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# Perioperative Hemoglobin Trajectory in Adult Cardiac Surgical Patients

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**Abstract:** Preoperative anemia and nadir hemoglobin (Hb) during cardiopulmonary bypass (CPB) have been identified as significant risk factors for blood transfusion during cardiac surgery. The aim of this study was to confirm the association between preoperative anemia, perioperative fluid management, and blood transfusion. In addition, the proportion of elective cardiac surgery patients presenting for surgery with anemia was identified to examine whether the opportunity exists for timely diagnosis and intervention. Data from referral until hospital discharge were comprehensively reviewed over a 12-month period for all nonemergency cardiac surgical patients operated on in our institution. Of the 342 patients identified, elective cases were referred a median of 35 days before preoperative clinic and operated on a median of 14 days subsequently. Subacute cases had a median of 3 days from referral to surgery. As per the World Health Organization (WHO) criteria for anemia, 24.2% of elective and 29.6% of subacute patients were anemic. Blood transfusion was administered to 46.2% of patients during their admission. Transfusion was more likely in patients who were female (odds ratio [OR]: 2.45, 95% confidence interval [CI]: 1.28–4.70), had a low body mass index (BMI) (OR: .89, 95% CI: .84–.94), preoperative anemia (OR: 5.15, 95% CI: 2.59–10.24), or renal impairment (OR: 5.44, 95% CI: 2.42–12.22). Hemodilution minimization strategies reduced the Hb fall during CPB, but not transfusion rates. This study identifies a high prevalence of preoperative anemia with sufficient time for elective referrals to undergo appropriate diagnosis and interventions. It also confirms that low red cell mass (anemia and low BMI) and renal impairment are predictors of perioperative blood transfusion. Perfusion strategies to reduce hemodilution are effective at minimizing the intraoperative fall in Hb concentration but did not influence transfusion rate. **Keywords:** anemia, blood management, cardiopulmonary bypass, cardiac surgery. *JECT. 2015;47:167–173*

There is significant variation in transfusion rates between cardiac surgical centers. A 2013 audit of cardiac surgical units in the United Kingdom identified a threefold variation (22–67%) in the number of patients receiving at least one unit of blood perioperatively (1). Variation may be accounted for by the complexity of cases, with transfusion rates for the most complex surgery approaching 100%, and by local transfusion policies. There is a clear dose–response relationship describing increased morbidity and mortality when blood products are transfused (2,3), although it is hard to prove there is a causal relationship between transfusion and poor outcomes. Specific morbidities associated with blood use include transfusion-related acute lung injury, transfusion-associated circulatory overload, dilutional coagulopathy, and rarely, infective complications such as HIV or hepatitis (4,5). The benefits of transfusion are clear, particularly in life-saving situations, but there is also increasing awareness of the adverse outcomes associated with perioperative anemia in less critical situations (6–8).

Variation in blood usage and the need to balance risks and benefits have encouraged the use of pragmatic and evidence-based strategies to optimize blood component administration. An example of a global strategy is the Perioperative Blood Management (PBM) Strategy promoted by the Australian National Blood Authority (9). There are three "pillars" of PBM: 1) preoperative hemoglobin (Hb) optimization, 2) intraoperative minimization of blood loss, and 3) postoperative tolerance of anemia. Preoperative optimization of Hb is an appealing target for intervention, with the potential to decrease exposure to blood transfusion (10).

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The World Health Organization (WHO) defines anemia as a Hb of less than 130 g/L in males and 120 g/L in females and suggests that it affects about a quarter of the population (11). In surgical patients, and particularly cardiac surgical patients, the proportion who present with anemia may be up to 50% (12). If anemia is to be treated as a reversible risk factor for cardiac surgery, it must be detected early so that causative factors can be identified and treatments initiated with the presumption that reversal of anemia will lead to better outcomes and less transfusions.

