A score to estimate 30-day mortality after intensive care admission after cardiac surgery

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ABSTRACT

Objective: Several risk-scoring systems have been developed to predict surgical mortality and complications in cardiac surgical patients, but none of the current systems include factors related to the intraoperative period. The purpose of this study was to develop a score that incorporates both preoperative and intraoperative factors so that it could be used for patients admitted to a cardiac surgical intensive care unit (ICU) immediately after surgery.

Method: Preoperative and intraoperative data from 30,350 patients in four hospitals were used to build a multiple logistic regression model estimating 30-day mortality after cardiac surgery. Sixty percent of the patients were used as a derivation group and forty percent as a validation group.

Results: Mortality occurred in 2.6% of patients (n = 790). Preoperative factors identified in the model were age, female sex, emergency status, pulmonary hypertension, peripheral vascular disease, renal dysfunction, diabetes, peptic ulcer disease, history of alcohol abuse, and refusal of blood products. Intraoperative risk factors included the need for an intra-aortic balloon pump, ventricular assist device or extracorporeal membrane oxygenation leaving the operating room, presence of any intraoperative complication reported by the surgeon, the use of inotropes, high-dose vasopressors, red blood cell transfusion, and cardiopulmonary bypass time. When used after surgery at ICU admission, the model had C-statistics of 0.86 in both derivation and validation sets to estimate the 30-day mortality.

Conclusions: Preoperative and intraoperative variables can be used on admission to a cardiac surgical ICU to estimate 30-day mortality. The score could be used for risk stratification after cardiac surgery and evaluation of performance of cardiac surgical ICUs. (*J Thorac Cardiovasc Surg* 2017;153:1118-25)

Receiver operating characteristic curve for determining 30-day mortality.

Central Message

The intensive care unit score could be used for risk stratification after cardiac surgery and evaluation of performance of cardiac surgical intensive care unit.

Perspective

Cardiac surgical intensive care unit (ICU) management has been the focus of many recent advances. Still, the evaluation of an ICU performance is difficult to separate from surgical and anesthesiology expertise. A score was designed to help clinicians assess patients recovering from heart surgery and determine their estimated 30-day mortality when entering the ICU. This score could help in benchmarking cardiac ICU performance.

See Editorial Commentary page 1126.

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Many risk-scoring systems have been developed to predict outcomes for cardiac surgical patients. Most of those scores are designed to be used preoperatively, to predict postoperative outcomes such as operative mortality,¹⁻⁴ long-term mortality,⁵ or postoperative morbidity.^{1,2,6-8} By design, they are based on premorbid conditions of the patient and the predicted surgery.

Scanning this QR code will take you to supplemental tables for this article.

Abbreviations and Acronyms

CABG	= coronary artery bypass grafting
CPB	= cardiopulmonary bypass
ECMO	= extracorporeal membrane oxygenation
EuroSCORE	= European System for Cardiac Operative Risk Evaluation
IABP	= intra-aortic balloon pump
ICU	= intensive care unit
OR	= odds ratio
ROC	= receiver operating characteristic
STS	= Society of Thoracic Surgeons
VAD	= ventricular assist device

Specific risk-scoring systems (the Sequential Organ Failure Assessment score,⁹ Acute Physiology and Physical Health Evaluation score,¹⁰ Multiple Organ Dysfunction score)¹¹ currently are used in the intensive care unit (ICU). Those systems are used to counsel patients and their families about the risk of poor outcomes as well as to evaluate the performance of a unit against expected outcomes. Cardiac surgical patients are a relatively low-risk intensive care population.¹² This makes the use of general ICU scoring systems inadequate.

However, both preoperative and ICU systems do not include intraoperative information to refine their predictive probability. Only a few systems were designed and derived from small populations to identify the key factors affecting mortality on entrance to the cardiac surgical ICU, including preoperative and operative variables.¹³⁻¹⁵ Those scores, however, were developed more than a decade ago from single centers, in an era during which surgical patients and ICU strategies differed significantly from contemporary practice. The purpose of this study was to create a new score to estimate 30-day mortality based on preoperative factors and operative information available when leaving the operating room and entering the ICU.

