The impact of a multidisciplinary blood conservation protocol on patient outcomes and cost after cardiac surgery

Niv Ad, MD,^a Sari D. Holmes, PhD,^a Jay Patel, BS,^b Deborah J. Shuman, BS,^b Paul S. Massimiano, MD,^c Elmer Choi, MD,^b David Fitzgerald, CCP,^d Linda Halpin, RN, MSN,^b and Lisa M. Fornaresio, PhD^a

ABSTRACT

Objective: Although associations between transfusion and inferior outcomes have been documented, there is a lack of blood transfusion standardization in cardiac surgery. At the Inova Heart and Vascular Institute, a multidisciplinary, criterion-driven algorithm for transfusion management was implemented. We examined the effect of our blood conservation protocol on transfusion rates and outcomes after cardiac surgery and on stability of transfusion over time.

Methods: Patients undergoing first-time cardiac surgery from 2006 (full year before protocol) were compared with those in 2009 (after protocol) and propensity score matched to improve balance. Data were prospectively collected. Stability of transfusion incidence also was compared (2005-2006 vs 2008-2014).

Results: After matching, 890 patients from each year were included. Use of blood products decreased from 54% in 2006 to 25% in 2009 ($P < .001$). Patients in 2009 had a lower incidence of postoperative renal failure (2.6% vs 4%, $P = .04$), reoperations for bleeding (2% vs 4%, $P = .004$), and readmissions at less than 30 days (6% vs 12%, $P < .001$). No differences were found for operative mortality, deep sternal wound infection, or permanent strokes. Patients in 2009 had greater improvement in physical ($P = .001$) and mental ($P = .02$) quality of life than patients in 2006. Reduction of blood products led to significant cost savings for packed erythrocytes ($P < .001$) and platelets ($P < .001$). After protocol implementation, transfusion incidence remained 30% or less, with less than 28% in most years.

Conclusions: A multidisciplinary blood conservation program can significantly control blood transfusion rates, improve outcomes, and be sustained over time. Efforts are needed to implement evidence-based protocols to standardize and decrease blood use in cardiac surgery to improve outcomes and reduce cost. (J Thorac Cardiovasc Surg 2017;153:597-605)

Incidence of blood product transfusion before and after implementation of blood protocol.

Central Message

A multidisciplinary blood conservation program can control blood transfusion, improve outcomes, and be sustained over time.

Perspective

Adherence to standardized blood conservation protocols had a positive effect on postoperative outcomes of patients undergoing cardiac surgery. Cardiac surgery programs should consider measuring transfusion indications and rates as indicators of quality. Communication and involvement from all clinicians involved in cardiac surgical cases are key to success of a blood conservation protocol.

See Editorial Commentary page 606.

Cardiac surgery accounts for a significant proportion of all blood products transfused in the United States.^{1,2} Data from the Society of Thoracic Surgeons (STS) database indicate that up to 50% of patients undergoing cardiac surgery receive blood transfusion.³ As these patients continue to

present with increasing complexity and acuity, these rates can be expected to increase.⁴⁻⁶

Despite the existence of guidelines from numerous national and international organizations for perioperative blood transfusion,⁷⁻¹⁵ wide discrepancies persist with regard to blood transfusions, not only among institutions but also among key decision makers (eg, surgeons and anesthesiologists).¹⁶⁻²² The recommendations that do exist are based chiefly on expert opinion rather than verifiable

From the ^aDivision of Cardiothoracic Surgery, West Virginia University, Morgantown, WV; ^bInova Fairfax Hospital, Falls Church, Va; ^cCardiovascular Surgery, Washington Adventist Hospital, Takoma Park, Md; and ^dDivision of Cardiovascular Perfusion, The Medical University of South Carolina, Charleston, SC.

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Address for reprints: Niv Ad, MD, Division of Cardiothoracic Surgery, West Virginia University, 1 Medical Center Drive, Morgantown, WV 26506 (E-mail: niv.ad@wvumedicine.org).

