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ORIGINAL ARTICLE

Predicted Risk of Mortality Score predicts 30-day readmission after coronary artery bypass grafting

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Abstract

Objective Quality metrics and reimbursement models focus on 30-day readmission rates after coronary artery bypass grafting (CABG). Certain preoperative variables are associated with higher rates of readmission. The purpose of this study was to determine whether STS Predicted Risk of Mortality (PROM) scores predict 30-day readmission following CABG.

Methods A retrospective review of all patients undergoing isolated CABG between 2002 and 2017 at a US academic institution was performed. Logistic regression analysis was used to determine the association between PROM and 30-day readmission, and the area under the receiver-operator curve (ROC) was calculated to estimate predictive accuracy.

Results During the study period, 21,719 patients underwent CABG and 2,023 (9.2%) were readmitted within 30 days. Readmitted patients were sicker with higher rates of comorbid conditions and higher STS PROM scores (1.03% vs 1.42%, GMR 1.33, CI 1.27–1.38, $p < 0.0001$). Median time to readmission was 8 days (IQR 4–15) with length of stay 5 days (4–6). By PROM quintile, higher PROM scores were associated with increased odds of readmission. PROM-adjusted 30-day mortality was higher in the readmitted group (1.04% vs 0.21%, OR 4.53, CI 2.67–7.69, $p < 0.001$), and mid-term survival was worse as well. PROM alone was a modest predictor of readmission (area under ROC 0.59, CI 0.57–0.60) compared to insurance status (0.55, 0.53–0.56), ejection fraction (0.52, 0.50–0.54), and history of heart failure (0.51, 0.50–0.52).

Conclusion STS PROM scores are associated with increased risk of readmission following CABG.

Keywords Readmission · CABG · STS PROM

Abbreviations

AUC	Area under the curve
CABG	Coronary artery bypass graft
PROM	STS Predicted Risk of Mortality Score
ROC	Receiver–operator curve
STS	Society of Thoracic Surgeons

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Introduction

Coronary artery bypass grafting (CABG) is the most commonly performed cardiac operation in the United States and accounts for more resources expended than any other cardiac surgical procedure [1]. Early hospital readmission following CABG occurs at a high rate, with about one in six post-CABG patients readmitted within 30 days of their operation [2, 3]. Among CABG patients who were readmitted within 30 days, nearly a quarter (23.9%) required acute care, including emergency department and intensive care unit admissions; these readmissions were associated with increased morbidity, mortality, and increased facility costs [4, 5].

Understandably, many efforts are underway to accurately predict which CABG patients are at high risk for readmission. An analysis of Medicare patients in New York state showed that of $102.6 billion Medicare hospital payments, $17.4 billion (17%) was for unplanned readmission costs, and CABG patients accounted for 87% of the 16% cardiac procedure readmission rate [3]. In an effort to reduce cost,

some groups have tried to identify patient, operative, and hospital characteristics associated with readmission risk [6], but no strong pre-discharge predictive variables have been identified to date.

The Society of Thoracic Surgeons Predicted Risk of Mortality (PROM) score has been designed and validated to accurately predict 30-day mortality following cardiac operations, including CABG. Recent literature shows that the pre-operative PROM score is also a strong predictor of long-term patient outcomes [7]. The PROM score has also been shown to correlate with longer post-operative length of stay and higher healthcare costs [8]. To date, the utility of the PROM score to characterize 30-day readmission has not been investigated.

Given the increased cost and resource utilization associated with post-CABG hospital readmission, identifying patients at high risk would be advantageous. A predictive tool would be requisite to further develop early intervention programs at the hospital level (and perhaps regional or national) with a purpose of ultimately preventing readmission. The goal of this study was to determine the utility of pre-operative characteristics, including PROM, as predictors of 30-day readmission following CABG, to develop models aimed at identifying patients at high risk for readmission.

Patients and methods

Study population

The Emory University institutional STS Adult Cardiac Surgery Database was queried for consecutive patients undergoing elective or urgent isolated primary CABG at Emory Healthcare Hospitals between January 1, 2002 and June 30, 2016. Patients were excluded if they were undergoing concomitant cardiac operations, if revascularization was emergent or salvage, if they were in cardiogenic shock, or if they died during the index hospitalization.