METHODS**Data Source and Study Population**

The British Columbia Provincial Cardiac Registry, administered by Cardiac Services BC, an agency of the Provincial Health Services Authority in British Columbia, is a prospective clinical registry created in 1990 for documentation, research, and educational needs of cardiac surgeons in the province.¹⁶ This registry has collected information on every cardiac surgical procedure, including cardiac surgery, angioplasty, and pacemaker/defibrillator surgery that were done at all 4 cardiac surgery centers that provided adult open-heart surgery services in this Canadian province. These 4 centers are the only providers of cardiac surgery in British Columbia, with a population of 4.7 million in 2015. More than 3700 heart surgeries are performed annually at these centers.

After each operation, surgeons were requested to complete a 16-page questionnaire that contained more than 200 demographic and clinical fields

with details of the patient's preoperative risk factors as well as relevant intraoperative information. To report intraoperative complications, a nonexclusive list was provided to surgeons with an open field to allow them to enter this subjective information. The presence or absence of complication was considered as a binary event for analysis. The data were collected and entered into the database by a clerk, which simultaneously generated an operative report that was later uploaded to the central provincial database for vital status yearly. Reliability of the data contained in the registry was demonstrated previously with an audit, which found a consistency rate of 86.4% between data from the registry and patient charts.¹⁶

All adult patients (≥ 18 years) who had on- and off-pump coronary artery bypass grafting (CABG), valvular replacements and repairs, ascending aortic procedures, and combined procedures performed in British Columbia between January 2000 and December 2009 were included from this registry. Patients undergoing transcatheter valvular interventions, congenital surgical interventions, percutaneous coronary interventions, and ventricular assist device (VAD) implantation surgeries were excluded. Regarding VAD insertion, long-term VADs were excluded but unplanned postcardiotomy extracorporeal membrane oxygenation (ECMO) or temporary VAD (Impella) was included in the study. Pediatric patients (< 18 years) also were excluded from the study. Procedural success was not required for inclusion. If the same patient came back in the study period, he/she was entered as a new patient unless reoperation occurred within 30 days, in which case only the first procedure was considered. The database was anonymized before analysis to assure confidentiality. Potential risk factors were chosen from existing literature and our clinical experience, and the association of each with 30-day mortality was examined. This study was approved by the University of British Columbia - Providence Health Care Research Ethics Board.

Statistical Analysis

A logistic regression model was developed and validated to estimate 30-day mortality. The study population was divided randomly into 2 cohorts. The first, a derivation cohort consisting of 60% of cases, was used to develop the risk score model (derivation data set). The second comprised the remaining 40% of cases and was used to validate the constructed model (validation data set). Random allocation was achieved by designing the SAS program to divide the cohort to 60% and 40% by completely random selection.

Candidate variables for estimating 30-day mortality after surgery included patient demographics, comorbidities, various clinical features and intraoperative risk factors (Table E1). Continuous variables such as renal function were divided into clinically meaningful categories. The χ^2 and Student *t* test were used to compare variables between derivation and validation sets. The univariate logistic model was used to determine the univariate association between these variables and 30-day mortality in the derivation set. Variables that were significantly associated ($P < .05$) with 30-day mortality in the univariate analysis or that were considered to be clinically important risk factors for 30-day mortality were assessed in a stepwise logistic regression analysis. Only significant risk factors ($P < .05$) in the multiple logistic regression analysis were kept in the final predictive model. Cases with missing values for any of the identified risk factors were excluded from the model building and validation. When there was a missing value for any covariates in the final model, the entire case was excluded from the final model.

For each patient, a risk score was calculated based on the final multivariable model and the area under the receiver operating characteristic (ROC) curve was constructed for both derivation set and validation set to assess the predictive ability of the model. The Hosmer-Lemeshow goodness of fit test was used to evaluate the model fit for both data sets. All statistical analyses were carried out with the statistical analysis software SAS 9.1.3 (SAS Institute Inc, Cary, NC).

