Predictors of massive transfusion with thoracic aortic procedures involving deep hypothermic circulatory arrest

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Objective: Massive perioperative blood product transfusion may be required with thoracic aortic operations and is associated with poor outcomes. We analyzed independent predictors of massive transfusion in thoracic aortic surgical patients undergoing deep hypothermic circulatory arrest.

Methods: The study consisted of 168 consecutive patients undergoing open thoracic aortic procedures involving deep hypothermic circulatory arrest between July 2005 and August 2008. We identified 26 preoperative and procedural variables as potentially related to blood product use, tested for association with total blood products transfused by multivariate linear regression model, and constructed logistic regression model for massive transfusion (requiring ≥ 5 units of transfused packed red blood cells between incision and 48 postoperative hours).

Results: Multivariate linear regression determined that 6 significant variables accounted for 42% of variation in total blood products transfused: age ($P = .008$), preoperative hemoglobin ($P = .04$), weight ($P = .02$), cardiopulmonary bypass time ($P < .0001$), emergency status ($P < .0001$), and re sternotomy ($P < .0001$). Final predictive logistic regression model included 1-g/dL increase in preoperative hemoglobin (odds ratio, 0.54; 95% confidence interval, 0.43–0.69; $P < .0001$), 10-minute increase in cardiopulmonary bypass time (odds ratio, 1.15; 95% confidence interval, 1.05–1.26; $P = .0026$), and emergency status (odds ratio, 4.02; 95% confidence interval, 1.53–10.55; $P = .0047$).

Conclusions: Cardiopulmonary bypass time, emergency status, and preoperative hemoglobin were independent predictors of massive transfusion. These variables, along with weight, age, and re sternotomy, were associated with total blood product use in thoracic aortic operations involving deep hypothermic circulatory arrest. (J Thorac Cardiovasc Surg 2011;141:1283–8)

Massive perioperative transfusion may occur with thoracic aortic operations. Although there is certainly no substitute for meticulous surgical technique, the etiology of unusually high transfusion requirement is often multifactorial. Hemostatic derangements in aortic surgery are caused by a multitude of interrelated factors, including interference with the vascular integrity, surgical dissection, deep hypothermic circulatory arrest (DHCA), ischemia and reperfusion, dilution of coagulation factors from large-volume fluid resuscitation, transient need for heparinization, and the use of cardiopulmonary bypass (CPB).¹ Patient-level factors include age, sex, diabetes, preoperative hemoglo-

bin, platelets, prothrombin time, and partial thromboplastin time.^{2–4}

There are few clinical data addressing predictors of massive transfusion specific to operations for disease of the thoracic aorta, particularly those involving DHCA.^{5,6} The DHCA used for neuroprotection in thoracic aortic surgery slows coagulation cascade activity, reduces coagulation factor synthesis, increases fibrinolysis, decreases platelet count, and impairs platelet function.⁷ The prosthetic grafts used for aortic repair consume platelets and other factors.⁸ Aortic disease itself may also predispose toward coagulopathy through the exposure of tissue factor and other mechanisms.^{9,10}

Adverse outcomes attributable to the sequelae of massive perioperative transfusion are well recognized in the cardiac surgical literature, including a strong independent association with mortality.^{11,12} Identification of patients at high risk for requiring massive transfusion not only will allow improved risk stratification and preoperative counseling but also may create an opportunity for therapeutic modalities targeted toward individual patients in the perioperative period. Our objective was to determine the predictors of massive perioperative transfusion with open thoracic aortic procedures involving DHCA. We therefore tested the hypothesis that patient and procedural

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Abbreviations and Acronyms

CPB	= cardiopulmonary bypass
DHCA	= deep hypothermic circulatory arrest
IQR	= interquartile range
PRBCs	= packed red blood cells

characteristics could be used to model the need for transfusion with thoracic aortic surgery.

