ORIGINAL RESEARCH

Institutional Red Blood Cell Transfusion Rates Are Correlated Following Endovascular and Surgical Cardiovascular Procedures: Evidence That Local Culture Influences Transfusion Decisions

Eirini Apostolidou, MD, MSc; Dhaval Kolte, MD, PhD; Kevin F. Kennedy, MS; Charles E. Beale, MD; J. Dawn Abbott, MD; Afshin Ehsan, MD; Hitinder S. Gurm, MD; Jeffrey L. Carson, MD; Shafiq Mamdani, MD; Herbert D. Aronow, MD, MPH

BACKGROUND: The relationship between local hospital culture and transfusion rates following endovascular and surgical cardiovascular procedures has not been well studied.

METHODS AND RESULTS: Patients undergoing coronary revascularization, aortic valve replacement, lower extremity peripheral vascular intervention, or carotid artery revascularization from up to 852 US hospitals in the Nationwide Readmissions Database were identified. Crude and risk-standardized red blood cell transfusion rates were determined for each procedure. Pearson correlation coefficients were calculated between respective procedural transfusion rates. Median odds ratios were estimated to reflect between-hospital variability in red blood cell transfusion rates following the same procedure for a given patient. There was wide variation in red blood cell transfusion rates across different procedures, from 2% following carotid endarterectomy to 29% following surgical aortic valve replacement. For surgical and endovascular modalities, transfusion rates at the same hospital were highly correlated for aortic valve replacement ($r=0.67$; $P<0.001$), moderately correlated for coronary revascularization ($r=0.56$; $P<0.001$) and peripheral vascular intervention ($r=0.51$; $P<0.001$), and weakly correlated for carotid artery revascularization ($r=0.19$, $P<0.001$). Median odds ratios were all $>2$, highest for coronary artery bypass graft surgery and surgical aortic valve replacement, indicating substantial site variation in transfusion rates.

CONCLUSIONS: After adjustment for patient-related factors, wide variation in red blood cell transfusion rates remained across surgical and endovascular procedures employed for the same cardiovascular condition. Transfusion rates following these procedures are highly correlated at individual hospitals and vary widely across hospitals. In aggregate, these findings suggest that local institutional culture significantly influences the decision to transfuse following invasive cardiovascular procedures and highlight the need for randomized data to inform such decisions.

Key Words: blood transfusion ■ endovascular procedures ■ surgical procedures ■ variability
In the absence of robust randomized data to guide transfusion practices following most cardiovascular procedures,11–13 significant variability exists in RBC transfusion thresholds employed for various surgical and endovascular cardiovascular procedures.14–19 Prior data from statewide PCI and CABG registries indicate that RBC transfusion rates are correlated at an institutional level, suggesting that a local transfusion culture may exist.20 We sought to extend these observations to the larger US population and to include a broader array of endovascular and surgical cardiovascular procedures.

METHODS

Data Source
The Nationwide Readmissions Database (NRD) is a publicly available, all-payer database, developed by the Agency for Healthcare Research and Quality for the Healthcare Cost and Utilization Project (HCUP). The 2014 NRD contains data on 15 million discharges from 22 states representing ≈50% of the total US resident population and 50% of all US hospitalizations. The year 2014 was chosen as it is the final year during which International Classification of Disease, Ninth Edition (ICD-9) coding was used and where complete data are available. A single year was used because hospital identifications do not track across multiple years. The Agency for Healthcare Research and Quality uses numerous quality assurance procedures to ensure data quality for each data source participating in HCUP. The study was deemed exempt by the Lifespan–Rhode Island Hospital Institutional Review Board, as the NRD is a publicly available limited dataset.

Patient and Hospital Characteristics
Patient demographics (age, sex, primary expected payer, median household income) and comorbid conditions (hypertension, dyslipidemia, diabetes mellitus, smoking, obesity, heart failure, coronary artery disease, carotid artery disease, peripheral artery disease, prior transient ischemic attack/stroke, chronic kidney disease, chronic lung disease, liver disease, anemia, coagulopathy, cancer, and total number of Elixhauser comorbidities21) were extracted, as were index hospitalization length of stay, discharge disposition, and hospital characteristics (bed size, location, and teaching status). ICD-9-CM codes used to

Nonstandard Abbreviations and Acronyms

| Acronym | Description                                      |
|---------|--------------------------------------------------|
| CAS     | carotid artery stenting                          |
| CEA     | carotid endarterectomy                           |
| HCUP    | Healthcare Cost and Utilization Project          |
| MOR     | median odds ratio                                |
| NRD     | Nationwide Readmissions Database                 |
| PVI     | peripheral vascular intervention                 |
| SAVR    | surgical aortic valve replacement                |
| TAVR    | transcatheter aortic valve replacement            |

deformability of stored RBCs, prothrombotic effects of released procoagulant factors and transfusion-associated immunosuppression.2

CLINICAL PERSPECTIVE

What Is New?
• Red blood cell transfusion rates vary significantly across surgical and endovascular procedures employed for treatment of the same disease state.
• Postprocedure red blood cell transfusion rates are significantly correlated following surgical and endovascular cardiovascular procedures at any given hospital.

What Are the Clinical Implications?
• Local institutional culture appears to strongly influence the decision for transfusion following invasive cardiovascular procedures.
• In the future, blood management programs may focus on improving institutional practice to optimize blood transfusion administration after cardiovascular procedures.

Nonstandard Abbreviations and Acronyms

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|---------|--------------------------------------------------|
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| CEA     | carotid endarterectomy                           |
| HCUP    | Healthcare Cost and Utilization Project          |
| MOR     | median odds ratio                                |
| NRD     | Nationwide Readmissions Database                 |
| PVI     | peripheral vascular intervention                 |
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| TAVR    | transcatheter aortic valve replacement            |

International Classification of Disease, Ninth Edition, Clinical Modification (ICD-9-CM) diagnosis and procedure codes (Tables S1 and S2) were used to identify all hospitalizations during which coronary revascularization, aortic valve replacement for any aortic valve pathology, lower extremity peripheral vascular intervention (PVI) or carotid revascularization was performed. Complementary endovascular and surgical procedure pairs were constructed as follows: (1) PCI—CABG; (2) TAVR—surgical aortic valve replacement (SAVR); (3) lower extremity endovascular—surgical PVI; and (4) carotid artery stenting (CAS)—carotid endarterectomy (CEA). Hospitals were included if at least 5 of each procedure in a complementary pair were performed. The minimum required volume for each procedure was set at this level to ensure adequate volume for statistical analysis. Patients <18 years of age, those who underwent hybrid (endovascular and surgical) peripheral revascularization procedures, or those who underwent >1 of the above procedures during the same hospitalization were excluded (Figure 1).
define comorbidities appear in Table S2. All comorbidity measures were assumed to be present before the hospital stay.

Outcomes
The primary outcome of interest was RBC transfusion during the index hospitalization.

Statistical Analysis
Unweighted data were used for all analyses. Continuous variables appear as mean± SD or median with interquartile range; and are compared with Student t or Wilcoxon rank sum tests, as appropriate. Categorical data appear as frequencies and percentages and are compared with chi-square or Fisher's exact tests, as appropriate.

Both crude and risk-standardized RBC transfusion rates were calculated for endovascular and surgical procedures at each hospital. Variables that were plausibly related to the outcome of interest were included in risk-standardized models and their source appears in Table S3. The statistical methodology used to calculate risk-standardized transfusion rates is identical to that employed by the Centers for Medicare and Medicaid Services for calculating risk-standardized readmission rates. Specifically, we calculated risk-standardized hospital-specific transfusion rates using hierarchical generalized logistic regression models with site entered as a random effect. These rates were computed as the ratio of the predicted transfusions to expected transfusions multiplied by the registry unadjusted transfusion rate. The predicted number of transfusions was calculated using the hospital's own case mix and specific intercept, whereas the expected number of transfusions was estimated using the average hospital intercept of all sites in the registry. The publicly available SAS package (SAS Institute, Cary, NC) was used to construct a hierarchical logistic regression model using proc Glimmix with the fixed effects described above and a random hospital-specific intercept. Discrimination for each procedural transfusion model was calculated using the C-statistic.