Although previous studies have identified preoperative anemia as a risk for blood transfusion in cardiac surgery, none to date have carefully examined the opportunities before surgery where anemia may be detected. Such information would provide the first step in planning effective strategies. Other studies have investigated the role of transfusion thresholds in influencing outcomes. The nadir Hb during cardiopulmonary bypass (CPB) acts as a trigger for transfusion and perfusion strategies such as minimizing priming volume are used to minimize the fall in Hb concentration. To address these factors, it is important to know at what stage of the perioperative pathway transfusion occurs and the factors that influence the decision to transfuse.

The aims of this project were, in a contemporary practice environment, to 1) confirm the association between preoperative anemia and blood transfusion risk, 2) identify the proportion of elective cardiac surgery patients presenting for surgery with anemia, 3) demonstrate whether the opportunity exists for timely diagnosis and intervention during normal clinical referral pathways, 4) identify the effect of hemodilution preventive strategies, and 5) identify the clinical areas where perioperative transfusion occurs.

## MATERIALS AND METHODS

This was a retrospective audit of all elective and subacute patients undergoing cardiac surgery at St. Vincent's Hospital, Melbourne, Australia, in the 12 months from January to December 2012. This project was submitted to the hospital Human Research Ethics Committee and given approval as a quality assurance investigation. Patients were initially identified from the Cardiac Perfusion Database, a prospective clinical database that includes details of every CPB pump run in addition to clinical and operative data. Patient medical records were then accessed to identify first contact, usually the original cardiology investigation (usually coronary angiography or echocardiography), which generated the referral to cardiac surgery. Hematology data were accessed for this time where available. Preadmission clinic attendance was then identified that usually constituted second contact. Laboratory data including full blood examination (FBE) and renal status (serum creatinine and estimated glomerular filtration rate [eGFR], if available) was obtained at this stage. Renal impairment was defined as a serum creatinine >125 mM/L or an eGFR of <60 mL/min. Hospital admission for surgery provided the final preoperative stage for most elective patients, with additional laboratory data being obtained at this time.

Patients were also included if they were referred for surgery to be undertaken within 30 days. These subacute or "emergent" cases were often referred following a myocardial infarction and the identification of severe coronary artery disease, valvular disease, or ongoing symptoms. Emergency patients, requiring surgery within 24 hours, were excluded.

CPB was performed using membrane oxygenation and a centrifugal arterial pump head (Stockert S/5; Sorin S.p.A., Milan, Italy). Reduced prime volume circuits, when used, used an optimized open reservoir design to minimize tubing lengths. All pump blood was drained and returned to the patient "as is" following CPB. Antegrade and retrograde tepid blood cardioplegia was used with a variable mixing ratio of a crystalloid concentrate from 25 to 10%. Intraoperative cell salvage was used selectively—for reoperations, major aortic surgery, or where postoperative bleeding was excessive.

Intraoperative data included Hb measurements after induction of anesthesia, after commencing CPB, nadir Hb on CPB, final Hb on CPB before weaning, and postbypass Hb. Postoperatively, FBE results were collected from arrival and departure from the intensive care unit (ICU) and the ward and included the nadir Hb in these locations. Blood (homologous packed red blood cells) and blood product administration was identified for the preoperative, intraoperative, and postoperative periods. Additional information collected included duration of CPB and surgery, including the postbypass surgical time, details of fluids administered during surgery, and CPB, prime volumes, and nadir temperature during surgery.

Univariable analysis was performed using Student's $t$ test for continuous data, and Chi-square or Fisher's exact test (two-tailed) for nonparametric data. Multivariable analysis for the primary outcome (homologous blood transfusion) was applied using logistic regression with entry set at a univariable $p$ value of <.2. Analysis for factors associated with nadir Hb on CPB was done using linear regression (with stepwise exclusion of $p$ values >.2). Multicollinearity was tested for using variance inflation factor analysis. Data distribution is reported as mean and standard deviation (SD) or median and interquartile range (IQR). Odds ratios (ORs) are expressed with 95% confidence intervals (95% CI). Anemia was defined using the WHO criteria of <130 g/L for males and <120 g/L for females. Analysis was performed using STATA (Version 12.1; Stata Corp., College Station, TX). A probability value of <.05 was taken to indicate statistical significance.