RESULTS

A total of 30,350 patients were enrolled in the British Columbia Cardiac Surgery Registry from January 2000 to December 2009. In this population, overall 30-day mortality rate was 2.6%. The mean age of the studied population was 66, and 75.6% of patients were male. As for surgical interventions, 64.0% of patients underwent isolated CABG, 16.8% had a valve procedure of which 13.6% were single valve and 3.2% were multiple valves, 14.2% had CABG plus a valve procedure of which 12.6% were with single valve and 1.6% were with multiple valves, and 4.9% underwent an aortic procedure. Patients in the derivation and validation data sets had similar clinical characteristics except for number of diseased vessels and ongoing myocardial infarctions (Table 1).

A total of 18,207 patients were identified in the derivation cohort, of whom 492 (2.7%) died. The greatest mortality rates were observed in patients undergoing CABG with multiple valve procedures (8.1%), followed by multiple valve procedures (7.3%) and aortic procedures (6.4%). Univariate analysis (Table E2) identified age, sex, body surface area, New York Heart Association class, pulmonary hypertension, diabetes, renal function, peptic ulcer, alcohol abuse, refusal of blood products, type of surgery, emergency and urgent status for surgery, ongoing myocardial infarction, peripheral and cerebrovascular diseases, congestive heart failure, preoperative arrhythmia, impaired pulmonary function, history of open heart surgery, preoperative intra-aortic balloon pump (IABP) insertion, intraoperative complications (Table E3), time in operating room, cardiopulmonary bypass (CPB) time, transfusion of blood products, use of high-dose vasopressors, use of inotropes, ECMO, and VAD as independent risk factors of in-hospital mortality. In addition to the surgical procedure performed, 18 factors were identified (Table 2). A total of 11 preoperative variables categorized as demographic (age and female sex) or comorbidities and clinical features (emergency status, left main stenosis/3-vessel disease, pulmonary hypertension, peripheral vascular disease, renal function, diabetes, peptic ulcer/gastrointestinal bleed history, alcohol abuse, and refusal of blood products) and 7 intraoperative variables (usage of intraoperative IABP, VAD/ECMO, inotropes, high-dose vasopressors, packed cells, intraoperative complications, and CPB time) were associated with 30-day mortality. Detailed definitions of variables are provided in Table 3. Surgical procedure groups were forced into the final model. A total of 134 (0.7%) cases were excluded from model building because of missing values for any of the identified risk factors. A total of 18,207 observations were read in; 18,073 observations were used. No imputation was performed on the final model. The ROC curve for the derivation data set is shown in Figure 1. The area under the ROC curve was 0.857,

indicating strong model discrimination. The Hosmer-Lemeshow statistic was not significant ($\chi^2_{8df} = 5.9070$; $P = .6577$), indicating a good model calibration.

The final model was assessed for discrimination and calibration in the validation data set. A total of 298 of 12,143 (2.5%) patients died in this cohort. Only 109 (0.9%) cases were excluded from the validation set due to missing values. The predictive accuracy of the model was measured by an area under the ROC curve of 0.856 (Figure 2), and the Hosmer-Lemeshow statistic was not significant ($\chi^2_{8df} = 2.5841$; $P = .9577$), indicating good calibration.

The risk score was derived from the final logistic regression model. Estimated risk of mortality (in percent) for each patient was calculated by the use of weights assigned to each risk factor via the following equation:

$$\text{Estimated Mortality (\%)} = 100 \left(\frac{e^{(\beta_0 + \sum \beta_i X_i)}}{1 + e^{(\beta_0 + \sum \beta_i X_i)}} \right)$$

where β_0 is the intercept and β_i is the estimate of the variable X_i in the logistic regression model. For categorical risk factors, $X_i = 1$ if the risk is present and 0 if absent. CPB time is entered in hours with $X_i = 0$ for off pump procedures. As for age, $X_i = \text{age}/10$.

