Blood transfusion and adverse surgical outcomes: The good and the bad

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Introduction. *Every experienced surgeon has a patient whose life was saved by a blood transfusion (the "good"). In contrast, an overwhelming amount of evidence suggests that perioperative blood transfusion can be associated with adverse surgical outcomes (the "bad"). We wondered what patient characteristics, if any, can explain this clinical dichotomy with certain patients benefiting from transfusion, whereas others are harmed by this intervention.*

Methods. *We queried the American College of Surgeons National Surgical Quality Improvement Project database containing patient information entered between 2010 and 2012 to identify differences in mortality and morbidity among patients receiving blood transfusion within 72 hours of their operative procedure compared with those who did not receive any blood. We calculated the relative risk of developing a serious complication or of operative mortality in propensity-stratified patients with equivalent predicted risk of developing a serious complication or operative mortality.*

Results. *There were 470,407 patients in the study group. Of these, 32,953 patients (7.0%) received at least a single blood transfusion within 72 hours of operation. The percent of transfused patients who died or developed serious morbidity was 11.3% and 55.4% compared with 1.3% and 6.1% in nontransfused patients (both* $P < .001$*). Operative mortality, rates of failure to rescue, and serious postoperative complications are increased in patients who receive a postoperative transfusion, both in unadjusted comparisons and in propensity-matched comparisons. Dividing patients into regression-stratified deciles with equal numbers of deaths in each group found that patients at the greatest risk for development of death or serious complications had nonsignificant risk of harm from blood transfusion, whereas patients in the least risk deciles had between an 8- and 12-fold increased risk of major adverse events associated with transfusion.*

Conclusion. *We found that high-risk patients do not have a significant risk from blood transfusion, but low-risk patients have between an 8- and 10-fold excess risk of adverse outcomes when they receive a blood transfusion. We speculate that careful preoperative assessment of transfusion risk and intervention based on this assessment could minimize operative morbidity and mortality, especially because the patients at least risk are more likely to undergo elective operations and provide time for therapeutic interventions to improve transfusion risk profiles. (Surgery 2015;158:608-17.)*

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BLOOD TRANSFUSION can be both "good" and "bad," depending on the clinical situation. Every experienced surgeon has seen blood transfusion save lives. Unfortunately, an abundance of current literature suggests that transfusions of blood product in non–life-saving situations may carry a risk of adverse outcomes in excess of any meaningful value,[1-3] especially in the critically ill.[4] We wondered how to reconcile these 2 divergent findings. Many of the published benefits of blood transfusion stem from studies dealing with trauma, especially penetrating trauma.[5,6] By evaluating the benefit of blood transfusion in penetrating trauma, results are skewed toward potential benefit, especially for patients requiring massive transfusion, and such a selection bias limits the perception of benefit of blood transfusion. In contrast, anemia is a potent risk factor for adverse outcomes in most operative procedures, especially in critically ill patients.[7-10] Red cell transfusions can increase

The authors have made the following disclosures: Victor A. Ferraris—CMEology/Baxter Healthcare (CME event), NovoNordisk (unpaid consultant); Sibu P. Saha—CVRx and Baxter HealthCare (research trials).

Presented at the 10th Annual Academic Surgical Congress in Las Vegas, Nevada, February 3-5, 2015.

Accepted for publication February 27, 2015.

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0039-6060/$ - see front matter

Published by Elsevier Inc.

http://dx.doi.org/10.1016/j.surg.2015.02.027

oxygen delivery in anemic patients, but the associated increases in tissue oxygenation and oxygen utilization do not always follow transfusion or provide necessary benefit, especially in the sickest patients.[11] Blood transfusion carries risks, including immune modulation, systemic infection such as onset of the systemic inflammatory response syndrome, and transmission of certain diseases (albeit very rare).[3,12] Further, the risks of blood transfusion seem to be dose dependent, with increasing risks accruing to patients with increasing units of blood transfused.[13] Given the paradigm that blood transfusion can benefit some patients while harming others, we asked the question whether there is an identifiable set of patient characteristics that can separate those who will be helped by blood transfusion while identifying those who may be harmed by transfusion. Our hypothesis was that blood transfusion represents a balance with risks accruing to some patients, whereas others are harmed by transfusion. To test this hypothesis, we used the American College of Surgeons National Surgical Quality Improvement Project (ACS-NSQIP) database to evaluate outcomes in surgical patients with or without perioperative transfusion.

