


Original Investigation

Patterns and Outcomes of Red Blood Cell Transfusion in Patients Undergoing Percutaneous Coronary Intervention

Matthew W. Sherwood, MD; Yongfei Wang, MS; Jephtha P. Curtis, MD; Eric D. Peterson, MD, MPH; Sunil V. Rao, MD

 Supplemental content at jama.com

IMPORTANCE Studies have shown variation in the use of red blood cell transfusion among patients with acute coronary syndromes. There are no definitive data for the efficacy of transfusion in improving outcomes, and concerning data exist about possible association with harm. Current transfusion practices in patients undergoing percutaneous coronary intervention (PCI) are not well understood.

OBJECTIVE To determine the current patterns of blood transfusion among patients undergoing PCI and the association of transfusion with adverse cardiac outcomes across hospitals in the United States.

DESIGN, SETTING, AND PARTICIPANTS Retrospective cohort study of all patient visits from the CathPCI Registry from July 2009 to March 2013 that included PCI, excluding those with missing data on bleeding complications or who underwent in-hospital coronary artery bypass graft surgery (N = 2 258 711 visits).

MAIN OUTCOMES AND MEASURES Transfusion rates in the overall population and by hospital (N = 1431) were the primary outcomes. The association of transfusion with myocardial infarction, stroke, and death after accounting for a patient's propensity for transfusion was also measured.

RESULTS The overall rate of transfusion was 2.14% (95% CI, 2.13%-2.16%) and quarterly transfusion rates slightly declined from July 2009 to March 2013 (from 2.11% [95% CI, 2.03%-2.19%] to 2.04% [95% CI, 1.97%-2.12%]; $P < .001$). Patients who were more likely to receive transfusion were older (mean, 70.5 vs 64.6 years), were women (56.3% vs 32.5%), and had hypertension (86.4% vs 82.0%), diabetes (44.8% vs 34.6%), advanced renal dysfunction (8.7% vs 2.3%), prior myocardial infarction (33.0% vs 30.2%), or prior heart failure (27.0% vs 11.8%). Overall, 96.3% of sites gave a transfusion to less than 5% of patients and 3.7% of sites gave a transfusion to 5% of patients or more. Variation in hospital risk-standardized rates of transfusion persisted after adjustment, and hospitals showed variability in their transfusion thresholds. Receipt of transfusion was associated with myocardial infarction (42 803 events; 4.5% vs 1.8%; odds ratio [OR], 2.60; 95% CI, 2.57-2.63), stroke (5011 events; 2.0% vs 0.2%; OR, 7.72; 95% CI, 7.47-7.98), and in-hospital death (31 885 events; 12.5% vs 1.2%; OR, 4.63; 95% CI, 4.57-4.69), irrespective of bleeding complications.

CONCLUSIONS AND RELEVANCE Among patients undergoing PCI at US hospitals, there was considerable variation in blood transfusion practices, and receipt of transfusion was associated with increased risk of in-hospital adverse cardiac events. These observational findings may warrant a randomized trial of transfusion strategies for patients undergoing PCI.

JAMA. 2014;311(8):836-843. doi:10.1001/jama.2014.980

Author Affiliations: Duke Clinical Research Institute, Durham, North Carolina (Sherwood, Peterson, Rao); Department of Internal Medicine, Yale University School of Medicine, New Haven, Connecticut (Wang, Curtis).

Corresponding Author: Matthew W. Sherwood, MD, Duke Clinical Research Institute, 2400 Pratt St, PO Box 17969, Durham, NC 27715 (matthew.sherwood@dm.duke.edu).

Red blood cell transfusion among patients with coronary artery disease is controversial. A growing body of evidence suggests that transfusion in the setting of acute coronary syndromes (ACS)¹⁻⁸ and in hospitalized patients with a history of coronary artery disease may be associated with an increase in risk of myocardial infarction (MI) and death.⁹ This is in addition to the other risks described with transfusion of allogeneic blood, such as infection and circulatory overload. However, anemia is a well-known risk factor

ACS acute coronary syndromes

CHF congestive heart failure

MI myocardial infarction

PCI percutaneous coronary intervention

RSTR risk-standardized transfusion rate

for exacerbation of myocardial ischemia,^{10,11} and increasing hemoglobin through red blood cell transfusion should increase oxygen delivery and mitigate ischemic outcomes. This paradox between the pathophysiological rationale for transfusion and observational studies demonstrating worse clinical outcomes has led to uncertainty surrounding transfusion practice in these patients. Current guideline statements make cautious recommendations for restricted transfusion strategies in hospitalized patients with a history of coronary artery disease and make no recommendation on transfusion in the setting of ACS citing an absence of definitive evidence.¹²

Given the lack of evidence-based guidelines for transfusion in patients with coronary artery disease, a registry-based analysis showed that there is marked variation in the use of red blood cell transfusion among patients with ACS.¹³ Similar to patients with ACS, patients undergoing percutaneous coronary intervention (PCI) receive potent antithrombotic therapies and undergo arteriotomy, placing this subset of patients at particularly high risk of bleeding and transfusion. A single-center study showed that a large proportion of patients undergoing PCI received transfusion for indications outside of published guidelines¹⁴; however, the transfusion guidelines have been updated to reflect uncertainty regarding transfusion recommendations in patients with coronary artery disease. Moreover, the practice of PCI has evolved to include “bleeding avoidance strategies.”¹⁵ Therefore, the use of red blood cell transfusion may have undergone significant change over time.

Using data from the CathPCI Registry, we sought to describe transfusion practice patterns in a broadly representative population of patients undergoing PCI across the United States. We also sought to evaluate how patient factors are associated with red blood cell transfusion and to determine the association between transfusion and outcomes in the PCI population.