MATERIALS AND METHODS**Data Source**

The Duke Thoracic Aortic Surgery Database is a prospectively maintained, comprehensive clinical registry of all patients who have undergone any thoracic aortic procedure at Duke University Medical Center (Durham, NC) since 2005. This study included all patients who underwent a thoracic aortic procedure with DHCA between July 2005 and August 2008, excluding only patients who underwent a separate procedure in the perioperative period that resulted in massive transfusion. All procedures were performed by a single surgeon (G.C.H.), thus minimizing the contribution of variation in surgical technique to the findings. This study was approved by the Duke University institutional review board, which waived the need for individual patient consent. The Duke Thoracic Aortic Surgery Database provided baseline characteristics, clinical variables, and surgical procedure details. Review of individual medical records was undertaken to complete any missing clinical data points, and blood bank records provided precise information regarding amounts of blood products administered.

Conduct of Procedures and Anesthesia

Nonpulsatile CPB was conducted for each case with a membrane oxygenator after a crystalloid and mannitol prime and with an arterial line filter. Porcine heparin was administered as a bolus of 300 U/kg and supplemented to maintain an activated clotting time longer than 480 seconds. A 5000-unit bolus of heparin was given before circulatory arrest. During CPB, temperature-adjusted flow rates of 2.5 L/(min · m²) were used, and mean arterial pressure was generally maintained between 50 and 70 mm Hg. Anesthesia was maintained with isoflurane (0.5%–1.0%) by the oxygenator. Alpha stat management was used for maintenance of normal pH, Po₂, and Pco₂ values. Antegrade and retrograde cold blood cardioplegic solutions were used for myocardial protection. Our institutional preference is to perform open thoracoabdominal (extent I–III) and descending aortic aneurysm repairs with DHCA.

Before the portion of the aortic reconstruction requiring DHCA, the patient was cooled on CPB until electrocerebral inactivity was detected by electroencephalography by previously described techniques¹³; electrocerebral inactivity was usually reached at a nasopharyngeal temperature between 14°C and 18°C. Once electrocerebral inactivity was achieved through hypothermia, the circulation was stopped. Antegrade cerebral perfusion (5–15 mL/[kg · min]) was typically used for adjunct cerebral perfusion during the period of systemic DHCA. After aortic reconstruction, CPB was reinstituted, and the patient was gradually rewarmed to a normal temperature after a 5-minute period of cold reperfusion for free radical washout. Four units of fresh-frozen plasma were typically added to the circuit to ensure adequate anticoagulant factors during DHCA. A hematocrit of 0.18 to 0.20 was generally acceptable during CPB, although this was increased to more than 0.20 for separation from CPB. Protamine sulfate was administered after separation from CPB to reverse heparin anticoagulation until the activated clotting time returned to baseline or the ratio of 1 mg to 100 units of heparin was reached. We maintained a general approach of

avoiding unnecessary use of blood products, which were not administered unless bleeding or anemia was observed. After separation from CPB, red blood cells were transfused according to the patient's preoperative condition, volume status, and hemoglobin concentration.

Standard practice included intraoperative administration of an antifibrinolytic therapy. Before its withdrawal from the US market, aprotinin (Bayer Corporation, West Haven, Conn) was used (2-MKIU bolus and 0.5-MKIU/h infusion until bleeding cessation). Subsequently, ε-aminocaproic acid was administered as a 10-g bolus followed by a 1-g/h infusion, with an additional 5-g bolus before separation from CPB to account for that lost during hemofiltration, which was performed in all cases to remove excess crystalloid before separation from CPB. The return of washed, shed red blood cells (BRAT II blood cell salvage machine; Cobe Cardiovascular Inc, Arvada, Colo) to the patient was routine. Transfusion decisions in the perioperative period were aided by local guidelines and use of chest tube output, activated clotting time, platelet count, fibrinogen level, thromboelastography, prothrombin time, and partial thromboplastin time, as recommended by the American Society of Anesthesiologists published guidelines.¹⁴ Clopidogrel and other P2Y₁₂ inhibitors, regardless of dose, were withheld 7 days before the operation. Aspirin (325 mg) was withheld 5 days before the operation. Aspirin (81 mg) was not withheld before the operation. All antiplatelet agents were restarted at preoperative dosages on postoperative day 1 unless active bleeding was present.