Pearson correlation coefficients were calculated between site-level crude and risk-standardized RBC transfusion rates for PCI and CAGB, TAVR and SAVR, endovascular and surgical PVI, and CAS and CEA. Similarly, correlation coefficients were calculated between crude and risk-standardized RBC transfusion rates for any endovascular and any surgical procedure. To account for the possibility that some operators at the same hospital might perform both procedures within a given procedure pair, which could increase the correlation between observed RBC transfusion rates, a sensitivity analysis examining the correlation between transfusion rates for all studied procedures, was conducted. Separate sensitivity analyses were also performed, where: a) the minimum required volume was set to 20 procedures; b) patients who underwent the same procedure more than once during the study period were excluded; c) only postprocedure transfusions were included; and, d) where transfusion of any blood product was

Figure 1. Study flowchart.
CAGB indicates coronary artery bypass grafting; PCI, percutaneous coronary intervention; SAVR, surgical aortic valve replacement; and TAVR, transcatheter aortic valve replacement.
included (ICD-9 codes used for respective blood products appear in Table S4).

To quantify the amount of site variability in transfusion rates for each procedure, we calculated median odds ratios (MORs) for each procedure pair. The MOR is interpreted as the odds that the same patient undergoing the same procedure would be transfused at one versus another randomly selected hospital; risk-adjusted transfusion rates were used for MOR calculations. To determine whether the observed variability, as reflected by the MOR, was influenced by patient- or hospital-level characteristics, statistical models were also generated where age and sex, HCUP comorbidity variables and major bleeding were sequentially added. All statistical analyses were performed with SAS 9.4 (SAS Institute). The level of statistical significance was set at a 2-sided \( P<0.05 \).

**RESULTS**

Hospitals and Patients

We identified 852 US hospitals that performed the endovascular and surgical procedures of interest (Table 1). Coronary revascularization, peripheral vascular revascularization, aortic valve replacement, and carotid artery revascularization were performed in 527, 824, 166, and 331 hospitals, respectively. Approximately half of the hospitals were large, and one third were medium size; most were urban teaching hospitals.

Patients’ characteristics by transfusion status in the overall population and separately by cardiovascular procedure type are shown in Tables S5 and S6, respectively. Patients who were transfused had a longer length of stay compared with those who were not (12.4 versus 5.7 days; \( P<0.001 \)) and a greater number of chronic conditions, including underlying anemia (37.4% versus 14.4%; \( P<0.001 \)), chronic heart failure (6.8% versus 3.1%; \( P<0.001 \)), coagulopathy (22.4% versus 7%; \( P<0.001 \)) and renal failure (36% versus 18.9%; \( P<0.001 \)).

Transfusion Rates

The overall crude RBC transfusion rates for endovascular and surgical procedures were 5.9% and 19.4%, respectively (\( P<0.001 \)). There was wide variation in blood product transfusion rates across different procedures. The crude rates of RBC transfusion following TAVR (n=1521), SAVR (n=3983), PCI (n=5020), CABG (n=16 944), endovascular PVI (n=7564), surgical PVI (n=8160), CAS (n=227), and CEA (n=444) were 18.3%, 27%, 2.9%, 22%, 14.1%, 21.3%, 3.5%, and 2%, respectively. Median (IQR) risk-standardized transfusion rates for the same procedures were 20.5% (10.2%–30.7%), 34.2% (15.7%–46.7%), 3.4% (1.8%–4.8%), 29.1% (12.9%–40.5%), 15.4% (10.1%–20.7%), 23.2% (14.8%–31.6%), 2.5% (2.2%–5.4%), and 1.6% (1%–3.5%), respectively. Most transfusions occurred postprocedure (TAVR, 96%; SAVR, 94.7%; PCI, 82%; CABG, 95%; endovascular PVI, 83.9%; surgical PVI, 94%; CAS, 93.4%; and, CEA, 91.2%).

Cross-Procedure Transfusion Correlations

The correlation between risk-standardized transfusion rates was strongest for the SAVR-TAVR (\( r=0.67; P<0.001 \)), intermediate for the CABG-PCI (\( r=0.56; P<0.001 \)) and surgical-endovascular PVI (\( r=0.51; P<0.001 \)) and weaker for the CEA-CAS procedure pairs (\( r=0.19; P<0.001 \)) (Figure 2). The correlation for risk-standardized RBC transfusion rates for all endovascular and surgical procedures was 0.5 (\( P<0.001 \)). Risk-standardized transfusion rates for unpaired procedures were also significantly correlated, suggesting that paired-procedure correlations could not have solely resulted from operators performing

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both procedures in a given pair (data not shown). In separate sensitivity analyses, where the minimum required procedural volume for a given procedure pair was set to 20 (Table S7), patients who underwent the same procedure more than once during 2014 (11.8% of the study population) were excluded (Table S8); only postprocedure transfusions were included (Table S9); and where all blood product transfusions were included in the primary outcome (Table S10), cross-procedure correlations were not materially changed.

**Hospital-Level Variation in Transfusion**

The distribution of risk-standardized transfusion rates at the hospital level, ranked from lowest to highest, is shown for each procedure in Figure 3. Median odds ratios (MORs) were calculated for RBC transfusion...
Apostolidou et al Transfusion Practices in Cardiovascular Procedures following each procedure and appear in Table 2. MORs were all >2, indicating substantial site variation in transfusion rates. MORs were highest for CABG and SAVR, each of which were >3.5, indicating that if the same patient underwent the same procedure at 2 different randomly selected hospitals, the odds of transfusion would be almost 4 times greater at one hospital than at the other. After adding age and sex, HCUP comorbidity variables, and major bleeding, MORs in the endovascular (unadjusted, 2.83 [2.65–3.00], 2.76 [2.60–2.94], 2.64 [2.49–2.80], and 2.97 [2.77–3.16], respectively) and surgical (unadjusted, 3.24 [3.03–3.46], 3.30 [3.09–3.52], 3.25 [3.04–3.47], and 3.54 [3.29–3.78], respectively) cohorts were not significantly altered.

Figure 3. A distribution of risk standardized transfusion rates at the hospital level for all endovascular and surgical procedures, ranked from lowest to highest for each procedure. CABG indicates coronary artery bypass grafting; CAS, carotid artery stent; CEA, carotid endarterectomy; PCI, percutaneous coronary intervention; PVI, peripheral vascular intervention; SAVR, surgical aortic valve replacement; and TAVR, transcatheter aortic valve replacement.
Table 2. Risk-Adjusted MORs for RBC Transfusion Following Endovascular and Surgical Procedures

| Procedure                | MOR (95% CI) |
|--------------------------|--------------|
| TAVR                     | 3.16 (2.63–3.72) |
| SAVR                     | 3.68 (3.09–4.30) |
| PCI                      | 2.88 (2.65–3.11) |
| CABG                     | 4.44 (3.99–4.90) |
| CAS                      | 3.64 (2.99–4.33) |
| CEA                      | 3.20 (2.75–3.67) |
| Endovascular PVI         | 2.51 (2.35–2.67) |
| Surgical PVI             | 2.88 (2.68–3.08) |

CABG indicates coronary artery bypass grafting; CAS, carotid artery stent; CEA, carotid endarterectomy; MOR, median odds ratio; PCI, percutaneous coronary intervention; PVI, peripheral vascular intervention; RBC, red blood cell; SAVR, surgical aortic valve replacement; and TAVR, transcatheter aortic valve replacement.

DISCUSSION

In a large, nationally representative study of hospitalizations for coronary revascularization, aortic valve replacement, lower extremity PVI, or carotid revascularization procedures in the United States, we observed the following: (1) There was wide hospital-level variation in RBC transfusion rates across different cardiovascular procedures; (2) at any given hospital, postprocedure RBC transfusion rates were highly correlated for SAVR and TAVR, and moderately correlated for PCI and CABG, surgical and endovascular PVI, and for any surgical and any endovascular procedure; (3) for each procedure studied, there was substantial variation in the associated RBC transfusion rate across hospitals such that the same patient was >2 to 4 times more likely to receive a transfusion at one randomly selected hospital than at another. To our knowledge, this study is the first to relate RBC transfusion rates following a variety of surgical and endovascular cardiovascular procedures to the hospitals at which care was rendered.

