%–39%). When stratifying patients by preoperative hematocrit quartiles, significant variability in intraoperative transfusion probability was seen among all quartiles (lowest quartile: mean hematocrit value, 30.5% ± 4.1%, probability range, 17%–89%; highest quartile: mean hematocrit value, 44.8% ± 2.5%; probability range, 1%–35%).**

Conclusions. **Significant variation in intercenter RBC transfusion practices exists for both intraoperative and postoperative transfusions, even after risk adjustment, among our state's centers. Variability in intraoperative RBC transfusion persisted across quartiles of preoperative hematocrit values.**

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Red blood cell (RBC) transfusion practices have garnered much attention in the modern cardiac surgical literature. Transfusion has been associated with increased risks of postoperative infection and morbidity, prolonged hospital lengths of stay, and early and late mortality [1, 2]. Moreover, restrictive approaches to transfusion have been associated with at least equivalent morbidity and mortality compared with liberal strategies in the cardiac surgery population [3–5].

Despite the accumulation of literature supporting the restriction of blood transfusion to varying degrees in patients undergoing cardiac operations, wide variation among these practices persists [6–8]. In the United States, perioperative transfusion rates have been documented to vary widely in cardiac surgery centers, with rates of RBC transfusion ranging from 7.8% to 92.8% [9]. Moreover, details regarding center-level data have not been thoroughly explored, nor has the distinction between intraoperative and postoperative transfusions. As standardization of medical practice draws increasing

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Address correspondence to Dr Whitman, 1800 Orleans St, Zayed 7107, Baltimore, MD 21287; email: gwhitman@jhmi.edu.

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Abbreviations and Acronyms

AVR = aortic valve replacement
BMI = body mass index
CAB = coronary artery bypass
CI = confidence interval
COPD = chronic obstructive pulmonary disease
CVD = cerebrovascular disease
LVEF = left ventricular ejection fraction
GFR = glomerular filtration rate
MI = myocardial infarction
PAD = peripheral arterial disease
RBC = red blood cell

attention from both providers and policy makers, we felt an examination of our statewide RBC transfusion practices would be an essential first step in improving patient care.

The purpose of this study was to explore variability in transfusion rates and associated risk factors in 10 centers performing cardiac operations in Maryland. These centers recently formed a nonprofit collaborative, the Maryland Cardiac Surgery Quality Initiative (MCSQI), to share data and standardize best practices in the name of improving patient care. We conducted a retrospective cohort study of patients undergoing cardiac operations at any 1 of the 10 MCSQI hospitals between 2011 and 2014 to test the hypothesis that significant intercenter variation in blood transfusion practices exists even after performing risk adjustment for patient and operative characteristics. We also sought to explore the interaction between preoperative hematocrit values and center variations, hypothesizing that patients with relatively lower preoperative hematocrit values would more likely require intraoperative RBC transfusions (ie, transfusion would be common for these patients at any center).

Patients and Methods

MCSQI Collaborative and Patient Population

The MCSQI was founded in 2013 as a nonprofit consortium of 10 cardiac surgery programs from across the state of Maryland. In addition to holding regular meetings and conference calls to discuss best practices, the MCSQI functions to collect data from member hospitals for analysis after project approval by the MCSQI's research committee.

After obtaining appropriate approval from the MCSQI board as well as our institutional review board, we included the records of patients undergoing isolated coronary artery bypass (CAB) and isolated aortic valve replacement (AVR) on cardiopulmonary bypass at each of the 10 MCSQI hospitals from 2011 to 2014. Patients who had any other concomitant procedure were excluded. Patient and hospital identifiers were removed before analysis.

Primary Outcomes and Variable Definitions

The primary outcomes were the occurrence of transfusion of 1 or more units of packed red blood cells (RBCs) either intraoperatively or postoperatively. Each outcome was considered independently. The intraoperative period was defined as the time between the patient entering the operating room and the time the patient leaves the operating room, whereas the postoperative period encompassed the period from postoperative intensive care unit (ICU) admission to hospital discharge. Variable definitions were collected according to The Society of Thoracic Surgeons data abstraction guide, versions 2.73 and 2.81 [10].

Statistical Analysis

Demographic, clinical, and operative characteristics were analyzed in patients who did and those who did not receive any RBC transfusion intraoperatively and between patients who did and those who did not receive any RBC transfusion postoperatively. Continuous variables were compared using *t* tests or rank-sum tests, or both, according to distribution, whereas χ^2 tests were used to compare categorical variables. A p value of less than 0.05 was the threshold for significance for all tests performed. Statistical analysis was performed using STATA, version 12.0 (StataCorp LP, College Station, TX).