Outcome Measures

The 26 candidate variables for the analysis included age, sex, race, American Society of Anesthesiologists grade, diabetes, preoperative creatinine level, warfarin (Coumadin) use, partial thromboplastin time, platelet count, international normalized ratio, hemoglobin concentration, weight, height, body surface area, blood pressure, aprotinin use, previous cardiac surgical procedure, emergency status, concomitant cardiac procedure, total arch versus hemiarch repair, thoracoabdominal aortic aneurysm type, aortic crossclamp time, cerebral circulatory arrest time (period when brain was receiving less than 100% of normal cerebral blood flow, including antegrade or retrograde cerebral perfusion), systemic circulatory arrest time (period during which lower body was not perfused, longer than cerebral circulatory arrest time for total arch replacement and open descending or thoracoabdominal aortic repairs and equal to cerebral circulatory arrest time for hemiarch repairs), and CPB time. Allogeneic blood product use included all products given from the time of incision through postoperative days 0, 1, and 2, including any given at the time of return to the operating room for bleeding. Volume of intraoperative blood cell salvage machine transfusion was not included in this calculation, because this blood is not allogeneic. Considering the need for massive transfusion as a dichotomous outcome, we used a previously described definition of massive transfusion.¹¹ Patients who received at least 5 units of packed red blood cells (PRBCs) were defined as having had massive transfusion.

Statistical Analysis

Patient and operative characteristics are summarized according to presence or absence of massive transfusion. Table 1 presents categorical variables as percentages; continuous variables are presented as mean ± SD unless otherwise stated. For comparisons, the Wilcoxon rank sum test was used for continuous variables, and the χ^2 test was used for categorical variables, with an alternative hypothesis that the rates across columns were not equal.

We evaluated the association of patient and procedural characteristics with the need for transfusion in 2 ways. Primarily, a linear regression model was developed with total blood products transfused as the outcome variable. Total blood products included all allogeneic products from the case start time through 48 postoperative hours. Because blood product use was not normally distributed, a log transform was performed before