Significant variability exists in RBC transfusion thresholds following different cardiovascular procedures, and the likelihood of transfusion may be influenced by patient- and provider-level factors. At the patient level, preprocedure anemia, procedure-related hemodilution, blood loss following cardiopulmonary bypass, and vascular access site complications are common indications for transfusion. That RBC transfusions are administered more commonly following surgical than endovascular cardiac procedures has been observed in prior studies and is not surprising. This observation may be explained by the fact that endovascular procedures are associated with less blood loss, hemodilution, and volume shifts than surgical procedures.

The relatively high transfusion rates observed for some procedures deserves comment. Transfusion rates have fallen over time for some procedures, such as TAVR, and may not be as high today as they were in 2014. Also, global transfusion rates for a given procedure may not reflect the likelihood of transfusion for all patients undergoing these procedures. For example, one would expect the overall risk-standardized RBC transfusion rate for endovascular PVI to be higher in those with critical limb ischemia than in those with claudication.

In the present study, we demonstrated that RBC transfusion rates within assigned procedure pairs were highly correlated at individual hospitals. In fact, based on the associated $R^2$ values, approximately one third to one half of the variation in a hospital’s RBC transfusion rate following CABG or SAVR can be explained by its rate in PCI or TAVR, respectively. Though still statistically significant, the correlations between a hospital’s RBC transfusion rate for surgical and endovascular PVI and for CEA and CAS were weaker compared with those observed for other complementary procedures. The close cooperation of cardiac surgery and interventional cardiology through Heart Team participation may contribute to some of this observed concordance; similarly, the rarity of multidisciplinary vascular teams may in part explain the weaker correlation between surgical PVI and endovascular PVI and between CEA and CAS, where physician operators may not be collaborating as closely.

Substantial variability in transfusion practices at the hospital level has been reported previously among patients undergoing CABG and PCI. A study from 33 Michigan centers found that local hospital practice patterns influenced the likelihood of transfusion; centers that transfused patients more often following CABG were also more likely to transfuse patients after PCI. In our study, we observed similar wide variability in hospital-level transfusion practices for coronary revascularization procedures and extended these observations to all other surgical and endovascular procedures studied, including aortic valve replacement, lower extremity PVI, and carotid revascularization procedures.

For each procedure studied, on the basis of the observed MORs, we found that the same patient following the same procedure was ~2 to 3 times more likely to receive a transfusion at one hospital than at another following PCI, CAS, CEA, surgical PVI, or endovascular PVI. For patients undergoing CABG or SAVR, the likelihood of receiving a transfusion was ~4 times higher at one randomly selected hospital than at another. When age and sex, HCUP comorbidity variables, and major bleeding were added in a sequential fashion to MOR models, results were not materially different in the endovascular or surgical cohorts, suggesting that patient-level factors were not likely responsible for the observed hospital-level...
difference in transfusion rates. Together, these observations suggest that institutional culture strongly influences the decision to transfuse following invasive cardiovascular procedures.

There are noteworthy limitations to our study. First, it is retrospective and observational in design, and despite adjustments for patient characteristics, the potential for unmeasured confounding and bias remains. We acknowledge that additional factors, not addressed in the current manuscript, may contribute to transfusion requirements after a cardiovascular procedure, including the technical approach (eg, radial versus femoral PCI or PVI; minimally invasive versus open surgery) and frequency of postprocedure hemoglobin measurements. Second, the NRD does not capture laboratory (eg, hemoglobin) data, procedural detail (eg, blood loss, number of transfusions administered) or medications (eg, antiplatelet or anticoagulant agents); we attempted to account for the absence of preprocedure hemoglobin, by adjusting for preprocedural anemia and comorbidities. Because the NRD is an administrative claims data set, some ICD-9-CM codes that were used to define diagnoses, procedures, and in-hospital outcomes may not be attributable to the index hospitalization but may instead be historical in nature. Notwithstanding this limitation, many prior studies employing the NRD have used a similar approach.\textsuperscript{30,31} While variability was observed across hospitals, this analysis should not inform decisions about whether blood transfusion is beneficial or harmful following cardiovascular procedures; ongoing randomized studies such as MINT (Myocardial Ischemia and Transfusion; ClinicalTrials.gov identifier: NCT02981407) may help do so. Finally, some of the procedures studied may be performed in the outpatient setting (eg, PCI, endovascular PVI), especially in healthier patients; consequently, the denominator for these procedures may be larger than estimated in our study and the corresponding transfusion rates overestimated.

**CONCLUSIONS**

RBC transfusion rates vary significantly across surgical and endovascular procedures employed for treatment of the same disease state. Postprocedure RBC transfusion rates are significantly correlated following surgical and endovascular procedures at any given hospital and vary widely across hospitals for the same procedure. Our findings suggest that local institutional culture weighs heavily on the decision to transfuse patients following invasive cardiovascular procedures.

**ARTICLE INFORMATION**

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SUPPLEMENTAL MATERIAL
Table S1: ICD-9 Codes for Cardiovascular Procedures

| Cardiovascular Procedure | ICD-9 Code          |
|--------------------------|---------------------|
| TAVR                     | 3505, 3506          |
| SAVR                     | 3521, 3522          |
| PCI                      | 3600, 3606, 3607, 3609, 0066 |
| CABG                     | 3610, 3611, 3612, 3613, 3614, 3615, 3616, 3619 |
| CAS                      | 0061, 0063, 0064    |
| CEA                      | 3812                |
| Endovascular PVI         | 0055, 0060, 3950, 3990 |
| Surgical PVI             | 3808, 3818, 3838, 3848, 3868, 3888, 3925, 3929 |

Abbreviations for Table S1: TAVR: Transcatheter Aortic Valve Replacement, SAVR: Surgical Aortic Valve Replacement, PCI: Percutaneous Coronary Intervention, CABG: Coronary Artery Bypass Grafting, CAS: Carotid Artery Stent, CEA: Carotid Endarterectomy, PVI: Peripheral Vascular Intervention
### Table S2: ICD-9 Codes for Cardiovascular Diagnoses and Cardiovascular Complications

| Cardiovascular Diagnosis                  | ICD-9 Code                                                                 |
|------------------------------------------|---------------------------------------------------------------------------|
| Aortic Valve Disease                     | 3950, 3951, 3952, 3959, 4241                                              |
| Hypertension                             | 40519, 40591, 40599                                                      |
| Old Myocardial Infarction                | 412                                                                       |
| Coronary artery disease                  | 41400-41407, 4142-4144, 4148, 4149                                        |
| Atrial Fibrillation                      | 42731                                                                    |
| Chronic Heart Failure                    | 4280, 4281, 42820, 42822, 42830, 42832, 42840, 42842                    |
| Transient Ischemic Attack                | 4358, 4359                                                               |
| Stroke (Intracranial Bleed)              | 430, 431, 4320, 4321, 4329                                               |
| Stroke (Ischemia/ Thrombosis)            | 43301, 43311, 43321, 43331, 43381, 43391, 43401, 43411, 43491, 4350, 4351, 4353, 436, 4370, 4371, 4378, 43794380 |
| Peripheral Arterial Disease             | 4400, 4401, 4404, 4408, 4409, 44020-44024, 44029-44032, 43300, 43310, 43320, 43330, 43380, 43390 |
| Intracranial Hemorrhage                  | 430, 431, 432.x                                                         |
| Intraocular hemorrhage                   | 362.43, 362.81, 363.61, 363.62, 363.72, 364.41, 376.32, 377.42, 379.23  |
| Hemopericardium                          | 423.0                                                                    |
| Contusion of Extremity/ Abdomen          | 923.xx, 924.xx, 922.2, 922.31-33, 922.8, 922.9                             |
| Gastrointestinal Hemorrhage             | 456.0, 456.20, 530.7, 530.82, 531.00, 531.01, 531.20, 531.21, 531.40, 531.41, 531.60, 531.61, 532.00, 532.01, 532.20, 532.21, 532.40, 532.41, 532.60, 532.61, 533.00, 533.01, 533.20, 533.21, 533.40, 533.41, 533.60, 533.61, 534.00, 534.01, 534.20, 534.21, 534.40, 534.41, 534.60, 534.61, 569.3, 578.0, 578.1, 578.9 |
| Hemorrhage Unspecified                   | 459.0                                                                    |
| Hemarthrosis                             | 719.1                                                                    |
| Hemoperitoneum                           | 568.81                                                                   |
| Hematuria                                | 599.70, 599.71                                                          |
| Epistaxis                                | 784.7                                                                    |
| Transfusion of red blood cell (RBC)      | 9904                                                                     |
Table S3: Variables included in the risk-adjusted models