For each primary outcome—intraoperative or postoperative RBC transfusion—2 multivariable logistic regression models with progressive degrees of adjustment were developed to assess the probability of RBC transfusion in each surgical center. These models were derived across all 8,141 patients. Model I assessed the unadjusted probability of receiving RBC transfusions by center. Model II further adjusted for demographic characteristics, including age and sex; clinical characteristics, including body mass index, diabetes, cerebrovascular disease (CVD), lung disease, immunocompromised status, myocardial infarction (MI) within 21 days of operation, glomerular filtration rate (GFR), left ventricular ejection fraction (LVEF), use of anticoagulants preoperatively, use of nonaspirin antiplatelet agents preoperatively, use of thrombolytic agents preoperatively, and preoperative hematocrit value; operative variables, including bypass time, cross-clamp time, previous cardiac operations, urgent or emergent operative status, and coronary artery bypass grafting (compared with AVR). These 2 models were executed for each primary outcome of intraoperative and postoperative RBC transfusion, as well as in aggregate (ie, any RBC transfusion during the hospital stay).

To define intercenter variation, the anonymized center identifier (1–10) was included as a factor variable in our multivariable models and was forced into the 4 models. Centers were reranked in descending order of patients contained within the database, with center 1 defined as the center contributing the greatest number of patients to the MCSQI database and center No. 10 as the center with the fewest patients. Centers were then included in a multivariable analysis. The 2 logistic regression models

were used to generate predicted probabilities of intra- and postoperative RBC transfusions for each patient, and these probabilities were grouped by center and reported with corresponding 95% confidence intervals (CIs).

As a secondary analysis, to assess whether intercenter differences tended to be observed more in patients with higher preoperative hematocrit values versus those with lower values, we also recreated a multivariable model for intraoperative RBC transfusion stratifying patients by quartiles according to preoperative hematocrit value.

Results

A total of 8,141 patients were included in the analysis. Of these, 6,378 (78%) underwent isolated CAB, whereas 1,763 (22%) underwent isolated AVR. The raw transfusion rate for any intra- or postoperative transfusion was 49.5% (4,032 of 8,141), with a mean of 1.7 ± 3.6 units transfused in total. For CAB versus AVR procedures, the transfusion rates were 48.8% versus 52.4%, respectively ($p = 0.007$), and the mean number of units transfused was 1.7 ± 3.5 and 1.9 ± 3.9 units, respectively ($p = 0.03$). Patients who received RBC transfusions either intra- or postoperatively were older and had lower body mass indices and higher incidences of comorbidities, including hypertension, diabetes, peripheral arterial disease (PAD), diabetes, CVD, chronic obstructive pulmonary disease (COPD), lower GFRs, and lower preoperative hematocrit values (Table 1). Redo median sternotomy (ie, reoperation) was performed in 348 patients (4.3% overall rate), and patients undergoing repeated cardiac operations were significantly more likely to receive a blood transfusion. Patients who received any RBCs intraoperatively received a mean of 2.7 ± 2.0 units. Similarly, patients who received any postoperative RBCs received a mean of 2.9 ± 4.2 units.

Preoperative hematocrit values in each center were clinically similar, ranging from 36.5% ± 7.4% to 39.8% ± 5.25, although statistically different ($p < 0.001$). However, intraoperatively, the proportion of patients receiving an RBC transfusion varied from 12.8% to 60.3% of patients by center. Postoperatively, RBC transfusion rates ranged from 15.6% to 40.7% (Table 2).

After risk adjustment, significant intercenter variation in both intraoperative and postoperative RBC transfusion probabilities remained (Table 3; Fig 1). Even after maximal risk adjustment in model II, predicted probabilities of intraoperative transfusion ranged from 4% (3%–5%) to 59% (56%–63%), whereas probabilities of postoperative transfusion ranged from 13% (5%–21%) to 39% (34%–43%). Shown graphically (Fig 1), there were no consistent trends in probabilities either when comparing centers with each other or when comparing intraoperative and postoperative transfusion practices at individual centers. Five centers were significantly more likely to transfuse patients postoperatively compared with intraoperatively (centers 3, 4, 5, 6, and 8), whereas the opposite was true in 1 center (center 2). Other significant predictors of transfusion included age, female sex, BMI, PAD, COPD, immunosuppressed status, MI less than 21 days previously, GFR, hematocrit value, bypass time, redo sternotomy, urgent/emergent operative status, and CAB (versus AVR) (Supplemental Table).