METHODS

Study population. We used the ACS-NSQIP database to evaluate the effect of procedure-related blood transfusion on operative outcomes.* The study group included patients entered into the ACS-NSQIP database between 2010 and 2012. This database contains deidentified patient information available freely to participants who sign and comply with the ACS-NSQIP Data Use Agreement. The Data Use Agreement uses the data protections of the Health Insurance Portability and Accountability Act of 1996. We analyzed the ACS-NSQIP participant use file containing operative procedures submitted by > 300 acute care hospitals throughout the United States. It is important to understand that this database excludes trauma and pediatric patients. We excluded patients with Current Procedural Terminology (CPT) codes listed as "procedure not otherwise specified" because of uncertainty about the type of procedures performed and because of the lack of associated work relative value units (wRVUs) with the unspecified procedures. Exclusions from the analysis also included patients with missing values in key variables used in the multivariate analyses and a few patients who underwent cardiac operations or aortic procedures requiring cardiopulmonary bypass (total exclusions approximately 7% of patients). To understand the effect of blood transfusion on surgical outcomes, we compared outcome differences in patients who received any blood transfusion within 72 hours of operation with those patients who did not receive a blood transfusion.

*American College of Surgeons National Surgical Quality Improvement Program and the hospitals participating in the ACS NSQIP are the source of the data used herein; they have not verified and are not responsible for the statistical validity of the data analysis or the conclusions derived by the authors.

Study design. The ACS-NSQIP database includes >50 demographic and preoperative clinical risk variables, as well as 30-day morbidity and mortality variables. We used demographic and preoperative clinical variables to identify risk predictors (Appendix 1; online only). The ACS-NSQIP database records postoperative transfusion as a single variable that reflects transfusion of any blood product within 72 hours of operation. To avoid confounding by procedure specialty, we only evaluated procedures performed by the surgery specialties with the greatest patient acuity as measured by average wRVUs. Four surgery specialties accounted for 80% of blood transfusions—cardiothoracic surgery, general surgery, neurosurgery, and vascular surgery. These surgery specialties had the 4 greatest wRVUs and represented the only procedures included in the study group.

We identified 7 serious complications within the ACS-NSQIP database (Table I). Patients with 1 or any combination of these 7 variables served as the composite morbidity group. We compared transfusion differences in patients with or without composite morbidity. We made similar comparisons with 30-day operative mortality and with failure to rescue. We computed the rate of failure to rescue by measuring the number of operative deaths in patients who developed any serious morbidity. The wRVUs, duration of hospital stay, and operating room times measured differences in resource utilization in patients with and without transfusion. Comparisons included univariate and multivariate analyses of transfusion-related differences, as well as analysis of outcomes in propensity-matched groups with equivalent predicted risks of having a transfusion.

Statistical analysis. *Unadjusted univariate comparisons.* We compared unadjusted preoperative risk factors and surgical outcomes in patients who did or did not receive a blood transfusion. Chi-square analysis tested differences between discrete variables in patients with or without blood transfusion. One-way analysis of variance tested for differences between continuous variables.

Multivariate determinants of postoperative complications and operative mortality. To assess the ability to

Table I. Seven serious postoperative complications identified in ACS-NSQIP and used to compare outcome differences between transfused and nontransfused patients

Variable	*Definition*
Wound complication	Deep organ space surgical site infection, deep surgical wound infection, and wound dehiscence.
Pulmonary complications	Pneumonia, unplanned intubation, pulmonary embolism, deep vein thrombosis, or mechanical ventilation >48 h.
Renal complications	Acute kidney injury or dialysis.
Central nervous system complications	New postoperative stroke, transient ischemic attack, or coma.
Cardiac complications	Myocardial infarction or cardiac arrest
Septic complications	Systemic inflammatory response syndrome, septic shock or blood-borne sepsis
Return to the operating room	Unplanned return to the operating room with 30 days of the initial procedure.

predict operative outcomes from variables in the ACS-NSQIP database, we performed logistic regression analyses to identify multivariate predictors of both operative mortality and of development of any serious morbidity. Odds ratios from logistic regression identified the risk of either operative mortality or major morbidity. For this analysis, logistic regression with backward, stepwise removal of predictor variables allowed estimation of the predictors of relative risk of major morbidity or mortality. This multivariate analysis used a probability of .05 to enter and .10 to remove independent variables from the regression equation in a backward, stepwise manner. After deriving the regression model, we tested the predictive accuracy using receiver operating characteristic (ROC) curves.