TABLE 1. Patient characteristics and operative variables

Characteristic	Overall (n = 168)	MT (n = 49)	No MT (n = 119)	P value
Age (y)	57.4 ± 14.2	60.6 ± 15.5	56.1 ± 13.4	.06
Female	29% (49)	38% (18)	25% (30)	.09
Nonwhite	6% (10)	9% (4)	5% (6)	.27
American Society of Anesthesiologists grade	3.5 ± 0.5	3.8 ± 0.4	3.4 ± 0.5	< .0001
Diabetes	3% (5)	4% (2)	2% (3)	.66
Preoperative creatinine (mg/dL)	1.3 ± 1.3	1.6 ± 1.8	1.2 ± 0.9	.11
Preoperative warfarin	16% (26)	20% (10)	14% (16)	.31
Preoperative partial thromboplastin time (s)	32.6 ± 9.6	31.5 ± 9.6	33.1 ± 9.7	.32
Preoperative platelets (10 ⁹ cells/L)	214.6 ± 58.1	216.1 ± 62.2	213.9 ± 56.5	.82
Preoperative international normalized ratio	1.05 ± 0.16	1.12 ± 0.26	1.03 ± 0.09	.001
Preoperative hemoglobin (g/dL)	13.5 ± 2.0	12.0 ± 2.1	14.1 ± 1.7	< .0001
Weight (kg)	83.3 ± 18.9	78.6 ± 16.4	85.3 ± 19.6	.03
Height (cm)	174.7 ± 11.2	172.0 ± 12.7	175.8 ± 10.4	.07
Body surface area (m ²)	1.98 ± 0.24	1.91 ± 0.23	2.01 ± 0.25	.01
Total blood products (units, median with 25th–75th percentile)	13 (8–20)	22 (18–31)	9 (6–13)	< .0001
Recombinant factor VIIa	3% (5)	10% (5)	0% (0)	< .0001
Aprotinin	48% (81)	48% (24)	48% (57)	.97
Maximum aortic diameter (cm)	5.85 ± 1.01	6.04 ± 1.19	5.77 ± 0.92	.14
Reoperation (resterotomy)	27% (45)	39% (21)	21% (24)	.01
Emergency status	24% (40)	39% (20)	17% (20)	.001
Crossclamp time (min)	136.9 ± 51.1	142.2 ± 57.3	136.6 ± 48.2	.38
Cerebral circulatory arrest time (min)	22.2 ± 7.4	24.6 ± 7.4	21.1 ± 7.1	.004
Systemic circulatory arrest time (min)	28.0 ± 19.6	34.8 ± 19.6	25.1 ± 17.4	.001
Cardiopulmonary bypass time (min)	225.8 ± 60.5	248.7 ± 85.8	216.1 ± 42.3	.01
Concomitant procedure	22% (36)	34% (17)	16% (19)	.007
Location of aortic repair				.004
Root or ascending only	1.2% (2)	2% (1)	0.8% (1)	
Arch involvement	89% (150)	82% (40)	92% (110)	
Total arch	9.5% (16)	16% (8)	6.7% (8)	
Descending or thoracoabdominal	10% (16)	20% (10)	5% (6)	
Blood cell salvage device volume (mL)	537 ± 475	715 ± 663	464 ± 351	.01
12-h chest tube drainage (mL)	664 ± 568	1050 ± 864	517 ± 341	.0003
Taken back to operating room for bleeding	6% (10)	18.4% (9)	0.84% (1)	< .0001
30-d Mortality	3.0% (5)	4.1% (2)	2.5% (3)	.09

Categorical data are given as percentages, with the number of patients in parentheses and continuous data as mean ± SD, except as noted. MT, Massive transfusion.

analysis. Secondly, we developed a logistic regression model for massive transfusion (≥5 units of PRBCs) as a dichotomous outcome.

We identified 26 preoperative and procedural variables as being potentially related to blood product use. Univariate associations were assessed with 1-way analysis of variance for categorical variables and correlation tests for continuous variables. Race was defined as white versus nonwhite. Of the 26 variables, 16 had *P* values lower than .05 when testing for a difference between the groups. These 16 variables were included in a backward stepwise procedure that eliminated nonsignificant variables individually until only significant variables remained. In this manner, a final predictive model was developed. To create the linear regression models for total blood products and CPB time, linear univariate association tests were used, with nonsignificant variables dropped from the multivariate model 1 at a time until only significant variables remained in the model.

Finally, with Pearson correlation coefficients, we conducted a post hoc assessment of the relationship of blood product transfusion with other metrics of perioperative bleeding by examining correlations with volume of processed blood (blood cell salvage machine) returned to the patient intraoperatively and chest tube drainage from time of intensive care unit arrival to 12 postoperative hours. We also evaluated the proportion of total blood products given during CPB to distinguish between anemia during CPB and

continued bleeding after CPB as reasons for requiring transfusion. All statistical analyses were performed with SAS statistical software version 9.1.3 (SAS Institute Inc, Cary, NC).

RESULTS

Patient and Operative Variables

One hundred seventy thoracic aortic procedures with DHCA were performed during the period of study. Only two patients were excluded, both of whom had major blood loss and massive transfusion from another procedure in the perioperative period. Thus 168 thoracic aortic procedures were available for data abstraction and fulfilled selection criteria, representing a single-center, single-surgeon experience.