During the study period, a total of 21,719 patients underwent primary, isolated, non-emergent CABG and survived the index hospitalization. The study was approved by the Emory University Institutional Review Board in compliance with HIPAA regulations and the Declaration of Helsinki. Individual patient consent was waived by the IRB secondary to the retrospective nature of the study.

Study variable and short-term outcomes

The STS database includes a value for STS PROM for each patient. PROM can be calculated using an online risk calculator (riskcalc.sts.org) and includes: age, height, weight, race, gender, hematocrit, leukocyte count, platelet count, serum creatinine, dialysis, hypertension, immunocompromised state, peripheral artery disease, cerebrovascular disease, mediastinal radiation, cancer within 5 years, family history of coronary artery disease, sleep apnea, liver disease, unresponsive state, syncope, diabetes, endocarditis, severity of chronic lung disease, illicit drug and alcohol use, history of pneumonia, tobacco use, previous cardiac intervention of surgery, recent myocardial infarction, heart failure, NYHA classification, left ventricle ejection fraction, dysrhythmias, recent antiplatelet use, number of diseased coronary vessels, percent stenosis of left main, any concomitant valvular abnormalities, and any mechanical assist devices in place.

The primary outcome of interest was same-institution readmission within 30 days of discharge from an index CABG operation. Readmission causes and timing were collected and abstracted from the STS database. Post-operative clinical outcomes collected in the STS database were analyzed as descriptive outcomes in relation to readmission status. Specifically, 30-day mortality, stroke, myocardial infarction, mediastinitis or deep sternal wound infection, renal failure or new dialysis, prolonged ventilation, and reoperation for bleeding was of interest.

All-cause mortality was determined for all patients entered in the database prior to December 31, 2010, by comparing to the Social Security Death Index (SSDI). The SSDI is a publicly available national database extracted from the US Social Security Administration (SSA) Death Master File which lists all patients with a Social Security Number whose death is reported to the SSA. For patients in our dataset entered on January 1, 2011 and after, correlation to SSDI data is no longer available, thus they are censored in our analysis after 30 days.

Statistical analysis

Pre-operative risk factors and demographics were summarized and reported by whether the patient was readmitted. Categorical variables were reported as count and frequency whereas continuous variables were reported as either mean and standard deviation or median and interquartile range depending on their distribution. Categorical variables were assessed for statistical significance with the chi-squared test. Continuous variables were assessed with the two-sample *t* test; continuous variables that violated the normality assumption were log-transformed for testing and reported with the geometric mean ratio. Intraoperative variables were stratified by readmission status and assessed through the same methods as pre-operative risk factors.

Thirty-day readmission was reported through descriptive statistics. Readmission was also stratified by PROM quintiles to illustrate the trend between increasing predicted risk of mortality (PROM) and the increased odds of readmission. Odds ratios were calculated for each quintile with the first quintile as the reference group. To determine

associations between readmission and adverse events within 30 days post-surgery, logistic regression models were built. Each model controlled for the PROM score to account for potential confounders. Using mid-term mortality data, a Kaplan–Meier curve was drawn to show the mid-term survival between patients who were and were not readmitted. The log-rank test was used to assess significant differences between the curves.

To determine the predictive ability of PROM, reciever-operator curve (ROC) were created and from the curve, the area under the curve (AUC) statistic was calculated. Three a priori predictors of readmission were then modeled through logistic regression as univariate, bivariate, and multivariate predictors of readmission. Each model was assessed through ROC curves and the respective AUC statistics were compared to show the relative predictive ability of 30-day readmission.

