

## NCDR REPORT

# An Updated Bleeding Model to Predict the Risk of Post-Procedure Bleeding Among Patients Undergoing Percutaneous Coronary Intervention

## A Report Using an Expanded Bleeding Definition From the National Cardiovascular Data Registry CathPCI Registry

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**Objectives** This study sought to develop a model that predicts bleeding complications using an expanded bleeding definition among patients undergoing percutaneous coronary intervention (PCI) in contemporary clinical practice.

**Background** New knowledge about the importance of periprocedural bleeding combined with techniques to mitigate its occurrence and the inclusion of new data in the updated CathPCI Registry data collection forms encouraged us to develop a new bleeding definition and risk model to improve the monitoring and safety of PCI.

**Methods** Detailed clinical data from 1,043,759 PCI procedures at 1,142 centers from February 2008 through April 2011 participating in the CathPCI Registry were used to identify factors associated with major bleeding complications occurring within 72 h post-PCI. Risk models (full and simplified risk scores) were developed in 80% of the cohort and validated in the remaining 20%. Model discrimination and calibration were assessed in the overall population and among the following pre-specified patient subgroups: females, those older than 70 years of age, those with diabetes mellitus, those with ST-segment elevation myocardial infarction, and those who did not undergo in-hospital coronary artery bypass grafting.

**Results** Using the updated definition, the rate of bleeding was 5.8%. The full model included 31 variables, and the risk score had 10. The full model had similar discriminatory value across pre-specified subgroups and was well calibrated across the PCI risk spectrum.

**Conclusions** The updated bleeding definition identifies important post-PCI bleeding events. Risk models that use this expanded definition provide accurate estimates of post-PCI bleeding risk, thereby better informing clinical decision making and facilitating risk-adjusted provider feedback to support quality improvement. (J Am Coll Cardiol Intv 2013;6:897–904) © 2013 by the American College of Cardiology Foundation

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Bleeding complications after percutaneous coronary intervention (PCI) are common and are associated with an increased short- and long-term risk of morbidity and mortality as well as increased costs (1,2). Several bleeding avoidance strategies (BAS), such as bivalirudin, radial approach, and, in some studies, vascular closure devices, have been proposed to reduce periprocedural bleeding among higher-risk patient groups (3–6). Yet previous studies have demonstrated a “risk-treatment” paradox with respect to the use of BAS among patients undergoing PCI: BAS are used the least among patients with the highest bleeding risk (7). Among high-risk patients, such as those with ST-segment elevation myocardial infarction, some of these BAS are associated with reduced mortality (8,9), underscoring the importance of applying BAS in patients most likely to benefit. Moreover, Medicare has begun considering peri-PCI bleeding as a component of its Acute Care Episode Demonstration Project, suggesting the growing importance of bleeding as an indicator of quality.

Previous studies have identified patient factors associated with bleeding in the context of acute coronary syndrome (10,11); however, these studies used a definition of bleeding specific to the dataset in which the models were developed and did not include a broad population of patients undergoing PCI. Given the importance of PCI outcomes as performance measures and the interest in public reporting of PCI-related quality of care (12), pre-procedural identification of patients undergoing PCI who are at higher bleeding risk could support more efficient use of BAS to improve the safety of PCI. Moreover, pre-procedural identification could facilitate better patient informed consent (13) and provide risk-adjusted bleeding outcomes feedback to sites participating in quality improvement registries.

The National Cardiovascular Data Registry (NCDR) CathPCI Registry is an ongoing contemporary quality improvement registry of patients undergoing PCI in the United States. The data elements recorded in the registry undergo periodic review and are updated to support continuous quality improvement. We previously published a model predicting the risk of bleeding for patients undergoing PCI using the data elements captured in the registry (14), but the bleeding definition relied on site identification of hemorrhagic events and was restrictive compared with bleeding definitions used in other studies. For example, bleeding events were not considered complications if they were not associated with a prolonged hospital stay or a hemoglobin decrease of at least 3 g/dl. In 2009, the CathPCI Registry implemented a new data collection form with more detailed data elements associated with bleeding events to capture important

complications that were not available in previous versions. Using these data elements, a new CathPCI Registry post-procedure bleeding definition was created, with which we sought to: 1) define contemporary bleeding event rates; 2) define major independent predictors of bleeding; and 3) develop and validate a full pre-procedure risk prediction model as well as a simple bedside additive risk prediction tool.