Finally, in an attempt to explain some of the wide variability in the use of intraoperative RBC transfusions, we calculated average predicted probabilities by quartiles of preoperative hematocrit values (Table 4). At the lowest quartile, which included 2,043 patients with a mean preoperative hematocrit value of 30.5% ± 4.1%, predicted intraoperative transfusion probabilities ranged from 17% (14% –21%) to 89% (87%–91%). At the highest quartile (1,925 patients) with a mean preoperative hematocrit value of 44.8% ± 2.5%, these probabilities ranged from 1% (1%–2%) to 35% (31%–40%). Shown graphically (Fig 2), all centers exhibited a negative relationship between increasing preoperative hematocrit value and decreasing intraoperative transfusion probability. At the lowest preoperative hematocrit quartile, CIs overlapped for 3 centers in the 14% to 33% probability range and for 6 centers roughly in the 47% to 82% range; center 2 was a high outlier in the 87% to 91% range. By comparison, in the highest preoperative hematocrit quartile, the same 3 centers clustered in the 1% to 3% probability range, the same 6 centers clustered in the 5% to 20% range, and center 2 was again an outlier in the 31% to 40% range. Put another way, the centers' curves of predicted probabilities at each of the 4 quartiles did not tend to cross each other, suggesting relative consistency of transfusion practices on a per-center basis across the range of preoperative hematocrit values (within the limits of inference resulting from the relatively wide CIs at some centers).

Comment

In the present study, we documented that even after risk adjustment among centers with relatively similar preoperative hematocrit values, significant intercenter differences in RBC transfusion practices exist among 10 centers in the state of Maryland. Predicted probabilities of intraoperative and postoperative transfusion differed significantly both before (ie, model I) and after (ie, model II) thorough risk adjustment. There were no discernable patterns of transfusion between centers when comparing intraoperative and postoperative transfusion probabilities. Moreover, there appeared to be a negative relationship between preoperative hematocrit values and intraoperative transfusion probability for all centers. The centers' transfusion probability curves tended to remain parallel and not cross, suggesting relative consistency in intraoperative transfusion habits across a range of preoperative hematocrit values. In documenting significant risk-adjusted intercenter variation in intraoperative transfusion probabilities among patients in all hematocrit quartiles, we found evidence to reject our hypothesis that practices would be similar between centers for certain preoperative hematocrit ranges.

Our evidence mirrors other studies documenting wide intercenter variation in transfusion practices, even after risk adjustment. These and other findings raise a "red flag" for the apparent lack of standardization regarding RBC transfusion practices in cardiac operations. A

Table 1. Demographic, Comorbidity, Presentation, Operative, and Transfusion Data for All Patients, Stratified by Patients Who Did and Those Who Did Not Receive an Intraoperative Transfusion or Postoperative Transfusion