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Abbreviations and Acronyms

CABG	= coronary artery bypass grafting
HgB	= hemoglobin
RBC	= red blood cell
STS	= Society of Thoracic Surgeons

evidence.^{10,11,23} This state of affairs suggests that many transfusions may be unnecessary and reflects the general uncertainty in determining the need for transfusion, including the role of hemoglobin (HgB) levels and clinical assessment in the decision to transfuse.^{18-20,24,25}

Beginning in mid-2007, a multidisciplinary team at the Inova Heart and Vascular Institute began to develop a blood conservation protocol to lower transfusion rates and establish a uniform transfusion standard across our cardiac surgery program. This comprehensive, criterion-driven algorithm for transfusion included modifications to cardiopulmonary bypass techniques, anesthesia, management of bleeding, and clear criteria for transfusion. The purpose of this study was to examine the impact of our institutional protocol on blood use and patient outcomes and the stability of blood use after the protocol was implemented.

MATERIALS AND METHODS

Patients

The study sample comprised patients who underwent cardiac surgery at the Inova Heart and Vascular Institute before and after the implementation of a blood conservation protocol that was developed in 2007. The changes in clinical practice that took place because of this protocol did not occur all at once, but rather were incrementally instituted throughout the year of 2007 and into 2008. Therefore, we examined patients who underwent surgery in 2009, when the blood conservation protocol had been fully in place and adhered to for a complete year, and compared them with similar patients who underwent surgery in 2006, the year before the protocol was developed.

The primary outcomes of interest included blood product use, clinical complications and survival, and cost. Secondary outcome analyses examined the degree to which the protocol had been implemented and adhered to from 2008 to 2014 in relation to the incidence of blood use from 2005 to 2007, before the protocol was developed. All patient outcome data were collected prospectively and obtained from our local STS database and institutional cardiac surgery database. Data on mortality during follow-up were updated through the use of the National Death Index, the Social Security Death Index, patients' medical records, and information from family members. Cost data for blood products were available from our institutional finance department. The study was approved by our institutional review board (study 6.022 and 12.055).

Blood Conservation Protocol

To facilitate a reduction in blood use, the Inova Heart and Vascular Institute developed and implemented a multifaceted blood conservation protocol over the course of the year 2007. Principal among the changes in perfusion practice were the expanded use of cell salvage blood in place

of cardiomy suction, the widespread adoption of acute normovolemic hemodilution, and the routine use of retrograde autologous priming of the cardiopulmonary bypass circuit.

At the time that the changes in perfusion practice took place, a criterion-driven algorithm for blood transfusion was developed with the input of a multidisciplinary team of clinical nurses, anesthesiologists, cardiac surgeons, and physician assistants. This algorithm was developed in conjunction with the 2007 STS guidelines⁸ and is outlined in Figure 1. According to the protocol, intraoperative blood transfusion is performed only for an HgB level less than 6 g/dL or a hematocrit level less than 18% in the presence of clinical indices of malperfusion. Likewise, an HgB level less than 7 g/dL or a hematocrit level less than 21% postoperatively with suggestive clinical indices may prompt a transfusion.

The multidisciplinary team comprises cardiac surgeons, anesthesiologists, intensivists, nurses along the service line, and perfusionists, all of whom are familiar with the blood conservation protocol and are in communication with each other about each surgical case. In all instances, the decision to transfuse blood is ultimately made solely at the discretion of the attending cardiac surgeon.

Statistical Analysis

Continuous data are presented as mean $\pm$ standard deviation, and categorical data are presented as frequency (percent) unless otherwise noted. A *P* value $< .05$ was considered statistically significant. All analyses were conducted using SPSS version 17.0 (SPSS Inc, Chicago, Ill). To determine differences in preoperative characteristics of patients in 2006 and 2009, the chi-squared or Fisher exact tests were used for categorical variables and Student independent-samples *t* test was used for continuous measures. Patients who underwent surgery in 2009 were propensity score matched to patients in 2006 to simulate randomization and improve balance on preoperative clinical and demographic variables.^{26,27} A logistic model was used to create propensity scores (c statistic = 0.622) that included the following covariates selected a priori: age, gender, body mass index, ejection fraction, diabetes, chronic pulmonary disease, peripheral vascular disease, previous cardiovascular intervention (including prior surgery), congestive heart failure, emergency status, dialysis, triple-vessel disease, hypertension, coronary artery bypass grafting (CABG) surgery, valve surgery, surgical ablation, and cardiopulmonary bypass time. A caliper of 0.25 propensity score standard deviations was used to match patients in 2009 and 2006. The matching procedure was successful in improving balance between the 2 groups (Figure E1), and most covariates achieved more than 70% improvement. All further analyses used the propensity score-matched patients (*n* = 890 in each group).