## Methods

**Study population.** The CathPCI Registry is an initiative of the American College of Cardiology and the Society for Cardiovascular Angiography and Interventions and has been previously described (15). This registry records data on patient and hospital characteristics, clinical presentation, hospital length of stay, treatments, and in-hospital outcomes for PCI procedures from >1,000 sites across the United States. The NCDR has a comprehensive data quality program, including both data quality report specifications for data capture and transmission, and an auditing program. Dataset variables are determined and defined by physician work groups; data collection forms and dictionaries can be found on the NCDR website (<http://www.ncdr.com>).

For this study, we included all PCI procedures performed between February 2008 and April 2011 that had collected data using version 4 of the CathPCI Registry data collection form. Nonindex PCI procedures during the same hospitalization were excluded, as were patients who died the same day as their procedure. In addition, we excluded patients who had missing data on bleeding events and sites that reported no bleeding events (Fig. 1).

**Definitions and outcomes.** The primary outcome for this analysis was post-PCI bleeding. Using the updated data collection form and the desire to improve the capture of clinically important bleeding events, a panel of experts amended the definition of bleeding as any of the following occurring within 72 h after PCI or before hospital discharge (whichever occurs first): site-reported arterial access site bleeding, which may be either external or a hematoma >10 cm for femoral access, >5 cm for brachial access, or >2 cm for radial access; retroperitoneal, gastrointestinal, or genitourinary bleeding; intracranial hemorrhage; cardiac tamponade; post-procedure hemoglobin decrease of 3 g/dl in patients with a pre-procedure hemoglobin level  $\leq 16$  g/dl; or post-procedure nonbypass surgery-related blood transfusion for patients with a pre-procedure hemoglobin level  $\geq 8$  g/dl. This definition includes events such as intracranial hemorrhage, tamponade, hemoglobin decreases that account for potential hemodilution, and transfusions that account for severe anemia that were not included in the previous definition. The definitions of the other data elements are available at <http://www.ncdr.com>.

**Statistical analysis.** Categorical variables are summarized as frequencies and percentages and compared with Pearson

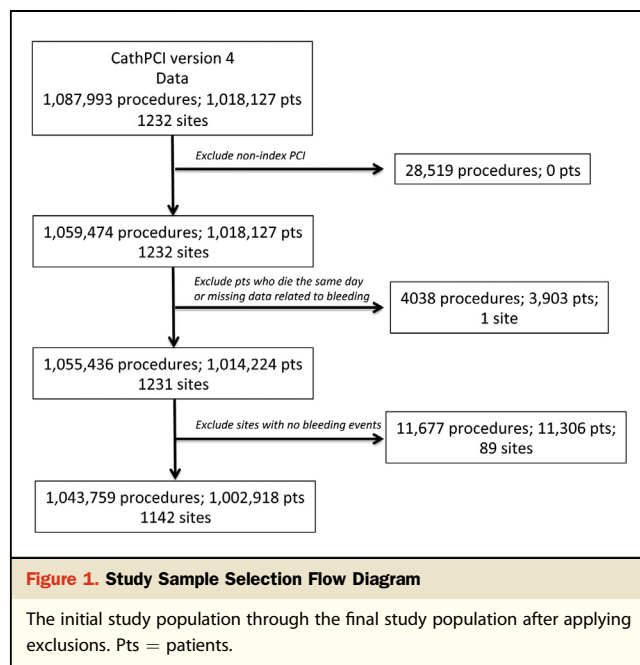
### Abbreviations and Acronyms

**BARC** = Bleeding Academic Research Consortium

**BAS** = bleeding avoidance strategies

**BMI** = body mass index

**NCDR** = National Cardiovascular Data Registry



chi-square tests. Continuous variables are summarized as median (interquartile range) and compared using Wilcoxon rank sum tests. Ordinal variables were tested using a chi-square test based on the rank of the group mean score.