Methods

Study Sample

The CathPCI Registry is an initiative of the American College of Cardiology Foundation and the Society for Cardiovascular Angiography and Interventions and is the largest ongoing reg-

istry of PCI in the United States. Descriptions of the registry have been published previously.¹⁶ Briefly, the registry collects data on patient and hospital characteristics, clinical presentation, procedural characteristics, and in-hospital outcomes for PCI procedures from more than 1400 sites across the United States (approximately 85% of all cardiac catheterization laboratories). Data are entered into National Cardiovascular Data Registry (NCDR)-certified software at participating institutions and exported in a standard format to the American College of Cardiology. The registry has a comprehensive data quality program, including data quality report specifications for data capture and transmission as well as an auditing program. An NCDR committee prospectively defines the variables (available at <http://www.ncdr.com>).

All patients who underwent cardiac catheterization or PCI from July 2009 to March 2013 were included in the study sample, with the following exceptions: patient visits in which the patient subsequently underwent in-hospital coronary artery bypass graft surgery, patient visits in which a PCI was not performed or that did not represent the first PCI visit during a hospital stay, and procedures with missing data on bleeding events, procedural complications, or discharge status. The study was approved by the institutional review board of Yale University Medical Center and was determined to meet the definition of research not requiring informed consent given that patient information is collected anonymously without unique patient identifiers and only aggregate data are reported.

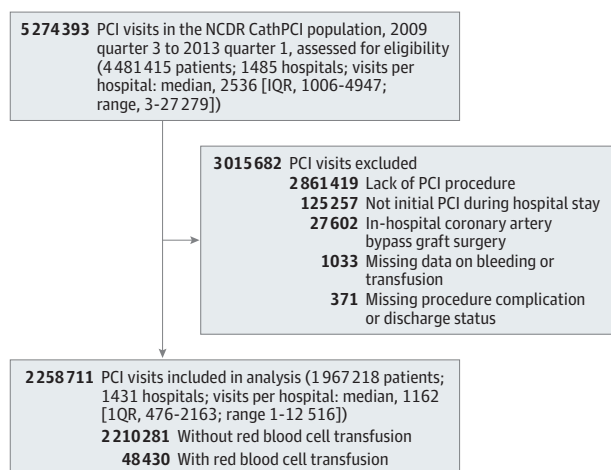
Outcomes and Definitions

The primary outcome was transfusion in the overall population. This outcome was examined with calculation of transfusion rates in the overall population and by hospital (N = 1431), as well as by the occurrence of a bleeding event. These were also calculated quarterly from quarter 3 of 2009 to quarter 1 of 2013. Secondary outcomes included in-hospital MI, congestive heart failure, cardiogenic shock, stroke, and death. The definitions used for transfusion, bleeding events, MI, congestive heart failure, cardiogenic shock, stroke, and death are taken from the CathPCI data collection form, version 4.4,¹⁷ and can be found in the eAppendix in the Supplement.

Statistical Analysis

Rates of transfusion were examined in the overall cohort, by hospital site, and in groups of patients with or without documentation of a procedural bleeding complication. We also examined the change in rates over time by quarters from quarter 3 of 2009 to quarter 1 of 2013 using the Cochrane-Armitage trend test. Hierarchical logistic regression modeling was used to calculate risk-standardized, site-based rates of transfusion (RSTR). The variables included in the model were age, sex, body mass index, ACS presentation, PCI status, cardiogenic shock, New York Heart Association class IV congestive heart failure (CHF), history of CHF, peripheral vascular disease, chronic lung disease, diabetes, dialysis, previous PCI, and glomerular filtration rate. All of these variables have been previously validated in the CathPCI Registry mortality and bleeding risk models.^{18,19}

Figure 1. Study Sample Flow



IQR indicates interquartile range; NCDR, National Cardiovascular Data Registry; PCI, percutaneous coronary intervention.

For the hospital-level analysis, hospitals were divided into low-, medium-, and high-transfusing groups based on the tertiles of their RSTR. Hospitals with an RSTR at or below the 33rd percentile were considered low transfusing (<1.78% of patients underwent transfusion), hospitals between the 33rd and 66th percentiles were considered medium transfusing (1.78% to <2.79% of patients underwent transfusion), and hospitals above the 66th percentile ($\geq 2.79\%$ of patients underwent transfusion) were considered high transfusing. Transfusion frequencies were then plotted by postprocedure hemoglobin values for each group to determine whether hospital-level transfusion practices were different, specifically by transfusion threshold.

Hospital characteristics were also reported by division into low-, medium-, and high-transfusing hospitals according to their RSTR. Characteristics such as bed number, region, and ownership are reported per number of hospitals. Procedural characteristics such as anticoagulant use and discharge medications are reported per patient visit. The median odds ratios for transfusion among hospitals to quantify the variation of transfusion use among different hospitals and the between-hospital variance were also calculated using PROC GLIMMIX in SAS.

The patient population was divided into cohorts according to whether they had received a transfusion, and baseline characteristics and in-hospital outcomes were compared between these 2 groups. Differences were evaluated using the χ^2 test for categorical variables and using the *t* test for continuous variables. Means and standard deviations for continuous variables and frequency rates for categorical variables are reported.

To account for potential confounding in the use of transfusion, inverse probability weighting based on the propensity modeling for transfusion was used in the logistic regression models to determine the association between transfusion and MI, CHF, stroke, and death. Variables included in the pro-

ensity model for transfusion were age, sex, race, body mass index, prior MI, prior coronary artery bypass graft/valvular surgery, cardiogenic shock, cardiac arrest, use of intra-aortic balloon pump, prior CHF, peripheral vascular disease, cerebrovascular disease, tobacco use, chronic lung disease, diabetes, hyperlipidemia, family history, dialysis, glomerular filtration rate, New York Heart Association class IV, location of lesion, PCI indication, PCI status, and hospital characteristics such as public vs private ownership, core-based statistical area, number of beds, PCI volume, teaching facility status, and region. Many of these variables have been previously validated in the NCDR mortality risk model.¹⁸ To assess model performance in our sample, we calculated the area under the receiver operating characteristic curve (C statistic). The model showed excellent discrimination, with a C statistic of 0.839. Odds ratios for patient outcomes comparing use of transfusion with no receipt of transfusion are reported with 95% confidence intervals.

