

Development and Validation of a Score to Predict the Risk of Readmission After Adult Cardiac Operations

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Background. The purpose of this study was to develop and validate a risk score for readmissions after cardiac operations.

Methods. Adults surviving to discharge after cardiac operations at a single institution from 2008 to 2013 were randomly divided 3:1 into training and validation cohorts. The primary outcome was readmission within 30 days of discharge. A multivariable model was constructed in the training cohort incorporating variables associated with 30-day readmission in univariate logistic regression. Points were assigned to predictors in the multivariable model proportional to their odds ratios.

Results. Among 5,193 patients undergoing cardiac operations and surviving to discharge, the 30-day readmission rate was 10.3% ($n = 537$). The most common reasons for readmission were volume overload (24%; $n = 131$) and infection (21%; $n = 113$). The risk score incorporated 5 multivariable predictors and was out of 20 possible points. The predicted rate of 30-day

readmission based on the training cohort ranged from 5.9% (score = 0) to 54.7% (score = 20). Patients were categorized as low (score = 0; readmission 5.7%), moderate (score 1-7; readmission 11.0%), and high risk (score >7; readmission 24.2%) ($p < 0.001$). Thirty-day readmission rates based on these score categories were similar in the validation cohort (low 6.4%, moderate 11.0%, high 17.4%; $p < 0.001$). There was a robust correlation between predicted rates of readmission in the training cohort based on the composite risk score and actual rates of readmission in the validation cohort ($r = 0.95$; $p < 0.001$).

Conclusions. We developed and validated a risk score for readmission after cardiac operations that may have utility in targeting interventions and modifying risk factors in high-risk populations.

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Hospital readmissions are increasingly being scrutinized in the US health care system. In fact, the Affordable Care Act established the Hospital Readmissions Reduction Program, which requires the Centers for Medicare and Medicaid Services to reduce payments to hospitals with excess readmissions [1]. In cardiac operations, there is often a high acuity of care, complex patients and procedures, and multiple organ systems with potential for derangements related to or as a consequence of cardiac operations, all of which make frequent readmissions a real possibility. Individual provider and institutional efforts to reduce this readmission risk are undoubtedly prudent in today's health care environment. Although clinicians caring for patients who

have undergone cardiac operations often have a sense of who is at high risk for readmission, and previous studies have indeed identified several risk factors for readmission, there currently exists no composite risk stratification system to identify high-risk patients. In this study, we derive and validate a risk score for readmission after cardiac operations.

Patients and Methods

Study Population

Data were collected from electronic medical records of adult patients (>17 years of age) undergoing cardiac operations at a single institution and surviving to hospital discharge. Patients with in-hospital mortality after cardiac operations were excluded. Patients undergoing ventricular assist device implantation, heart transplantation, or lung transplantation were also excluded. The study period extended from January 1, 2008 to December 31, 2013. The Institutional Review Board of Johns Hopkins University granted this study exempt status.

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Derivation of Risk Score

The study population was randomly divided 3:1 into training and validation cohorts. The primary outcome was all-cause readmission within 30 days of hospital discharge. The association between multiple pre-, intra-, and post-operative variables collected before hospital discharge and the primary outcome were evaluated by univariate logistic regression analysis in the training cohort. Preoperative variables included age, sex, race, body mass index, insurance status, chronic lung disease and severity (mild, moderate, severe), smoking status, congestive heart failure, myocardial infarction, ejection fraction, cerebrovascular disease, diabetes mellitus, coronary artery disease, hypertension, immunosuppression, peripheral vascular disease, dialysis, hyperlipidemia, previous cardiac operations, family history of coronary artery disease, most recent laboratory measurements (white blood cell count, serum creatinine level, hematocrit value), blood transfusion, shock, and use of a preoperative intraaortic balloon pump. Intraoperative variables included type of operation (isolated coronary artery bypass grafting [CABG], isolated valve operations, combined CABG and valve operations, aortic valve operations, or other operations), cardiopulmonary bypass time, cross-clamp time, circulatory arrest, blood transfusion, year of operation, use of an intraoperative intraaortic balloon pump, and urgency of operation (elective versus urgent/emergent). Postoperative variables included time spent in the intensive care unit, readmission to the intensive care unit, postoperative blood transfusion, postoperative intraaortic balloon pump use, blood transfusion, creatinine level at discharge, postoperative complications (reintubation, acute limb ischemia, deep sternal wound infection, stroke or transient ischemic attack, reoperation, atrial fibrillation, cardiac arrest, gastrointestinal bleeding or mesenteric ischemia, tamponade, pneumonia, prolonged mechanical ventilation, new-onset dialysis, acute renal failure, sepsis, aortic dissection, pulmonary embolism), and discharge location (home versus facility).