Based on each patient's logistic probability of developing a serious postoperative complication, we divided the population into ordered deciles of increasing risk of developing a serious postoperative complication, but with equal numbers of serious complications in each decile. The purpose of dividing patients into 10 groups with equal numbers of serious complications per group was to decrease the potential nonlinear interaction between transfusion and serious complications. This approach allowed assessment of the association of serious morbidity outcomes with blood transfusion in each morbidity risk decile adjusted for nonlinear, transfusion-related interactions. We performed a similar analysis using operative mortality as the dependent variable in place of composite morbidity.

Multivariate determinants of transfusion. We developed a robust predictive model to determine the probability of receiving a blood transfusion within 72 hours after operation. For this purpose, a logistic regression model allowed calculation of a multivariate probability variable for each patient that predicted the need for transfusion with good accuracy. To construct this robust model, >30 preoperative variables were entered into a logistic regression analysis to compute a probability of transfusion for each patient in the study group with complete preoperative variable data (Appendix 1). The derived probability values allowed both stratification of patients according to their risk of receiving a transfusion and propensity matching of patients based on their probability risk of receiving a transfusion.

Propensity matching. To minimize confounding when estimating the effect of blood transfusion among patients with differing risks of developing postoperative complications, we performed a robust propensity analysis.[14,15] Logistic regression probability (ie, propensity scores) corrected for measured preoperative variables identified each patient's propensity risk of receiving a blood transfusion. Matching based on their propensity score allowed balancing of measured relevant preoperative risk variables between transfused and nontransfused patients. We calculated the propensity scores using logistic regression with only preoperative variables entered into the model (Appendix 1). We used the FUZZY extension command (v. 1.3.0) in IBM SPSS v. 22.0 to derive the matched sets using a matching tolerance of 0.001. Inferences about treatment effect made using propensity score matching are valid only if patients with and without transfusion have similar distributions of measured preoperative covariates in the matched sample. We minimized the standardized differences of preoperative variables in the matched set to obtain an optimal matched set with similar distributions of measured preoperative variables (Appendix 2; on-line only).[15,16] The standardized difference compared the difference in

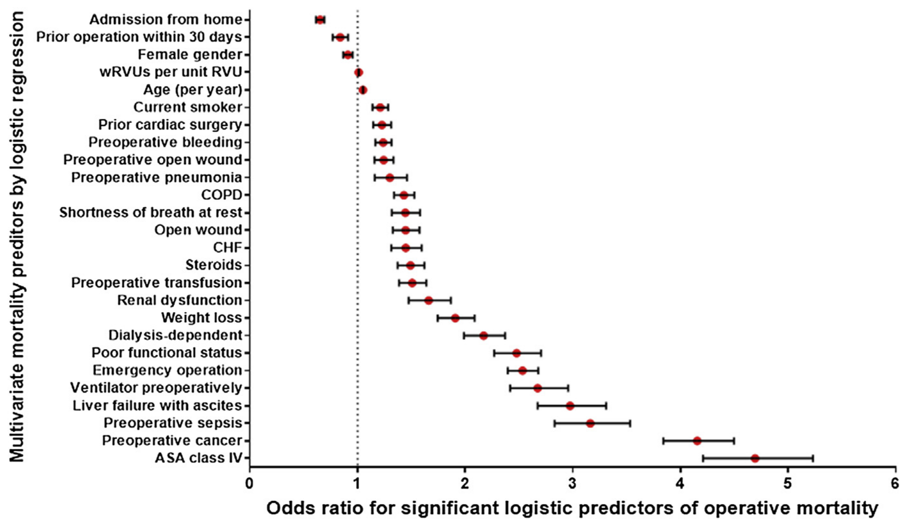

Fig 1. Predictors of mortality. *ASA*, American Society of Anesthesiologists; *CHF*, congestive heart failure; *COPD*, chronic obstructive pulmonary disease; *RVU*, relative value unit; *wRVUs*, work relative value units.