To account for the possibility that bleeding events could drive transfusion as well as outcomes, a secondary analysis was performed to determine the association between transfusion and outcomes among patients who did or did not have reported postprocedure bleeding events. To determine the relationship between preprocedure hemoglobin, transfusion, and outcomes, the study sample was stratified by preprocedure hemoglobin levels and the modeling was repeated.

A 2-sided $P < .05$ was considered significant for all tests. All the statistical calculations were performed at the Yale Center for Outcomes Research and Evaluation with SAS software, version 9.2.0 (SAS Institute Inc).

Results

Study Sample Characteristics

For the purpose of this study, the original sample consisted of 5 274 393 patient visits to the cardiac catheterization laboratory from 1485 sites. Percutaneous coronary intervention occurred during 2 412 974 patient visits. After applying the aforementioned exclusion criteria, 2 258 711 patient visits remained in the study sample (Figure 1) from 1431 hospitals (96% of original sites). There were 48 430 patient visits during which a patient received a postprocedure transfusion. Baseline demographic and procedural characteristics are shown in Table 1. Patients who received transfusion were older, more often female, and more often had comorbidities such as hypertension, diabetes, advanced renal dysfunction, prior MI, and prior CHF. These patients also had a lower estimated glomerular filtration rate, more often presented with ST-segment elevation MI, and less often underwent PCI for elective as opposed to urgent or emergency indications.

Rates of Transfusion

The overall rate of transfusion was 2.14% (95% CI, 2.13%-2.16%). Quarterly transfusion rates from July 2009 to March 2013 slightly declined from 2.11% (95% CI, 2.03%-2.19%) to

Table 1. Clinical Characteristics Stratified by Transfusion Status^a

Patient Characteristics	Overall		Inverse Probability-Weighted Cohort	
	Without RBCT (n = 2 210 281)	With RBCT (n = 48 430)	Without RBCT (n = 2 210 281)	With RBCT (n = 48 401)
Age, mean (SD), y	64.6 (12.0)	70.5 (12.1)	64.8 (12.2)	66.1 (12.0)
Body mass index, mean (SD) ^b	30.0 (6.4)	28.8 (7.2)	30.0 (6.5)	29.7 (49.0)
Female	707 309 (32.5)	27 275 (56.3)	707 309 (32.6)	27 266 (39.8)
White race	1 944 032 (88.0)	40 927 (84.5)	1 944 032 (87.9)	40 902 (86.5)
Hypertension	1 812 770 (82.0)	41 864 (86.4)	1 812 770 (82.1)	41 845 (82.3)
Hyperlipidemia	1 758 531 (79.6)	36 180 (74.7)	1 758 531 (79.4)	36 161 (76.2)
Diabetes	765 050 (34.6)	21 693 (44.8)	765 050 (34.9)	21 686 (36.1)
Peripheral vascular disease	272 079 (12.3)	11 268 (23.3)	272 079 (12.6)	11 265 (15.1)
Cerebrovascular disease	269 404 (12.2)	10 519 (21.7)	269 404 (12.4)	10 517 (14.3)
Chronic lung disease	332 160 (15.0)	12 139 (25.1)	332 160 (15.3)	12 135 (18.2)
GFR, mean (SD), mL/min/1.73 m ²	76.3 (30.5)	56.2 (33.2)	75.9 (31.0)	79 (25.7)
ESRD with dialysis	50 433 (2.3)	4207 (8.7)	50 433 (2.4)	4207 (3.6)
Prior myocardial infarction	666 457 (30.2)	15 970 (33.0)	666 457 (30.2)	15 962 (30.0)
Prior PCI	909 311 (41.1)	16 537 (34.2)	909 311 (41.0)	16 529 (39.4)
Prior congestive heart failure	259 934 (11.8)	13 090 (27.0)	259 934 (12.1)	13 089 (15.0)
Prior CABG/valve surgery	443 168 (20.1)	10 650 (22.0)	443 165 (20.1)	10 649 (20.6)
Family history of coronary artery disease	549 619 (24.9)	7829 (16.2)	549 619 (24.7)	7820 (23.5)
Current tobacco use	609 145 (27.6)	10 854 (22.4)	609 145 (27.4)	10 842 (28.0)
PCI status				
Elective	977 094 (44.2)	9046 (18.7)	977 094 (43.6)	9030 (41.6)
Urgent	856 917 (38.8)	20 884 (43.1)	856 917 (38.8)	20 876 (38.9)
Emergent	368 547 (16.7)	17 468 (36.1)	368 547 (17.1)	17 463 (19.0)
Salvage	6703 (0.3)	1015 (2.1)	6703 (0.4)	1015 (0.4)
PCI indication				
STEMI	347 617 (15.7)	15 741 (32.5)	347 617 (16.1)	15 736 (18.5)
NSTEMI/unstable angina	1 060 254 (48.0)	23 938 (49.4)	1 060 254 (47.9)	23 924 (51.0)
Staged	137 271 (6.2)	1540 (3.2)	137 271 (6.1)	1537 (6.0)
Other	664 361 (30.1)	7196 (14.9)	664 361 (29.8)	7189 (24.5)
Location of lesion				
Mid left anterior descending artery, proximal left circumflex artery, proximal right coronary artery	825 914 (37.4)	18 827 (38.9)	825 914 (37.4)	18 817 (37.0)
Proximal left anterior descending artery	387 071 (17.5)	9915 (20.5)	387 071 (17.6)	9912 (18.4)
Left main	50 692 (2.3)	3277 (6.8)	50 692 (2.4)	3276 (2.8)
Other	946 604 (42.8)	16 411 (33.9)	940 370 (42.3)	16 281 (41.5)
Unknown	6234 (0.3)	115 (0.2)	6234 (0.3)	115 (0.3)
Coronary artery disease presentation				
STEMI	337 686 (15.3)	15 370 (31.7)	337 686 (15.7)	15 365 (17.9)
NSTEMI/unstable angina	1 267 282 (57.3)	26 286 (54.3)	1 267 282 (57.2)	26 271 (59.7)
Elective	604 761 (27.4)	6768 (14.0)	604 761 (27.1)	6759 (22.4)
NYHA class IV congestive heart failure	47 976 (2.2)	6518 (13.5)	47 976 (2.5)	6517 (3.7)
Cardiogenic shock	35 700 (1.6)	7394 (15.3)	35 700 (2.0)	7392 (3.4)
Cardiac arrest	39 202 (1.8)	4800 (9.9)	39 202 (2.0)	4799 (3.2)
Use of intra-aortic balloon pump	40 061 (1.8)	7867 (16.2)	40 061 (2.2)	7866 (3.6)
Preprocedure hemoglobin level, mean (SD), g/dL	13.6 (1.9)	11.0 (2.1)		

