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Hemoglobin Drift after Cardiac Surgery

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Abstract

Introduction—Recent literature suggests that a restrictive approach to red blood cell transfusions is associated with improved outcomes in cardiac surgery (CS) patients. Even in the absence of bleeding, intravascular fluid shifts cause hemoglobin levels to drift postoperatively, possibly confounding the decision to transfuse. We undertook this study to define the natural progression of hemoglobin levels in postoperative CS patients.

Methods—We included all CS patients from 10/10-03/11 who did not receive a postoperative transfusion. Primary stratification was by intraoperative transfusion status. Change in hemoglobin was evaluated relative to the initial postoperative hemoglobin. Maximal drift was defined as the maximum minus the minimum hemoglobin for a given hospitalization. Final drift was defined as the difference between initial and discharge hemoglobin.

Results—Our final cohort included 199 patients, 71(36%) received an intraoperative transfusion while 128(64%) did not. The average initial and final hemoglobin for all patients were 11.0 ± 1.4 g/dL and 9.9 ± 1.3 g/dL, respectively, an final drift of 1.1 ± 1.4 g/dL. The maximal drift was 1.8 ± 1.1 g/dL and was similar regardless of intraoperative transfusion status ($p=0.9$). Although all patients' hemoglobin initially dropped, 79% of patients reached a nadir and experienced a mean recovery of 0.7 ± 0.7 g/dL by discharge. On multivariable analysis, increasing CPB time was significantly associated with total hemoglobin drift (Coefficient/hour: $0.3[0.1-0.5]$ g/dL, $p=0.02$).

Conclusions—In this first report of hemoglobin drift following CS, although all postoperative patients experienced downward hemoglobin drift, 79% of patients exhibited hemoglobin recovery prior to discharge. Physicians should consider the eventual upward hemoglobin drift prior to administering red cell transfusions.

Keywords

Blood; Blood conservation; Blood transfusion

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INTRODUCTION

Red blood cell transfusions are a common and important therapy in cardiac surgery(CS). In fact, in some institutions, close to 100% of CS patients receive blood transfusions.[1–3] Moreover, as much as 20% of the annual world-wide blood supply is used in coronary artery bypass surgery patients alone.[2,1] Although blood transfusions can be life-saving when used appropriately, there is increasing evidence that not all transfusions are appropriate; in fact, transfusions can be harmful, resulting in significant morbidity and mortality.[1,4–9] Several recent clinical trials suggest that a restrictive approach to red blood cell transfusions is associated with equivalent and potentially improved clinical outcomes in critically ill patients,[10] with similar outcomes seen in postoperative orthopedic[11] and CS patients.[1] Since blood resources are both finite and expensive, a judicious and cautious approach to red blood cell transfusion is warranted.[12]

CS patients can require significant fluid resuscitation in the early postoperative period. Additionally, substantial intraoperative fluid requirements combined with the inflammatory effects of surgical manipulation and the cardiopulmonary bypass(CPB) circuit can result in sizeable fluid shifts.[12–14] Thus, even in the absence of bleeding, CS patients can experience significant changes or *drift* in their hemoglobin levels postoperatively. To our knowledge, no one has investigated the natural history of hemoglobin drift in the early postoperative period. A better understanding of the pattern of hemoglobin drift after surgery may help to avoid unnecessary transfusions. We undertook this study to characterize postoperative hemoglobin drift in CS patients.

MATERIAL AND METHODS

We conducted a retrospective review of our prospectively maintained CS database. Our study included all adult(≥ 18 years) patients who underwent CS from 10/2010 -03/2011 who did not receive a postoperative blood transfusion. Patients receiving intraoperative transfusions were included. This study was approved by the Johns Hopkins Medicine institutional review board.

We examined pertinent variables in our database, including: demographics and comorbidities(age, gender, race, height, weight, and body mass index); and operative variables(type of operation, need for reoperative sternotomy, and CPB and aortic cross clamp time).