The study population was randomly split into a development sample consisting of 80% of admissions and a validation sample consisting of the remaining 20% of admissions. Baseline patient characteristics and variables from diagnostic catheterization were considered candidate variables. Candidate variables had <0.5% missing data except for estimated glomerular filtration rate (7.8%), pre-procedure hemoglobin level (9.5%), and ejection fraction (29.4%). Missing values were imputed to the lower risk group for discrete variables and replaced with sex-specific medians for body mass index (BMI), sex, and renal failure/dialysis-specific medians for estimated glomerular filtration rate, median value for hemoglobin, and congestive heart failure/cardiogenic shock/previous myocardial infarction-specific medians for ejection fraction. We used logistic regression with backward selection to stay criterion of  $p < 0.05$  to develop a model predicting post-PCI bleeding. Variables that showed nonlinear associations with the outcome were transformed using splines.

We developed a full post-PCI bleeding model using all potential predictive variables. We also developed a risk prediction score by taking the regression coefficients from the pre-procedure model and assigning them an integer weighted to the comparative odds ratio associated with the risk factors (16). Covariates selected for the risk score were those with a chi-square >500. An individual patient's bleeding risk score is the sum of their integer weights. Patients were defined as at low, medium, and high risk of

**Table 1. Baseline Characteristics of the Development and Validation Samples**

Characteristics	Overall (N = 1,043,759)	Development (n = 834,696)	Validation (n = 209,063)
<b>Demographic</b>			
Age yrs	65.0 (56.0–74.0)	64.0 (56.0–74.0)	65.0 (56.0–74.0)
Female	32.7	32.6	32.8
BMI, kg/m <sup>2</sup>	29.1 (25.7–33.3)	29.1 (25.7–33.3)	29.1 (25.7–33.3)
<b>Medical conditions</b>			
Diabetes mellitus	35.9	35.9	35.9
Hypertension	81.8	81.8	81.9
Peripheral vascular disease	12.4	12.4	12.4
Chronic kidney disease	3.6	3.6	3.6
Previous PCI	40.3	40.3	40.3
Previous CABG	18.8	18.9	18.7
Median pre-procedure Hb, g/dl	13.7 (12.4–14.9)	13.7 (12.4–14.9)	13.7 (12.4–14.9)
<b>Procedural</b>			
<b>Procedure status</b>			
Elective	45.2	45.2	45.1
Urgent	37.5	37.5	37.7
Emergent	17.0	17.0	16.9
Salvage	0.3	0.3	0.3
STEMI	16.0	16.0	15.9
Lytics before PCI for STEMI	8.1	8.0	8.2
Shock	2.5	2.5	2.4
Cardiac arrest within 24 h of PCI	1.7	1.7	1.7
<b>Hospital</b>			
Beds	410.0 (283.0–571.0)	410.0 (283.0–571.0)	409.0 (282.0–569.0)
University hospital	11.3	11.3	11.3
Annual PCI cases	726.0 (445.1–1,177.9)	726.6 (445.1–1,183.1)	726.6 (448.0–1,177.9)

Values are median (25th–75th percentile) or %. All p values >0.05.

BMI = body mass index; CABG = coronary artery bypass grafting; Hb = hemoglobin; PCI = percutaneous coronary intervention; STEMI = ST-segment elevation myocardial infarction.

bleeding based on the predicted risk of bleeding derived from the prediction score. Patients with a predicted risk of bleeding at or below the 25th percentile probability were considered low risk, patients with a predicted risk of bleeding between the 25th and 75th percentile probability were considered moderate risk, and patients with a predicted risk of bleeding at or above the 75th percentile probability were considered high risk.

The C-statistic was used to compare discrimination between models and in clinical subgroups of interest including patients with ST-segment elevation myocardial infarction, females, those older than 70 years of age, those

**Table 2. In-hospital Bleeding Rates Overall and in Pre-specified Subgroups in the Development and Validation Samples**

Group	Overall (N = 1,043,759)	Development (n = 834,696)	Validation (n = 209,063)
All patients	5.8	5.8	5.8
STEMI	14.1	14.2	14.0
Females	8.6	8.7	8.5
Age >70 yrs	7.5	7.5	7.5
Diabetes	5.9	6.0	5.9
Excluding in-hospital CABG	5.4	5.4	5.4
Values are %. Abbreviations as in Table 1.			

with diabetes mellitus, and those who did not undergo in-hospital coronary artery bypass grafting. Calibration plots were used to assess goodness of fit. A p value <0.05 was considered statistically significant. All statistical tests were 2 sided. All statistical analyses were performed at the Duke Clinical Research Institute using SAS software (version 9.2, SAS Institute, Cary, North Carolina) and Stata version 11 (StataCorp LP, College Station, Texas).