Abbreviations: CABG, coronary artery bypass graft; ESRD, end-stage renal disease; GFR, glomerular filtration rate; NSTEMI, non-ST-elevation myocardial infarction; NYHA, New York Heart Association; PCI, percutaneous coronary intervention; RBCT, red blood cell transfusion; STEMI, ST-elevation myocardial infarction.

^a Data are expressed as No. (%) of visits that included percutaneous coronary intervention, unless otherwise indicated.

^b Body mass index is calculated as weight in kilograms divided by height in meters squared.

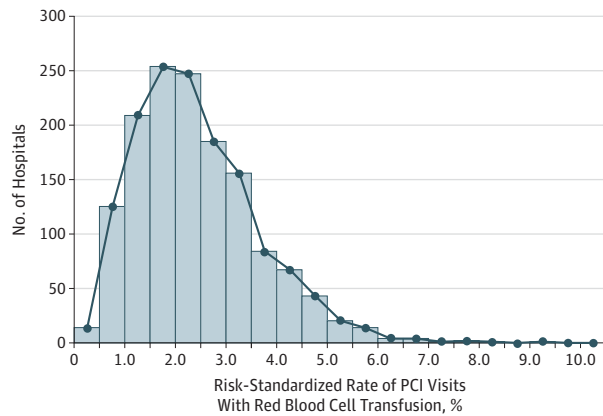
2.04% (95% CI, 1.97%-2.12%) of visits ($P < .001$ for trend). Unadjusted transfusion rates by hospital varied between 0 and 13% (eFigure 1 in the Supplement). The majority of hospitals

(96.3%) gave a transfusion to less than 5% of their patients, with 25.5% of hospitals providing transfusion for less than 1% of patients. However, 3.7% of hospitals in the population gave more

than 5% of patients a transfusion. After adjustment, there was still a broad variation in patterns of transfusion across hospitals. As shown in **Figure 2**, the risk-standardized rates of transfusion across hospitals ranged from 0.3% to 9.3%, with a median of 2.5%.

When stratified by occurrence of a bleeding event, more patients who experienced a bleeding event received transfusion at all postprocedure hemoglobin values compared with patients who did not experience a bleeding event (eFigure 2 in the Supplement). Among patients who did not have a bleeding event, the rates of transfusion increased at postprocedure hemoglobin values of 8 g/dL or lower.

Figure 2. Distribution of Hospital Risk-Standardized Rates of Transfusion



Variations in frequency of receipt of transfusion by hospital (N=1431) after adjustment for patient risk factors such as age, sex, body mass index, acute coronary syndromes presentation, percutaneous coronary intervention (PCI) status, cardiogenic shock, New York Heart Association class IV congestive heart failure (CHF), history of CHF, peripheral vascular disease, chronic lung disease, diabetes, dialysis, previous PCI, coronary lesion $\geq 50\%$, and glomerular filtration rate.

Hospital Characteristics by Transfusion Rate

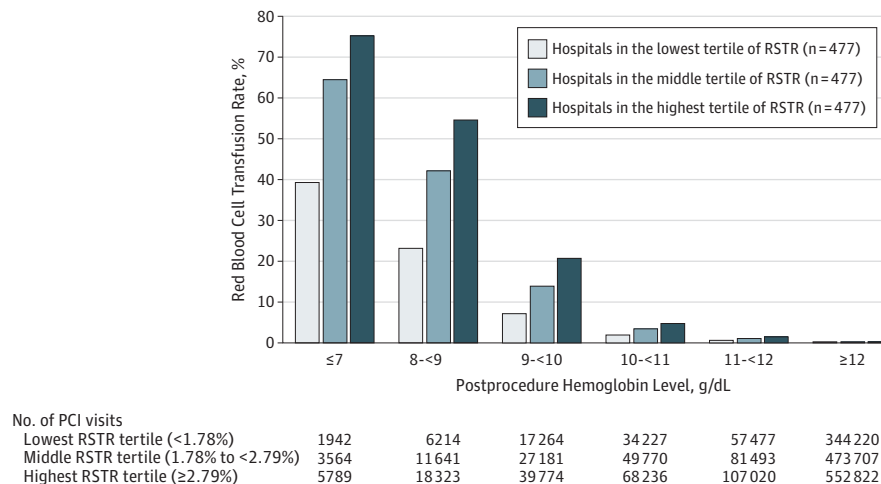
When hospitals were divided into low- (<1.78%), medium- (1.78% to <2.79%), and high- ($\geq 2.79\%$) transfusing hospitals by tertiles of RSTR, transfusion was more frequent at all postprocedure hemoglobin values (≤ 7 g/dL to ≥ 12 g/dL) at high-transfusing hospitals compared with medium- and low-transfusing hospitals (**Figure 3**). High-transfusing hospitals seemed to have a transfusion threshold between 9 g/dL and 10 g/dL, whereas low-transfusing hospitals seemed to have a transfusion threshold between 8 g/dL and 9 g/dL.