	Intraoperative RBC Transfusion			Postoperative RBC Transfusion		
	No	Yes	*p* Value	No	Yes	*p* Value
N	5,523	2,618		5,415	2,726	
Age (μ ± SD; y)	63.7 (10.6)	68.4 (11.2)	<0.001[c]	64.3 (10.9)	67.2 (10.9)	<0.001[c]
BMI (μ ± SD; kg/m^2)	31.5 (14.3)	30.6 (21.3)	0.042[a]	31.6 (17.6)	30.4 (15.4)	0.002[b]
Male sex (%)	80.8 (4,462)	49.2 (1,288)	<0.001[c]	73.7 (3,993)	64.5 (1,757)	<0.001[c]
Hypertension (%)	83.1 (4,590)	87.3 (2,285)	<0.001[c]	84.0 (4,549)	85.3 (2,326)	0.121
Diabetes (%)	40.1 (2,214)	49.3 (1,291)	<0.001[c]	42.3 (2,288)	44.6 (1,217)	0.040[a]
PAD (%)	10.1 (555)	15.6 (408)	<0.001[c]	10.2 (551)	15.1 (412)	<0.001[c]
Previous CVD (%)	12.0 (665)	18.5 (484)	<0.001[c]	12.8 (693)	16.7 (456)	<0.001[c]
COPD (%)	17.9 (989)	19.2 (502)	0.167	17.2 (929)	20.6 (562)	<0.001[c]
Immunocompromised status (%)	1.6 (88)	3.3 (87)	<0.001[c]	1.6 (86)	3.3 (89)	<0.001[c]
GFR (μ ± SD; units?)	84.3 (34.2)	61.7 (33.0)	<0.001[c]	81.4 (35.0)	68.2 (34.6)	<0.001[c]
LVEF (μ ± SD; %)	51.5 (12.4)	50.7 (13.7)	0.006[b]	52.0 (12.4)	49.9 (13.7)	<0.001[c]
MI within 7 d (%)	22.5 (1,242)	29.0 (760)	<0.001[c]	22.9 (1,242)	27.9 (760)	<0.001[c]
MI within 21 d (%)	25.0 (1,381)	33.7 (883)	<0.001[c]	25.4 (1,374)	32.7 (890)	<0.001[c]
Preoperative anticoagulation (%)	34.4 (1,898)	42.4 (1,109)	<0.001[c]	35.6 (1,928)	39.6 (1,079)	<0.001[c]
Preoperative antiplatelet agents (nonaspirin) (%)	4.6 (256)	4.9 (129)	0.562	4.0 (216)	6.2 (169)	<0.001[c]
Preoperative thrombolytic agents (%)	0.14 (8)	0.2 (6)	0.391	0.2 (8)	0.2 (6)	0.457
Preoperative hematocrit value (%)						
<30	2.9 (160)	19.9 (522)	<0.001[c]	5.2 (292)	14.3 (390)	<0.001[c]
≥30 to <40	42.9 (2,369)	64.6 (1,693)		45.1 (2,411)	59.5 (1,621)	
≥40	54.2 (2,994)	15.4 (403)		49.5 (2,682)	26.2 (715)	
Previous median sternotomy (%)	2.9 (160)	7.2 (188)	<0.001[c]	3.2 (171)	6.5 (177)	<0.001[c]
Urgent-emergent procedure (%)	54.5 (3,007)	61.7 (1,616)	<0.001[c]	54.5 (2,949)	61.4 (1,674)	<0.001[c]
CAB (%)	79.2 (4,375)	76.5 (2,003)	<0.001[c]	78.3 (4,239)	78.5 (2,139)	0.849
AVR (%)	20.8 (1,148)	23.5 (615)	0.006[b]	21.7 (1,176)	21.5 (587)	0.849
Bypass time (μ ± SD; min)	87.9 (31.2)	104.4 (42.9)	<0.001[c]	90.1 (33.2)	99.5 (40.9)	<0.001[c]
Cross-clamp time (μ ± SD; min)	63.7 (24.3)	72.0 (28.9)	<0.001[c]	65.0 (25.2)	69.2 (27.8)	<0.001[c]
Intraoperative transfusion units						
RBC (μ ± SD)	0.0 (0.0)	2.7 (2.0)	<0.001[c]	0.6 (1.4)	1.4 (2.1)	<0.001[c]
FFP (μ ± SD)	0.1 (0.5)	1.1 (2.0)	<0.001[c]	0.3 (1.0)	0.7 (1.7)	<0.001[c]
Platelets (μ ± SD)	0.3 (1.0)	1.1 (2.1)	<0.001[c]	0.4 (1.2)	0.9 (1.8)	<0.001[c]
Cryoprecipitate (μ ± SD)	0.0 (0.3)	0.2 (1.4)	<0.001[c]	0.1 (0.8)	0.1 (1.0)	<0.001[c]

(*Continued*)

Table 1. Continued

	Intraoperative RBC Transfusion			Postoperative RBC Transfusion		
	No	Yes	*p* Value	No	Yes	*p* Value
Postoperative transfusion units						
RBC (μ ± SD)	0.6 (1.4)	1.7 (4.4)	<0.001[c]	0.0 (0.0)	2.9 (4.2)	<0.001[c]
FFP (μ ± SD)	0.2 (0.9)	0.6 (2.1)	<0.001[c]	0.0 (0.3)	0.8 (2.3)	<0.001[c]
Platelets (μ ± SD)	0.2 (0.9)	0.4 (1.8)	<0.001[c]	0.0 (0.4)	0.6 (2.1)	<0.001[c]
Cryoprecipitate (μ ± SD)	0.2 (1.5)	0.3 (2.0)	<0.001[c]	0.1 (0.7)	0.6 (2.6)	<0.001[c]

[a] = significant at $p < 0.05$; [b] = $p < 0.01$; [c] = $p < 0.001$.

All data shown as % (n) or mean ± SD.

AVR = aortic valve replacement; BMI = body mass index; CAB = coronary artery bypass; COPD = chronic obstructive pulmonary disease; CVD = cerebrovascular disease; FFP = fresh frozen plasma; GFR = glomerular filtration rate; LVEF = left ventricular ejection fraction; MI = myocardial infarction; PAD = peripheral arterial disease; RBC = red blood cell.

multicenter study of critically ill patients found evidence for a strong institutional effect even after controlling for a range of patient- and disease-specific characteristics on multivariable analysis [8]. In the cardiac surgery population, variation in transfusion rates has been documented to vary dramatically both between surgeons and between centers [7, 9, 11–14]. The study of Bennett-Guerrero and colleagues [9] included more than 100,000 patients at 798 centers performing CAB and noted that case mix differences explained only 20% of variation in RBC use, and hospital characteristics (ie, geography, volume, academic status) explained only another 11% of variations. Another study from the Virginia Cardiac Surgery Quality Initiative did not specifically comment on intercenter differences in transfusion rates but found that issuing a guideline to all 17 participating centers was associated with a reduction in the transfusion rate both intraoperatively (24% versus 18%; $p < 0.001$) and postoperatively (39% versus 33%; $p < 0.001$) after risk adjustment [4]. The finding that standardization of practice reduces blood product use supports the idea that significant variation in practice likely existed beforehand.