| Variable                                    | Definition                        |
|---------------------------------------------|-----------------------------------|
| Age                                         |                                   |
| Sex                                         |                                   |
| Primary Payer                               |                                   |
| Heart Failure (HF)                          | HCUP Defined comorbidity          |
| Chronic Pulmonary disease                   | HCUP Defined comorbidity          |
| Liver disease                               | HCUP Defined comorbidity          |
| Hypertension                                | HCUP Defined comorbidity          |
| Diabetes Mellitus (uncomplicated)           | HCUP Defined comorbidity          |
| Diabetes Mellitus (with chronic complications) | HCUP Defined comorbidity      |
| Peripheral Arterial Disease                 | HCUP Defined comorbidity          |
| Valvular Disease                            | HCUP Defined comorbidity          |
| Renal Failure                               | HCUP Defined comorbidity          |
| Other neurologic disorders                  | HCUP Defined comorbidity          |
| Paralysis                                   | HCUP Defined comorbidity          |
| Metastatic Cancer                           | HCUP Defined comorbidity          |
| Lymphoma                                    | HCUP Defined comorbidity          |
| Fluid and electrolyte disturbances          | HCUP Defined comorbidity          |
| Hypothyroidism                              | HCUP Defined comorbidity          |
| Obesity                                     | HCUP Defined comorbidity          |
| Pulmonary Circulation Disorders              | HCUP Defined comorbidity          |
| Alcohol use                                 | HCUP Defined comorbidity          |
| Drug abuse                                  | HCUP Defined comorbidity          |
| Immunodeficiency/ AIDS                      | HCUP Defined comorbidity          |
| Deficiency anemias                          | HCUP Defined comorbidity          |
| Chronic blood loss                          | HCUP Defined comorbidity          |
| Coagulopathy                                | HCUP Defined comorbidity          |
| Diagnosis                  | ICD-10 Code(s)                                                                 |
|---------------------------|------------------------------------------------------------------------------|
| Peptic ulcer disease      | HCUP Defined comorbidity                                                      |
| Depression                | HCUP Defined comorbidity                                                      |
| Psychoses                 | HCUP Defined comorbidity                                                      |
| Dypsnea                   | 786.0                                                                        |
| Stable Angina             | 413.9                                                                        |
| Unstable Angina           | 411.1                                                                        |
| CAD                       | 414.00                                                                       |
| CIHD                      | 414.9                                                                        |
| AMI                       | 410.x                                                                        |
| Acute HF                  | 428.21, 428.31                                                               |
| Chronic HF                | 428.22, 428.32                                                               |
| Major Bleeding            | 430, 431, 432.0, 432.1, 432.9, 336, 362.43, 362.81, 363.61, 363.62, 363.72, 364.41, 377.42, 379.23, 423.0, 729.71, 729.72, 729.73, 456.0, 456.20, 530.7, 530.82, 531.00, 531.01, 531.20, 531.21, 531.40, 531.41, 531.60, 531.61, 532.00, 532.01, 532.20, 532.21, 532.40, 532.41, 532.60, 532.61, 533.00, 533.01, 533.20, 533.21, 533.40, 533.41, 533.60, 533.61, 534.00, 534.01, 534.20, 534.21, 534.40, 534.41, 534.60, 534.61, 569.3, 578.0, 578.1, 578.9, 568.81, 599.70, 599.71, 784.7, 784.8, 459, 998.11, 998.12, 285.1, 998.00, 998.09, 785.50, 785.59, 276.52 |

Abbreviations for Table S3: AIDS: Acquired Immune Deficiency Syndrome, CAD: Coronary Artery Disease, CIHD: Chronic Ischemic Heart Disease, AMI: Acute Myocardial Infarction, HF: Heart Failure
Table S4: ICD-9 Codes for other blood products

| Blood Product         | ICD-9 Code |
|-----------------------|------------|
| Whole Blood           | 9903       |
| Platelets             | 9905       |
| Coagulation factors   | 9906       |
| Serum                 | 9907       |
| Blood Expander        | 9908       |
| Other substance       | 9909       |
Table S5: Patients’ Characteristics by Transfusion Status