variable means in units of the pooled standard deviation.[15] Unlike *t* tests and other statistical tests of hypothesis, the standardized difference was not influenced by sample size. The use of the standard difference compared balance in measured variables between transfused and nontransfused patients in the propensity-matched sample with that in the unmatched, unadjusted sample. Standardized differences in the propensity-matched sample were <0.1, with 2 exceptions (preoperative transfusion of >4 U of blood and preoperative American Society of Anesthesiologists class). To optimize matching, these 2 variables were omitted from the matching algorithm, which resulted in 2 optimally matched groups with equal numbers of transfused and nontransfused patients having equivalent risks of receiving a transfusion (Appendix 2). All statistical analyses used IBM SPSS v. 22.0 software for calculations of univariate statistics and for statistical modelling.

RESULTS

Study population characteristics. There were 470,407 patients in the study group. Of these, 32,953 patients (7.0%) received ≥1 blood transfusion within 72 hours of operation. The percent of transfused patients having operative mortality or serious morbidity was 11.3% and 55.4% compared with the transfusion rate of 1.3% and 6.1% in nontransfused patients (both $P < .001$).

Blood transfusion and operative risk. The ACS-NSQIP database allowed prediction of operative mortality and morbidity with good prognostic accuracy. Figure 1 shows the multivariate logistic odds ratios of significant preoperative variables that predicted operative mortality. Preoperative variables had excellent predictive accuracy for the probability of operative mortality. The C-statistic of the ROC curve for predictive accuracy of operative mortality is 0.927 (95% CI, 0.924–0.929). Multivariate predictors of any serious morbidity (data not shown) were very similar to the variable list shown in Fig 1 and again the regression-derived individual probabilities showed good predictive ability. This finding suggests that preoperative risk factors available in ACS-NSQIP can identify patients at risk for serious adverse operative outcomes.

There were dramatic differences in unadjusted preoperative risks between patients who received a transfusion compared with those who did not. Table II shows unadjusted preoperative patient comparisons between those with and without transfusion. Logistic regression analysis allowed creation of a probability profile for receiving a blood transfusion. Figure 2 shows the significant odds ratios derived from the logistic regression model to identify predictor variables for receiving any transfusion. The C-statistic for the ROC curve of this regression model was 0.873 (95% CI, 0.871–0.875). Transfusion risks encompass many of the same risk factors that predict operative mortality, but vary in their influence on the dependent variable. For example, the preoperative need for transfusion within 3 days of operation is highly predictive of the probability of postoperative transfusion (odds ratio, 5.82; 95% CI, 5.49–6.17; $P < .001$), whereas the same variable is still a highly significant predictor of operative mortality, but contributes much less to the regression-derived

Table II. Unadjusted comparisons of preoperative variables in patients with and without blood transfusion

Preoperative risk factor	*No transfusion*	*Transfusion*	*Odds ratio for transfusion in patients with discrete risk factor (95% CI)*
Age (y)	55.3 ± 16.8	65.2 ± 14.5*	—
Work RVU of proposed procedure	16.6 ± 9.1	27.2 ± 12.7*	—
Transfer from outside facility	4.3%	19.1%*	5.25 (5.09–5.42)
ASA class ≥ 3	46.0%	88.1%*	8.66 (8.37–8.95)
Female gender	56.5%*	48.7%	0.730 (0.714–0.746)
Preoperative angina	0.8%	4.8%*	6.57 (6.18–6.98)
Prior cardiac surgery	5.1%	13.4%*	2.89 (2.79–2.99)
Preoperative pneumonia	0.4%	2.7%*	6.30 (5.81–6.82)
Prior operation within 30 days	2.3%	9.2%*	4.27 (4.09–4.45)
Preoperative sepsis	0.5%	5.1%*	11.45 (10.72–12.22)
Adult-onset diabetes	15.4%	26.4%*	1.97 (1.92–2.03)
Current smoker	20.0%	24.3%*	1.29 (1.25–1.32)
Preoperative ventilator	0.6%	6.6%*	12.4 (11.7–13.1)
Chronic obstructive pulmonary disease	4.8%	11.4%*	2.53 (2.44–2.63)
Liver failure with ascites	0.6%	3.0%*	5.26 (4.88–5.67)
Congestive heart failure	0.8%	5.2%*	7.03 (6.62–7.46)
Hypertension	46.0%	67.9%*	2.48 (2.42–2.54)
Renal dysfunction	0.5%	2.9%*	6.30 (5.83–6.81)
Dialysis dependent	1.8%	5.6%*	3.24 (3.08–3.42)
Preoperative cancer diagnosis	2.1%	6.3%*	3.14 (2.99–3.30)
Preoperative open wound	4.0%	14.5%*	4.07 (3.93–4.21)
Steroid use	3.1%	6.8%*	2.27 (2.16–2.37)
Preoperative weight loss	1.8%	6.6%*	3.93 (3.74–4.13)
Preexisting bleeding disorder	5.1%	17.7%*	4.00 (3.7–4.12)
Preoperative transfusion of ≥4 U blood	0.7%	11.1%*	16.89 (16.09–17.74)
Emergency operation	13.2%	25.3%*	2.23 (2.17–2.29)
Shortness of breath at rest	1.1%	5.4%*	5.37 (5.08–5.68)
Dependent functional status	1.0%	6.8%*	7.27 (6.90–7.66)
Dirty/infected wound	6.5%	14.7%*	2.47 (2.39–2.56)