Results

There were a total of 21,719 patients meeting inclusion criteria who underwent CABG during the study period. Of these, 2023 patients (9.3%) were readmitted within 30 days following discharge. Pre-operative characteristics for all patients are shown in Table 1. In general, those patients who required 30-day readmission were sicker, with higher rates of all comorbid conditions present pre-operatively. STS PROM scores were significantly higher in the readmitted group compared to non-readmitted (1.42 vs 1.03, GMR 1.33, CI 1.27–1.28, $p < 0.0001$). Only age, pre-operative ejection fraction, and smoking status were similar between groups. Intraoperative variables were mostly similar between readmitted and non-readmitted patients (Table 2). Off-pump CABG utilization was higher in the readmitted group (57.9% vs 50.4%, OR 1.36, CI 1.24–1.49, $p < 0.0001$). Although CPB and cross-clamp times were statistically significantly longer in the readmitted group,

Table 1 Pre-operative patient characteristics

Variables	Total ($N = 21,719$)	No readmission ($n = 19,696$)	Readmitted ($n = 2023$)	OR/difference/GMR (95% CI)	p-value
Age	63.46 (10.73)	63.41(10.66)	63.94 (11.38)	0.53 (0.04–1.02)[a]	0.04
Status					
Elective	13,919 (64.09%)	12,800 (64.99%)	1119 (55.31%)	1 (ref)	-
Urgent	7800 (35.91%)	6896 (35.01%)	904 (44.69%)	1.50 (1.37–1.64)	< 0.0001
Hypertension	18,767 (86.41%)	16,961 (86.11%)	1806 (89.27%)	1.34 (1.16–1.55)	< 0.0001
Ejection fraction	55.0 (45.0, 60.0)	55.0 (45.0, 60.0)	55.0 (45.0, 60.0)	1.00 (0.98–1.01)[b]	0.73
NYHA class 3/4	6403 (29.48%)	5734 (29.11%)	669 (33.07%)	1.20 (1.09–1.33)	0.0002
Prior CVA	585 (2.69%)	512 (2.60%)	73 (3.61%)	1.40 (1.09–1.80)	0.008
COPD					< 0.0001
None	17,945 (82.95%)	16,389 (83.55%)	1556 (77.11%)	1 (ref)	-
Mild	2198 (10.16%)	1942 (9.90%)	256 (12.69%)	1.39 (1.21–1.60)	< 0.0001
Moderate	641 (2.96%)	548 (2.79%)	93 (4.61%)	1.79 (1.43–2.24)	< 0.0001
Severe	850 (3.93%)	737 (3.76%)	113 (5.60%)	1.61 (1.32–1.98)	< 0.0001
Diabetes	8839 (40.70%)	7837 (39.79%)	1002 (49.53%)	1.49 (1.35–1.63)	< 0.0001
Previous MI	5839 (26.88%)	5218 (26.49%)	621 (30.70%)	1.23 (1.11–1.36)	< 0.0001
CVD	3593 (16.54%)	3161 (16.05%)	432 (21.35%)	1.42 (1.27–1.59)	< 0.0001
PAD	3208 (14.77%)	2834 (14.39%)	374 (18.49%)	1.35 (1.20–1.52)	< 0.0001
Serum creatinine	1.0 (0.9, 1.2)	1.0 (0.9, 1.2)	1.0 (0.9, 1.3)	1.10 (1.07–1.12)[b]	< 0.0001
Current smoker	687 (3.16%)	618 (3.14%)	69 (3.41%)	1.09 (0.85–1.40)	0.50
Immunosuppressed	766 (3.53%)	651 (3.31%)	115 (5.68%)	1.76 (1.44–2.16)	< 0.0001
STS PROM	1.05 (0.59, 2.13)	1.03 (0.58, 2.05)	1.42 (0.74, 3.01)	1.33 (1.27–1.38)[b]	< 0.0001
Body mass index	28.4 (25.3, 32.3)	28.4 (25.3, 32.2)	28.9 (25.2, 33.3)	1.02 (1.01–1.03)[b]	0.0002

Values represent number of patients (percent of group) or mean ± standard deviation

COPD chronic obstructive pulmonary disease, *CVA* cerebrovascular accident, *CVD* cerebrovascular disease, *GMR* geometric mean ratio, *MI* myocardial infarction, *OR* odds ratio, *PAD* peripheral arterial disease, *PROM* predicted risk for mortality, STS Society of Thoracic Surgeons