Differences in perioperative and postoperative outcomes by group were evaluated using the chi-squared or Fisher exact test for categorical variables and Student independent-samples *t* test for continuous measures, except when the Mann-Whitney test was used because of heterogeneity of variance. For units of blood products, groups were created because of the highly skewed and zero-inflated nature of these data (0 units, 1-2 units, 3-5 units, and 6+ units), and chi-squared tests were conducted for comparison between surgery year groups. For similar reasons, groups were created for red blood cells (RBCs) (0 USD, <450 USD, and $\geq$ 450 USD) and platelet (0 USD, $\leq$ 1750 USD, and >1750 USD) cost data. Kaplan-Meier analysis with the log-rank test was conducted to compare cumulative survival curves between the 2 groups.

RESULTS

Patient Characteristics

A total of 2041 patients who received cardiac surgery in 2006 or 2009 were identified for analysis. These 2 cohorts

FIGURE 1. Flow diagram of institutional blood conservation protocol. RBC, Red blood cell; Hgb, hemoglobin; HCT, hematocrit; SVO₂, venous blood oxygen saturation; HCO₃, bicarbonate. Reprinted with permission from Ad N, Massimiano PS, Burton NA, Halpin L, Pritchard G, Shuman DJ, Holmes SD. Effect of patient age on blood product transfusion after cardiac surgery. *J Thorac Cardiovasc Surg.* 2015;150:209-14.

differed significantly in relation to several preoperative variables (Table 1). The groups became balanced on all preoperative characteristics after propensity score matching was applied to simulate randomization (Table 2).

TABLE 1. Baseline patient characteristics before propensity score matching

Characteristic*	Year 2006 (n = 1097)	Year 2009 (n = 944)	P value
Age, y	62.8 ± 12.2	63.3 ± 11.7	.44
Female	275 (25)	271 (29)	.06
Body mass index (kg/m ²)	28.3 ± 5.4	29.3 ± 5.9	<.001
Congestive heart failure	191 (17)	217 (23)	.002
Dialysis	28 (3)	30 (3)	.40
Preoperative creatinine level (mg/dL)	1.2 ± 1.0	1.3 ± 1.1	.18
Cerebrovascular disease	139 (13)	126 (13)	.65
Peripheral vascular disease	110 (10)	98 (10)	.79
Diabetes	346 (32)	305 (32)	.71
Hypertension	746 (68)	722 (77)	<.001
Triple-vessel disease	611 (56)	499 (53)	.20
Previous cardiovascular intervention	252 (23)	253 (27)	.05
Chronic lung disease	152 (14)	197 (21)	<.001
Ejection fraction (%)	54 ± 12	55 ± 12	.15
Emergency status	61 (6)	26 (3)	.002
euroSCORE (additive)	5.5 ± 3.6	5.6 ± 3.5	.81
CABG	808 (74)	630 (67)	<.001
Valve	362 (33)	380 (40)	<.001
Surgical ablation	89 (8)	85 (9)	.47
Cardiopulmonary bypass time	118.0 ± 53.4	115.7 ± 50.7	.32

euroSCORE, European System for Cardiac Operative Risk Evaluation; CABG, coronary artery bypass grafting. *Data are presented as mean ± standard deviation or N (%).