## RESULTS

Over the 12-month period, 370 patients underwent cardiac surgery using CPB. Following exclusion of urgent cases (23 cases), and missing data (five cases), 342 cases were available for analysis (Table 1). Elective patients comprised 71.4% of the patients, the remainder being subacute cases. Only 138 (40.4%) patients had Hb data identifiable at the time of referral; however, 336 (99.5%) had a preadmission clinic attendance where investigations were performed.

The Hb levels at key points throughout the clinical pathway are shown in Figure 1. There was no significant change in Hb level from referral to hospital admission in elective or subacute patients. For elective patients, referral conducted a median of 35 days before preadmission clinic attendance, with 84.4% of patients being referred at least 14 days before the clinic visit. Elective patients underwent surgery a median of 14 days following preadmission clinic. Subacute cases had a much shorter period between referral and surgery, with a median of 3 days. Subacute patients were more likely to still be on antiplatelet drugs, to be on intravenous heparin and to undergo coronary artery bypass grafting surgery.

As per the gender-based WHO criteria (above), anemia was present before hospital admission in 59 (24.2%) of elective and 29 (29.6%) of subacute cases (25.7% overall). On univariable analysis, preoperative anemia was associated with increasing age, diabetes, and renal impairment, but not body mass index (BMI), gender, antiplatelet therapy, or urgency. On multivariable analysis, preoperative anemia was strongly associated with preoperative renal impairment (OR: 3.24; 95% CI: 1.76–5.98; adjusted $p < .001$) and diabetes (OR: 2.46, 95% CI: 1.44–4.20; adjusted $p = .001$).

Overall, 46.2% of patients received a blood transfusion during their admission (Table 2). In elective patients, the transfusion incidence was 45.9%, and in semiurgent cases,

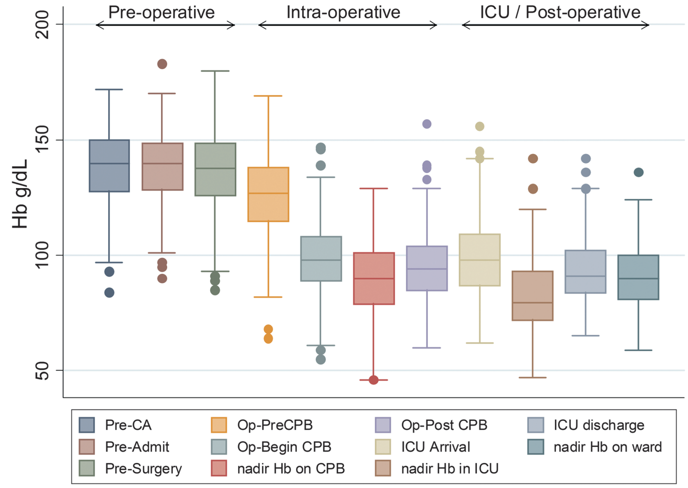


**Figure 1.** Preoperative and perioperative hemoglobin trajectory. Serial time-point Hb values from 342 patients. Data are presented as box plots with median lines, 25th and 75th percentile limits to the box and the whiskers representing the furthest outlier of those percentile groups. Timepoint labels: CA, coronary angiography; CPB, cardiopulmonary bypass; Hb, hemoglobin; ICU, intensive care unit.