High-transfusing hospitals were larger with respect to number of beds and had higher PCI volume compared with the other hospitals (eTable 1 in the Supplement). They also were less likely to be privately owned and less likely to be in rural areas but more likely to be teaching hospitals. High-transfusing hospitals were more likely to be in the New England and Pacific regions, although there was significant variation by region. These hospitals were also less likely to use bivalirudin during procedures and more likely to use GpIIb-IIIa medications but had similar use of radial access site between groups. High-transfusing hospitals prescribed evidenced-based medications on discharge at a similar high frequency compared with lower-transfusing hospitals. The median odds ratio for the likelihood of transfusion by hospital was 1.85 (95% CI, 1.79-1.90) and the between-hospital variation was 0.42 (95% CI, 0.38-0.46), indicating that hospital was responsible for a significant amount of the variation seen in transfusion rates.

Patient Outcomes

With regard to patient outcomes by transfusion status, patients who underwent transfusion were more likely to have in-hospital MI, stroke, CHF, cardiogenic shock, or death (eTable 2 in the Supplement). After adjustment, receipt of transfusion remained associated with an increased risk for in-hospital MI, stroke, or death individually, and also the composite outcome (**Table 2**). The analysis was repeated after

Figure 3. Use of Red Blood Cell Transfusion by Postprocedure Hemoglobin Level at High-, Medium-, and Low-Transfusing Hospitals



Frequency of red blood cell transfusion by postprocedure hemoglobin level when the study sample of hospitals is divided into high-, medium-, and low-transfusing hospitals. Rates of transfusion are higher at high-transfusing sites across all hemoglobin levels. PCI indicates percutaneous coronary intervention; RSTR, risk-standardized transfusion rate.

Table 2. Association of Transfusion and Outcomes: Adjusted Odds Ratios From Inverse Probability-Weighted Analysis^a

Visit Outcomes	Overall Population			Patients With Bleeding			Patients Without Bleeding		
	With RBCT, No. (%) [95% CI] (n = 48 430)	Without RBCT, No. (%) [95% CI] (n = 2 210 281)	OR (95% CI)	With RBCT, No. (%) [95% CI] (n=17 185)	Without RBCT, No. (%) [95% CI] (n=18 650)	OR (95% CI)	With RBCT, No. (%) [95% CI] (n=31 245)	Without RBCT, No. (%) [95% CI] (n=2 191 631)	OR (95% CI)
Myocardial infarction, stroke, or in-hospital death	8418 (17.4) [17.0-17.7]	67 907 (3.07) [3.05-3.10]	3.62 (3.59-3.66)	3152 (18.3) [17.8-18.9]	1772 (9.50) [9.08-9.92]	1.16 (1.11-1.22)	5266 (16.9) [16.4-17.3]	66 135 (3.02) [2.99-3.04]	3.66 (3.63-3.69)
Myocardial infarction	2202 (4.54) [4.36-4.73]	40 601 (1.84) [1.82-1.85]	2.60 (2.57-2.63)	950 (5.53) [5.19-5.87]	722 (3.87) [3.59-4.15]	1.35 (1.24-1.46)	1252 (4.01) [3.79-4.22]	39 879 (1.82) [1.80-1.84]	2.38 (2.35-2.41)
Stroke	988 (2.04) [1.91-2.17]	4023 (0.18) [0.176-0.188]	7.72 (7.47-7.98)	337 (1.96) [1.75-2.17]	173 (0.93) [0.79-1.07]	1.54 (1.34-1.77)	651 (2.08) [1.93-2.24]	3850 (0.18) [0.17-0.18]	8.49 (8.21-8.78)
In-hospital death	6052 (12.5) [12.2-12.8]	25 833 (1.17) [1.15-1.18]	4.63 (4.57-4.69)	2207 (12.8) [12.3-13.3]	1007 (5.40) [5.08-5.72]	1.07 (1.01-1.13)	3845 (12.3) [11.9-12.7]	24 826 (1.13) [1.12-1.15]	4.96 (4.89-5.03)

Abbreviations: OR, odds ratio; PCI, percutaneous coronary intervention; RBCT, red blood cell transfusion.

^a The inverse probability-weighted model included the following variables: age, sex, race, body mass index, prior myocardial infarction, prior coronary artery bypass graft/valvular surgery, cardiogenic shock, cardiac arrest, use of intra-aortic balloon pump, prior congestive heart failure (CHF), peripheral

vascular disease, cerebrovascular disease, tobacco use, chronic lung disease, diabetes, hyperlipidemia, family history, dialysis, glomerular filtration rate, New York Heart Association class IV CHF, location of lesion, percutaneous coronary intervention (PCI) indication, PCI status, and hospital characteristics such as public vs private ownership, core-based statistical area, number of beds, PCI volume, teaching facility status, and region.