**Ethical considerations.** The Institutional Review Board of Duke University Medical Center approved this analysis and determined that it met the definition of research not requiring informed consent.

## Results

**Study sample.** Between February 2008 and April 2011, 1,059,474 PCI procedures were performed at 1,232 sites and had data entered into version 4 of the CathPCI Registry data collection form. After applying exclusion criteria, 1,043,759 procedures from 1,142 sites remained (Fig. 1). Table 1 displays the baseline patient, procedure, and hospital characteristics of the development and validation samples. There were 60,194 PCI procedures that had post-procedure bleeding, yielding a post-PCI bleeding event rate of 5.8%. Of these events, 32% were site-reported at a specific anatomic location, whereas 44.6% were detected due to a pre- to post-procedure hemoglobin decrease, 21.8% by a blood transfusion, 1% by cardiac tamponade, and 0.6% were intracranial hemorrhage events.

**Risk factors for in-hospital bleeding.** Table 2 displays the in-hospital bleeding rates for the overall development and validation samples, as well as the rates for each pre-specified subgroup within the samples. The full model, which includes 33 variables, is displayed in Table 3. The most predictive factors, according to their chi-square, were female sex followed by shock or salvage PCI. In contrast, non-insulin-requiring diabetes mellitus was the least predictive. Several variables required transformation with splines such that the relationship with bleeding changed according to

**Table 3. The Full Model**

Category	OR	95% CI	Chi-Square
Demographic characteristics and medical history			
Female vs. male	1.97	1.93–2.02	4,045.30
Dialysis vs. no disease	1.88	1.80–1.95	975.02
Moderate chronic kidney disease (GFR = 30–44 ml/min) vs. no disease	1.68	1.62–1.73	918.89
Previous PCI	0.74	0.72–0.76	726.13
BMI (when BMI ≤ 30 kg/m <sup>2</sup> )*	0.96	0.96–0.97	594.60
Mild chronic kidney disease (GFR = 45–59 ml/min) vs. no disease	1.34	1.31–1.38	487.83
Heart Failure NYHA class IV within 2 weeks Heart failure NYHA class IV within 2 weeks vs. no heart failure within 2 weeks	1.63	1.56–1.70	458.03
Age (≤70 yrs)*	1.02	1.01–1.02	456.10
Chronic lung disease	1.23	1.19–1.26	241.87
Peripheral vascular disease	1.19	1.15–1.22	139.27
NYHA functional class IV HF within 2 weeks before PCI vs. NYHA functional class<IV	1.17	1.13–1.21	76.74
Cerebrovascular disease	1.13	1.10–1.16	74.81
Age (>70 yrs)*	1.01	1.00–1.01	51.20
Insulin requiring diabetes mellitus vs. no diabetes	1.09	1.06–1.13	32.29
Presenting characteristics and PCI status			
Shock within 24 h before and at start of PCI or Salvage procedure	6.02	5.67–6.39	3,511.54
Emergent procedure	2.88	2.76–3.00	2,557.14
Shock within 24 h or at start of PCI	4.39	4.13–4.66	2,334.84
Urgent procedure	1.50	1.46–1.54	948.41
Shock within 24 h and at start of PCI	5.22	4.56–5.98	571.96
Cardiac arrest within 24 h of PCI	1.75	1.66–1.83	533.55
Lytics before PCI for STEMI	1.12	1.04–1.19	10.11
Laboratory values			
Pre-PCI Hb (Hb ≤13 g/dl)*	0.80	0.79–0.81	2,300.92
Pre-PCI Hb (Hb >13 g/dl)*	1.11	1.10–1.12	621.50
Procedural characteristics			
2- or 3-vessel disease vs. no disease or 1-vessel disease	1.23	1.20–1.25	397.13
STEMI	1.45	1.40–1.50	376.49
SCAI lesion class II or III	1.25	1.22–1.28	330.45
SCAI lesion class IV	1.43	1.37–1.49	301.23
Pre-procedure TIMI flow grade = 0	1.24	1.20–1.29	151.28
Left main PCI	1.43	1.35–1.51	149.45
Subacute stent thrombosis	1.61	1.44–1.81	67.12
Proximal LAD PCI	1.10	1.07–1.12	51.43