[a]Difference measure

[b]Geometric mean ratio

Table 2 Intraoperative patient characteristics

Variables	Total ($N=21,719$)	No readmission ($n=19,696$)	Readmitted ($n=2023$)	OR/GMR (95% CI)	p-value
Multiple arterial grafts	3668 (16.89%)	3329 (16.90%)	339 (16.76%)	0.99 (0.88–1.12)	0.87
Distal anastomoses	3 (2, 4)	3 (2, 4)	3 (2, 4)	0.98 (0.97–1.01)[a]	0.16
Cross-clamp time (min)	59.0 (45.0, 76.0)	59.0 (45.0, 76.0)	63.0 (49.0, 79.0)	1.06 (1.02–1.09)[a]	0.001
CPB time (min)	89.0 (70.0, 110.0)	88.0 (70.0, 109.0)	95.0 (76.0, 115.0)	1.07 (1.04–1.10)[a]	<0.0001
OPCAB	11,098 (51.10%)	9926 (50.40%)	1172 (57.93%)	1.36 (1.24–1.49)	<0.0001
Intraoperative IABP	1182 (5.44%)	1064 (5.40%)	118 (5.83%)	1.08 (0.89–1.32)	0.42

Values represent number of patients (percent of group) or median (IQR)

CPB cardiopulmonary bypass, *GMR* geometric mean ratio, *IABP* intra-aortic balloon pump, *OPCAB* off-pump CABG, *OR* odds ratio

[a]Geometric mean ratio

the differences were small (4 min longer cross-clamp time, and 7 min longer CPB time) and could not be explained by other markers of surgical complexity—number of distal anastomoses and multi-arterial grafting—which were equivalent between the two groups.

Short-term perioperative outcomes when adjusted for PROM were similar between the two groups (Table 3). Readmitted patients had a significantly higher rate of 30-day mortality (1.04% vs 0.21%, OR 4.53, CI 2.67–7.69, $p<0.0001$). At up to 8 years of follow-up, readmitted patients had significantly lower all-cause survival compared to non-readmitted patients (Fig. 1, Kaplan Meier estimates, $p<0.001$).

Of the 2,023 patients who were readmitted to the same institution within 30 days of discharge from the index hospitalization, the majority of readmissions occurred within 9 days of discharge (Fig. 2, median 8 days, IQR 4–15) and lasted a median of 5 days (IQR 4–6 days). The reason for readmission was varied (Table 4), with the highest percentage of readmissions occurring for respiratory complaints (11.9%), cardiac complaints (arrhythmia—7.47%, heart failure—7.77%, myocardial infarction—5.48%), infectious complications (9.43%), and other CABG related (37.3%) and non-related (10.31%) complaints.

To evaluate PROM as a predictor of 30-day readmission, PROM was stratified according to quintile and readmission risk was assessed by quintile. A strong association between PROM and readmission was noted. When all patients were stratified by PROM quintile, the 30-day readmission rate increased from 14.1% in the lowest PROM quintile to 29.9% in the highest PROM quintile (OR 2.30, CI 1.99–2.67, $p<0.0001$). This finding was consistent across all PROM quintiles (Fig. 3).

To determine the predictive value of PROM for 30-day readmission, analysis of the area under the ROC was performed (Fig. 4, Supplemental Table 1). Individual variables were poor predictors of readmission (AUC for insurance status 0.55, ejection fraction 0.52, and prior heart failure 0.51). Combining two of these variables did not significantly improve the predictive value. PROM alone was a modest predictor of 30-day readmission (AUC 0.59, CI 0.57–0.60). Evaluation of individual components of the PROM score ("Full Model"), including ejection fraction, insurance status, prior heart failure, age, BMI, serum creatinine, emergent status, NYHA heart failure classification, COPD, cerebrovascular or peripheral vascular disease, and immunosuppression did not markedly improve readmission prediction compared to PROM score alone (AUC 0.61, CI 0.59–0.63).