**Table 1.** Demographic characteristics.

| | All ($n$ = 342) | Elective ($n$ = 246) | Semiurgent ($n$ = 96) | $p$ Value |
|---|---|---|---|---|
| Age (years) | 66.2 (11.7) | 66.1 (11.8) | 66.4 (11.5) | .790 |
| Height (cm) | 169.5 (9.2) | 168.9 (9.4) | 171.1 (8.4) | .053 |
| Weight (kg) | 83.1 (17.2) | 83.6 (17.4) | 81.9 (16.6) | .490 |
| BMI | 28.8 (5.2) | 29.2 (5.2) | 27.8 (4.7) | .018 |
| Gender, female | 25.1% | 26.0% | 77.1% | .582 |
| Diabetes | 34.8% | 32.5% | 40.6% | .167 |
| Renal impairment | 19.9% | 20.3% | 18.8% | .880 |
| Referral to | | | | |
| Preadmission (days) | | 36 (4–188) | 2 (0–47) | <.001 |
| Surgery (days) | | 57 (13–225) | 7 (2–25) | <.001 |
| Preadmission to surgery (days) | | 14 (1–56) | 3 (1–8) | <.001 |
| Hb (g/L) | | | | |
| Referral | 138.0 (17.2) | 137.0 (17.2) | 139.3 (17.3) | .430 |
| Preadmission | 138.1 (16.2) | 138.3 (16.0) | 137.4 (16.8) | .633 |
| Hospital admit | 135.0 (17.7) | 136.1 (15.7) | 133.6 (20.0) | .381 |
| Surgery type | | | | <.001 |
| CABG | 51.2% | 39.8% | 80.2% | |
| Valve | 18.1% | 22.8% | 6.3% | |
| CABG + valve | 15.5% | 18.3% | 8.3% | |
| Other | 15.2% | 19.1% | 5.2% | |
| Preoperative drugs | | | | |
| Aspirin | 62.9% | 52.9% | 88.5% | <.001 |
| Clopidogrel | 3.2% | 1.6% | 7.3% | .025 |
| IV Heparin | 10.2% | 0% | 35.4% | <.001 |

BMI, body mass index; Hb, hemoglobin; CABG, coronary artery bypass grafts; IV, intravenous.

**Table 2.** Blood transfusion during admission and operation type.

| Surgery Type | Transfused (%) | Not Transfused (%) | Median Units |
|---|---|---|---|
| CABG | 44.6 | 55.4 | 2.8 |
| Valve only | 35.5 | 64.5 | 3.8 |
| CABG + valve | 69.8 | 30.2 | 4.1 |
| Other | 40.4 | 59.6 | 3.3 |
| Overall | 46.2 | 53.8 | 3.3 |

CABG, coronary artery bypass graft surgery.

46.9% ($p$ = .90). Transfusion was lowest in elective valve surgery (33.9%). Approximately 10% of patients were transfused during CPB, 10% in the OR following CPB, with the majority of transfusions (35% of patients) occurring in ICU. Most patients received four or fewer units of blood during their admission, with 13% receiving 3 units, 23% receiving 2 units, and 17% receiving 1 unit.

The nadir Hb on CPB (CPB Hb nadir) was strongly associated with transfusion events (no transfusion 95.1 ± 12.9 g/L, any transfusion 80.6 ± 13.8 g/L; $p < .001$). Analysis of transfusion during CPB in our unit reveals a transfusion threshold of 65–70 g/L with 19.6% of patients being transfused at some point during surgery. Linear regression for factors predictive of lower CPB Hb nadir identified major effects from preoperative anemia, female gender, low BMI, high CPB prime volume, and a high volume of fluid given during CPB (Table 3).

Intraoperative red cell salvage using a cell saver occurred in 12.3% of cases. Cell salvage was not included in the analysis because of its selective use in high-risk patients in our practice.

Perioperative factors associated with blood transfusion are summarized in Table 4. A number of factors had univariable associations with a need for transfusion, and these were entered into the multivariable analysis with the exception of the nadir Hb on bypass. The nadir value was excluded despite being a strong predictor of transfusion because it is a consequence of many other factors and would confound the identification of potential causative factors. "Low-volume" prime circuits had a mean volume of 681 (SD 411) mL compared with routine prime volumes of 933 (SD 243) mL ($p < .001$). Factors strongly associated with red cell transfusion were renal impairment, preoperative anemia, low BMI, and female gender.

Postoperatively, factors associated with blood transfusion were Hb on arrival in ICU (OR: .93, 95% CI: .90–.97) and length of stay in ICU (OR: 1.02, 95% CI: 1.01–1.04).