\*Variables transformed using splines

CI = confidence interval; GFR = glomerular filtration rate; HF = heart failure; LAD = left anterior descending; NYHA = New York Heart Association; OR = odds ratio; SCAI = Society for Cardiovascular Angiography and Intervention; TIMI = Thrombolysis In Myocardial Infarction; other abbreviations as in Table 1.

knots at specific values. Pre-procedure hemoglobin value, BMI, and age all had nonlinear associations with bleeding and required transformation. Table 4 shows the bedside NCDR bleeding risk score derived from the pre-procedure

**Table 4. NCDR CathPCI Bleeding Risk Score**

Variable	Score			
STEMI	No	Yes		
	0	15		
Age, yrs	<60	60–70	71–79	≥80
	0	10	15	20
BMI	<20	20–30	31–39	≥40
	15	5	0	5
Previous PCI	No	Yes		
	10	0		
Chronic kidney disease	No	Mild	Moderate	Dialysis
	0	10	25	30
Shock	No	Yes		
	0	35		
Cardiac arrest within 24 h	No	Yes		
	0	15		
Female	No	Yes		
	0	20		
Hb	Hb <13	13 ≤Hb <15	Hb ≥15	
	5	0	10	
PCI status	Elective	Urgent	Emergency/salvage	
	0	20	40	

Abbreviations as in Table 1.

model. Using these 10 variables and the scoring system, the risk of post-PCI bleeding can be estimated by summing the point scores between 0 and 210 (Table 5, Fig. 2).

**Model performance.** The full bleeding risk model had good discrimination in both the development and validation samples (c-index, development sample 0.78; validation sample 0.77). Table 6 lists the c-indexes of the full model and the risk score in the overall development and validation samples, as well as in pre-specified subgroups. The c-indexes for the subgroups ranged from 0.70 to 0.78. The model calibration plot for the full model is shown in Figure 3. There was high concordance between the risk predicted by the models and the observed bleeding events. Model calibration plots for the pre-specified subgroups are shown in the Online Appendix. There was a high level of concordance among these subgroups as well.

## Discussion

Bleeding remains one of the most common complications of PCI. Accordingly, as part of its quality improvement efforts, the NCDR seeks to improve its data collection and update its risk models by leveraging new data elements and improving bleeding definitions to capture a range of additional clinically important variables. These new models can be used to improve the safety of PCI by enabling the prospective identification of patients who would benefit most from BAS and by creating the infrastructure to support risk-adjusted provider feedback reports.

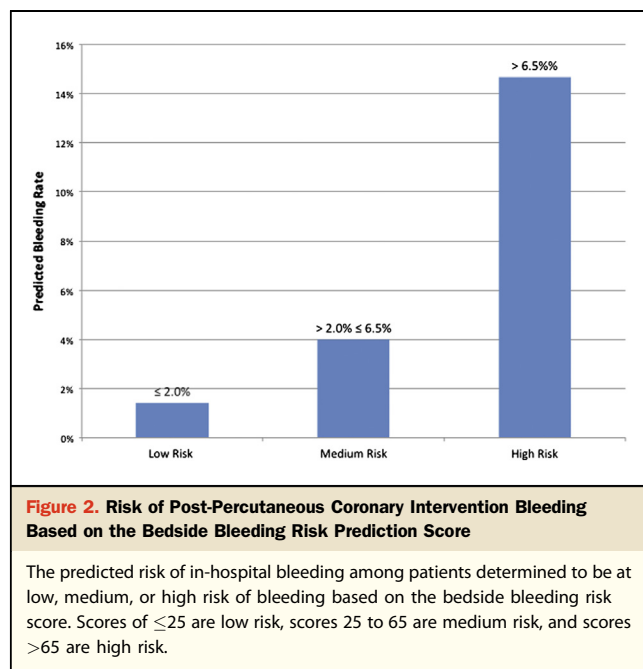
**Table 5. Risk of Bleeding Based on Point Totals From the NCDR CathPCI Registry Bleeding Risk Score**

Total Points	Risk of Bleeding, %
0	0.90
5	1.10
10	1.30
15	1.50
20	1.70
25	2.00
30	2.30
35	2.70
40	3.10
45	3.60
50	4.20
55	4.90
60	5.60
65	6.50
70	7.50
75	8.60
80	9.90
85	11.40
90	13.10
95	14.90
100	17.00
105	19.30
110	21.80
115	24.60
120	27.50
125	30.70
130	34.10
135	37.60
140	41.30
145	45.10
150	49.00
155	52.80
160	56.60
165	60.40
170	64.00
175	67.50
180	70.80
185	73.90
190	76.80
195	79.40
200	81.80
205	84.00
210	86.00

NCDR = National Cardiovascular Data Registry.