Figure 1 displays the use of the various blood products in the 168 study patients, with medians as well as upper and lower quartiles for PRBCs (median, 3 units; interquartile range [IQR], 1–6 units), platelets (3 units; IQR, 2–4 units), cryoprecipitate (0 units; IQR, 0–1 units), fresh-frozen

FIGURE 1. Blood products transfused. Note that y-axis values represent units of blood products, with total representing total units transfused. Cryoprecipitate is not included in graphic display because median number of units transfused was zero overall. PRBC, Packed red blood cells; FFP, fresh-frozen plasma; Non-MT, no massive transfusion; MT, massive transfusion.

plasma (6 units; IQR, 4–10 units), and total blood products transfused (13 units; IQR, 8–20 units). We classified 49 patients (29%) as having massive transfusion if they received at least 5 units of transfused PRBCs. The remaining 119 patients were classified as not receiving massive transfusion.

Table 1 describes patient and operative variables of the cohort and details a univariate comparison of characteristics from the massive transfusion and no massive transfusion groups. Of note, recombinant activated factor VII (NovoSeven; Novo Nordisk Inc, Princeton, NJ) was given to only 5 patients, all of whom had received massive transfusion (10% of this cohort). Uses of the pharmacologic agents Coumadin (preoperatively, 20% vs 14%, $P = .31$) and aprotinin (intraoperatively, 48.0% vs 48.4%, $P = 0.97$) were similar between the groups. Among the 40 emergency cases, none of the patients were taking clopidogrel preoperatively, and only 1 was taking aspirin at 325 mg (aspirin at 81 mg is not withheld before elective cases).

Overall, the type of aortic repair was root or ascending only in 1.2% (2% massive transfusion vs 0.8% no massive transfusion), hemiarch or total arch in 89% (82% massive transfusion vs 92% no massive transfusion), with 9.5% being total arch (16% massive transfusion vs 6.7% no massive transfusion), and descending or thoracoabdominal in 10% (20% massive transfusion vs 5% no massive transfusion). The procedure was classified as re sternotomy (reoperation) for 39% of the massive transfusion group, compared with 21% of the no massive transfusion group ($P = .01$); there were no reoperative descending or thoracoabdominal aortic aneurysm procedures. Patients with massive transfusion were also more likely to undergo concomitant procedures (34% vs 16%, $P = .001$) and more likely to have had emergency operations (39% vs 17%, $P = .001$). The thirty-six cases with concomitant procedures included coronary artery bypass grafting ($n = 24$, 67%), maze ($n = 3$, 8%), atrial septal defect repair ($n = 3$, 8%), and other ($n = 6$, 16%). The indication for emergency operation was acute type A aortic dissection in all cases. Aortic crossclamp times were equivalent between

the groups (142 vs 137 minutes, $P = .38$), whereas systemic circulatory arrest time (35 vs 25 minutes, $P = .001$) and CPB time (249 vs 216 minutes, $P = .007$) were significantly longer in the massive transfusion group.

Outcome Metrics

Return to the operating room for bleeding was required in 6% of cases. The return rate for bleeding among the massive transfusion group was 18%, versus 0.8% among the no massive transfusion group ($P < .0001$). Of note, mean blood cell salvage machine volumes returned to patients intraoperatively were 715 mL in the massive transfusion group and 464 mL in the no massive transfusion group ($P = .01$), and mean 12-hour chest tube drainage volumes were 1050 mL in the massive transfusion group and 517 mL in the no massive transfusion group ($P = .0003$). Mortality at 30 days was 3% overall and was higher in the massive transfusion group (4%) than in the no massive transfusion group (2.5%).

The Pearson correlation coefficients were 0.43 ($P = 0.001$) between total blood products transfused and volume of salvaged blood cells returned intraoperatively and 0.54 ($P < .0001$) between total blood products transfused and 12-hour chest tube drainage, while blood cell salvage machine volume and chest tube drainage had no association ($r = 0.049$, $P = .55$). The mean PRBC volume given during CPB was 1.3 ± 2.1 units (range, 0–16 units), compared with 3.9 ± 4.7 PRBC units (range, 0–26 units) given from procedure start time to 48 postoperative hours.