A multivariable model was then constructed in the training cohort that included variables associated with 30-day readmission ($p < 0.20$) and with less than 20% missing data. The inclusion of each variable into the model was evaluated in a stepwise fashion using the likelihood ratio test, with a p value less than 0.05 considered significant. The final multivariable model was evaluated using the Hosmer-Lemeshow goodness-of-fit test.

Risk points were then assigned to individual variables that were significantly associated with 30-day readmission in the multivariable model ($p < 0.05$). The points were assigned based on the relative magnitudes of the odds ratios in the model. A composite risk score was then generated by summing the individual points.

Validation of the Readmission Risk Score

The predictive capability of the composite risk score in evaluating the risk of 30-day readmission was then evaluated in the validation cohort using logistic regression analysis, the Akaike information criterion, the χ^2 test, the

c-index, and the Hosmer-Lemeshow goodness-of-fit test. Weighted linear regression analysis was also used to assess the association between predicted rates of 30-day readmission for each score in the training cohort and actual rates of 30-day readmission for the same score in the validation cohort. A correlation coefficient was generated based on this weighted linear regression. Weights in the linear regression analysis were based on the number of patients with that particular risk score.

Causes of Readmission

The primary reason for readmission was also collected in the data set. They were categorized as follows: volume overload (including pleural effusions requiring diuresis, thoracentesis, or tube thoracostomy), infection, noninfectious wound complications, arrhythmia, cerebrovascular accident, gastrointestinal bleeding, gastrointestinal disease excluding bleeding, angina or myocardial infarction, acute limb ischemia, fall/syncope/presyncope, fever without an identified source of infection, adjustment of anticoagulation agents, acute renal failure, blood pressure management, thromboembolism, anemia, pain excluding angina, blood glucose or electrolyte management, bleeding complication, or other reasons. All continuous data in our study are presented as mean $\pm$ standard deviation and all categorical data as number (percentage). Data analyses were performed with STATA, version 11, statistical software (StataCorp LP, College Station, TX).

Results

Study Population Characteristics

A total of 5,193 adult patients undergoing cardiac operations survived to hospital discharge and were included in the study. The study population was divided randomly into training (75%; $n = 3,898$) and validation (25%; $n = 1,295$) cohorts. The mean age was 61.8 ± 14.8 years, with 1,524 (29%) of patients being older than 70 years. There were 1,775 (34%) women, and the most common comorbidity was hypertension (55%; $n = 2,865$). Isolated coronary artery bypass grafting (CABG) was the most common type of operation performed (50%; $n = 2,576$), followed by isolated valve operations (20%; $n = 1,046$). The most common "other" operations were myectomy (10%; $n = 58$), cardiac tumor resection (5%; $n = 26$), septal defect repair (5%; $n = 26$), and pericardiectomy (3%; $n = 17$). Redo cases composed 17% ($n = 895$) of operations in the study cohort. The most common postoperative complication occurring before hospital discharge was atrial fibrillation (20%; $n = 1,021$). Nearly half (44%; $n = 2,307$) of the patients received a blood transfusion during the hospital stay. When comparing baseline characteristics between the training and validation cohorts, there were no significant differences observed between the groups (Table 1).

Readmission Rate and Primary Cause of Readmission

The overall 30-day readmission rate was 10% ($n = 537$) and was similar between the training and validation

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