**Table 3.** Factors predictive of the nadir Hb during cardiopulmonary bypass (CPB Hb nadir).

| CPB Hb Nadir | Coeff | $t$ | $P>\|t\|$ | 95% CI |
|---|---|---|---|---|
| Age (year) | –.09 | –1.75 | .081 | –.20, .01 |
| Gender (F) | –11.95 | –8.55 | .000 | –14.70, –9.20 |
| BMI (kg/m$^2$) | .49 | 4.18 | .000 | .26, .73 |
| Diabetes | –3.57 | –2.85 | .005 | –6.03, –1.10 |
| Aspirin preoperative | –2.80 | –2.32 | .021 | –5.18, –.42 |
| Anemic (WHO) | –15.44 | –11.24 | .000 | –18.14, –12.74 |
| Autologous hemodilution pre-CPB | –4.39 | –2.49 | .013 | –7.85, –.92 |
| Antifibrinolytic | –5.29 | –1.67 | .096 | –11.54, .95 |
| Volume administered pre-CPB (/mL) | .00 | –3.17 | .002 | –.01, .00 |
| Volume of prime (/mL) | –.01 | –4.05 | .000 | –.01, .00 |
| CPB min temp (°C) | .70 | 3.13 | .002 | .26, 1.15 |
| Volume on CPB (/mL) | .00 | –5.65 | .000 | .00, .00 |
| XC time (minimum) | –.04 | –2.09 | .037 | –.07, .00 |
| Residual constant | 92.85 | 9.2 | .000 | 73.00, 112.71 |

F, female; BMI, body mass index; WHO, World Health Organization; $R^2$ = .513.

## DISCUSSION

This study has identified that in our institution, a quarter of patients presenting for nonemergent cardiac surgery are anemic by WHO criteria. Anemia is an independent risk factor for poor perioperative outcomes and as we have demonstrated, its presence strongly predicts transfusion of packed red blood cells. Homologous red blood cell transfusion was given to 46.2% of patients during or after surgery. An important finding is that in most anemic patients (81.3%) the diagnosis was made over 2 weeks before surgery, making anemia a modifiable risk factor.

Many diagnoses can lead to anemia. In the United States, the most frequent identifiable cause in patients aged 65 years old and over are nutritional deficits (34.3%), with iron deficiency accounting for half of these (20% overall) (13). Other important causes include anemia of chronic disease and anemia secondary to renal failure. The cause of anemia in the cardiac surgical population may differ from the general population. A detailed evaluation of the cause of anemia in 200 cardiac surgical patients that included sternal marrow biopsy, identified nutritional iron deficiency in 7%, functional iron deficiency in an additional 42%, and the majority of the remainder being classified as anemia of chronic disease (49%) (3).

Management of anemia in the cardiac surgical patient requires the cause to be diagnosed and appropriate treatment instituted, frequently simultaneously. Initial diagnostic clues come from history taking and patient examination, followed by assessment of red cell morphology, Hb concentration, and the presence or absence of reticulocytes on a blood film. Further, more specialized tests include transferrin saturation, iron, B12, folate, and ferritin levels. Treatment of anemia can involve replacement of substrates such as iron, B12, folate, or stimulation of erythropoiesis with exogenous erythropoietin (EPO). Administration of EPO is expensive and has been associated with angina and thrombosis (14). Intravenous iron supplementation,

**Table 4.** Perioperative univariable and multivariable associations with blood transfusion. Continuous variables expressed as mean (standard deviation).