Clinical Outcomes

The incidence of overall blood product transfusion in the matched sample decreased from 54% in 2006 to 25% in 2009 (chi-squared = 166.4, $P < .001$). Notably, the reduction in transfusion was driven by changes in the postoperative period. The incidence of postoperative blood transfusion decreased from 48% in 2006 to 17% in 2009 (chi-squared = 205.4, $P < .001$). However, the frequencies of intraoperative blood transfusion in 2006 and 2009 were not significantly different (16% vs 18%; chi-squared = 0.68, $P = .41$). In addition, there were fewer patients in 2006 who received zero units of RBCs than patients in 2009 (55% vs 79%, chi-squared = 117.3, $P < .001$) and more patients in 2006 than 2009 who received 1 to 2 units (26% vs 11%, chi-squared = 66.9, $P < .001$), 3 to 5 units (13% vs 6%, chi-squared = 24.2, $P < .001$), and 6+ RBC units (6% vs 4%, chi-squared = 4.7, $P = .030$). Likewise, for non-RBC units, fewer patients in 2006 received zero units than patients in 2009 (57% vs 84%, chi-squared = 151.5, $P < .001$) and more patients in 2006 than 2009 who received 1 to 2 units (17% vs 6%, chi-squared = 57.8, $P < .001$), 3 to 5 units (12% vs 4%, chi-squared = 35.1, $P < .001$), and 6+ non-RBC units (14% vs 7%, chi-squared = 28.0, $P < .001$).

Median length of stay was significantly shorter for the 2009 cohort than for the 2006 cohort (median [interquartile range] = 4 [4] days vs 5 [4] days, $Z = -5.5$, $P < .001$). Furthermore, the incidence of hospital readmission within 30 days of surgery for the 2006 patients was double that for the 2009 patients (12% vs 6%, $P < .001$). Among the 2009 cohort, the incidence of

TABLE 2. Baseline patient characteristics after propensity score matching

Characteristic*	Year 2006 (n = 890)	Year 2009 (n = 890)	P value	Standardized difference
Age, y	62.8 ± 12.1	63.2 ± 11.6	.53	0.034
Female	242 (27)	244 (27)	.92	0.004
Body mass index (kg/m ²)	28.7 ± 5.6	29.0 ± 5.6	.33	0.054
Congestive heart failure	167 (19)	189 (21)	.19	0.060
Dialysis	27 (3)	25 (3)	.78	−0.012
Preoperative creatinine level (mg/dL)	1.2 ± 1.1	1.2 ± 1.0	.77	0.010
Cerebrovascular disease	115 (13)	117 (13)	.89	0.006
Peripheral vascular disease	99 (11)	90 (10)	.49	0.032
Diabetes	288 (32)	285 (32)	.88	−0.009
Hypertension	650 (73)	670 (75)	.28	0.052
Triple-vessel disease	479 (54)	478 (54)	.96	−0.002
Previous cardiovascular intervention	214 (24)	228 (26)	.44	0.037
Chronic lung disease	139 (16)	171 (19)	.05	0.079
Ejection fraction (%)	54 ± 12	54 ± 12	.92	0.008
Emergency status	25 (3)	26 (3)	.89	0.006
euroSCORE (additive)	5.47 ± 3.54	5.48 ± 3.45	.95	0.003
CABG	625 (70)	612 (69)	.50	−0.030
Valve	325 (37)	340 (38)	.46	0.035
Surgical ablation	77 (9)	77 (9)	>.999	0.000
Cardiopulmonary bypass time	116.2 ± 49.5	116.1 ± 51.4	.96	−0.002

euroSCORE, European System for Cardiac Operative Risk Evaluation; CABG, coronary artery bypass grafting. *Data are presented as mean ± standard deviation or N (%).

postoperative renal failure was lower (2.6% vs 4%, chi-squared = 4.3, $P = .04$), and of those patients who developed renal failure, fewer required dialysis (0.9% vs 3%, $P = .007$). The 2009 cohort also had significantly fewer reoperations for bleeding (2% vs 4%, $P = .004$). After RBC and non-RBC units were controlled for, patients in 2006 still had 2 times greater risk for 30-day readmissions (odds ratio, 2.07; 95% confidence interval, 1.47-2.90; $P < .001$) and reoperations for bleeding (odds ratio, 2.38; 95% confidence interval, 1.26-4.49; $P = .008$) than the patients in 2009.