Hemoglobin

Every hemoglobin level in the first 10 postoperative days was extracted from the medical record. Changes in hemoglobin levels over time were evaluated relative to the initial postoperative intensive care unit(ICU) hemoglobin level. Since many of our patients arriving in the ICU are still receiving their own blood recovered intraoperatively with a cell saver device, the analysis was performed with the initial hemoglobin defined as the first hemoglobin level on arrival in the ICU, and then, analyzed again, with the initial hemoglobin defined as the first hemoglobin level at least 6 hours after arrival in the ICU. Since our preliminary analysis suggested both definitions yielded similar results and the latter time point reflects a time after which no more cell saver blood was given, all further calculations were performed using the latter definition.

Maximal drift was defined as the maximum hemoglobin level minus the minimum hemoglobin level for a given hospital stay. *Final drift* was defined as the difference between the initial and the hospital discharge hemoglobin.

Blood Transfusion Practice

At our institution, intraoperative decisions about blood transfusion are at the discretion of the attending surgeon. There are no levels that trigger a blood transfusion preoperatively, on cardiopulmonary bypass, or postoperatively. Postoperatively, although blood transfusion is still ultimately at the discretion of the attending surgeon, our practice is to withhold transfusions in non-bleeding patients with a hemoglobin greater than 8 g/dL. Although we will transfuse patients at any hemoglobin level for bleeding based on chest tube output, this decision is a clinical decision based not only on the quantity of chest tube output but also on its character and the patient's overall, hemodynamic status.

It is not our standard practice to give erythropoietin. All patients do receive a multivitamin containing iron and all get aspirin. Patients rarely receive clopidogrel. Patients requiring anti-coagulation do not receive warfarin for the first 48 hours and we do not bridge with heparin for mechanical valves. We only bridge with heparin in patients being anti-coagulated for atrial fibrillation who have been in atrial fibrillation for greater than 48 hours.

Outcomes

Hemoglobin levels over time were plotted for all patients. Primary stratification was by the presence or absence of an intraoperative transfusion. Patients who only received cell saver transfusion of their own blood were considered not to have received an intraoperative transfusion. To evaluate trends in hemoglobin values, the curve of best fit for each population was determined with non-linear regression. A locally weighted scatterplot smoothing (Lowess) curve with a bandwidth of 0.8 was fit to each set of hemoglobin values. The primary outcome of interest was change in hemoglobin levels over time.

Statistical Analysis

We compared baseline characteristics by intraoperative transfusion status using the Student's t-test or the Wilcoxon rank-sum test (continuous variables) and the chi-square or Fisher's exact test (categorical variables) as appropriate. Maximal and final drift were also evaluated and compared by intraoperative transfusion status using the Student's t-test and the Wilcoxon rank-sum test. Lowess curves of trends in hemoglobin levels were compared using multilevel random effects modeling with the generalized estimating equation.

To examine the impact of several patient variables on the magnitude of hemoglobin drift, a multivariable linear regression model was constructed. To construct our multivariable model, all independent covariates were tested in univariate fashion. Variables associated with the outcome measured on exploratory analysis ($p < 0.20$), those with biological plausibility, and those previously reported in the literature to be significant were incorporated in forward and backward stepwise fashion into the multivariable models. The likelihood ratio test and Akaike's information criterion were utilized in a nested model approach to identify which model had the greatest explanatory power.

For all analyses, values of $p < 0.05$ (2-tailed) were considered statistically significant. Mean values are displayed with standard deviations and median values are displayed with their interquartile ranges (IQR). Regression coefficients are presented with their 95% confidence intervals (CI). Statistical analysis was performed using Stata 12.0 (StataCorp, College Station, TX).

RESULTS

From October 2010 through March 2011, 199 consecutive patients who did not receive a postoperative blood transfusion underwent CS at our institution. When stratified by

intraoperative transfusion status, 35.7%(n=71) patients received an intraoperative transfusion while 64.3%(n=128) did not. A comparison of patients by intraoperative transfusion status revealed several baseline differences(Table 1). Patients who received an intraoperative transfusion were older, more likely to be female, weighed less, and had longer CPB and aortic cross clamp times. They were also more likely to undergo a combined CABG/valve procedure. Both groups had a similar incidence of redo sternotomy, although the number of reoperative sternotomies not receiving a postoperative transfusion was small.