Using our updated bleeding definition, ~1 in 20 patients (5.8%) were observed to have a bleeding event. This rate is higher than previously reported (2.4%) and reflects the inclusion of bleeding complications (such as tamponade and transfusions in clinically appropriate groups) that were not included in the previous definition, but which enabled broader estimates of clinically important bleeding to be





generated. The bleeding rate reported in our study is also more consistent with the rate reported in clinical trials, such as the ACUTY (Acute Catheterization and Urgent Intervention Triage Strategy) trial, where the rate of bleeding among patients treated with glycoprotein IIb/IIIa inhibitors was 5.3% to 5.7% (17).

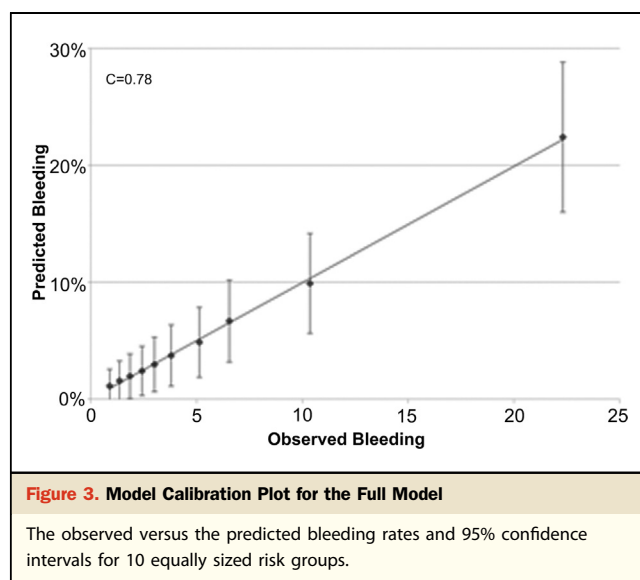
Studies indicate that the reported rate of bleeding is highly dependent on the definition used (18); a standardized bleeding definition, called the Bleeding Academic Research Consortium (BARC) definition, was recently proposed for clinical trials of patients with acute coronary syndrome or those undergoing PCI (19). The BARC definition includes many of the elements used in the current CathPCI Registry bleeding definition, but also relies heavily on adjudication. Although the size and scope of the CathPCI Registry makes adjudication of bleeding events impractical, the new bleeding definition is consistent with the major components

of the BARC definition. An ongoing randomized clinical trial, the SAFE-PCI (Study of Access site For Enhancement of PCI for Women [NCT01406236]), is using the CathPCI Registry as a platform for data collection and has BARC type 2 or greater bleeding as the primary endpoint. This study will provide estimates of the correlation between BARC-defined bleeding and the updated CathPCI Registry definition of bleeding.

Importantly, a number of patient characteristics were strongly associated with periprocedural bleeding. Many of the predictive factors that we identified have been shown in other studies to be predictive of bleeding events. For example, female sex is consistently associated with an increased risk of bleeding (20), as are other variables like age, renal function, and BMI (21). In addition to these factors, we also identified unique variables not present in other bleeding risk models, such as pre-procedure hemoglobin level, cardiac arrest, shock, and clinical status (e.g., salvage procedures). For the full model that will be used to support risk-adjusted hospital comparisons, the addition of such variables is a significant advantage over previous models that use clinical trial data where the acuity of clinical presentation is generally not as severe. The inclusion of these variables minimizes the risk that hospitals that disproportionately care for patients with these high-risk characteristics would not be unduly penalized. This model can be used to risk-adjust post-PCI bleeding rates for the centers participating in the CathPCI Registry, identify leaders and laggards, and ultimately improve the safety of PCI by encouraging the adoption of BAS at centers that have higher-than-expected risk-adjusted bleeding rates. For example, previous studies have shown substantially greater absolute risk reductions with BAS use among patients with higher bleeding risks, previously defined as  $> 1\%$  (14). Corresponding thresholds with the new bleeding definition would be a risk of  $\leq 2.0\%$  (integer score  $\leq 25$ ),  $> 2.0\%, \leq 6.5\%$  (integer bleeding risk score of 25 to 65), and high risk representing risks  $> 6.5\%$  (integer bleeding risk score  $> 65$ ). The use of the CathPCI Registry bleeding risk score may encourage greater adoption of bivalirudin, vascular closure devices, or radial approach among patients in these higher-risk categories. This may be