The overall negative relationship we documented between preoperative hematocrit values and the probability of RBC transfusion was unsurprising and has been previously documented in both single-center and multicenter studies [14–17]. This relationship remains important, because exposure to both preoperative anemia and perioperative transfusion may potentiate worse outcomes than exposure to either risk factor alone [18–20]. Because our data set did not contain ICU admission hematocrit values, the relationship between preoperative hematocrit values and intraoperative transfusion was logical but has not been clearly delineated before in multicenter studies. Whether examining patients in the lowest or highest quartile of preoperative hematocrit values, significant variation persisted between centers. We note that a particularly wide degree of intraoperative transfusion probability variation was observed in the lowest quartile of preoperative hematocrit values (Fig 2).

As a further reflection of variation in practice, we note that 8 of the 10 MCSQI centers have transfusion protocols in place addressing intraoperative and postoperative transfusion (all centers except 7 and 8). Marked heterogeneity in these protocols was observed, with transfusion-triggered hematocrit thresholds of 18% to 24% reported. Center-level data on protocol compliance was unavailable, but no discernible patterns or associations between the presence of a transfusion protocol and the probability of transfusion were observed. For example, across all hematocrit values, centers 7 and 8 had approximately average risk-adjusted intraoperative transfusion probabilities despite lacking transfusion protocols or restrictive thresholds for transfusion (Fig 2). These practices could undoubtedly be standardized, as was done in the study of LaPar and colleagues [4].

Finally, we wish to issue a cautionary note about the dangers of reporting unadjusted data. As shown in

Table 2. Raw Preoperative Hematocrit Means and Transfusion Rates by Center

Center ID No.	N	Mean Hematocrit Value μ ± SD	Any RBC Transfusion Yes: n (%)	Intraoperative RBC Transfusion Yes: n (%)	Postoperative RBC Transfusion Yes: n (%)
1	1,841	38.0 (5.7)	999 (54.3)	680 (36.9)	659 (35.8)
2	1,397	37.3 (5.8)	988 (70.7)	842 (60.3)	533 (38.2)
2	958	38.6 (5.2)	436 (45.5)	271 (28.3)	295 (30.8)
4	907	37.8 (6.4)	334 (36.8)	124 (13.7)	299 (33.0)
5	888	37.9 (5.6)	307 (34.6)	114 (12.8)	255 (28.7)
6	732	37.8 (5.4)	281 (38.4)	133 (18.2)	233 (31.8)
7	607	38.7 (6.2)	281 (46.3)	198 (32.6)	157 (25.9)
8	543	39.8 (5.2)	259 (47.7)	148 (27.3)	202 (37.2)
9	204	38.9 (6.1)	113 (5.4)	80 (39.2)	83 (40.7)
10	64	36.5 (7.4)	34 (53.1)	28 (43.8)	10 (15.6)
Overall	8,141		4032 (49.5)	2618 (32.2)	2726 (33.5)

95% CIs shown in parentheses. For both intraoperative and postoperative RBC transfusions, the highest and lowest raw transfusion rates are bolded in the fifth and sixth columns, respectively.

CI = confidence interval; RBC = red blood cell.

Table 3. Predicted Probabilities of Any, Intraoperative, and Postoperative RBC Transfusions