|                                      | Total n = 394525 | Transfusion n = 43863 | No transfusion n = 350662 | p-value |
|--------------------------------------|------------------|-----------------------|---------------------------|---------|
| **Age in years at admission**        |                  |                       |                           |         |
| Mean ± SD                            | 66.19 ± 12.48    | 68.71 ± 12.35         | 65.88 ± 12.46             | <0.001  |
| Median (IQR)                         | 67.00 (58.00, 75.00) | 70.00 (61.00, 78.00)  | 66.00 (58.00, 75.00)      |         |
| **Disposition of patient (uniform)** |                  |                       |                           |         |
| 1: Routine                           | 259532 (65.8%)   | 13850 (31.6%)         | 245682 (70.1%)            |         |
| 2: Transfer to short term Hospital   | 2191 (0.6%)      | 516 (1.2%)            | 1675 (0.5%)               | <0.001  |
| 5: Transfer to other: SNF            | 47570 (12.1%)    | 12515 (28.5%)         | 35055 (10.0%)             |         |
| 6: HHC                               | 73785 (18.7%)    | 14428 (32.9%)         | 59357 (16.9%)             |         |
| 7: AMA                               | 1475 (0.4%)      | 108 (0.2%)            | 1367 (0.4%)               |         |
| 20: Died                             | 9745 (2.5%)      | 2403 (5.5%)           | 7342 (2.1%)               |         |
| 99: Unknown                          | 85 (0.0%)        | 26 (0.1%)             | 59 (0.0%)                 |         |
| **Primary expected payer (uniform)** |                  |                       |                           | <0.001  |
| 1: Medicare                          | 235358 (59.7%)   | 30561 (69.7%)         | 204797 (58.5%)            |         |
| 2: Medicaid                          | 34032 (8.6%)     | 3786 (8.6%)           | 30246 (8.6%)              |         |
| 3: Private Insurance                 | 98887 (25.1%)    | 7666 (17.5%)          | 91221 (26.1%)             |         |
| 4: Self Pay                          | 13159 (3.3%)     | 846 (1.9%)            | 12313 (3.5%)              |         |
| 5: No charge                         | 2244 (0.6%)      | 125 (0.3%)            | 2119 (0.6%)               |         |
| 6: Other                             | 10279 (2.6%)     | 843 (1.9%)            | 9436 (2.7%)               |         |
| **Female**                           | 135003 (34.2%)   | 19377 (44.2%)         | 115626 (33.0%)            | <0.001  |
|                            | Total n = 394525 | Transfusion n=43863 | No transfusion n = 350662 | p-value |
|---------------------------|-----------------|---------------------|---------------------------|---------|
| **Length of stay (cleaned)** |                 |                     |                           |         |
| Mean ± SD                 | 6.48 ± 8.51     | 12.74 ± 11.91       | 5.69 ± 7.63               | <0.001  |
| Median (IQR)              | 4.00 (2.00, 8.00) | 9.00 (6.00, 15.00)  | 4.00 (2.00, 7.00)         |         |
| **Number of chronic conditions** |           |                     |                           |         |
| Mean ± SD                 | 7.28 ± 3.11     | 8.90 ± 3.35         | 7.07 ± 3.02               | <0.001  |
| Median (IQR)              | 7.00 (5.00, 9.00)| 9.00 (6.00, 11.00)  | 7.00 (5.00, 9.00)         |         |
| **Acquired immune deficiency syndrome** |     |                     |                           | <0.001  |
|                           | 588 (0.1%)      | 98 (0.2%)           | 490 (0.1%)                |         |
| **Alcohol abuse**         | 12336 (3.1%)    | 1588 (3.6%)         | 10748 (3.1%)              | <0.001  |
| **Deficiency anemias**    | 67058 (17.0%)   | 16398 (37.4%)       | 50660 (14.4%)             | <0.001  |
| **Rheumatoid arthritis/collagen vascular diseases** | 9965 (2.5%) | 1459 (3.3%) | 8506 (2.4%) | <0.001 |
| **Chronic blood loss anemia** | 3242 (0.8%) | 1400 (3.2%) | 1842 (0.5%) | <0.001 |
| **Congestive heart failure** | 13738 (3.5%) | 2987 (6.8%) | 10751 (3.1%) | <0.001 |
| **Chronic pulmonary disease** | 81925 (20.8%) | 11202 (25.5%) | 70723 (20.2%) | <0.001 |
| **Coagulopathy**          | 34377 (8.7%)    | 9822 (22.4%)        | 24555 (7.0%)              | <0.001  |
| **Depression**            | 30902 (7.8%)    | 3968 (9.0%)         | 26934 (7.7%)              | <0.001  |
| **Diabetes, uncomplicated** | 118109 (29.9%) | 12468 (28.4%)       | 105641 (30.1%)            | <0.001  |
| **Diabetes with chronic complications** | 40011 (10.1%) | 7434 (16.9%) | 32577 (9.3%) | <0.001 |
| **Drug abuse**            | 9043 (2.3%)     | 1078 (2.5%)         | 7965 (2.3%)               | 0.014   |
| **Hypertension (combine uncomplicated and complicated)** | 303544 (76.9%) | 34670 (79.0%) | 268874 (76.7%) | <0.001 |
| Condition                                      | Total (n = 394525) | Transfusion (n = 43863) | No transfusion (n = 350662) | p-value |
|-----------------------------------------------|--------------------|-------------------------|-----------------------------|---------|
| Hypothyroidism                                | 41629 (10.6%)      | 5825 (13.3%)            | 35804 (10.2%)               | <0.001  |
| Liver disease                                 | 7766 (2.0%)        | 1446 (3.3%)             | 6320 (1.8%)                 | <0.001  |
| Lymphoma                                      | 2200 (0.6%)        | 425 (1.0%)              | 1775 (0.5%)                 | <0.001  |
| Fluid and electrolyte disorders               | 89918 (22.8%)      | 19482 (44.4%)           | 70436 (20.1%)               | <0.001  |
| Metastatic cancer                             | 2301 (0.6%)        | 490 (1.1%)              | 1820 (0.5%)                 | <0.001  |
| Other neurological disorders                  | 17295 (4.4%)       | 2825 (6.4%)             | 14470 (4.1%)                | <0.001  |
| Obesity                                       | 68524 (17.4%)      | 7478 (17.0%)            | 61046 (17.4%)               | 0.060   |
| Paralysis                                     | 6451 (1.6%)        | 1351 (3.1%)             | 5100 (1.5%)                 | <0.001  |
| Peripheral vascular disorders                 | 92381 (23.4%)      | 15183 (34.6%)           | 77198 (22.0%)               | <0.001  |
| Psychoses                                     | 9303 (2.4%)        | 1496 (3.4%)             | 7807 (2.2%)                 | <0.001  |
| Pulmonary circulation disorders               | 3428 (0.9%)        | 835 (1.9%)              | 2593 (0.7%)                 | <0.001  |
| Renal failure                                 | 81913 (20.8%)      | 15788 (36.0%)           | 66125 (18.9%)               | <0.001  |
| Solid tumor without metastasis                | 5603 (1.3%)        | 889 (2.0%)              | 4174 (1.2%)                 | <0.001  |
| Peptic ulcer disease excluding bleeding        | 105 (0.0%)         | 21 (0.0%)               | 84 (0.0%)                   | 0.003   |
| Valvular disease                              | 6020 (1.5%)        | 1177 (2.7%)             | 4843 (1.4%)                 | <0.001  |
| Acute Heart Failure                           | 11960 (3.0%)       | 1668 (3.8%)             | 10292 (2.9%)                | <0.001  |
| Unstable Angina                               | 49301 (12.5%)      | 3826 (8.7%)             | 45475 (13.0%)               | <0.001  |
| Acute Myocardial Infarction                   | 140049 (35.5%)     | 10375 (23.7%)           | 129674 (37.0%)              | <0.001  |
| Weight loss                                   | 13046 (3.3%)       | 3866 (8.8%)             | 9180 (2.6%)                 | <0.01   |
Table S6: Patient’s characteristics by procedure type