Multivariate Models and Predictors

The correlation coefficient for PRBC and total blood product transfusion was greater than 0.90, with total blood products used as the primary, continuous outcome variable. The linear regression model is described in Table 2, with 6 significant variables independently associated with total blood product transfusion: age ($P = .008$), preoperative hemoglobin ($P = .04$), weight ($P = .02$), CPB time ($P < .0001$), emergency status ($P < .0001$), and reoperation status ($P < .0001$). The adjusted R^2 for this model was 0.42, indicating that these variables accounted for 42% of the variability in blood products transfused.

The logistic regression model for the outcome massive transfusion is shown in Table 3. The odds ratios for the outcome of massive transfusion are as follows: for every 1-g/dL

TABLE 2. Multivariate linear regression model for log-transformed total blood products

Variable	Regression slope	P value
Age	0.009	.008
Preoperative hemoglobin	−0.05	.04
Weight	−0.006	.02
Cardiopulmonary bypass time	0.004	<.0001
Emergency status	0.52	<.0001
Reoperation	0.47	<.0001

TABLE 3. Predictors of massive transfusion (logistic regression model)

Variable	Odds ratio	95% Wald confidence interval	Predictor P value
Preoperative hemoglobin (per 1-g/dL increment)	0.543	0.428–0.688	<.0001
Cardiopulmonary bypass time (per 10-min increase)	1.15	1.05–1.26	.0026
Emergency status	4.02	1.532–10.553	.0047

increase in preoperative hemoglobin, odds ratio was 0.54 (95% confidence interval, 0.43–0.69; $P < .0001$); for every 10-minute increase in CPB time, odds ratio was 1.15 (95% confidence interval, 1.05–1.26; $P = .0026$); and for emergency status, odds ratio was 4.02 (95% confidence interval, 1.53–10.55; $P = .0047$). Many procedural factors correlated with CPB time and therefore were not independent predictors of bleeding. These included crossclamp time, body surface area, concomitant procedure, and reoperation. The univariate associations with massive transfusion are noted in Table 1. A multivariable regression analysis predicting CPB time (R^2 for the model of 0.26) showed that increased body surface area, concomitant procedure, and reoperation were all significant predictors (Table 4).

DISCUSSION

In this observational study of consecutive patients undergoing thoracic aortic procedures involving DHCA from 2005 through 2008, we were able to identify the patient and procedural characteristics associated both with overall blood product use and with massive transfusion. First, independent predictors of total blood products transfused included age, preoperative hemoglobin, weight, CPB time, and emergency status. Second, a logistic regression model determined massive perioperative transfusion to be independently predicted by 3 variables: preoperative hemoglobin level, CPB time, and emergency operation status.

An initial descriptive analysis of patient variables found that patients in the massive transfusion group tended to be older, smaller (lower preoperative weight and body surface area), and sicker (higher American Society of Anesthesiologists grade, lower preoperative hematocrit). Durations of CPB and of both systemic and cerebral circulatory arrest were longer for the massive transfusion group. Many of the variables showed expected univariate associations with

blood product use, but collinearity of variables confounded persistence of independent association in a multivariate model. For example, although it was an independent predictor in the linear regression model, reoperation did not remain so in the final logistic regression model because it did not independently contribute to the model of massive transfusion more than did CPB time alone.

CPB time and emergency operation are recognized predictors of transfusion,^{2,3,5} and the time required to achieve DHCA further prolongs CPB time, likely causing platelet and enzyme dysfunction.^{1,3,7} The value of preoperative anemia as a prognosticator for adverse outcomes has been replicated by several groups^{11,15-17}; however, previous studies have not examined anemia in a model for transfusion requirement in thoracic aortic surgery with DHCA. In our patient sample, hemoglobin may be a marker of broader physiologic reserve and consumption of platelets and coagulation factors by various aortic pathologies.