TABLE 3. Comparison of postoperative complications among 2006 and 2009 patients after propensity score matching*

Complication	Year 2006 n = 890	Year 2009 n = 890	P value
Permanent stroke	10 (1)	10 (1)	>.999
Pneumonia	22 (3)	19 (2)	.64
Deep sternal wound infection	3 (0.3)	4 (0.4)	.73
Renal failure	39 (4)	23 (3)	.04
Requiring dialysis	24 (3)	8 (0.9)	.007
Reoperation for bleeding	39 (4)	17 (2)	.004
Atrial fibrillation during stay	155 (17)	128 (14)	.08
Postoperative ventilation (h)	25.1 ± 96.2	25.3 ± 112.0	.98
Length of stay (d)†	5 [4]	4 [4]	<.001
Readmissions <30 d	109 (12)	57 (6)	<.001
Operative death <30 d	14 (2)	13 (1)	.85

*Data are presented as mean ± standard deviation or N (%). †Median [interquartile range], evaluated with Mann-Whitney test.

No differences were found for operative mortality, deep sternal wound infections, or permanent strokes, and the incidence of these events was relatively low for both groups (Table 3). Similar 1-year cumulative survival was documented for the 2006 and 2009 cohorts (95.5% vs 95.4%, log rank = 0.03, $P = .859$) (Figure 2), as well as similar 5-year cumulative survival (86.2% vs 86.5%, log rank = 0.04, $P = .842$).

Reduction in the use of blood products from 2006 to 2009 led to a significant cost savings on the institutional level. In addition, cost data were available for RBC and platelet units in this sample. Comparison of costs for the 2 patient groups revealed that for RBC costs, patients in 2006 were less likely than patients in 2009 to incur 0 USD (55% vs 79%, chi-squared = 117.3, $P < .001$) and more likely to incur 0 to 450 USD (26% vs 11%, chi-squared = 66.9, $P < .001$) and 450 or more USD (20% vs 10%, chi-squared = 29.7, $P < .001$). Similarly for platelet costs, patients in 2006 were less likely than patients in 2009 to incur 0 USD (66% vs 86%, chi-squared = 101.0, $P < .001$) and more likely to incur 0 to 1750 USD (16% vs 6%, chi-squared = 46.9, $P < .001$) and more than 1750 USD (19% vs 8%, chi-squared = 41.1, $P < .001$). The reduction in costs occurred even though the charged cost per blood unit increased between 2006 and 2009.

Stability of Transfusion After Protocol

After implementation of the blood conservation protocol at the Inova Heart and Vascular Institute, the incidence of

FIGURE 2. Kaplan–Meier 1-year survival curves comparing patients undergoing cardiac surgery in 2009 with patients in 2006 (Y axis scale truncated to 0.80–1.00; log-rank = 0.03, $P = .859$). *CI*, Confidence interval.

blood product transfusion in patients undergoing first-time cardiac surgery decreased significantly and has remained stable over time (Figure 3). In each year for which complete data were available after the protocol was implemented (2008–2014), the incidence of any blood product transfusion, intraoperative or postoperative, remained at 30% or less and in most years was less than 28%. Most

recently, in 2014, 24% of patients undergoing first-time cardiac surgery received blood product transfusion during their entire hospital stay. When examined separately, intraoperative transfusion remained less than 22% and reached a low of 15% in 2013, and postoperative transfusion remained less than 21% and reached a low of 15% in 2010.

The greatest stability in the use of blood product transfusion since the blood protocol implementation, as well as the lowest incidence, was found for patients undergoing first-time isolated CABG surgery (Figure 4). Blood product use was highest in patients undergoing CABG and valve surgery procedures, with or without other procedures, but has steadily declined since the introduction of our blood conservation protocol. Stability in blood product use, particularly for postoperative blood product transfusion, has been lowest for patients undergoing isolated valve surgery and stand-alone or concomitant surgical ablation.

DISCUSSION

The purpose of this study was to examine the effect of an institutional blood conservation protocol on transfusion rates, patient outcomes, and costs after cardiac surgery. Nuttall and colleagues²⁸ have demonstrated that a transfusion algorithm alone can significantly decrease transfusion rates in patients undergoing cardiac surgery;

FIGURE 3. Incidence of blood product transfusion over time before and after implementation of the institutional blood administration protocol.