Outcomes

Postoperative hemoglobin levels tended to drift downward over the first 4 postoperative days and then drift upward over the next 6 postoperative days. As described in our methodology, analysis using the value of the initial hemoglobin upon arrival in the ICU, prior to completion of return of the cell saver blood(Figure 1a), or after cell saver infusion was complete(Figure 1b) demonstrated similar patterns. All subsequent analyses are based on the first ICU Hgb value after cell saver transfusion.

All patients eventually experienced a downward drift in their hemoglobin, reaching a nadir around postoperative day 4. In most patients, this was followed by an upward drift over the next 6 postoperative days. Patients who received intraoperative blood transfusions tended to experience less upward drift from their nadir as seen both by the degree of upward drift(0.7 ± 0.7 vs. 0.8 ± 0.6 g/dL, $p=0.6$) and examination of the Lowess curve of best fit of the data. However, the overall patterns of drift were not statistically significant(generalized estimating equation: $p=0.5$).

The mean initial postoperative hemoglobin for all patients was 11.0 ± 1.4 g/dL while the mean final hemoglobin prior to discharge was 9.9 ± 1.3 g/dL, representing a final drift of 1.1 ± 1.4 g/dL. The nadir hemoglobin was 9.1 ± 1.2 g/dL resulting in a mean maximal drift of 1.8 ± 1.1 g/dL, which was similar between those who received an intraoperative transfusion and those who did not(1.8 ± 1.0 vs. 1.8 ± 1.2 g/dL, $p=0.9$). Although all patients' hemoglobin levels declined initially, 79%(n=157) experienced a subsequent upward drift of their hemoglobin level, with a mean hemoglobin recovery of 0.7 ± 0.7 g/dL by discharge. The distribution of maximal and final drift among CS patients is displayed in Figure 3.

Patients who did not exhibit recovery of their hemoglobin levels were of similar age, gender, race, and body habitus as those who experienced upward drift. These patients also had a similar distribution of operations with similar CPB times and were equally likely to receive intraoperative blood transfusions($p>0.05$).

Multivariable Analysis

To further evaluate predictors of hemoglobin drift, a multivariable linear regression model of total hemoglobin drift was constructed. After adjusting for age, intraoperative blood transfusion status, and weight, increasing CPB time was a significant predictor of the degree of total hemoglobin drift(Coefficient: 0.26 [0.04 to 0.47] g/dL per hour of CPB, $p=0.02$; Table 2). Increasing patient weight was also predictive of drift(Coefficient: 0.01 [0.001 to 0.02] g/dL per kg, $p=0.04$). Neither patient age nor intraoperative blood transfusion status were significant.

COMMENT

To our knowledge, this is the first study to evaluate the course of postoperative hemoglobin drift after CS. We undertook this study to better understand the natural history of hemoglobin levels in postoperative CS patients, anticipating that a better understanding of these trends would better guide transfusion related therapy. In order to assess the normal

pattern, or drift, of hemoglobin levels, we analyzed all postoperative hemoglobin levels in a cohort of CS patients, none of whom received any postoperative blood transfusions. We included patients who received intraoperative transfusions, though, as our study was meant to guide postoperative transfusions.

These data show that in CS patients who are not transfused postoperatively, hemoglobin gradually drifts downward over the first 4 postoperative days, with a maximal drift of slightly less than 2 g/dL, followed by a gradual upward drift, with a recovery of close to 50% of the maximal drift by postoperative day 10. There was a trend in patients who received intraoperative blood transfusions not to recover from their nadir as much as those who were not transfused, but the difference in recovery between these two groups did not reach statistical significance. Although this recovery from maximal drift may differ slightly between patients who did or did not receive intraoperative transfusions, it is notable that 80% of all patients recovered from their nadir to some degree. Analysis of multiple variables showed that the maximal drift appeared to be increased by the duration of CPB, and, to a lesser degree, increasing body weight.