Table 6. c-Indexes of the Full Model and Risk Score Models in the Overall Dataset and in Pre-Specified Subgroups						
Group	n		Full Model		Risk Score	
	Development Sample	Validation Sample	Development Sample	Validation Sample	Development Sample	Validation Sample
Overall	834,696	209,063	0.78	0.77	0.76	0.75
STEMI	133,649	33,311	0.71	0.71	0.70	0.70
Women	272,357	68,540	0.74	0.74	0.73	0.72
Age $> 70$ yrs	275,089	69,015	0.76	0.76	0.74	0.74
Diabetes	299,402	75,003	0.78	0.78	0.76	0.76
Excluding in-hospital CABG	824,414	205,510	0.79	0.78	0.76	0.76

Abbreviations as in Table 1.



particularly important given the interest in public reporting of PCI-related outcomes (12). The distribution of risk using the new bleeding definition potentially broadens the proportion of patients who might benefit from BAS implementation, but future comparative effectiveness studies are needed to confirm this hypothesis. The bedside risk score that we developed, using 10 key variables, has further utility by facilitating pre-procedure identification of patients at high risk of bleeding, as well as informing the consent process (13).

**Study limitations.** First, in many states, participation in the CathPCI Registry is voluntary; therefore, this registry may not be completely representative of all PCI procedures performed in the United States. Nevertheless, the CathPCI Registry is the largest ongoing contemporary registry of PCI and there are no a priori reasons to believe that the associations between patient characteristics and periprocedural bleeding would differ among hospitals that do and do not participate in the NCDR. Second, the new definition of bleeding still includes site-identified bleeding complication data, although these data have objective definitions, sites may vary in their threshold for reporting these events. Nevertheless, the definition now also includes blood transfusion, hemoglobin decreases, and intracranial hemorrhage, thereby making it likely to detect the most clinically significant bleeding events. The use of blood transfusion in the registry may not necessarily reflect clinical bleeding, and its use is controversial in patients with coronary artery disease. Although some may argue that other physicians involved in patient care may be ordering “unnecessary” blood transfusions, the limitation of the new definition to only include those transfusions that occur in patients with hemoglobin values  $>8$  mg/dl is congruent with previous data showing harm from transfusions in this population (22,23).

## Conclusions

Using data from the NCDR CathPCI Registry, we updated the definition of bleeding to capture hemorrhagic events previously excluded and developed and validated contemporary predictive and risk-adjustment models for post-PCI bleeding. The models had good operating characteristics in the overall dataset of patients undergoing PCI, as well as among high-risk subgroups. This model will serve as the basis for providing risk-adjusted feedback on bleeding rates for sites participating in the CathPCI Registry, and the bedside bleeding risk score can facilitate the use of BAS in patients most likely to benefit.