FIGURE 4. Incidence of blood product transfusion over time by surgery group after implementation of the institutional blood administration protocol. CABG, Coronary artery bypass grafting.

however, we believed that the best results would be achieved through a comprehensive, multimodality approach. We found that the implementation of our protocol led to a significant decrease in the overall incidence of transfusion among patients undergoing first-time cardiac surgery at the Inova Heart and Vascular Institute. This decrease was driven mostly by changes in the postoperative period, in which a 65% decrease in transfusions was observed.

The high percentage of patients undergoing cardiac surgery receiving transfusions persists despite the efforts of the STS and the Society of Cardiovascular Anesthesiologists to promote blood conservation.^{8,14} This variation cannot be entirely due to differences in the clinical characteristics of patients undergoing cardiac surgery. In fact, in a recent study of more than 4000 patients undergoing cardiac surgery at a single institution, the practice patterns of individual decision makers, specifically, surgeons and anesthesiologists, were identified as greatly contributing to the significant variability in perioperative transfusion rates.²² In light of this finding, as well as those of numerous other reports,²⁹⁻³¹ it is clear that institutions must develop and adhere to blood conservation

protocols to succeed in efforts not only to reduce the incidence of blood transfusion but also to improve outcomes and minimize health care costs.

A crucial element of any successful blood conservation protocol is an appreciation for the physiology and tolerance of asymptomatic anemia. Although there is scant evidence to support definitive criteria for transfusion in certain noncritical patients, STS guidelines suggest that Hgb levels as low as 6 g/dL may be reasonably tolerated in certain situations before blood transfusion is ordered.¹⁴ That these recommendations are not widely adopted is mainly due to the notion that perioperative anemia may be associated with increased morbidity and mortality, as well as the perception that transfusion is safe and effective in treating anemia.^{1,18,25,32-34}

In a multistudy review of 19 randomized controlled trials encompassing more than 6000 patients over more than 50 years, a restrictive Hgb level cutoff was compared with a nonrestrictive cutoff.³⁵ When a restrictive Hgb cutoff of 7 to 10 g/dL was applied in the review study, it resulted in conservation of approximately 1 RBC unit of blood per patient, reduced mortality rates, and a possible reduction in the incidence of myocardial infarction.³⁵ Otherwise, an

Hgb-restrictive approach was not shown to have a significant impact on the incidence of other complications, recovery time, or time to discharge.³⁵ Although uncommon, the possibility of transfusion complications, such as hemolytic transfusion reactions, acute lung injury, and circulatory overload, cannot be discounted in any transfusion.³⁶ In addition, the benefit of a restrictive protocol may be undermined by the type of pathology present in the patient. For example, in patients with acute coronary syndrome, a restrictive Hgb cutoff has been shown to result in increased mortality and cardiac events.^{6,37}

A recent study showed that a restrictive transfusion protocol, in addition to producing no harm and limiting negative outcomes, also limits costs.³⁸ In another study, 586 patients from 2 New Jersey institutions with well-established blood conservation programs (the conservation cohort) were compared with a propensity score-matched cohort of 586 patients from other New Jersey institutions representing the common practice of transfusion.³⁹ An increased incidence of complications was noted in all patients who received any blood transfusion, and there was no evidence of increased complications related to a strict transfusion protocol.³⁹

Our finding of a decreased incidence of renal failure with blood transfusion conservation is in agreement with a previous study in which a nonanemic patient transfused with 3 units of blood was found to be approximately twice as likely as a nontransfused patient to experience acute kidney injury.⁴⁰ This risk was further increased in anemic patients, who were approximately 4 times as likely to experience an acute kidney injury.⁴⁰ The incidence of acute kidney injury was proportional to the amount of erythrocytes transfused.⁴⁰

Several authors have reported decreased survival for cardiac surgical patients who received a blood transfusion.⁴¹⁻⁴³ This effect has been shown even in patients who received a total of 2 or less RBC units.⁴⁴ One review article noted a strong association between transfusion and a wide variety of postoperative complications during the hospital stay and up to a 5-year impact on mortality rate.⁵