The purpose of this study was to help guide transfusion therapy by describing the natural course of hemoglobin levels postoperatively. It is becoming increasingly evident that a more restrictive approach to red blood cell transfusion is associated with equivalent and in some cases improved outcomes compared to a liberal strategy.[1,10,11] Blood product transfusions can be associated with the transmission of viral and bacterial disease, acute hemolytic and non-hemolytic reactions, transfusion-related acute lung injury, and immunosuppression.[1,5] In CS, red blood cell transfusions have been associated with increased short and long-term mortality,[4,6–9,11] an increased length of stay,[4,6] and neurologic,[8] cardiac,[1,8] pulmonary,[1,4,5] renal,[1,4,5] and infectious complications.[4,5,8] Furthermore, several studies have suggested that the negative impact of red blood cell transfusions may be additive, with each transfused unit causing an incremental increase in risk.[4,8] Given the risk associated with each transfusion, it is crucial that every unnecessary transfusion be avoided.

In clinical practice, it is not uncommon to transfuse hemodynamically stable patients with declining hemoglobin levels either before they leave the ICU or the hospital, with the presumption that their hemoglobin levels will continue to decline. In our study, although we found that all patients experience a decline in their hemoglobin levels, the vast majority of patients' hemoglobin levels recover significantly prior to discharge. Moreover, since most CS patients do not remain in the hospital for 10 days, the data suggests final hemoglobin levels will continue to drift upward after discharge. Physicians should therefore be cautious about prophylactic postoperative transfusions in anticipation of increasing anemia, as the majority of the time, the exact opposite occurs: Hemoglobin rises between the 4th and 10th postoperative day, and may continue to do so.

However, if patients transfused intraoperatively do recover less hemoglobin, it suggests that CPB may affect transfused red cell survival. Although data suggests that transfused red blood cells have a mean survival of approximately 90 days,[15] it is possible that interaction with the CPB circuit decreases the survival of transfused red blood cells. Thus, while intraoperatively transfused blood keeps hemoglobin levels high in the early postoperative period, these cells have poor survival, are removed from circulation over the first postoperative week, and account for the lack of rebound in the hemoglobin level.

Alternatively, intraoperative transfusions may result in an increased inflammatory response, delaying the upward drift beyond the 10 postoperative days of our study, and therefore the upward drift still occurs but is not evident in this study. Regardless, although patients who

receive intraoperative transfusions may not experience the same degree of upward drift as those who were not transfused, their hemoglobin levels did rise and were stable prior to discharge.

To improve our understanding of the factors responsible for the course of hemoglobin levels postoperatively, we conducted a multivariable analysis of predictors of drift. Increased CPB time and, to a lesser degree, an increase in patient weight proved to be important factors in magnifying the drift a patient experienced during his or her hospitalization. CPB is associated with a significant systemic inflammatory response which leads to a capillary leak syndrome and a decrease in circulating blood volume.[12–14] Studies have shown that this third-spacing of fluid begins within minutes of the initiation of CPB and can result in an increase in the extravascular fluid volume of several liters over the first 24 hours.[16,17] The decreased circulating blood volume necessitates fluid resuscitation leading to hemodilution. We speculate that an increased duration of CPB leads to greater inflammation resulting in more third-spacing necessitating more fluid resuscitation. The resultant hemodilution causes greater total hemoglobin drift.

The inflammation caused by CPB may explain the entire pattern of hemoglobin drift observed in our study. Tschaikowsky et al.[17] have shown that post-CPB inflammatory third-spacing peaks at 4 hours postoperatively. Subsequent fluid mobilization occurs and circulating blood volume normalizes and may actually exceed normal levels by 48–72 hours. Thus, the combined effects of initial postoperative bleeding, inflammatory third-spacing, and fluid resuscitation result in an initial hemodilution causing downward hemoglobin drift. As the inflammatory process dissipates over the first 24–48 hours, fluid mobilization begins, increasing circulating blood volume and causing further hemodilution. By postoperative day 4, the circulating blood volume has reached its maximum and thus hemoglobin levels reach their nadir. As the patient diureses over the next several days without being offset by fluid mobilization because it is complete, circulating blood volume decreases, resulting in hemoconcentration and upward hemoglobin drift.

