The effect of cardiopulmonary bypass prime volume on the need for blood transfusion after pediatric cardiac surgery

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Objective: There is increasing awareness that erythrocyte transfusions after pediatric cardiac surgery have deleterious effects. Despite reports of decreased transfusion requirements associated with smaller cardiopulmonary bypass circuits, the relationship between circuit prime volume and need for transfusion has not been systematically examined.

Methods: Pediatric patients at our institution who underwent cardiopulmonary bypass between January 2005 and December 2010 were reviewed. Demographics, intraoperative data, and transfusion of packed red blood cells were retrospectively recorded. Cardiopulmonary bypass prime volume was indexed by patient body surface area. Logistic regression analysis was used to correlate these variables with need for transfusion.

Results: In the perioperative period, 1912 patients received transfusions and 266 did not. In univariate analysis, indexed prime volume was a significant predictor of transfusion (odds ratio, 1.007; $P < .001$). Other significant variables in univariate analysis included age, surgeon, Risk Adjustment for Congenital Heart Surgery 1 (RACHS-1) category, preoperative hemoglobin, total bypass time, aortic crossclamp time, use and duration of deep hypothermic circulatory arrest, lowest body core temperature, and cardiopulmonary bypass flow rate. Previous cardiac surgery was not a significant predictor. In multivariable analysis controlling for RACHS-1 category, surgeon, minimal core body temperature, and preoperative hemoglobin, indexed prime volume remained an independent predictor of transfusion (odds ratio, 1.006; 95% confidence interval, 1.005-1.007, $P < .001$).

Conclusions: Perioperative need for transfusion in pediatric cardiac surgical patients is independently related to the prime volume of the cardiopulmonary bypass circuit. It therefore seems prudent to minimize circuit prime volumes to avoid unnecessary use of blood products. (J Thorac Cardiovasc Surg 2013;145:1058-64)

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Recent publications have shown that the need for a blood transfusion in the postoperative period may increase the duration of mechanical ventilation and hospitalization in children undergoing surgical repair of congenital heart disease.[1,2] Furthermore, even if donor blood is safe from infections, there still remain significant morbidities related to the use of donor packed red blood cells (pRBCs), including anaphylactoid transfusion reactions. Despite the almost universal agreement that avoidance of blood products is desirable, there has not been a recent evaluation of factors contributing to the use of blood transfusions in this population. In the past decade, advances in cardiopulmonary bypass (CPB) circuits have resulted in the ability to have smaller prime volumes, decreasing the patient's initial intraoperative exposure to donor blood. The decreased prime volume may also contribute to improved outcomes, especially in smaller infants and children.

This study was designed to examine the factors that lead to the need for transfusions of pRBCs in the perioperative period and to examine whether CPB prime volume affects the risk of receiving a pRBC transfusion in the perioperative period in children undergoing surgery with CPB for congenital heart disease.

MATERIALS AND METHODS

Study Population

This study was approved by the institutional review board of Columbia University. All patients younger than 18 years who underwent cardiac surgery with CPB at the Morgan Stanley Children's Hospital of New York between January 1, 2005, and December 31, 2010, were considered for inclusion. Patients undergoing ventricular assist device implantation, repair of cardiac trauma, or reoperation for hemorrhage were excluded, because these patients differ dramatically from other cardiac surgical patients in transfusion strategy. Furthermore, patients undergoing heart transplant were excluded because immunologic factors may play a role in whether they receive a transfusion.

Study Design

Demographic, surgical, and perfusion related data were collected from a prospectively collected institutional database. These data included sex, age at surgery, surgeon, body surface area (BSA) in square meters (as calculated according to the Haycock formula), surgical procedure, anatomic

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Abbreviations and Acronyms

BSA	= body surface area
CPB	= cardiopulmonary bypass
DHCA	= deep hypothermic circulatory arrest
MUF	= modified ultrafiltration
pRBCs	= packed red blood cells
RACHS-1	= Risk Adjustment for Congenital Heart Surgery 1

diagnosis, number of previous cardiac surgical procedures, number of previous cardiac surgical procedures with CPB, preoperative hemoglobin in grams per deciliter, CPB circuit prime volume in milliliters, total CPB time in minutes, aortic crossclamp time in minutes, deep hypothermic circulatory arrest (DHCA) time in minutes, minimal core body temperature in °C, maximum CPB circuit flow rate in liters per minute, hospital stay in days, and mortality. A separate clinical database was reviewed to assess whether each patient had received any transfusions with pRBCs in the perioperative period, defined as the time from when the patient arrived in the operating room (postoperative day 0) through postoperative day 6 (or hospital discharge if sooner). Surgical procedures were risk categorized according to the Risk Adjustment for Congenital Heart Surgery 1 (RACHS-1) method.[3] The RACHS-1 method uses 6 categories of surgical risk, with category 1 having the lowest risk and 6 the highest. Specific surgical procedures are assigned to each category, so those surgical procedures that did not fit into one of the RACHS-1 categories were labeled as ''none.'' Both CPB circuit prime volume and maximum CPB circuit flow rate were indexed for BSA, resulting in the variables of indexed prime volume in milliliters per square meter and indexed flow rate in liters per minute per square meter. For analysis purposes, patients were divided into 2 groups, those who received any volume of pRBC transfusion in the perioperative period and those who did not.