Table 3. Association of Transfusion and Outcomes by Preprocedure Hemoglobin Level: Adjusted Odds Ratios From Inverse Probability-Weighted Analysis^a

Myocardial Infarction, Stroke, or In-Hospital Death	Preprocedure Hemoglobin Level, g/dL			
	≤10	>10 to ≤13	>13 to ≤15	>15
Overall Population				
With RBCT, No. (%) [95% CI] of PCI visits	2384 (13.3) [12.8-13.8]	3588 (18.1) [17.5-18.6]	1508 (23.0) [22.0-24.1]	504 (25.9) [24.0-27.9]
Without RBCT, No. (%) [95% CI] of PCI visits	4425 (5.7) [5.5-5.9]	22 329 (3.38) [3.34-3.42]	24 377 (2.71) [2.68-2.74]	12 519 (2.81) [2.76-2.86]
OR (95% CI)	1.56 (1.51-1.62)	3.62 (3.57-3.68)	5.86 (5.78-5.95)	8.12 (7.96-8.29)
Patients With Bleeding				
With RBCT, No. (%) [95% CI] of PCI visits	581 (17.0) [15.8-18.3]	1459 (17.6) [16.8-18.4]	728 (20.0) [18.7-21.3]	249 (22.9) [20.4-25.4]
Without RBCT, No. (%) [95% CI] of PCI visits	82 (15.4) [12.3-18.5]	580 (11.9) [11.0-12.8]	655 (8.79) [8.15-9.44]	393 (7.82) [7.08-8.57]
OR (95% CI)	0.74 (0.66-0.83)	1.01 (0.93-1.08)	1.51 (1.38-1.65)	2.24 (1.99-2.53)
Patients Without Bleeding				
With RBCT, No. (%) [95% CI] of PCI visits	1803 (12.5) [11.9-13.0]	2129 (18.4) [178.7-19.1]	780 (26.9) [25.2-28.5]	255 (29.8) [26.7-32.9]
Without RBCT, No. (%) [95% CI] of PCI visits	4343 (5.62) [5.46-5.79]	21 749 (3.32) [3.27-3.36]	23 722 (2.66) [2.63-2.69]	12 126 (2.75) [2.70-2.80]
OR (95% CI)	1.54 (1.48-1.60)	3.83 (3.77-3.89)	8.84 (8.71-8.98)	10.06 (9.84-10.29)

Abbreviations: OR, odds ratio; PCI, percutaneous coronary intervention; RBCT, red blood cell transfusion.

^a The inverse probability-weighted model included the following variables: age, sex, race, body mass index, prior myocardial infarction, prior coronary artery bypass graft/valvular surgery, cardiogenic shock, cardiac arrest, use of intra-aortic balloon pump, prior congestive heart failure (CHF), peripheral vascular disease, cerebrovascular disease, tobacco use, chronic lung disease, diabetes, hyperlipidemia, family history, dialysis, glomerular filtration rate, New York Heart Association class IV CHF, location of lesion, percutaneous coronary intervention (PCI) indication, PCI status, and hospital characteristics such as public vs private ownership, core-based statistical area, number of beds, PCI volume, teaching facility status, and region.

stratifying patients by whether they experienced a bleeding event. Regardless of the occurrence of bleeding, transfusion was associated with increased risk of in-hospital MI, stroke, or death (Table 2). In an analysis of the relationship between hemoglobin (preprocedure) and clinical outcomes, transfusion was consistently associated with an increased risk of in-hospital MI, stroke, or death regardless of hemoglobin value, except in patients with bleeding and preprocedure hemoglobin values less than 10 g/dL (Table 3). In this group of patients, transfusion was associated with a significantly decreased risk of the composite outcome. The risk in all other groups increased with higher hemoglobin levels.

Discussion

There was marked variation in transfusion practice patterns across the United States among patients undergoing PCI. Within this variation there appeared to be patients who underwent transfusion in the absence of clinical bleeding events and patients who underwent transfusion with nearly normal post-procedure hemoglobin values. These patient-level data, as well as our finding that transfusions were more common across all hemoglobin values at some hospitals, suggest that thresholds for transfusion may have been driven more by local prac-

tice patterns than by clinical necessity. We also found that transfusion was associated with an increased risk of in-hospital adverse outcomes. In the context of prior observational studies that have shown a similar association^{1-8,13} or small randomized trials that have shown no benefit of liberal transfusion,²⁰⁻²² the present analysis suggests that further research is needed to clearly delineate the appropriate use of transfusion in patients undergoing PCI.

Our data showed that the majority of transfusions among patients without bleeding occurred at hemoglobin values of 8 g/dL or lower. In contrast, patients with bleeding events received transfusion across the spectrum of hemoglobin values. Although this may have indicated brisk blood loss in some patients despite higher postprocedure hemoglobin values, the overall rate of bleeding was low in our study sample. Thus, this aggressive transfusion practice may in fact have reflected the biases of the physicians caring for these patients. The variation seen in transfusion practice patterns throughout this study was consistent with the limited data that have been previously reported.^{13,23}

This variation may be related to several factors, including previously held beliefs about the benefit of transfusion and recently published data indicating the lack of benefit and potential hazard associated with transfusion.¹⁻⁶ However, among these studies there is little randomized clinical trial evidence for transfusion practice and none for the broad population of patients undergoing PCI. This creates a lack of consensus that is reflected in the American Association of Blood Banks' guidelines published in 2012,¹² which do not make any recommendations for transfusion strategies in patients with ACS. The guidelines do present cautious recommendations for transfusion in patients hospitalized with coronary artery disease. These include a restrictive strategy, limiting transfusion to those with either symptomatic anemia or a hemoglobin level of 8 mg/dL or lower. The uncertainty in the guidelines may be reflected by the slight decline of transfusion rates over time seen in our population, perhaps due to observational data that raise questions about the benefit of transfusion in these patients. The current data highlight the need for further evidence, in the form of randomized clinical trials, to assess the role of transfusion as therapy in these patients.