*$P < .001$ compared with the corresponding transfusion group.

probability of mortality (odds ratio, 1.48; 95% CI, 1.42–1.53; $P < .001$).

Unadjusted and propensity-adjusted analysis of the effect of blood transfusion on operative outcomes. To further explore the relationship between blood transfusion and operative mortality, we created 10 groups from the database with increasing predicted risk of mortality and with equal numbers of deaths in each decile group. Figure 3, *A* shows the relationship between the mean logistic regression-predicted operative mortality risk and the observed odds ratio for the association of blood transfusion with mortality. Figure 3, *B* shows a similar relationship between predicted serious regression-derived morbidity risk and the observed odds ratio for the relationship between blood transfusion and serious complication rates, again broken into 10 groups with equal numbers of serious complications per decile. Any transfusion translates into a highly significant increase in the odds ratios for operative mortality and for operative morbidity as the predicted risk of mortality or serious complications decreases. Patients with the greatest predicted risks of either mortality or serious morbidity have insignificant risks associated with blood transfusion. In contrast, those patients with a low predicted risk of operative mortality or morbidity have between an 8- and 12-fold increase in adverse outcomes associated with transfusion.

Operative mortality, rates of failure to rescue, and serious postoperative complications are increased in patients who receive a postoperative transfusion, both in unadjusted comparisons (Table III) and in propensity-matched comparisons (Table IV). When patients were matched according to their preoperative risk of receiving a transfusion, surgical outcomes were significantly worse in transfused patients. Measures of resource utilization are increased in patients who receive a transfusion, both in unadjusted and propensity matched comparisons (Table V).

Transfusion in the face of anemia. We evaluated the relationship between blood transfusion and

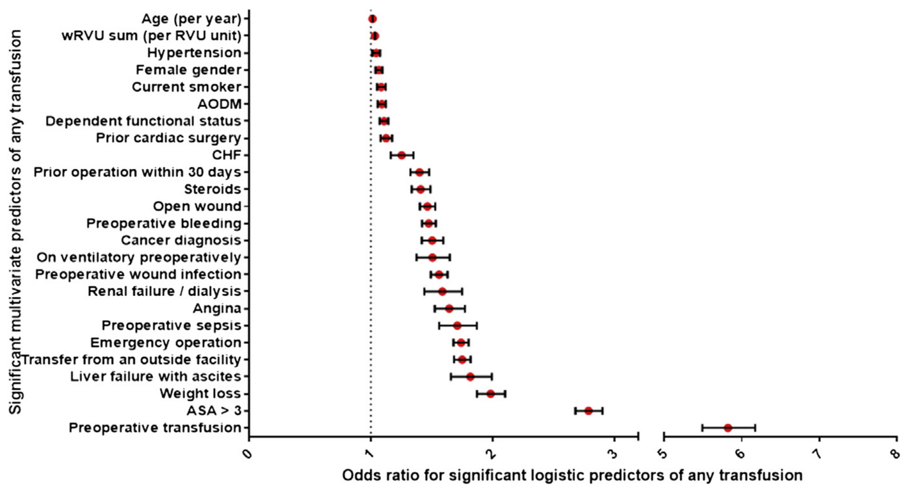

Fig 2. Predictors of any transfusion. *AODM*, Adult-onset diabetes mellitus; *ASA*, American Society of Anesthesiologists; *CHF*, congestive heart failure; *RVU*, relative value unit.