Furthermore, previous research suggests that capillary leakage and thus thirdspacing is proportional to body weight which may explain why patient weight was also a significant driver of maximal drift.[13] Although reoperative sternotomy did not prove to be a significant factor driving drift, our numbers were too small to evaluate this. It is highly likely that there were insufficient reoperative sternotomy patients in this analysis to truly understand the behavior of postoperative hemoglobin concentration in the reoperative population. Further investigation of the drivers of hemoglobin drift is warranted.

Limitations

Our study has several limitations. First, a subset of our patients received their own blood, recovered with a cell saver device, upon arrival in our ICU. We elected to include these patients in our study because cell recovery is a common and recommended technique of blood conservation.[18,19] However, it is possible that these transfusions affected hemoglobin drift. Thus, these results are best generalized to patients who undergo similar cardiectomy blood recovery. Furthermore, although it is rare for patients to receive preoperative blood transfusion, they occasionally do. There is no evidence that preoperative transfusion affects postoperative drift and thus we included these patients in this study. However, this is a possible confounder.

Second, our study is retrospective in nature. Although we attempted to control for relevant confounders, it is possible that important variables were not included and that residual confounding remains. In this retrospective study, it was hard to quantify postoperative bleeding and thus this variable was excluded. While chest tube output is a surrogate for

bleeding, retrospectively it is impossible to evaluate its sanguinity. We would argue that although initial postoperative blood loss may have affected the maximal drift, it should not have affected the subsequent recovery that occurred after postoperative day 4. However, blood loss may be an important consideration and our study should be considered in light of this deficiency.

Third, in an effort to understand the natural history of postoperative hemoglobin drift, we limited our study to patients who were not transfused postoperatively. While this allows us to examine the natural drift of hemoglobin values, it represents a significant selection bias. It is thus possible that our findings can only be applied to patients who do not receive postoperative transfusions. Hemoglobin drift following a postoperative transfusion may follow a different pattern.

Fourth, our study only captures hemoglobin values during the initial hospitalization. During the 10 day follow-up period, patients are gradually discharged and subsequent hemoglobin data represents an increasingly smaller number of patients. This attrition may introduce a sample size bias and may limit the widespread applicability of our findings.

Finally, the sample size is relatively modest and thus the study is susceptible to type II errors. The sample size may be inadequate to fully identify all the predictors of hemoglobin drift and to identify practitioner-specific differences in blood transfusion practices. Further investigation with larger sample sizes is warranted to further understand hemoglobin drift.

CONCLUSION

To our knowledge, this is the first report of hemoglobin drift following CS. Although all postoperative CS patients experience downward hemoglobin drift, 79% of patients will begin to drift upward before discharge. Moreover, the degree of drift can be predicted by the duration of cardiopulmonary bypass. Physicians should consider the eventual upward hemoglobin drift prior to administering prophylactic transfusions.

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REFERENCES

1. Hajjar LA, Vincent JL, Galas FR, et al. Transfusion requirements after cardiac surgery: the TRACS randomized controlled trial. *JAMA*. 2010; 304(14):1559–1567. [PubMed: 20940381]
2. Snyder-Ramos SA, Mohnle P, Weng YS, et al. The ongoing variability in blood transfusion practices in cardiac surgery. *Transfusion*. 2008; 48(7):1284–1299. [PubMed: 18422857]
3. Bennett-Guerrero E, Zhao Y, O'Brien SM, et al. Variation in use of blood transfusion in coronary artery bypass graft surgery. *JAMA*. 2010; 304(14):1568–1575. [PubMed: 20940382]
4. Koch CG, Li L, Duncan AI, et al. Morbidity and mortality risk associated with red blood cell and blood-component transfusion in isolated coronary artery bypass grafting. *Crit Care Med*. 2006; 34(6):1608–1616. [PubMed: 16607235]
5. Engoren MC, Habib RH, Zacharias A, et al. Effect of blood transfusion on long-term survival after cardiac operation. *Ann Thorac Surg*. 2002; 74(4):1180–1186. [PubMed: 12400765]