| Procedure | TAVR \(n = 8327\) | SAVR \(n = 14743\) | PCI \(n = 173762\) | CABG \(n = 76874\) | Endo PVI \(n = 53724\) | Surgical PVI \(n = 38237\) | CAS \(n = 6462\) | CEA \(n = 22396\) |
|-----------|----------------------|----------------------|---------------------|---------------------|-----------------------|------------------------|-----------------|-----------------|
| **Age in years at admission** | | | | | | | | |
| Mean ± SD | 81.22 ± 8.30 | 65.80 ± 13.77 | 65.07 ± 12.47 | 65.55 ± 10.35 | 65.79 ± 14.41 | 66.75 ± 12.76 | 68.85 ± 11.35 | 71.02 ± 9.17 |
| Median (IQR) | 83.00 (77.00, 87.00) | 68.00 (58.00, 76.00) | 65.00 (56.00, 74.00) | 66.00 (59.00, 73.00) | 67.00 (57.00, 76.00) | 67.00 (59.00, 76.00) | 70.00 (62.00, 77.00) | 71.00 (65.00, 78.00) |
| **Disposition of patient (uniform)** | | | | | | | | |
| 1: Routine | 2968 (35.6%) | 5272 (35.8%) | 145941 (84.0%) | 32130 (41.8%) | 29442 (54.8%) | 19375 (50.7%) | 5069 (78.5%) | 19335 (86.3%) |
| 2: Transfer to short term Hospital | 82 (1.0%) | 154 (1.0%) | 719 (0.4%) | 474 (0.6%) | 382 (0.7%) | 314 (0.8%) | 40 (0.6%) | 26 (0.1%) |
| 5: Transfer to other: SNF | 1999 (24.0%) | 2641 (17.9%) | 8609 (5.0%) | 13149 (7.6%) | 12970 (16.9%) | 8114 (21.2%) | 680 (10.5%) | 1068 (4.8%) |
| 6: HHC | 3019 (36.3%) | 6268 (42.5%) | 12970 (16.9%) | 29693 (38.6%) | 10488 (19.5%) | 8766 (22.9%) | 541 (8.4%) | 1861 (8.3%) |
| 7: AMA | “<=10” (0.0%) | 379 (2.6%) | “<=10” (0.0%) | “<=10” (0.0%) | “<=10” (0.0%) | “<=10” (0.0%) | 12 (0.2%) | 23 (0.1%) |
| 20: Died | 254 (3.1%) | “<=10” (0.0%) | “<=10” (0.0%) | “<=10” (0.0%) | “<=10” (0.0%) | “<=10” (0.0%) | 116 (1.8%) | 79 (0.4%) |
| 99: Unknown | “<=10” (0.0%) | “<=10” (0.0%) | “<=10” (0.0%) | “<=10” (0.0%) | “<=10” (0.0%) | “<=10” (0.0%) | “<=10” (0.0%) | “<=10” (0.0%) |
|                      | TAVR  
|----------------------|------|
|                      | n = 8327  |
| Primary expected payer (uniform) |     |
| 1: Medicare          | 7606 (91.4%) |
| 2: Medicaid          | 83 (1.0%)   |
| 3: Private Insurance | 483 (5.8%)  |
| 4: Self Pay          | 33 (0.4%)   |
| 5: No charge         | “<=10”(0.0%) |
| 6: Other             | 115 (1.4%)  |
| Male                 | 877 (54.7%) |
| Female               | 3773 (45.3%)|
| Length of stay (cleaned) |     |
| Mean ± SD            | 7.71 ± 7.88 |
| Median (IQR)         | 5.00 (3.00, 9.00) |
| Number of chronic conditions |     |
| Mean ± SD            | 9.60 ± 3.12 |
| Median (IQR)         | 9.00 (7.00, 12.00) |
| RBC Transfusion      | 1521 (18.3%) |
|                      |     |
|                      | SAVR  
|                      | n = 14743  |
| Primary expected payer (uniform) |     |
| 1: Medicare          | 8654 (58.8%) |
| 2: Medicaid          | 962 (6.5%)   |
| 3: Private Insurance | 4530 (30.8%) |
| 4: Self Pay          | 240 (1.6%)   |
| 5: No charge         | 35 (0.2%)    |
| 6: Other             | 308 (2.1%)   |
| Male                 | 8397 (56.5%) |
| Female               | 5629 (38.2%)|
| Length of stay (cleaned) |     |
| Mean ± SD            | 10.54 ± 10.63 |
| Median (IQR)         | 7.00 (5.00, 12.00) |
| Number of chronic conditions |     |
| Mean ± SD            | 7.93 ± 3.12 |
| Median (IQR)         | 8.00 (6.00, 10.00) |
| RBC Transfusion      | 3983 (27.0%) |
|                      |     |
|                      | PCI  
|                      | n = 17362  |
| Primary expected payer (uniform) |     |
| 1: Medicare          | 93071 (53.6%) |
| 2: Medicaid          | 16357 (9.4%)  |
| 3: Private Insurance | 49257 (28.4%) |
| 4: Self Pay          | 439 (0.6%)   |
| 5: No charge         | 5266 (3.0%)  |
| 6: Other             | 35 (0.2%)    |
| Male                 | 15328 (88.7%)|
| Female               | 56215 (32.4%)|
| Length of stay (cleaned) |     |
| Mean ± SD            | 3.94 ± 5.31 |
| Median (IQR)         | 3.00 (2.00, 4.00) |
| Number of chronic conditions |     |
| Mean ± SD            | 6.91 ± 2.91 |
| Median (IQR)         | 7.00 (5.00, 9.00) |
| RBC Transfusion      | 5020 (2.9%)  |
|                      |     |
|                      | CABG  
|                      | n = 76874  |
| Primary expected payer (uniform) |     |
| 1: Medicare          | 42320 (55.2%) |
| 2: Medicaid          | 6153 (8.0%)   |
| 3: Private Insurance | 23374 (30.5%) |
| 4: Self Pay          | 2301 (3.0%)   |
| 5: No charge         | 439 (0.6%)    |
| 6: Other             | 2122 (2.8%)   |
| Male                 | 19425 (25.3%)|
| Female               | 19425 (25.3%)|
| Length of stay (cleaned) |     |
| Mean ± SD            | 10.03 ± 7.86 |
| Median (IQR)         | 8.00 (6.00, 12.00) |
| Number of chronic conditions |     |
| Mean ± SD            | 7.61 ± 2.94 |
| Median (IQR)         | 7.00 (5.00, 9.00) |
| RBC Transfusion      | 16944 (22.0%)|
|                      |     |
|                      | Endo PVI  
|                      | n = 53724  |
| Primary expected payer (uniform) |     |
| 1: Medicare          | 37702 (70.2%) |
| 2: Medicaid          | 5544 (10.3%)  |
| 3: Private Insurance | 8183 (15.2%)  |
| 4: Self Pay          | 1029 (1.9%)   |
| 5: No charge         | 200 (0.4%)    |
| 6: Other             | 1018 (1.9%)   |
| Male                 | 15963 (29.5%)|
| Female               | 15963 (29.5%)|
| Length of stay (cleaned) |     |
| Mean ± SD            | 8.53 ± 12.15 |
| Median (IQR)         | 5.00 (2.00, 10.00) |
| Number of chronic conditions |     |
| Mean ± SD            | 8.02 ± 3.56 |
| Median (IQR)         | 7.00 (5.00, 9.00) |
| RBC Transfusion      | 8160 (21.3%) |
|                      |     |
|                      | Surgical PVI  
|                      | n = 38237  |
| Primary expected payer (uniform) |     |
| 1: Medicare          | 24695 (64.7%) |
| 2: Medicaid          | 3636 (9.4%)   |
| 3: Private Insurance | 7808 (20.5%)  |
| 4: Self Pay          | 888 (2.3%)    |
| 5: No charge         | 171 (0.4%)    |
| 6: Other             | 968 (2.5%)    |
| Male                 | 19760 (40.9%)|
| Female               | 19760 (40.9%)|
| Length of stay (cleaned) |     |
| Mean ± SD            | 8.54 ± 11.07 |
| Median (IQR)         | 5.00 (3.00, 10.00) |
| Number of chronic conditions |     |
| Mean ± SD            | 7.15 ± 3.25 |
| Median (IQR)         | 7.00 (5.00, 9.00) |
| RBC Transfusion      | 2414 (37.4%) |
|                      |     |
|                      | CAS  
|                      | n = 6462  |
| Primary expected payer (uniform) |     |
| 1: Medicare          | 4468 (69.3%) |
| 2: Medicaid          | 439 (6.8%)    |
| 3: Private Insurance | 1249 (19.4%)  |
| 4: Self Pay          | 139 (2.2%)    |
| 5: No charge         | 24 (0.4%)     |
| 6: Other             | 131 (2.0%)    |
| Male                 | 4468 (69.3%) |
| Female               | 4468 (69.3%) |
| Length of stay (cleaned) |     |
| Mean ± SD            | 4.87 ± 9.12 |
| Median (IQR)         | 2.00 (1.00, 5.00) |
| Number of chronic conditions |     |
| Mean ± SD            | 6.62 ± 2.98 |
| Median (IQR)         | 6.00 (5.00, 8.00) |
| RBC Transfusion      | 227 (3.5%)  |
|                      |     |
|                      | CEA  
|                      | n = 22396 |
| Primary expected payer (uniform) |     |
| 1: Medicare          | 16842 (75.3%) |
| 2: Medicaid          | 858 (3.8%)    |
| 3: Private Insurance | 4003 (17.9%)  |
| 4: Self Pay          | 271 (1.2%)    |
| 5: No charge         | 52 (0.2%)     |
| 6: Other             | 351 (1.6%)    |
| Male                 | 16842 (75.3%)|
| Female               | 16842 (75.3%)|