Statistical Analysis

All continuous variables were examined for normality. Normal variables are expressed as mean ± SD; nonnormal variables are expressed as median with either range or interquartile range. Factors were compared between the transfusion groups with the Student *t* test, Mann-Whitney U test, or χ^2 analysis as appropriate. Univariate logistic regression was used to evaluate the association between each variable and the outcome of pRBC transfusion. A multivariable model was then created to evaluate the association of indexed prime volume to the outcome of pRBC transfusion after controlling for other factors. All variables with a P value less than 0.1 in the univariate analysis were considered for inclusion in the multivariable model, and surgeon was chosen a priori to be in the model regardless of statistical considerations. Other candidate variables were not included in the final model if (1) they were not significant predictors of outcome and (2) there was no appreciable effect on the remaining variables whether or not they were included in the model (ie, a <10% change in the β coefficient). All statistical tests were 2-sided. Statistical analyses were performed with SPSS Statistics 18 for Windows software (IBM Corporation, Armonk, NY).

RESULTS

Population Demographics

The total number of patients meeting inclusion and exclusion criteria for the study was 2268. Of these, 90 (4%) were further excluded for missing data required for the calculation of the primary predictor variable of indexed prime volume (height, weight, BSA, or prime volume). This left 2178 patients for inclusion and analysis. The median age at surgery was 6 months (range, 1 day-17.9 years; interquartile range, 25 days-2.8 years), and 58.3% of the patients were male. Weight at surgery ranged from 1.1 kg to 151 kg (median, 6.2 kg; interquartile range, 3.6-13 kg). Simple structural heart disease was the indication for surgery in 44.1% of cases, whereas 22.8% had cyanotic heart disease, 5.1% had complex acyanotic heart disease, and 26.4% had single-ventricle physiology. In total, 652 patients(30%) had previously undergone cardiac surgery, with 266 having more than 1 previous operation. Of these, only 83 patients had previously undergone surgery that did not involve CPB.

Operative Characteristics

The most common surgical procedure performed was ventricular septal defect closure (9.6%), with total cavopulmonary connection (8.8%), tetralogy of Fallot repair (8.3%), and superior cavopulmonary anastomosis (8%) the second, third, and fourth most frequent procedures, respectively. The vast majority of procedures were classified as RACHS-1 category 2 (37.5%) or category 3 (36.4%). RACHS-1 category 1 procedures only accounted for 7% of all procedures, and category 4 accounted for 11.1%. Only 1 procedure was classified as RACHS-1 category 5, and 6% (131) were classified as category 6. There were 42 procedures (2.2%) that were not classifiable under the RACHS-1 method, most of which were repairs of pulmonary vein stenosis. Only 16 patients did not have a measured hemoglobin value within the 2-week period before surgery. The mean preoperative hemoglobin value in the remaining 2162 patients (99%) was 13.6 ± 2.3 g/dL. Absolute CPB circuit prime volume ranged from 27 to 1400 mL. When indexed for patient BSA, the mean prime volume was 780 ± 300 mL/m^2. The mean CPB time was 104 ± 49 minutes, with a mean indexed flow rate of 2.3 ± 0.7 L/(min/m^2). Aortic crossclamp with cardioplegia was used in 86.8% of procedures, with a mean crossclamp time of 50.6 ± 30.2 minutes. DHCA was used in 32.6% of cases, with a mean arrest time of 31.4 ± 17.8 minutes. The mean minimal core body temperature was 31.3°C ± 3.8°C for patients in whom DHCA was not used and 18.8°C ± 2.4°C in those in whom it was.

Group Comparisons

When the total study population was divided into those who required pRBC transfusion (n = 1912) and those who did not (n = 266), differences in demographic and intraoperative factors became apparent (Table 1). Specifically, patients who did not require pRBC transfusions were significantly older (5.7 vs 0.4 years; P < .001), heavier (21.2 vs 5.5 kg; P < .001), and larger in BSA (0.8 vs 0.31 m^2; P < .001). Patients who did not require pRBC transfusion also tended to have a lower RACHS-1

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