Any RBC Transfusion	Model I	Model II
1	0.54 (0.52–0.57)	0.59 (0.56–0.61)
2	0.71 (0.68–0.73)	0.73 (0.70–0.76)
3	0.46 (0.42–0.49)	0.47 (0.43–0.51)
4	0.37 (0.34–0.40)	0.35 (0.31–0.38)
5	0.35 (0.31–0.38)	0.27 (0.24–0.30)
6	0.38 (0.35–0.42)	0.37 (0.33–0.42)
7	0.46 (0.42–0.50)	0.50 (0.45–0.55)
8	0.48 (0.43–0.52)	0.53 (0.48–0.58)
9	0.55 (0.49–0.62)	0.54 (0.46–0.62)
10	0.53 (0.41–0.65)	0.52 (0.38–0.67)
Intraoperative RBC Transfusion		
1	0.37 (0.35–0.39)	0.34 (0.31–0.36)
2	0.60 (0.58–0.63)	0.59 (0.56–0.63)
3	0.28 (0.25–0.31)	0.20 (0.17–0.24)
4	0.14 (0.11–0.16)	0.06 (0.05–0.08)
5	0.13 (0.11–0.15)	0.04 (0.03–0.05)
6	0.18 (0.15–0.21)	0.11 (0.09–0.13)
7	0.33 (0.29–0.36)	0.28 (0.24–0.32)
8	0.27 (0.24–0.31)	0.22 (0.18–0.26)
9	0.39 (0.33–0.46)	0.30 (0.22–0.37)
10	0.44 (0.32–0.56)	0.36 (0.21–0.52)
Postoperative RBC Transfusion		
1	0.36 (0.34–0.38)	0.35 (0.33–0.38)
2	0.38 (0.36–0.41)	0.33 (0.31–0.36)
3	0.31 (0.28–0.34)	0.30 (0.27–0.33)
4	0.33 (0.30–0.36)	0.32 (0.29–0.36)
5	0.29 (0.26–0.32)	0.25 (0.22–0.28)
6	0.32 (0.28–0.35)	0.32 (0.28–0.35)
7	0.26 (0.22–0.29)	0.26 (0.22–0.29)
8	0.37 (0.33–0.41)	0.39 (0.34–0.43)
9	0.41 (0.34–0.47)	0.37 (0.30–0.44)
10	0.16 (0.07–0.25)	0.13 (0.05–0.21)

Probabilities shown as numbers between 0 and 1, with corresponding 95% CIs shown in parentheses.

Model I: unadjusted; model II: adjusted for demographic characteristics: age and sex; clinical characteristics: body mass index, diabetes mellitus, previous CVD, COPD, immunocompromised status, previous MI within 21 days, eGFR, LVEF, use of anticoagulants preoperatively, use of antiplatelet agents (nonaspirin) preoperatively, use of thrombolytic agents preoperatively, and preoperative hematocrit value; surgical characteristics: bypass time, cross-clamp time, previous CABG or AVR, urgent/emergent operative status, and CABG (compared with AVR).

AVR = aortic valve replacement; CABG = coronary artery bypass grafting; CI = confidence interval; COPD = chronic obstructive pulmonary; CVD = cerebrovascular disease; eGFR = estimated glomerular filtration rate; LVEF = left ventricular ejection fraction; MI = myocardial infarction; RBC = red blood cell.

Table 3, marked differences were demonstrated between unadjusted (model I) and risk-adjusted (model II) probabilities of intraoperative and postoperative transfusions. Some centers saw marked decreases in their unadjusted

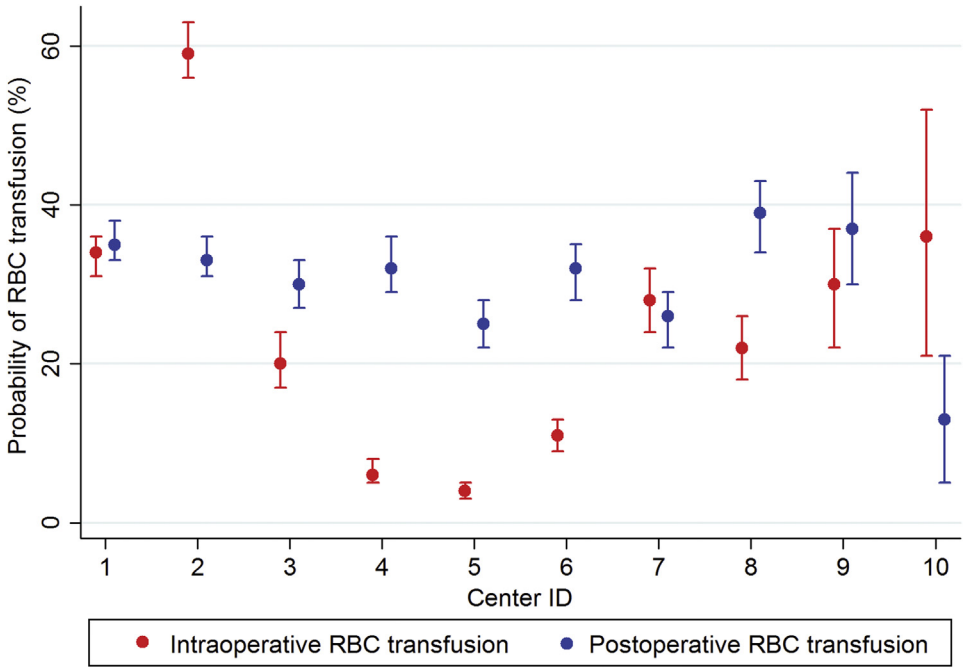

Fig 1. Risk-adjusted predicted probabilities shown by center for intraoperative (red markers) and postoperative (blue markers) red blood cell (RBC) transfusions. Probabilities and 95% confidence intervals (CIs) taken from model II in Table 3.

versus risk-adjusted probabilities of transfusion, such as the probability of intraoperative transfusion for centers 4 and 5. Other centers saw an increased risk-adjusted probability compared with unadjusted figures, as for postoperative transfusions at center 8. If centers were ordered by increasing probability of intraoperative or postoperative transfusion, the use of unadjusted versus adjusted probabilities would alter such rankings. These differences underscore the perils of publically reporting unadjusted data that do not reflect individual centers' true case mixes.