| Length of stay (cleaned) |     |
| Mean ± SD            | 2.83 ± 4.83 |
| Median (IQR)         | 2.00 (1.00, 3.00) |
| Condition                                      | TAVR n = 8327 | SAVR n = 14743 | PCI n = 173762 | CABG n = 76874 | Endo PVI n = 53724 | Surgical PVI n = 38237 | CAS n = 6462 | CEA n = 22396 |
|-----------------------------------------------|---------------|----------------|----------------|----------------|---------------------|------------------------|--------------|--------------|
| Acquired immune deficiency syndrome           | “<=10” (0.0%) | “<=10” (0.0%)  | 235 (0.1%)     | 103 (0.1%)     | 163 (0.3%)          | 59 (0.2%)              | “<=10” (0.1%) | 14 (0.1%)    |
| Alcohol abuse                                 | 91 (1.1%)     | 490 (3.3%)     | 5120 (2.9%)    | 2807 (3.7%)    | 1580 (2.9%)         | 1595 (4.2%)           | 171 (2.6%)   | 482 (2.2%)   |
| Deficiency anemias                            | 1952 (23.4%)  | 2566 (17.4%)   | 21261 (12.2%)  | 13669 (17.8%)  | 18521 (34.5%)       | 6735 (17.6%)          | 665 (10.3%)  | 1689 (7.5%)  |
| Rheumatoid arthritis/collagen vascular diseases | 442 (5.3%)    | 463 (3.1%)     | 4058 (2.3%)    | 1675 (2.2%)    | 1694 (3.2%)         | 997 (2.6%)            | 117 (1.8%)   | 519 (2.3%)   |
| Chronic blood loss anemia                     | 115 (1.4%)    | 218 (1.5%)     | 695 (0.4%)     | 977 (1.3%)     | 675 (1.3%)          | 467 (1.2%)            | 24 (0.4%)    | 71 (0.3%)    |
| Congestive heart failure                      | 1891 (22.7%)  | 304 (2.1%)     | 2809 (1.6%)    | 882 (1.1%)     | 4614 (8.6%)         | 957 (2.5%)            | 665 (10.3%)  | 1616 (7.2%)  |
| Chronic pulmonary disease                     | 2787 (33.5%)  | 3029 (20.5%)   | 30855 (17.8%)  | 16679 (21.7%)  | 11396 (21.2%)       | 10877 (28.4%)         | 1362 (21.1%) | 4940 (22.1%) |
| Coagulopathy                                  | 1882 (22.6%)  | 4954 (33.6%)   | 5728 (3.3%)    | 14598 (19.0%)  | 3697 (6.9%)         | 2962 (7.7%)           | 158 (2.4%)   | 398 (1.8%)   |
| Depression                                    | 610 (7.3%)    | 1282 (8.7%)    | 12566 (7.2%)   | 5886 (7.7%)    | 4921 (9.2%)         | 3225 (8.4%)           | 546 (8.4%)   | 1866 (8.3%)  |
| Diabetes, uncomplicated                       | 2336 (28.1%)  | 3018 (20.5%)   | 55465 (31.9%)  | 27457 (35.7%)  | 12607 (23.5%)       | 8668 (22.7%)           | 1856 (28.7%) | 6702 (29.9%) |
| Diabetes with chronic complications           | 604 (7.3%)    | 713 (4.8%)     | 11995 (6.9%)   | 7965 (10.4%)   | 13127 (24.4%)       | 4398 (11.5%)           | 296 (4.6%)   | 913 (4.1%)   |
| Drug abuse                                    | 30 (0.4%)     | 443 (3.0%)     | 4435 (2.6%)    | 1653 (2.2%)    | 1283 (2.4%)         | 954 (2.5%)            | 94 (1.5%)    | 151 (0.7%)   |
| Condition                                      | TAVR n = 8327 | SAVR n = 14743 | PCI n = 173762 | CABG n = 76874 | Endo PVI n = 53724 | Surgical PVI n = 38237 | CAS n = 6462 | CEA n = 22396 |
|------------------------------------------------|---------------|----------------|----------------|----------------|---------------------|------------------------|--------------|--------------|
| Hypertension (combine uncomplicated and complicated) | 6613 (79.4%)  | 10363 (70.3%)  | 131428 (75.6%) | 62333 (81.1%)  | 40588 (75.5%)       | 28604 (74.8%)          | 5100 (78.9%) | 18515 (82.7%) |
| Hypothyroidism                                 | 1611 (19.3%)  | 1902 (12.9%)   | 17492 (10.1%)  | 7788 (10.1%)   | 6202 (11.5%)        | 3306 (8.6%)           | 762 (11.8%)  | 2566 (11.5%)  |
| Liver disease                                  | 259 (3.1%)    | 398 (2.7%)     | 2686 (1.5%)    | 1520 (2.0%)    | 1889 (3.5%)         | 736 (1.9%)            | 62 (1.0%)    | 216 (1.0%)    |
| Lymphoma                                       | 128 (1.5%)    | 136 (0.9%)     | 851 (0.5%)     | 368 (0.5%)     | 421 (0.8%)          | 189 (0.5%)            | 31 (0.5%)    | 76 (0.3%)     |
| Fluid and electrolyte disorders                | 2216 (26.6%)  | 6036 (40.9%)   | 27963 (16.1%)  | 25935 (33.7%)  | 16225 (30.2%)       | 9187 (24.0%)          | 751 (11.6%)  | 1605 (7.2%)   |
| Metastatic cancer                              | 42 (0.5%)     | 30 (0.2%)      | 789 (0.5%)     | 145 (0.2%)     | 876 (1.6%)          | 340 (0.9%)            | 24 (0.4%)    | 64 (0.3%)     |
| Other neurological disorders                   | 485 (5.8%)    | 768 (5.2%)     | 7305 (4.2%)    | 3084 (4.0%)    | 3678 (6.8%)         | 1821 (4.8%)           | 105 (1.6%)   | 49 (0.2%)     |
| Obesity                                        | 1243 (14.9%)  | 3165 (21.5%)   | 30670 (17.7%)  | 19140 (24.9%)  | 6912 (12.9%)        | 4307 (11.3%)          | 639 (9.9%)   | 2448 (10.9%)  |
| Paralysis                                      | 162 (1.9%)    | 237 (1.6%)     | 1897 (1.1%)    | 1193 (1.6%)    | 1600 (3.0%)         | 917 (2.4%)            | 306 (4.7%)   | 139 (0.6%)    |
| Peripheral vascular disorders                  | 2264 (27.2%)  | 3258 (22.1%)   | 20047 (11.5%)  | 11964 (15.6%)  | 27603 (51.4%)       | 20512 (53.6%)         | 1706 (26.4%) | 5027 (22.4%)  |
| Psychoses                                      | 149 (1.8%)    | 372 (2.5%)     | 3763 (2.2%)    | 1819 (2.4%)    | 1755 (3.3%)         | 1002 (2.6%)           | 117 (1.8%)   | 326 (1.5%)    |
| Pulmonary circulation disorders                | 628 (7.5%)    | 128 (0.9%)     | 595 (0.3%)     | 221 (0.3%)     | 1073 (2.0%)         | 276 (0.7%)            | 132 (2.0%)   | 375 (1.7%)    |
| Renal failure                                  | 2993 (35.9%)  | 2271 (15.4%)   | 28387 (16.3%)  | 13296 (17.3%)  | 24438 (45.5%)       | 7071 (18.5%)          | 798 (12.3%)  | 2659 (11.9%)  |
| Solid tumor without metastasis                 | 184 (2.2%)    | 179 (1.2%)     | 1994 (1.1%)    | 841 (1.1%)     | 963 (1.8%)          | 537 (1.4%)            | 116 (1.8%)   | 249 (1.1%)    |
| Condition                                    | TAVR n = 8327 | SAVR n = 14743 | PCI n = 173762 | CABG n = 76874 | Endo PVI n = 53724 | Surgical PVI n = 38237 | CAS n = 6462 | CEA n = 22396 |
|----------------------------------------------|---------------|----------------|----------------|----------------|-------------------|------------------------|--------------|-------------|
| Peptic ulcer disease excluding bleeding      | "<=10" (0.0%) | "<=10" (0.1%)  | 34 (0.0%)      | 25 (0.0%)      | 24 (0.0%)         | "<=10" (0.0%)          | "<=10" (0.0%) | "<=10" (0.0%) |
| Valvular disease                             | 514 (6.2%)    | 309 (2.1%)     | 925 (0.5%)     | 383 (0.5%)     | 1361 (2.5%)       | 367 (1.0%)            | 507 (7.8%)   | 1654 (7.4%) |
| Acute Heart Failure                          | 158 (1.9%)    | 567 (3.8%)     | 7169 (4.1%)    | 3349 (4.4%)    | 409 (0.8%)        | 238 (0.6%)            | 16 (0.2%)    | 54 (0.2%)   |
| Unstable Angina                              | 41 (0.5%)     | 89 (0.6%)      | 30850 (17.8%)  | 17961 (23.4%)  | 220 (0.4%)        | 82 (0.2%)             | 82 (0.2%)    | 29 (0.4%)   |
| Acute Myocardial Infarction                  | 152 (1.8%)    | 279 (1.9%)     | 112898 (65.0%) | 24685 (32.1%)  | 1076 (2.0%)       | 747 (2.0%)            | 66 (1.0%)    | 146 (0.7%)  |
| Weight loss                                  | 419 (5.0%)    | 786 (5.3%)     | 2742 (1.6%)    | 2483 (3.2%)    | 3871 (7.2%)       | 2471 (6.5%)           | 110 (1.7%)   | 164 (0.7%)  |