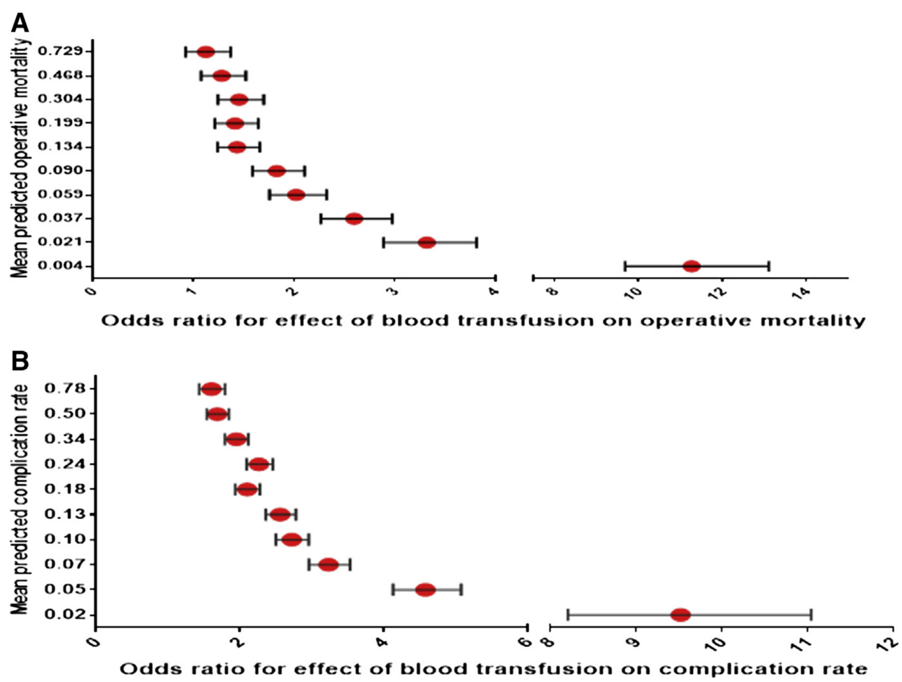

Fig 3. Transfusion risks of (*A*) operative mortality and (*B*) serious complications.

anemia in the study group. Figure 4 summarizes the outcomes seen in patients with preoperative anemia (defined as hematocrit of ≤30%) either alone or in combination with blood transfusion. The situation with the greatest risk for adverse surgical outcomes was the combination of anemia and transfusion. Interestingly, there were only 10,597 of 29,600 patients (33.1%) with anemia who received a transfusion. Perhaps more important, 66.9% of transfused patients did not meet these criteria for preoperative anemia; this finding suggests uncertainty in decisions about the need for transfusion in the perioperative setting.

DISCUSSION

This analysis suggests a strong adverse impact on operative outcomes associated with perioperative blood transfusion. We found that patients at the least risk for operative mortality or serious operative morbidity had the greatest odds of suffering an adverse surgical outcome if transfusions are given (the "bad"). Our results suggest that there is a

Table III. Unadjusted comparisons associated with any perioperative transfusion

	Unadjusted comparisons	
Complication	*Percent of nontransfused patients* (n = *437,454*) *with complication*	*Percent of transfused patients* (n = *32,953*) *with complication*
Operative mortality (n = 9,248)	1.3%	11.3%*
Failure to rescue (n = 7,074)	0.8%	11.3%*
Any serious complication besides blood transfusion (n = 59,493)	6.1%	55.4%*
Deep organ space surgical site infection, deep surgical wound infection, and wound dehiscence. (n = 12,110)	2.1%	8.3%*
Pneumonia, unplanned intubation, pulmonary embolism, deep vein thrombosis, or mechanical ventilation for >48 h (n = 17,348)	2.4%	21.2%*
Acute kidney injury or dialysis (n = 4,015)	0.5%	5.4%*
Stroke, coma, or transient ischemic attack (n = 1,826)	0.3%	1.9%*
Myocardial infarction or cardiac arrest (n = 4,081)	0.6%	5.0%*
Systemic inflammatory response syndrome, septic shock or blood-borne sepsis (n = 13,148)	2.0%	12.7%*
Unplanned return to the operating room (n = 21,615)	3.7%	16.2%*

*$P < .001$.