Although we did find an increase in morbidities for the patients with surgery in 2006 in our study, we also found no increase in 30-day or 1-year survival for patients before and after the blood conservation protocol was implemented. A prospective randomized controlled trial by Hajjar and colleagues¹⁹ compared liberal and strict transfusion protocols in 512 randomized cardiac surgical patients. The restrictive arm was found to be noninferior to the liberal arm for the 30-day end point, but the incidence of complications increased with each additional unit transfused. Although concerns^{45,46} have

been raised about the noninferiority design of the study by Hajjar and colleagues,¹⁹ their results confirm the safety of strict transfusion criteria for cardiac surgical patients while providing further evidence of the deleterious effects of blood transfusion, as shown by our study.

In addition to the direct clinical benefits for our patients, the Inova Heart and Vascular Institute has realized substantial cost savings as a direct result of our protocol, as evidenced by the data presented in the current article on blood product cost. Although the complete data were not available for statistical analyses, the direct cost savings for patients undergoing CABG alone have been estimated by the Inova Heart and Vascular Institute's financial department at \$3.75 million per year, and the indirect cost savings from decreased morbidity rates, although difficult to quantify, could add considerably to this amount.

Study Limitations

Some limitations of our study should be noted. The use of prospectively collected data with retrospective analyses to examine effects of the blood protocol has inherent limitations. However, these limitations are minimized by the use of propensity score-matching analysis, which allowed for balanced groups across time. Moreover, clinical and cost data were collected prospectively. Therefore, data elements that would have been useful to include in these analyses, namely, preoperative Hgb, were not available for all patients. In 2006, data were collected with the STS National Database version 2.52, which did not include Hgb, precluding it from being accounted for in the propensity score model or other analyses. It is possible that preoperative Hgb was lower for the 2009 group because they represented a sicker cohort (before matching), which could mean that blood transfusion was reduced in 2009 despite the fact that Hgb levels were lower. In addition, the fact that patients were similar on other preoperative characteristics after propensity score matching could suggest that other nonmeasured preoperative factors became balanced as well, which is a goal for this technique. However, without the data, the effect of preoperative Hgb has not been accounted for, and it is unclear exactly how these results are affected, which represent a limitation of this study.

Although bias in this study could not be entirely controlled because of its observational design, it was not feasible to randomize patients because the groups were surgical-year cohorts. Because of the inherent difference in surgery dates for these 2 groups, it is possible that other practice changes may have occurred in addition to the blood protocol implementation. In addition,

subjective factors involved with the clinical decision making for patient care could have been present. However, propensity score matching was used (independently of outcomes) to reduce this temporal and clinical care bias and simulate randomization so that both unknown confounding factors and differences between the groups would be controlled for.⁴⁷

CONCLUSIONS

It is troubling that despite efforts to better educate and inform practitioners about the benefits of blood conservation through clinical guidelines,^{8,14} a minority of practitioners seem to have implemented changes on the basis of these consensus recommendations.⁴⁸ In light of the abundance of data supporting the practice of conserving blood and minimizing its use in cardiac surgery, cardiac surgery programs should consider measuring transfusion rates and indications as indicators of quality.

This study confirms the positive effect of a standardized blood conservation protocol on the postoperative outcomes of cardiac surgery. Our results and those of other researchers demonstrate the need for standardized protocols for blood transfusion at all busy cardiac surgical centers. Communication and involvement on the part of all clinicians and stakeholders involved in cardiac surgical cases are key to the success of such a protocol, and we recommend the adoption of this approach by all facilities where cardiac surgery is performed.

Conflict of Interest Statement

N.A. is a consultant for Medtronic, a member of the speaker's bureau for AtriCure, proctor and member of the speaker's bureau for LivaNova, on the advisory board for Nido Surgical, and a co-owner for Left Atrial Appendage Occlusion, LLC. All other authors have nothing to disclose with regard to commercial support.

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Key Words: blood transfusion, cardiac surgery, patient outcomes

FIGURE E1. Jitter plot demonstrating the distribution of propensity scores for 2009 (treatment units) and 2006 (control units).