Several limitations should be considered when interpreting the findings of this study. First, this was a retrospective, observational study, for which causality cannot be inferred. The effects of unknown or unmeasured confounders on the observed associations cannot be excluded. A major limitation of other studies investigating predictors of perioperative blood loss in cardiac surgery has been that the investigations compared cases across different surgical, anesthesia, and intensive care unit teams, resulting in wide, unadjusted variation in surgical practices and perioperative management strategies.^{2,3,18} We reduced but did not eliminate surgical technique and institutional practice as confounders by reporting a large series of patients undergoing aortic surgery with DHCA conducted by a single surgeon and postsurgical care unit with a protocol-driven approach to transfusion.

Although this study represents the largest to date examining factors associated with transfusion in the DHCA population, a relatively large number of variables were determined a priori to be of clinical importance in considering predictors of massive transfusion, which increases the chance of a type II error. We chose not to use a principal components strategy to reduce the degrees of freedom by combining potential predictors because of the resulting inability to interpret individual coefficients. Also of note, a systematic change in the pharmacologic management of bleeding occurred during the study period. When aprotinin was officially removed from the US market in late 2007, patients received ϵ -aminocaproic acid as an alternative agent, although aprotinin use was similar between those with and without massive transfusion.

This analysis did not discriminate between transfusion to treat anemia and that to treat bleeding. This could be regarded as a weakness or a strength of the design; we elected to evaluate overall transfusion requirements, because deleterious effects of transfusion are related to the total number of units transfused. For the same reason, we extended our outcome to transfusion in the perioperative period, rather than

TABLE 4. Predictors of cardiopulmonary bypass time (linear regression model)

Variable	Regression slope	SE	t Value	P value
Body surface area	49.56	16.85	2.94	.0037
Concomitant procedure	53.70	10.24	5.24	<.0001
Reoperation	35.30	9.766	3.61	.0004

the day of surgery. Although there was a highly significant correlation between units of PRBCs transfused and both intraoperative bleeding (blood cell salvage machine volume transfused) and postoperative bleeding (chest tube drainage), approximately a third of the PRBC units transfused were given before separation from CPB to treat preexisting anemia, acute blood loss before CPB, or hemodilution during CPB. Intraoperative transfusions before closure of the chest have been excluded by other investigators on the basis of the premise that excessive bleeding during this part of the operation frequently reflects inadequate surgical hemostasis and may not reflect the hemostatic defect induced by CPB.^{2,3} Although deposition of platelets and circulating blood proteins, as well as nonsurgical bleeding related to graft porosity and needle hole injury, occur less with the polyethylene terephthalate (Dacron) graft material used in our series than with polytetrafluoroethylene and other graft materials, however, these interactions remain an important consideration.¹⁹ The use of large prosthetic vascular conduits and DHCA is unique to aortic surgery and has an immediate effect on the coagulation cascade, which would be lost to analysis without inclusion of intraoperative transfusions and the volume of salvaged blood cells returned intraoperatively, correlated closely with total blood product use.

Our model for predicting massive perioperative transfusion may allow more focused use of both established and novel strategies for reducing perioperative blood loss, including correction of hypothermia and perioperative pharmacologic interventions available for reducing the coagulation dysfunction associated with CPB and aortic surgery.^{20,21} Typical pharmacologic interventions have focused on antifibrinolytic agents but could also focus on intraoperative adjuncts for the prevention of platelet dysfunction^{7,22} or the promotion of hemostasis with fibrinogen concentrate²¹ or recombinant factor VII.²³ The etiology of preoperative anemia in patients undergoing elective cardiac operations has been described, and it is suggested that in most cases the anemia is preventable.²⁴ Specifically, diagnosis of chronic anemia and its correction through iron supplementation or erythropoietin²⁵ for elective cases is worth investigating with further clinical studies.

CONCLUSIONS

Our data support a model of CPB time, emergency status, and preoperative hemoglobin as independent predictors of massive perioperative transfusion in thoracic aortic procedures involving DHCA. This finding creates an opportunity for clinical investigations directed toward targeted therapeutic maneuvers for high-risk patients.

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