Table 3 PROM-adjusted short-term outcomes

Variables	Total ($N=21,719$)	No readmission ($n=19,696$)	Readmitted ($n=2023$)	OR (95% CI)	p-value
30-day mortality	63 (0.29%)	42 (0.21%)	21 (1.04%)	4.53 (2.67–7.69)	<0.0001
Sternal infection	13 (0.06%)	4 (0.02%)	9 (0.44%)	22.45 (6.87–73.41)	<0.0001
Stroke	226 (1.04%)	203 (1.03%)	23 (1.14%)	1.03 (0.66–1.59)	0.9
Prolonged ventilation	1947 (8.96%)	1708 (8.67%)	239 (11.81%)	1.24 (1.07–1.44)	0.005
Pneumonia	641 (2.95%)	581 (2.95%)	60 (2.97%)	0.92 (0.70–1.21)	0.55
Post-op dialysis	149 (0.69%)	132 (0.67%)	17 (0.84%)	1.05 (0.62–1.76)	0.86
Renal failure	441 (2.03%)	379 (1.92%)	62 (3.06%)	1.45 (1.10–1.91)	0.008
Reoperation	386 (1.78%)	338 (1.72%)	48 (2.37%)	1.33 (0.98–1.80)	0.07

Values represent number of patients (percent of group)

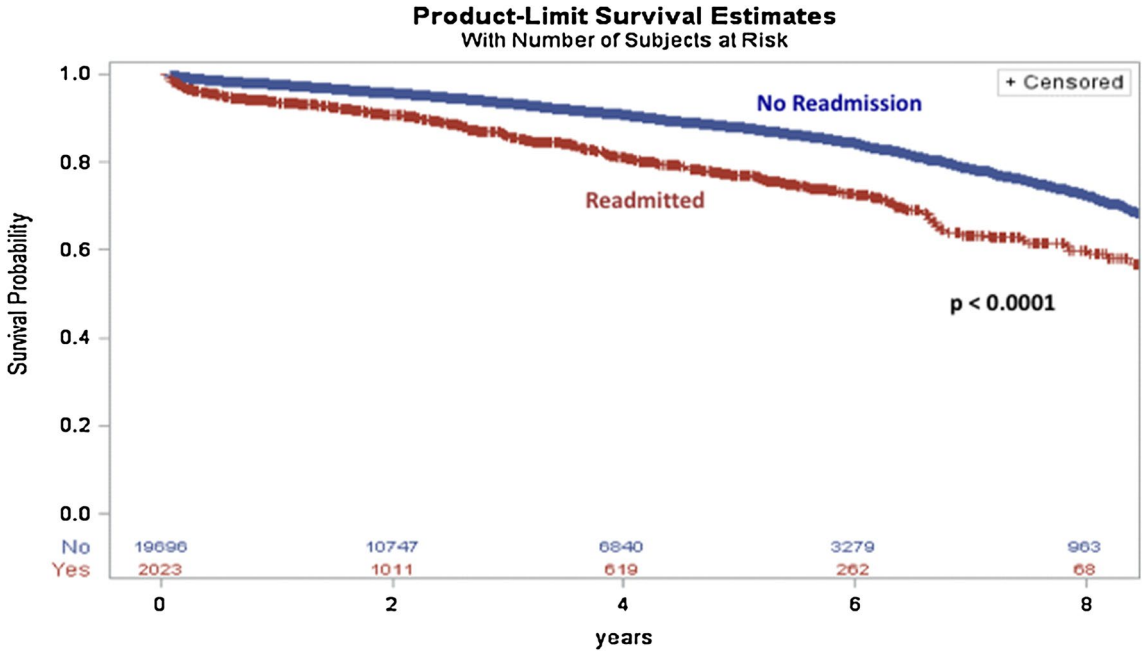

Fig. 1 Kaplan–Meier estimates for all-cause survival in readmitted (red) and not readmitted (blue) patients. Shaded areas represent the 95% confidence interval for the survival estimates