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## REFERENCES

- Doyle BJ, Rihal CS, Gastineau DA, Holmes DR Jr. Bleeding, blood transfusion, and increased mortality after percutaneous coronary intervention: implications for contemporary practice. *J Am Coll Cardiol* 2009;53:2019–27.
- Rao SV, Kaul PR, Liao L, et al. Association between bleeding, blood transfusion, and costs among patients with non-ST-segment elevation acute coronary syndromes. *Am Heart J* 2008;155:369–74.
- Sherev DA, Shaw RE, Brent BN. Angiographic predictors of femoral access site complications: implication for planned percutaneous coronary intervention. *Catheter Cardiovasc Interv* 2005;65:196–202.
- Kirtane AJ, Piazza G, Murphy SA, et al. Correlates of bleeding events among moderate- to high-risk patients undergoing percutaneous coronary intervention and treated with eptifibatide: observations from the PROTECT-TIMI-30 trial. *J Am Coll Cardiol* 2006;47:2374–9.
- Verheugt FW, Steinhilb SR, Hamon M, et al. Incidence, prognostic impact, and influence of antithrombotic therapy on access and non-access site bleeding in percutaneous coronary intervention. *J Am Coll Cardiol Interv* 2011;4:191–7.
- Rao SV, Ou FS, Wang TY, et al. Trends in the prevalence and outcomes of radial and femoral approaches to percutaneous coronary intervention: a report from the national cardiovascular data registry. *J Am Coll Cardiol Interv* 2008;1:379–86.
- Marso SP, Amin AP, House JA, et al. Association between use of bleeding avoidance strategies and risk of periprocedural bleeding among patients undergoing percutaneous coronary intervention. *JAMA* 2010;303:2156–64.
- Stone GW, Witzenbichler B, Guagliumi G, et al. Bivalirudin during primary PCI in acute myocardial infarction. *N Engl J Med* 2008;358:2218–30.
- Jolly SS, Yusuf S, Cairns J, et al. Radial versus femoral access for coronary angiography and intervention in patients with acute coronary syndromes (RIVAL): a randomised, parallel group, multicentre trial. *Lancet* 2011;377:1409–20.
- Subherwal S, Bach RG, Chen AY, et al. Baseline risk of major bleeding in non-ST-segment elevation myocardial infarction: the CRUSADE (Can Rapid risk stratification of Unstable angina patients Suppress Adverse outcomes with Early implementation of the ACC/AHA Guidelines) Bleeding Score. *Circulation* 2009;119:1873–82.

11. Mehran R, Pocock SJ, Nikolsky E, et al. A risk score to predict bleeding in patients with acute coronary syndromes. *J Am Coll Cardiol* 2010;55:2556-66.
12. Moscucci M. Public reporting of PCI outcomes and quality of care: one step forward and new questions raised. *JAMA* 2012;308:1478-9.
13. Arnold SV, Decker C, Ahmad H, et al. Converting the informed consent from a perfunctory process to an evidence-based foundation for patient decision making. *Circ Cardiovasc Qual Outcomes* 2008;1:21-8.
14. Mehta SK, Frutkin AD, Lindsey JB, et al., National Cardiovascular Data Registry. Bleeding in patients undergoing percutaneous coronary intervention: the development of a clinical risk algorithm from the National Cardiovascular Data Registry. *Circ Cardiovasc Interv* 2009;2:222-9.
15. Brindis RG, Fitzgerald S, Anderson HV, Shaw RE, Weintraub WS, Williams JF. The American College of Cardiology-National Cardiovascular Data Registry (ACC-NCDR): building a national clinical data repository. *J Am Coll Cardiol* 2001;37:2240-5.
16. Sullivan L, Massaro J, D'Agostino R. Presentation of multivariate data for clinical use: the Framingham Study risk score functions. *StatMed* 2004;23:1631-60.
17. Stone GW, McLaurin BT, Cox DA, et al. Bivalirudin for patients with acute coronary syndromes. *N Engl J Med* 2006;355:2203-16.
18. Rao SV, O'Grady K, Pieper KS, et al. A comparison of the clinical impact of bleeding measured by two different classifications among patients with acute coronary syndromes. *J Am Coll Cardiol* 2006;47:809-16.
19. Mehran R, Rao SV, Bhatt DL, et al. Standardized bleeding definitions for cardiovascular clinical trials: a consensus report from the Bleeding Academic Research Consortium. *Circulation* 2011;123:2736-47.
20. Alexander KP, Chen AY, Newby LK, et al. Sex differences in major bleeding with glycoprotein IIb/IIIa inhibitors: results from the CRUSADE (Can Rapid risk stratification of Unstable angina patients Suppress ADverse outcomes with Early implementation of the ACC/AHA guidelines) initiative. *Circulation* 2006;114:1380-7.
21. 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;28:1193-204.
22. Rao SV, Jollis JG, Harrington RA, et al. Relationship of blood transfusion and clinical outcomes in patients with acute coronary syndromes. *JAMA* 2004;292:1555-62.
23. Alexander KP, Chen AY, Wang TY, et al. Transfusion practice and outcomes in non-ST-segment elevation acute coronary syndromes. *Am Heart J* 2008;155:1047-53.

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**Key Words:** bleeding complications ■ bleeding risk models ■ percutaneous coronary intervention ■ quality improvement.

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## APPENDIX

For supplemental material, please see the online version of this article.