| Factor | Not Transfused | Transfused | Univariable *p* Value | Multivariable *p* Value | Odds Ratio (95% CI) |
|---|---|---|---|---|---|
| *n* | 184 (53.8%) | 158 (46.2%) | | | |
| Age (years) | 63.5 (11.5) | 69.3 (11.2) | <.001 | .086 | 1.02 (.99, 1.05) |
| BMI | 29.9 (5.2) | 27.6 (4.9) | <.001 | <.001 | .89 (.84, .94) |
| Gender (% female) | 21.7% | 30.0% | .134 | .007 | 2.45 (1.28, 4.70) |
| Preoperative anemia (WHO) | 11.4% | 42.4% | <.001 | <.001 | 5.15 (2.59, 10.24) |
| Renal impairment | 8.7% | 32.9% | <.001 | <.001 | 5.44 (2.42, 12.22) |
| Diabetes | 32.6% | 37.3% | .365 | >.2 | |
| Aspirin | 57.6% | 69.0% | .033 | .044 | 1.81 (1.02, 3.22) |
| Elective | 54.1% | 45.9% | .90 | >.2 | |
| Antifibrinolytic | 94.6% | 98.7% | .042 | >.2 | |
| Volume prebypass (mL) | 1024 (361) | 914 (383) | .007 | .068 | .999 (.999,1.00) |
| RAP/VAP | 65.8% | 68.4% | .646 | .16 | 1.56 (.84, 2.9) |
| Prime volume (mL) | 885 (315) | 843 (318) | .213 | >.2 | |
| Volume on CPB, mL | 1018 (953) | 1496 (1334) | <.001 | .021 | 1.000 (1.000, 1.001) |
| Min Temp CPB (°C) | 33.2 (2.7) | 32.8 (2.5) | .170 | >.2 | |
| Type of surgery | | | .068 | >.2 | |
| Valve alone | 21.7% | 13.9% | | | |
| Other | 78.3% | 86.1% | | | |
| Reoperation (any) | 2.7% | 7.6% | .047 | >.2 | |
| Duration of surgery (minute) | 307 (66) | 337 (87) | <.001 | >.2 | |
| Duration of CPB (minute) | 123 (35) | 146 (53) | <.001 | .003 | 1.012 (1.004, 1.02) |
| Duration of XC, minimum | 95 (30) | 107 (40) | .002 | >.2 | |
| Duration post CPB (minute) | 73 (25) | 85 (36) | <.001 | .013 | 1.013 (1.003, 1.02) |

BMI, body mass index; WHO, World Health Organization; RAP/VAP, retrograde autologous prime/venous autologous prime; XC, aortic cross clamp; CPB, cardiopulmonary bypass; $R^2 = .29$.

with ferric carboxymaltose can provide 1000 mg of iron to a patient during a 15-minute infusion, with a very low risk of adverse events such as anaphylaxis (15). Critically, iron transfusion can be used in patients with both absolute and functional iron deficiency, meaning it may provide an avenue for treating anemia in almost half of patients presenting for cardiac surgery (3). The benefits of iron infusion seem to stretch beyond the reversal of anemia. Iron is a critical component of cellular and metabolic pathways, including the electron transport chain in mitochondria (4). Patients may feel reduced fatigue after an iron transfusion, even before their Hb recovers.

Blood transfusion was administered to 46.2% of patients studied, the risk of which was strongly associated with preoperative anemia and renal impairment and low BMI. Renal impairment has already been implicated as a significant cause of perioperative anemia; however, it is also associated with platelet dysfunction and coagulopathy and may lead to increased intra- and postoperative blood loss. The risk of transfusion is associated with BMI as it in turn is associated with a patient's total red cell mass, a measure of the total amount of Hb, rather than its concentration. If a patient has a low red cell mass, loss of a given amount of blood is more likely to lead to a clinically significant drop in Hb concentration and oxygen-carrying capacity.

Nadir Hb on CPB has also been linked to adverse outcomes, in this cohort, the nadir Hb on CPB was strongly associated with low red cell mass, female gender, diabetes, and less strongly with perfusion interventions designed to minimize hemodilution (low CPB prime volume, restriction of fluid in the pre-CPB period, and autologous blood collection before CPB). Only factors associated with red blood cell mass however were demonstrated to decrease transfusion rates overall. It could be hypothesized that although interventions designed to minimize hemodilution maintain Hb concentration, they do so without an effect on red cell mass itself, and therefore in the postoperative period are not effective at preventing transfusion. A second explanation for the failure of these techniques to decrease transfusion rates is that this study was not a controlled trial of these techniques—e.g., the difference between low prime volumes and high prime volumes was not sufficiently large in our institution where mean prime volumes are typically less than 900 mL. Surgical complexity not surprisingly plays a role in the rate of transfusion that was also associated with length of CPB and time from separation from CPB to wound closure.