Although we found one group in whom transfusion may be associated with improved outcomes, namely, patients who have post-PCI bleeding and a hemoglobin value lower than 10 g/dL, our study cannot determine which transfusion "trigger," as defined by a hemoglobin value, is appropriate for patients undergoing PCI. Clinical trials in the critical care population^{22,24,25} have consistently shown that there is no benefit in maintaining higher hemoglobin levels in patients who are critically ill²⁶; however, whether data from these trials are applicable to patients with ischemic heart disease is controversial. Moreover, these studies excluded patients who were actively bleeding. Data on patients with ischemic heart disease are available only from 2 small clinical trials that compared transfusion thresholds of 8 g/dL and 10 g/dL in patients presenting with ACS or stable angina.²¹ The CRIT Pilot trial showed a higher rate of death, MI, or heart failure in patients assigned to maintaining a hemoglobin level of 10 g/dL. Con-

versely, in the MINT trial, patients assigned to maintaining a hemoglobin level of 10 g/dL or higher had a significantly lower rate of 30-day mortality and numerically lower rates of MI and unscheduled revascularization.²⁷ The FOCUS trial, which was conducted in patients with a history of coronary artery disease recovering from hip arthroplasty, showed no difference in clinical outcomes between a hemoglobin level of 8 g/dL vs 10 g/dL, but the trial did not meet its prespecified sample size and thus may have been underpowered to detect a difference in outcomes.²⁰

In contrast, data from observational studies demonstrate an association between more aggressive transfusion in patients with either MI or ACS and adverse outcomes.¹⁻⁸ While observational data examining transfusion and outcome are subject to significant bias, physiological reasons may help explain why transfusion may reduce oxygen delivery and thus increase ischemic risk. The so-called "storage lesion" that occurs in stored red blood cells may impair oxygen delivery. Moreover, stored red blood cells are depleted of nitric oxide, which may be important for interaction with vascular endothelium and transfer of oxygen to ischemic tissues.²⁸ Transfusion of blood products may also have a prothrombotic effect through the release of platelet activation agents, a phenomenon that would be particularly harmful in post-PCI patients.⁹ In the context of this equipoise, an adequately powered randomized clinical trial is needed to guide transfusion practice in patients with ischemic heart disease and those undergoing PCI.

Limitations

This study has several limitations. First, the data are observational and thus have measured confounding as shown through our bivariable, multivariable, and propensity-modeling analyses, as well as unmeasured confounding that cannot be mitigated. Second, even though the CathPCI Registry captures data from the majority of United States cardiac catheterization laboratories, it does not include all hospitals and thus may not fully represent practice in the United States. Third, we analyzed transfusion patterns at the hospital and patient levels but did not evaluate individual practitioner level variation. It is likely that physicians other than the interventional cardiologist who performed the procedure care for many patients undergoing PCI in the United States, and these physicians may have made postprocedure transfusion decisions. The CathPCI Registry does not contain information on these other practitioners. Fourth, even though hemoglobin level, transfusion, and events were all defined as postprocedure, the absolute temporal relationship between these elements cannot be determined. Thus, the data demonstrate an association between transfusion and adverse in-hospital outcomes, but causality cannot be inferred based on these data.

Conclusions

Considerable variation in blood transfusion practice exists among patients undergoing PCI in the United States, and this variation persists after adjustment for patient differences. Moreover, transfusion thresholds vary widely across hospi-

tals. In this study, transfusion was independently associated with in-hospital adverse cardiac events, and this association remained significant in patients with and without bleeding events and at nearly all hemoglobin levels. These data highlight the need for randomized trials of transfusion strategies to guide practice in patients undergoing PCI. Until these trials have been completed, operators should use strategies that reduce the risk of bleeding and subsequent transfusion.

ARTICLE INFORMATION

Author Contributions: Drs Sherwood and Rao had full access to all of the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis.

Study concept and design: Sherwood, Curtis, Rao.

Acquisition of data: Sherwood, Wang.

Analysis and interpretation of data: Sherwood, Wang, Peterson, Rao.

Drafting of the manuscript: Sherwood.

Critical revision of the manuscript for important intellectual content: All authors.

Statistical analysis: Sherwood, Wang, Rao.

Administrative, technical, and material support: Sherwood.

Study supervision: Peterson, Rao.

Conflict of Interest Disclosures: All authors have completed and submitted the ICMJE Form for Disclosure of Potential Conflicts of Interest. Dr Curtis reports research grants from the National Institutes of Health/National Heart, Lung, and Blood Institute and the Centers for Medicare & Medicaid Services to develop measures for public reporting, salary support from the American College of Cardiology National Cardiovascular Data Registry (NCDR), and ownership of stock in Medtronic. Dr Peterson reports research grants to the Duke Clinical Research Institute from the American College of Cardiology, American Heart Association, Eli Lilly & Co, Janssen, and the Society of Thoracic Surgeons and consulting/honoraria from Boehringer Ingelheim, Genentech, Janssen, Merck & Co, and sanofi-aventis. No other disclosures were reported.

Funding/Support: This research was supported by the American College of Cardiology Foundation's NCDR. The analytic work for this investigator-initiated study was performed by the Yale Center for Outcomes Research, with financial support from the American College of Cardiology.

Role of the Sponsor: The manuscript was reviewed by the NCDR for compliance with registry description and representation but the sponsor had no role in the design and conduct of the study, analysis and interpretation of the data, preparation of the manuscript, or decision to submit the manuscript for publication.

Disclaimer: The views expressed in this article represent those of the authors and do not necessarily represent the official views of the NCDR or its associated professional societies, identified at <http://www.ncdr.com>. Dr Peterson, an associate editor for *JAMA*, was not involved in the editorial review of or the decision to publish this article.

REFERENCES

- Chatterjee S, Wetterslev J, Sharma A, Lichstein E, Mukherjee D. Association of blood transfusion with increased mortality in myocardial infarction. *JAMA Intern Med*. 2013;173(2):132-139.
- Jolicoeur EM, O'Neill WW, Hellkamp A, et al; APEX-AMI Investigators. Transfusion and mortality

in patients with ST-segment elevation myocardial infarction treated with primary percutaneous coronary intervention. *Eur Heart J*. 2009;30(21):2575-2583.