Table IV. Propensity-matched comparisons in patients with and without transfusion

	Propensity adjusted comparisons	
Complication	*Percent of nontransfused patients* (n = *17,567*) *with complication*	*Percent of transfused patients* (n = *17,567*) *with complication*
Operative mortality (n = 1,785)	3.2%	7.0%*
Failure to rescue (n = 1,578)	2.0%	7.0%*
Any serious complication besides blood transfusion (n = 19,776)	12.6%	100%*
Deep organ space surgical site infection, deep surgical wound infection, and wound dehiscence. (n = 2,080)	3.9%	8.0%*
Pneumonia, unplanned intubation, pulmonary embolism, deep vein thrombosis, or mechanical ventilation for >48 h (n = 3,665)	5.6%	15.2%*
Acute kidney injury or dialysis (n = 892)	1.2%	3.9%*
Stroke, coma, or transient ischemic attack (n = 355)	0.7%	1.4%*
MI or cardiac arrest (n = 910)	1.4%	3.7%*
Systemic inflammatory response syndrome, septic shock or blood-borne sepsis (n = 2,661)	4.3%	10.8%*
Unplanned return to the operating room (n = 1,862)	5.3%	5.3%

*$P < .001$.

balance in the use of blood transfusions with high-risk patients potentially benefiting the most from blood transfusion (the "good"). Other authors made related observations, especially in trauma and critically ill patients.[4,6,17-19] A corollary of this finding is that surgeons should be cautious about the need for a blood transfusion in patients at low risk for adverse operative outcomes.

Many authors outline the complications associated with blood transfusion, with clinical situations ranging from massive transfusion to transfusion of minimal amounts of blood.[13,20-22] Our results suggest that every serious postoperative complication is worse in patients who are transfused compared with those who are not, both before and after propensity adjustment. These results support the concept of limiting transfusion to minimize operative risks.

Unquestionably, transfusions are associated with anemia to a variable extent. There are risks associated with anemia, just as there are with blood transfusions.[7,10,11,23,24] Our results suggest that a conscious, balanced strategy is justified, and our findings draw attention to the particularly concerning clinical situation of anemia and transfusion coexisting in a given patient. Our findings suggest that some patients who are anemic and receive a transfusion are at particularly high risk of adverse surgical

Table V. Unadjusted and propensity-matched comparisons of resource utilization in patients with and without transfusions

Measure of resource utilization	Resource measure (unadjusted comparisons mean ± SD)		Resource measure (propensity-adjusted for equal predicted probability of receiving blood transfusion, mean ± SD)	
	No transfusion (n = 437,454)	Any transfusion (n = 32,953)	No transfusion (n = 17,567)	Any transfusion (n = 17,567)
Work relative value units	22.7 ± 17.9	45.4 ± 29.7**	34.0 ± 22.7	36.0 ± 20.4
Total hospital duration of stay (d)	3.8 ± 10.0	13.4 ± 19.8**	7.25 ± 13.3	11.5 ± 16.6**
Operating room time (min)	108 ± 87	224 ± 151**	148 ± 106	212 ± 142**

**$P < .001$ compared with no transfusion.

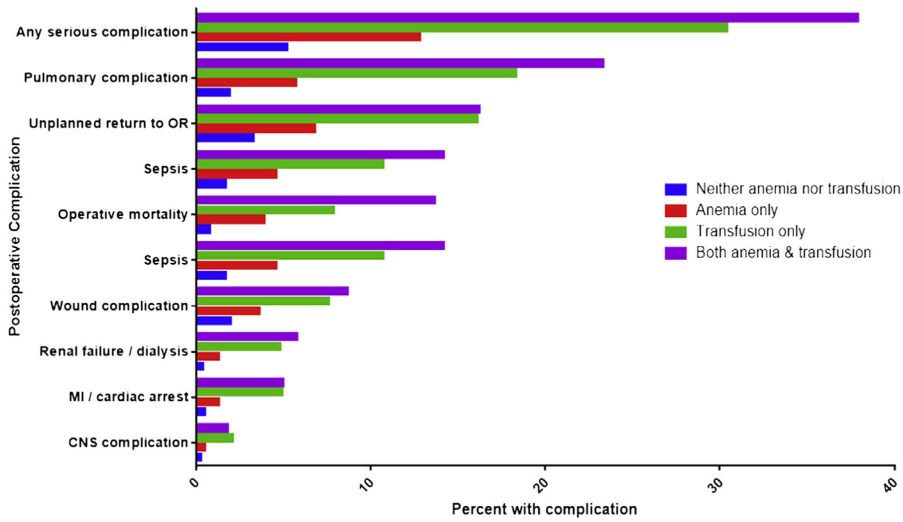

Fig 4. Effects of anemia and transfusion. *CNS*, Central nervous system; *MI*, myocardial infarction; *OR*, operating room.