6. Murphy GJ, Reeves BC, Rogers CA, et al. Increased mortality, postoperative morbidity, and cost after red blood cell transfusion in patients having cardiac surgery. *Circulation*. 2007; 116(22):2544–2552. [PubMed: 17998460]
7. Koch CG, Li L, Duncan AI, et al. Transfusion in coronary artery bypass grafting is associated with reduced long-term survival. *Ann Thorac Surg*. 2006; 81(5):1650–1657. [PubMed: 16631651]
8. Whitson BA, Huddleston SJ, Savik K, Shumway SJ. Risk of adverse outcomes associated with blood transfusion after cardiac surgery depends on the amount of transfusion. *J Surg Res*. 2010; 158(1):20–27. [PubMed: 19181341]
9. Kuduvali M, Oo AY, Newall N, et al. Effect of peri-operative red blood cell transfusion on 30-day and 1-year mortality following coronary artery bypass surgery. *Eur J Cardiothorac Surg*. 2005; 27(4):592–598. [PubMed: 15784356]
10. Hebert PC, Wells G, Blajchman MA, et al. A multicenter, randomized, controlled clinical trial of transfusion requirements in critical care. Transfusion Requirements in Critical Care Investigators, Canadian Critical Care Trials Group. *N Engl J Med*. 1999; 340(6):409–417. [PubMed: 9971864]
11. Carson JL, Terrin ML, Noveck H, et al. Liberal or restrictive transfusion in high-risk patients after hip surgery. *N Engl J Med*. 2011; 365(26):2453–2462. [PubMed: 22168590]
12. Cremer J, Martin M, Redl H, et al. Systemic inflammatory response syndrome after cardiac operations. *Ann Thorac Surg*. 1996; 61(6):1714–1720. [PubMed: 8651772]
13. Hamada Y, Kawachi K, Tsunooka N, et al. Capillary leakage in cardiac surgery with cardiopulmonary bypass. *Asian Cardiovasc Thorac Ann*. 2004; 12(3):193–197. [PubMed: 15353454]
14. Smith EE, Naftel DC, Blackstone EH, Kirklin JW. Microvascular permeability after cardiopulmonary bypass. An experimental study. *J Thorac Cardiovasc Surg*. 1987; 94(2):225–233. [PubMed: 3613621]
15. Luten M, Roerdinkholder-Stoelwinder B, Schaap NP, et al. Survival of red blood cells after transfusion: a comparison between red cells concentrates of different storage periods. *Transfusion*. 2008; 48(7):1478–1485. [PubMed: 18482180]
16. Seghaye MC, Grabitz RG, Duchateau J, et al. Inflammatory reaction and capillary leak syndrome related to cardiopulmonary bypass in neonates undergoing cardiac operations. *J Thorac Cardiovasc Surg*. 1996; 112(3):687–697. [PubMed: 8800157]
17. Tschaikowsky K, Neddermeyer U, Pscheidl E, von der Emde J. Changes in circulating blood volume after cardiac surgery measured by a novel method using hydroxyethyl starch. *Crit Care Med*. 2000; 28(2):336–341. [PubMed: 10708163]

Figure 1.

Scatter plot of absolute change in hemoglobin over time compared to first postoperative hemoglobin level (A) and compared to first hemoglobin level more than 6 hours postoperatively (B). Each point represents a single hemoglobin level. The solid line represents the Lowess curve of best fit.

Figure 2.

Scatter plot of absolute change in hemoglobin over time stratified by intraoperative blood transfusion status normalized to the first postoperative hemoglobin level (A) and normalized to the first hemoglobin level more than 6 hours postoperatively (B). Each point represents a single hemoglobin level. The solid red line represents the Lowess curve of best fit for patients not receiving intraoperative transfusions. The dashed blue line represents the Lowess curve of best fit for patients receiving intraoperative transfusions.