3. Nikolsky E, Mehran R, Sadeghi HM, et al. Prognostic impact of blood transfusion after primary angioplasty for acute myocardial infarction. *JACC Cardiovasc Interv*. 2009;2(7):624-632.

4. Shishehbor MH, Madhwal S, Rajagopal V, et al. Impact of blood transfusion on short- and long-term mortality in patients with ST-segment elevation myocardial infarction. *JACC Cardiovasc Interv*. 2009;2(1):46-53.

5. Aronson D, Dann EJ, Bonstein L, et al. Impact of red blood cell transfusion on clinical outcomes in patients with acute myocardial infarction. *Am J Cardiol*. 2008;102(2):115-119.

6. Wu WC, Rathore SS, Wang Y, Radford MJ, Krumholz HM. Blood transfusion in elderly patients with acute myocardial infarction. *N Engl J Med*. 2001;345(17):1230-1236.

7. Rao SV, Jollis JG, Harrington RA, et al. Relationship of blood transfusion and clinical outcomes in patients with acute coronary syndromes. *JAMA*. 2004;292(13):1555-1562.

8. Rao SV, Eikelboom JA, Granger CB, Harrington RA, Califf RM, Bassand JP. Bleeding and blood transfusion issues in patients with non-ST-segment elevation acute coronary syndromes. *Eur Heart J*. 2007;28(10):1193-1204.

9. Doyle BJ, Rihal CS, Gastineau DA, Holmes DR Jr. Bleeding, blood transfusion, and increased mortality after percutaneous coronary intervention. *J Am Coll Cardiol*. 2009;53(22):2019-2027.

10. Sabatine MS, Morrow DA, Giugliano RP, et al. Association of hemoglobin levels with clinical outcomes in acute coronary syndromes. *Circulation*. 2005;111(16):2042-2049.

11. Pilgrim T, Vetterli F, Kalesan B, et al. The impact of anemia on long-term clinical outcome in patients undergoing revascularization with the unrestricted use of drug-eluting stents. *Circ Cardiovasc Interv*. 2012;5(2):202-210.

12. Carson JL, Grossman BJ, Kleinman S, et al. Red blood cell transfusion: a clinical practice guideline from the AABB. *Ann Intern Med*. 2012;157(1):49-58.

13. Yang X, Alexander KP, Chen AY, et al; CRUSADE Investigators. The implications of blood transfusions for patients with non-ST-segment elevation acute coronary syndromes. *J Am Coll Cardiol*. 2005;46(8):1490-1495.

14. Moscucci M, Ricciardi M, Eagle KA, et al. Frequency, predictors, and appropriateness of blood transfusion after percutaneous coronary interventions. *Am J Cardiol*. 1998;81(6):702-707.

15. Marso SP, Amin AP, House JA, et al; National Cardiovascular Data Registry. Association between use of bleeding avoidance strategies and risk of periprocedural bleeding among patients

undergoing percutaneous coronary intervention. *JAMA*. 2010;303(21):2156-2164.

16. Brindis RG, Fitzgerald S, Anderson HV, Shaw RE, Weintraub WS, Williams JF. The American College of Cardiology-National Cardiovascular Data Registry (ACC-NCDR). *J Am Coll Cardiol*. 2001;37(8):2240-2245.

17. Moussa I, Hermann A, Messenger JC, et al. The NCDR CathPCI Registry: a US national perspective on care and outcomes for percutaneous coronary intervention. *Heart*. 2013;99(5):297-303.

18. Peterson ED, Dai D, DeLong ER, et al; NCDR Registry Participants. Contemporary mortality risk prediction for percutaneous coronary intervention. *J Am Coll Cardiol*. 2010;55(18):1923-1932.

19. Mehta SK, Frutkin AD, Lindsey JB, et al; National Cardiovascular Data Registry. Bleeding in patients undergoing percutaneous coronary intervention. *Circ Cardiovasc Interv*. 2009;2(3):222-229.

20. Carson JL, Terrin ML, Noveck H, et al; FOCUS Investigators. Liberal or restrictive transfusion in high-risk patients after hip surgery. *N Engl J Med*. 2011;365(26):2453-2462.

21. Cooper HA, Rao SV, Greenberg MD, et al. Conservative versus liberal red cell transfusion in acute myocardial infarction (the CRIT Randomized Pilot Study). *Am J Cardiol*. 2011;108(8):1108-1111.

22. Hébert PC, Wells G, Blajchman MA, et al; Transfusion Requirements in Critical Care Investigators for the Canadian Critical Care Trials Group. A multicenter, randomized, controlled clinical trial of transfusion requirements in critical care. *N Engl J Med*. 1999;340(6):409-417.

23. Corwin HL, Gettinger A, Pearl RG, et al. The CRIT study: anemia and blood transfusion in the critically ill—current clinical practice in the United States. *Crit Care Med*. 2004;32(1):39-52.

24. Hill SR, Carless PA, Henry DA, et al. Transfusion thresholds and other strategies for guiding allogeneic red blood cell transfusion. *Cochrane Database Syst Rev*. 2002;(2):CD002042.

25. Freudenberger RS, Carson JL. Is there an optimal hemoglobin value in the cardiac intensive care unit? *Curr Opin Crit Care*. 2003;9(5):356-361.

26. Hébert PC, Yetisir E, Martin C, et al; Transfusion Requirements in Critical Care Investigators for the Canadian Critical Care Trials Group. Is a low transfusion threshold safe in critically ill patients with cardiovascular diseases? *Crit Care Med*. 2001;29(2):227-234.

27. Carson JL, Brooks MM, Abbott JD, et al. Liberal vs restrictive transfusion thresholds for patients with symptomatic coronary artery disease. *Am Heart J*. 2013;165(6):964-971.

28. Rao SV, Califf RM. Is old blood bad blood? *Am Heart J*. 2010;159(5):710-712.