Abbreviations for Table S1: Transcatheter Aortic Valve Replacement, SAVR: Surgical Aortic Valve Replacement, PCI: Percutaneous Coronary Intervention, CABG: Coronary Artery Bypass Grafting, PVI: Peripheral Vascular Intervention, CAS: Carotid Artery Stent, CEA: Carotid Endarterectomy, RBC: Red Blood Cell
Table S7. Cross-procedure transfusion correlations when minimum required procedural volume set to > 20 procedures for each member of a complimentary procedure pair

|       | CABG      | PCI       | SAVR      | TAVR      | SURGICAL PVI | ENDOVASCULAR PVI | CEA   | CAS   |
|-------|-----------|-----------|-----------|-----------|--------------|------------------|-------|-------|
| CABG  |           | 0.57 (N=516) | 0.88 (n=132) | 0.73 (N=132) | 0.69 (n=428) | 0.69 (N=428) | 0.42 (n=106) | 0.43 (N=106) |
| PCI   | 0.57 (N=516) |           | 0.66 (N=132) | 0.48 (n=132) | 0.66 (N=428) | 0.67 (N=428) | 0.46 (N=106) | 0.55 (N=106) |
| SAVR  | 0.88 (n=132) | 0.66 (N=132) |           | 0.74 (N=132) | 0.78 (n=131) | 0.74 (n=131) | 0.52 (n=62) | 0.49 (N=62) |
| TAVR  | 0.73 (N=132) | 0.48 (n=132) | 0.74 (N=132) |           | 0.69 (n=131) | 0.55 (N=131) | 0.52 (N=62) | 0.28 (n=62) |
| SURGICAL PVI | 0.69 (n=428) | 0.66 (N=428) | 0.78 (n=131) | 0.69 (N=131) |           | -                | 0.65 (N=564) | 0.40 (N=108) | 0.44 (N=108) |
| ENDOVASCULAR PVI | 0.69 (N=428) | 0.67 (n=428) | 0.74 (n=131) | 0.55 (n=131) | 0.65 (N=564) |           | -                | 0.56 (N=108) | 0.52 (N=108) |
| CEA   | 0.42 (n=106) | 0.46 (N=106) | 0.52 (N=62) | 0.52 (N=62) | 0.40 (n=108) | 0.56 (N=108) |           | -                | 0.27 (N=110) |
| CAS   | 0.43 (N=106) | 0.55 (n=106) | 0.49 (N=62) | 0.28 (n=62) | 0.44 (N=180) | 0.52 (n=108) | 0.27 (N=110) | -                |
Table S8. Cross-procedure transfusion correlations after excluding patients who underwent more than 1 of the same procedure during 2014.

|          | CABG | PCI  | SAVR | TAVR | SURGICAL PVI | ENDOVASCULAR PVI | CEA  | CAS  |
|----------|------|------|------|------|--------------|------------------|------|------|
| CABG     | -    | 0.56 (N=527) | 0.87 (N=166) | 0.62 (N=166) | 0.62 (N=512) | 0.62 (N=512) | 0.29 (n=289) | 0.36 (N=289) |
| PCI      | 0.56 (N=527) | -    | 0.59 (N=166) | 0.42 (N=166) | 0.61 (N=512) | 0.64 (n=512) | 0.36 (N=289) | 0.42 (n=289) |
| SAVR     | 0.87(n=166) | 0.59 (N=166) | -    | 0.67 (N=166) | 0.74 (n=166) | 0.69 (n=166) | 0.40 (n=137) | 0.39 (N=137) |
| TAVR     | 0.62 (N=166) | 0.42 (n=166) | 0.67 (N=166) | -    | 0.56 (n=166) | 0.49 (n=166) | 0.36 (N=137) | 0.20 (N=137) |
| SURGICAL PVI | 0.62 (N=512) | 0.61 (N=512) | 0.74 (N=166) | 0.56(N=166) | -    | 0.51(N=824) | 0.44 (n=328) | 0.42 (N=328) |
| ENDOVASCULAR PVI | 0.62 (N=512) | 0.64 (N=512) | 0.69 (N=166) | 0.49 (N=166) | 0.51 (N=824) | -    | 0.29 (N=328) | 0.40 (N=328) |
| CEA      | 0.29 (n=289) | 0.36 (n=289) | 0.40 (n=137) | 0.36 (N=137) | 0.44 (n=328) | 0.29 (N=328) | -    | 0.19 (N=331) |
| CAS      | 0.36 (N=289) | 0.42 (n=289) | 0.39 (N=137) | 0.20 (n=137) | 0.42 (N=328) | 0.40 (n=328) | 0.19 (N=331) | -    |
Table S9. Cross-procedure transfusion correlations including only those with post-procedure transfusion.

|       | CABG   | PCI      | SAVR     | TAVR     | SURGICAL PVI | ENDO-VASCULAR PVI | CEA     | CAS     |
|-------|--------|----------|----------|----------|--------------|-------------------|---------|---------|
| CABG  | -      | 0.53(N=527) | 0.88(n=166) | 0.63(N=166) | 0.61(N=512) | 0.60(N=512) | 0.25(n=289) | 0.40(N=289) |
| PCI   | 0.53(N=527) | -        | 0.61(N=166) | 0.42(n=166) | 0.59(N=512) | 0.61(N=512) | 0.39(N=289) | 0.33(N=289) |
| SAVR  | 0.88(n=166) | 0.641(N=166) | -        | 0.68(N=166) | 0.74(N=166) | 0.68(N=166) | 0.39(n=137) | 0.34(N=137) |
| TAVR  | 0.63(N=166) | 0.42(n=166) | 0.68(N=166) | -        | 0.59(N=166) | 0.49(n=166) | 0.35(N=137) | 0.23(N=137) |
| SURGICAL PVI | 0.61(n=512) | 0.59(N=512) | 0.74(n=166) | 0.59(N=166) | -        | 0.49(N=824) | 0.43(n=328) | 0.37(N=328) |
| ENDOVASU CLAR PVI | 0.60(N=512) | 0.61(n=512) | 0.68(n=166) | 0.49(n=166) | 0.49(N=824) | -        | 0.28(N=328) | 0.32(n=328) |
| CEA   | 0.25(n=289) | 0.39(N=289) | 0.39(n=137) | 0.35(n=137) | 0.43(n=328) | 0.28(N=328) | -        | 0.09(N=331) |
| CAS   | 0.40(N=289) | 0.33(n=289) | 0.34(n=137) | 0.23(n=137) | 0.37(N=328) | 0.32(n=328) | 0.09(N=331) | -        |
|                | CABG  | PCI    | SAVR  | TAVR  | SURGICAL PVI | ENDO-VASCULAR PVI | CEA   | CAS   |
|----------------|-------|--------|-------|-------|--------------|-------------------|-------|-------|
| CABG           | -     | 0.58(N=527) | 0.90(n=166) | 0.65(N=166) | 0.64(N=512) | 0.61(N=512) | 0.31(N=289) | 0.38(N=289) |
| PCI            | 0.58(N=527) | -      | 0.65(N=166) | 0.48(N=166) | 0.63(N=512) | 0.65(N=512) | 0.36(N=289) | 0.30(N=289) |
| SAVR           | 0.90(n=166) | 0.65(N=166) | -      | 0.71(N=166) | 0.78(N=166) | 0.71(n=166) | 0.45(n=137) | 0.42(n=137) |
| TAVR           | 0.65(N=166) | 0.48(N=166) | 0.71(N=166) | -      | 0.63(N=166) | 0.54(n=166) | 0.39(n=137) | 0.23(n=137) |
| SURGICAL PVI   | 0.64(N=512) | 0.63(N=512) | 0.78(N=166) | 0.63(N=166) | -      | 0.54(N=824) | 0.45(n=328) | 0.37(N=328) |
| ENDOVASCULAR PVI | 0.61(N=512) | 0.65(N=512) | 0.71(N=166) | 0.54(N=166) | 0.54(N=824) | -      | 0.30(N=328) | 0.32(N=328) |
| CEA            | 0.31(N=289) | 0.36(N=289) | 0.45(N=137) | 0.39(N=137) | 0.45(N=328) | 0.30(N=328) | -      | 0.09(N=331) |
| CAS            | 0.38(N=289) | 0.30(N=289) | 0.42(N=137) | 0.23(N=137) | 0.37(N=328) | 0.32(N=328) | 0.09(N=331) | -      |

Table S10. Cross-procedure transfusion correlations when all blood product transfusions were included.