Figure 3. Distribution of hemoglobin drift stratified by degree. Solid black bars represent final hemoglobin drift (initial minus discharge hemoglobin). Striped black bars represent maximal hemoglobin drift (maximum minus minimum hemoglobin).

Table 1**Baseline Characteristics Stratified By Intraoperative Blood Transfusion**

Variable	Total Cohort (N=199)	No Intraoperative Blood (N=128)	Intraoperative Blood (N=71)	P-Value*
Age (years)	60 ± 14	57 ± 15	65 ± 12	<0.001
Male gender	122 (61.3%)	92 (71.9%)	30 (42.3%)	<0.001
White ethnicity	152 (76.4%)	102 (79.7%)	50 (70.4%)	0.1
Black ethnicity	24 (12.1%)	13 (10.2%)	11 (15.5%)	0.3
Other ethnicity	23 (11.6%)	13 (10.2%)	10 (14.1%)	0.4
Weight (kg)	86 ± 22	89 ± 21	80 ± 23	0.01
Height (cm)	170 ± 14	172 ± 11	165 ± 17	<0.001
Body mass index (kg/m ²)	32 ± 25	30 ± 7	30 ± 21	0.7
Preoperative ICU care	37 (18.6%)	17 (13.3%)	20 (28.2%)	0.01
Isolated CABG	67 (33.7%)	44 (34.4%)	23 (32.4%)	0.2
Isolated valve	65 (32.7%)	41 (32.0%)	24 (33.8%)	0.2
Combined CABG/valve	16 (8.0%)	5 (3.9%)	11 (15.5%)	0.01
Aortic procedure	18 (9.1%)	15 (11.7%)	3 (4.2%)	0.1
Other cardiac surgery	33 (16.6%)	23 (18.0%)	10 (14.1%)	0.4
Redo sternotomy	4 (2.0%)	1 (0.8%)	3 (4.2%)	0.1
CPB time (minutes)	88 ± 44	83 ± 42	100 ± 44	0.01
Cross clamp time (minutes)	59 ± 37	55 ± 33	66 ± 42	0.047

* P-value determined by Student's t-test or chi-square or Fisher's exact test

Abbreviations: CABG, coronary artery bypass grafting; CPB, cardiopulmonary bypass; ICU, intensive care unit; N, number.

Table 2

Multivariable Linear Regression of Predictors of Maximal Hemoglobin Drift

Variable	Univariate		Multivariable	
	Coefficient [95% CI]	P-Value ^a	Coefficient [95% CI]	P-Value ^b
Age (per year)	−0.01 [−0.02 to −0.001]	0.03	−0.01 [−0.02 to 0.001]	0.1
Male gender	0.01 [−0.31 to 0.33]	0.9		
White ethnicity	1 (Reference)			
Black ethnicity	−0.11 [−0.59 to 0.37]	0.7		
Other ethnicity	−0.18 [−0.67 to 0.31]	0.5		
Height (per m)	0.33 [−0.78 to 1.44]	0.6		
Weight (per kg)	0.01 [0.001 to 0.014]	0.04	0.01 [0.001 to 0.02]	0.04
BMI (per kg/m ²)	0.001 [−0.01 to 0.01]	0.9		
Preoperative	−0.32 [−0.71 to 0.08]	0.1		
ICU care				
Reoperative	−0.53 [−1.63 to 0.57]	0.3		
sternotomy				
Intraop blood	−0.003 [−0.33 to 0.32]	0.9	0.07 [−0.27 to 0.41]	0.7
transfusion				
CPB time (per hour)	0.26 [0.04 to 0.47]	0.02	0.26 [0.04 to 0.47]	0.02
Cross clamp time (per hour)	0.16 [−0.09 to 0.41]	0.2		

^aP-value based on simple linear regression.^bP-value based on multiple linear regression. Final model includes age, weight, intraoperative transfusion status, and cardiopulmonary bypass time.

Abbreviations: BMI, body mass index; CI, confidence interval; CPB, cardiopulmonary bypass; ICU, intensive care unit.