Our study has several limitations worth noting. First are the limitations inherent in a retrospective review of observational data, and as such our data must be regarded as hypothesis generating. Our data set was limited to a subset of The Society of Thoracic Surgeons database variables, which provided adequate covariates for risk adjustment but may nonetheless miss important confounders. For example, we were unable to capture whether bypass procedures were performed on or off cardiopulmonary bypass, although discussions with individual centers indicated that no centers preferentially

Table 4. Mean Risk-Adjusted Predicted Probabilities of Intraoperative Transfusion Stratified by Quartiles of Preoperative Hematocrit as Well as by Center

	Quartile 1	Quartile 2	Quartile 3	Quartile 4
Mean Preoperative Hematocrit Value ± SD	30.5 ± 4.1	36.9 ± 1.1	40.5 ± 1.0	44.8 ± 2.5
N	2,043	2,047	2,126	1,925
Center				
1	0.67 (0.63–0.70)	0.38 (0.34–0.41)	0.21 (0.19–0.24)	0.12 (0.10–0.14)
2	0.89 (0.87–0.91)	0.71 (0.67–0.74)	0.52 (0.47–0.56)	0.35 (0.31–0.40)
3	0.52 (0.47–0.57)	0.25 (0.21–0.28)	0.13 (0.10–0.15)	0.07 (0.05–0.08)
4	0.20 (0.16–0.23)	0.07 (0.05–0.08)	0.03 (0.02–0.04)	0.02 (0.01–0.02)
5	0.17 (0.14–0.21)	0.06 (0.04–0.07)	0.03 (0.02–0.03)	0.01 (0.01–0.02)
6	0.28 (0.23–0.33)	0.11 (0.08–0.13)	0.05 (0.04–0.06)	0.03 (0.02–0.03)
7	0.60 (0.55–0.66)	0.31 (0.26–0.36)	0.17 (0.14–0.20)	0.09 (0.07–0.12)
8	0.56 (0.50–0.63)	0.28 (0.23–0.33)	0.15 (0.12–0.18)	0.08 (0.06–0.10)
9	0.72 (0.64–0.80)	0.44 (0.35–0.53)	0.26 (0.19–0.33)	0.15 (0.10–0.20)
10	0.67 (0.52–0.82)	0.38 (0.22–0.54)	0.21 (0.10–0.33)	0.12 (0.05–0.20)

95% CIs shown in parentheses.

CIs = confidence intervals.