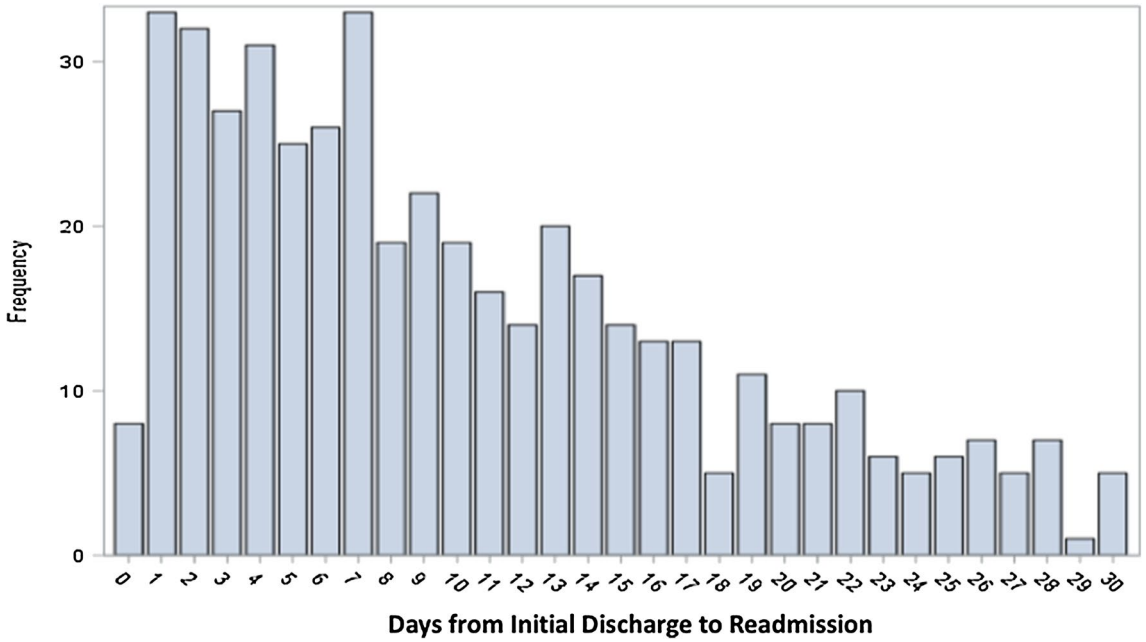

Fig. 2 Frequency of readmission by day post-discharge from index hospitalization

For comparison, PROM is a significant predictor of 30-day mortality (AUC 0.77, Supplemental Fig. 1).

Comment

In this retrospective study of post-CABG patients who survived initial hospitalization, nearly one in ten patients (9.3%) were readmitted within 30 days of discharge from

Table 4 30-day readmission causes

Cause	*N* (%)
Arrhythmia/heart block	150 (7.47%)
Congestive heart failure	156 (7.77%)
MI and/or recurrent angina	110 (5.48%)
Pericardial effusion	55 (2.74%%)
Respiratory complaint	241 (11.95%)
PE	20 (1.00%)
Pleural effusion	5 (0.40%)
Infectious complication	
Sternal	118 (5.88%)
Leg	70 (3.5%)
Endocarditis	1 (0.05%)
Cardiac catheterization	5 (0.25%)
Graft occlusion	9 (0.45%)
Renal failure	8 (0.40%)
Stroke/TIA	28 (1.40%)
Acute vascular complication	23 (1.15%)
OAC complication	36 (1.79%)
DVT	10 (0.50%)
Planned readmission	4 (0.20%)
Other, related	749 (37.30%)
Other, non-related	207 (10.31%)

DVT deep venous thrombosis, *MI* myocardial infarction, *OAC* oral anticoagulation, *PE* pulmonary embolism, *TIA* transient ischemic attack

Values represent number of patients (percent of group)

the index hospitalization. Prolonged post-operative ventilation and renal failure were associated with increased risk of 30-day readmission, and patients who were readmitted also had an associated 4.5-fold increase in mortality. Readmission rates increased coincidently with higher PROM scores, and the PROM score was a comparably equivalent predictor of readmission than the constructed risk factor model (AUROC 0.59 vs 0.61). The results of this study show that the PROM is a reasonable starting point in developing a model for predicting 30-day readmission. These results have important clinical implications—by identifying the patients who are at highest risk for post-operative readmission and poor post-CABG outcomes, care pathways could be improved to prevent returns to acute care.