It is necessary to minimize blood cell transfusion as the cells themselves are an expensive and limited resource and because transfusion itself is associated with adverse outcomes (4,16). There is criticism of this latter association as it is difficult if not impossible to control for all intra- and postoperative factors related to transfusion. Studies suggest that there is a dose–response link between transfusion and morbidity (12) and exposure to even a single unit of blood has adverse effects (5). In this study, 17% of patients received a single unit and 23% received 2 units of blood, perhaps this could have been decreased if additional measures to increase red cell mass had been undertaken.

Intraoperative cell salvage is a specific technique used to conserve red blood cell mass and has been shown to decrease transfusion across a variety of procedures (17), although its routine use in cardiac surgery has been questioned (18). During this study use of cell salvage was not associated with a decrease in red cell transfusion; this is likely to be due to its selective use in a small number (12%) of high-risk patients. A clear downside of cell salvage in the situation of large processing volumes is the loss of other blood components such as platelets and coagulation factors potentially leading to dilutional coagulopathy, with bleeding and an increased need for transfusion.

The transfusion rate of 46.2% in elective patients suggests that there is significant room for systematic improvement in Hb optimization related to cardiac surgery, although it should be recognized that many other factors affect the transfusion rate. Patient blood management (PBM) guidelines suggest that attention is targeted to minimizing preoperative anemia, using programs that investigate early and actively treat patients with anemia, minimizing intraoperative blood loss, through meticulous surgery and perfusion, and finally, instituting appropriate fluid management, transfusion thresholds, and policies in the postoperative period—especially in the ICU (9,19,20). Traditionally this postoperative period of PBM has been labeled, "tolerance of anemia," however, in the face of evidence to suggest that anemia may also lead to adverse outcomes, "appropriate transfusion," may be a better descriptor. Appropriate transfusion triggers are likely to be patient specific, it is not yet clear whether higher Hb concentrations should be aimed for in patients with ischemic heart disease or cardiac failure (6,8). The Transfusion Requirements in Cardiac Surgery III study is an international, multicenter, randomized controlled trial (NIH:NCT02042898), which will hopefully provide some clinical direction in this complex area by evaluating outcomes with restrictive vs. liberal transfusion strategies.

This study has a number of limitations. Although the databases and records from which the data are drawn are comprehensive and were prospectively designed to collect such data, they were not designed with specific question of modifiable risk factors for transfusion in mind and any retrospective analysis may also suffer from missing information and potentially low-quality data. The transfusion "triggers" were not strictly defined, as they would be for a prospective trial, and this will account for some variability in transfusion recipients. Finally, none of the factors identified as being associated with anemia or transfusion can be conclusively deemed as clinically significant unless appropriate randomized studies are undertaken.

An integrated approach is needed to reduce patient exposure to unnecessary blood transfusions and no single strategy is likely to have a large effect on its own. Evidence-based recommendations have been updated recently and provide support for a range of patient blood management strategies to minimize blood loss in surgery and lower transfusion requirements (8,19,20). In the intraoperative environment, minimizing blood loss relates to surgical skill and perfusion technique as much as maintaining an optimal hemostatic environment, which is not always easy. These recommendations recognize the risk of preoperative anemia as a factor in increased blood transfusion; however, there is little published data examining opportunities for timely preoperative intervention. Whether such interventions will translate to improved outcomes is yet to be proven, but seems logical (12,21). A simple intervention to raise awareness of red cell mass would be to calculate it at the start of each case; a number of equations exist to approximate blood volume, which can then be multiplied by the Hb concentration.

In summary, these results suggest that interventions designed to maintain red cell mass are likely to maximize nadir Hb on CPB and decrease transfusion rates. This finding highlights the likely importance of correcting preoperative anemia. A secondary finding was that specific interventions that maximize nadir Hb on CPB without effect on red cell mass, such as reducing prime volumes, although valuable are less effective. Evidence-based guidelines need to be adapted to individual hospital environments to develop strategies to optimize red cell mass prior to surgery.

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