outcomes, more so than patients who have untransfused anemia or who receive a transfusion alone without preoperative anemia. We found a 3- to 4-fold increase in major adverse complications and operative mortality in patients with preoperative anemia who received transfusions compared with anemic patients who do not receive a transfusion. That the majority of perioperative transfusions are not given to patients with preoperative anemia needs further study. There is a well-recognized variation in transfusion practices across surgeons and institutions,[25-27] and our findings may reflect these variations. At least some of the transfusions in our study group may have been given to nonanemic and nonbleeding patients because of these variations in practices of provider.

We also found that preoperative variables, including operative mortality, serious morbidity, and the need for perioperative blood transfusion, can predict the probability of adverse postoperative outcomes with good accuracy. Some observational evidence suggests that adverse effects of blood transfusion are dose dependent.[13] Anything that can decrease the amount of blood transfusion, even by 1 or 2 U of blood, offers the possibility of limiting operative mortality and morbidity, especially in patients at lesser risk. The regression equations and the associated predictors of transfusion can provide a means of preoperative risk assessment. Our results suggest that using the regression predictors to identify preoperative risk profiles offers the possibility of identifying those patients who may benefit the most from attempts to limit blood transfusion. The range of options for blood conservation is great and guidelines are available to help.[28,29] Potentially helpful interventions include treatment of preoperative anemia, intraoperative blood salvage, perioperative use of antifibrinolytic agents, and limiting antiplatelet or anticoagulant drug exposure.

Study limitations. There are limitations and shortcomings to our study. The limitations are largely those related to the construction of the database itself. The ACS-NSQIP was not constructed to evaluate bleeding and blood transfusion; as such, there are missing pieces in the database. Although the database tracks transfusion within 72 hours of operation, the amount and type of transfusion is uncertain. Further, the database suffers from missing values in key variables. We estimate that between 7 and 12% of variables are missing in key risk predictors and/or key outcome measures. Because of the shortcomings of the database, results and conclusions from studies like ours need to be considered "hypothesis generating" rather than definitive observations. Another shortcoming of our study relates to the issue of multicollinearity. There may be correlation (multicollinearity) among the predictor variables in the multivariate analyses of operative outcomes, when as many predictor variables as possible are included in the multivariate analysis. For example, risk factors such as chronic obstructive pulmonary disease and current cigarette use are highly correlated. In a database of the size of ACS-NSQIP, correlation among predictor variables is inevitable, which represents both a strength and a weakness. Multicollinearity does not decrease the predictive power or reliability of the model as a whole, and in fact multicollinearity may improve the predictive power of the regression model; however, multicollinearity affects calculations regarding individual predictors, such as anemia and blood transfusion. A multiple regression model with correlated predictors can indicate how well the indicator variables predict the outcome variable, but such models may not give valid results about any individual predictor or about which predictors are redundant with respect to others. One way to decrease multicollinearity is to increase the sample size. The large sample size of the ACS-NSQIP limits the effects of multicollinearity and enhances the predictive ability of regression models.

In conclusion, our study found that perioperative blood transfusion is a balance, with the patients at greatest operative risk having minimal risk associated with blood transfusion, whereas the patients at lesser risk have between an 8- and 12-fold increase in the odds of developing serious complications or operative mortality associated with transfusion. Decisions about transfusion are not related to preoperative anemia in most cases, although the most important postoperative predictor of transfusion is the need for preoperative transfusion. Our results must be considered hypothesis generating because of the inherent limitations of any observational database study. Nonetheless, these results raise questions about how transfusions are administered and what interventions can impact transfusion-related outcomes.

SUPPLEMENTARY DATA

Supplementary data related to this article can be found online at http://dx.doi.org/10.1016/j.surg.2015.02.027.

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