Many of the risk factors for readmission identified in this study, including congestive heart failure, chronic obstructive pulmonary disease, and diabetes, are consistent with previous studies of readmission following cardiac surgery [2, 9–13]. Of note, the PROM score and the constructed risk factor models had similar predictive value, as demonstrated by their similar AUC values. This suggests that the 30 different pre-operative patient risk factors incorporated into the STS PROM mathematic model affect early hospital readmission risk in a manner very similar to the manner in which they affect a patient's likelihood of surviving 30 days after CABG, but since the AUC values for readmission and mortality were different, there are likely other factors which impact readmission. A benefit to using PROM as a readmission predictor is that it represents a score that is routinely calculated for pre-operative risk assessment, and can be used for multiple outcomes, including 30-day mortality,

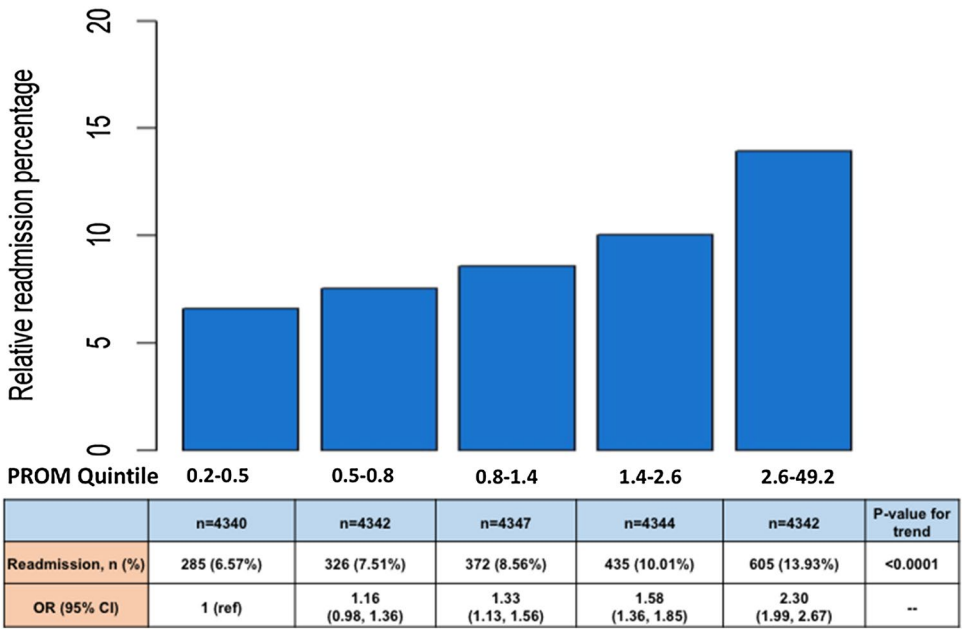

Fig. 3 Readmission by PROM quintile. Patients were divided into five equal groups based on PROM score

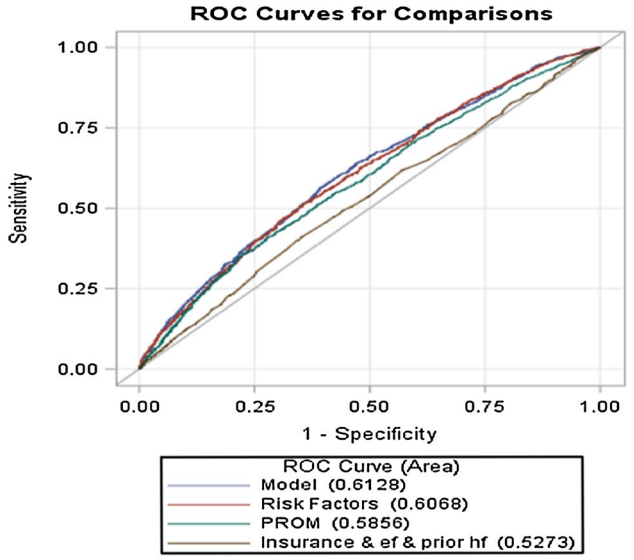

Fig. 4 Receiver-operator curves for predictive value of preoperative variables associated with 30-day readmission. Insurance status + ejection fraction + prior heart failure shown in brown, PROM alone shown in green, risk factors (age, BMI, previous creatinine, status, NYHA 3/4, COPD, diabetes, CVD, PAD, and immunocompromised) shown in red, and the model includes all risk factors and PROM shown in blue

long-term mortality, post-operative length of stay, and 30-day readmissions, without any additional calculations. Further investigation and validation of the PROM score for use in other risk-prediction analyses may expand its use for use in multiple clinical outcomes of significance.