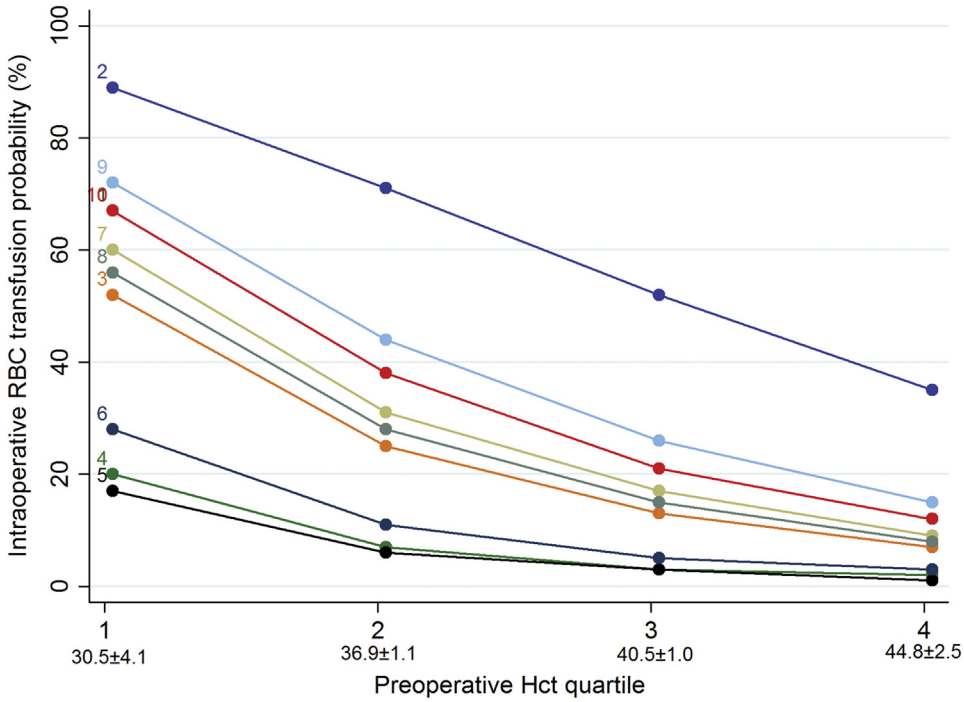

Fig 2. Mean risk-adjusted predicted probabilities of intraoperative transfusion stratified by quartiles of preoperative hematocrit (HcT) value as well as by center (95% confidence intervals [CIs]) shown in Table 4). Center identifier shown at left end of curves; note that centers 1 and 10 overlie each other. (RBC = red blood cell.)

performed off-pump bypass operations. Similarly, we lack data to adjust for the outside influence of high-volume surgeons in low-volume centers and their regard (or disregard) for transfusion protocols that may exist. Additionally, in our assessment of the relationship between preoperative hematocrit values and transfusion risk, we did not have a postoperative ICU admission hematocrit value as a variable in our data set nor was bleeding data available. This may obscure the true relationship between intraoperative and postoperative transfusions; for example, some centers may in reality use differing transfusion policies for intraoperative and postoperative transfusions. Although we cannot comment directly on this possibility, we do note that risk-adjusted probabilities of intraoperative versus postoperative transfusions appeared to differ at 6 centers (Fig 1). Finally, the absence of ICU admission hematocrit values as a covariate precluded analyzing the hematocrit value/transfusion probability relationship for postoperative transfusions as we did for intraoperative transfusions (Table 4; Fig 2).

In conclusion, significant variation among cardiac surgery centers in Maryland exists even after risk adjustment. Wide variation in intraoperative transfusion practices was particularly prominent across all quartiles of preoperative hematocrit values but was particularly notable across the lowest quartile. In light of accumulating data suggesting, at a minimum, the safety of blood conservation programs and their potential association with improved outcomes and resource use, the MCSQI plans to further study means by which transfusion practices can be standardized and blood products conserved on a statewide basis. Discussions are already under way to potentially establish a statewide protocol to limit transfusions in accordance with the best available evidence. We hope this study will represent the first step in the standardization process as we aim to optimize patient outcomes.

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INVITED COMMENTARY

Over the past several years, the number of articles addressing the impact of transfusion in cardiac operations has increased. These single-center and multicenter results have identified the wide variation in rates of intraoperative and perioperative transfusion, the association of transfusion with increased mortality and morbidity, and the increase in costs resulting from the blood components and adverse events of transfusion. The regional quality improvement initiatives in both Virginia and Michigan have specifically addressed many of these concerns in their state collaboratives and have previously documented their results.

The Maryland Cardiac Surgery Quality Initiative (MCSQI) is the newest regional collaboration to join the state quality groups already active in northern New England (the first such organization), Michigan, Virginia, Washington, and Texas. Although just over 18 months old, the MCSQI has already begun to focus on measuring the outcomes in cardiac operations in that region and are seeking to standardize the approach to surgical care with a shared vision to improve such care between and among all participants. This article [1] in *The Annals of Thoracic Surgery* was the first study to be published from that Initiative, and the authors are to be congratulated for attempting to document their results in such a transparent manner.

Specifically, the authors tested the hypothesis that "significant intercenter variation in blood transfusion practices exists even after performing risk adjustment for patient and operative characteristics" as well as identifying the "interaction between preoperative hematocrit and center variations, hypothesizing that patients with relatively lower preoperative hematocrits would more likely require intraoperative RBC transfusion." They found, not surprisingly, that "significant variation in intercenter RBC transfusion practices exist for both intraoperative and postoperative transfusion even after risk adjustment among our state's centers. Variability in intraoperative RBC transfusion persisted across quartiles of preoperative hematocrit."

Many have criticized such regional outcomes, correctly citing the limitations of such retrospective studies; variations in protocols used for transfusion, atrial fibrillation, glucose management, and early extubation; and the statistical methods applied in analyses of the regional results. These criticisms are often well founded. One wonders, however, how many of these critics are actually applying evidenced-based protocols to their individual or group practices, how many are evaluating their results and modifying their approaches to surgical or critical care as a response to such outcomes, and how many are altering their practice based on the Society of Thoracic Surgeons' semiannual risk-stratified results from their centers? Despite the shortcomings in process and application, this may be the real benefit of such regional collaborations that may measure, modify, and improve care more expeditiously than that might be seen on a national level.

The real challenge for the MCSQI is this: what are they going to do with their results? Will they be able to really

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