Interestingly, our data demonstrated a significant correlation between mortality and readmission, with a 4.5-fold increase in mortality in those patients who suffered 30-day readmission. Our analysis, however, does not take into account the possible competing risk of death within 30 days unless those mortalities occurred upon readmission to our institution. Our data are consistent with larger trends for all surgical procedures demonstrating higher mortality associated with early hospital readmission [14].

An increasing body of surgical literature has focused on frailty as an operative risk factor. Frailty is an independent predictor of mortality and complications in cardiac surgery, but is not formally included in the PROM score risk calculation [15, 16]. Lee et al. demonstrated that frailty is an independent risk factor for mortality, and is associated with a nearly 2-fold increase in hospital mortality and 1.5-fold increase in mortality at 2 years [17]. CABG patients with a slow pre-operative gait speed (≥ 6 s to walk 5 m) had a two- to threefold increased risk of mortality and major morbidity compared with normal speed, even after controlling for PROM [18]. Furthermore, the addition of frailty to pre-operative risk scores demonstrates potential for improved metrics; the FORECAST score has been shown to be a superior predictor of 1-year mortality than the PROM or EuroSCORE following cardiac surgery [19]. While frailty has been linked in cardiac surgery patients to poor perioperative, short-term, and long-term outcomes, none have clearly been able to link frailty to risk of readmission [20, 21]. Interestingly, in a small prospective study of CABG and valve-replacement patients, frailty was only associated with worse perioperative outcomes (length of ICU and hospital stay, discharge to acute care facility, and STS complications), but was not associated with major outcomes, operative mortality, or readmission [22]. Perhaps the greatest difficulty in the addition of frailty to pre-operative risk stratification is that some of these scoring systems can be complex and challenging to implement in the clinical setting, and that there are a multitude of scoring systems that would each require validation.

While we have shown that the PROM score provides a reasonable predictive model for 30-day readmission, further work is needed to develop a scoring tool that can be implemented to accurately quantify a patient's risk of 30-day readmission prior to discharge from their post-operative stay. Additionally, consideration of the discharge destination is needed, as discharge to home vs a medical care facility implies differing risk for readmission. Implementation of early intervention programs aimed at preventing readmission would require an accurate scoring tool to identify those patients at highest risk for readmission. PROM, however, does serve as a reasonable surrogate for readmission risk during the preoperative care phase.

There are several notable limitations to this study. First, our data only capture those patients who were readmitted to our institution. Thus, we are likely underestimating our overall readmission rate, and there is no way to determine whether there is a specific patient population that is at risk for this bias. Reflective of the complex nature of readmission, while the PROM score is a modest predictor of readmission, we clearly have room to improve. As this was a retrospective review of a large dataset, we were unable to perform detailed analysis of the reasons for readmission. There is a large subset of patients who were readmitted for a reason not otherwise classified, and the reasons for readmission likely play a role in the predictive capacity of the scoring model. Additionally, as this is a single-center study, practice patterns, surgical decision-making, and patient selection may make broad generalizations inappropriate. Finally, our model only incorporated pre-operative variables, and based on prior studies, readmission risk is also tied to intraoperative and post-operative variables.

The results from this study demonstrate that the STS PROM score is a reasonable predictor of early hospital readmission following CABG. The PROM score can be used to help identify patients at high risk for readmission during pre-operative consultation, develop and test interventions to optimize outpatient management and care integration,

and potentially prevent unnecessary early hospitalization to reduce healthcare costs and improve patient quality of life. Further investigation of the potentially preventable etiologies of early post-CABG readmissions is needed to develop appropriate treatment protocols to reduce unnecessary admissions and contribute to improved post-CABG patient care.

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Compliance with ethical standards

Conflict of interest There are no relevant conflicts of interest to report for any of the authors.

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