To test the hypothesis that incorporation of intraoperative variables improves the predictive performance of mortality risk, the model was rerun using only the preoperative variables plus the intended operation. The following intraoperative variables were excluded from reanalysis: IABP, VAD/ECMO, intraoperative complications, inotropes, high-dose vasopressors, packed cells, and CPB time. The C-statistic of the model decreased from 0.857 to 0.823 after rerunning it with only preoperative variables.

DISCUSSION

In this study, we describe a new scoring system based on preoperative and intraoperative risk factors designed to help clinicians assess the risk of 30-day mortality in patients at the time that they enter the cardiac surgical ICU. The final model included 18 factors that were associated with this outcome; model discrimination and calibration in both derivation and validation data sets were excellent.

The choice of variables was based on clinical experience of the ICU at the 4 participating centers, as well as existing literature. For instance, alcohol abuse has been associated previously with perioperative complications such as infections, cardiopulmonary complications, and bleeding in all types of surgeries.¹⁷ Our results corroborate this finding in cardiac surgery and identify alcohol abuse as one of 18 risk factors predictive of mortality. Pulmonary hypertension, a well-known prognostic factor in cardiac surgery, is associated with increased morbidity and mortality.¹⁸ It is therefore not surprising that it has been

TABLE 1. Comparison of baseline demographics, clinical characteristics, and hospital mortality rates between the derivation and validation cohorts

Variable	Derivation set, (%) (n = 18,207)	Validation set, n (%) (n = 12,143)	P value
Age, y, mean $\pm$ SD	66.3 $\pm$ 10.8	66.3 $\pm$ 10.8	.5023
Female sex	4448 (24.4)	2960 (24.4)	.9146
Body surface area, mean $\pm$ SD	1.9 $\pm$ 0.2	2.0 $\pm$ 0.2	.4910
Body mass index, mean $\pm$ SD	28.0 $\pm$ 5.2	27.9 $\pm$ 5.1	.6074
Left ventricular function (EF)	17,689 (97.2)	11,762 (96.9)	.5664
<35%	1053 (6.0)	666 (5.7)	
35%-50%	7440 (42.1)	4947 (42.1)	
>50%	9196 (52.0)	6149 (52.3)	
NYHA class	17,007 (93.4)	11,307 (93.1)	.7462
Class I (normal)	1351 (7.9)	919 (8.1)	
Class II (mild)	2802 (16.5)	1900 (16.8)	
Class III (moderate)	3198 (18.8)	2062 (18.2)	
Class IV (severe)	1168 (6.9)	771 (6.8)	
None	8488 (49.9)	5655 (50.0)	
Pulmonary hypertension	2570 (14.2)	1660 (13.7)	.2877
Diabetes mellitus	5376 (29.5)	3482 (28.7)	.1063
Renal function, mL/min/1.73 m ²	17,597 (96.7)	11,720 (96.5)	.0617
eGFR $\geq$ 60	11,902 (67.6)	8042 (68.6)	
30 $\leq$ eGFR $\leq$ 59	5132 (29.2)	3338 (28.5)	
15 $\leq$ eGFR $<$ 30	392 (2.2)	217 (1.9)	
0 $<$ eGFR $<$ 15 or dialysis	171 (1.0)	123 (1.1)	
Surgery	18,207 (100)	12,143 (100)	
Aortic procedure	877 (4.8)	623 (5.1)	.2167
CABG only	11,705 (64.3)	7732 (63.7)	.2749
CABG + single valve	2287 (12.6)	1547 (12.7)	.6461
CABG + multiple valves	283 (1.6)	202 (1.7)	.4575
Single valve	2482 (13.6)	1653 (13.6)	.9616
Multiple valves	573 (3.2)	386 (3.2)	.8773
Priority status for surgery	18,140 (99.6)	12,092 (99.6)	.0929
Emergency	770 (4.2)	485 (4.0)	
Priority I (urgent)	3581 (19.7)	2331 (19.3)	
Priority II	12,310 (67.9)	8201 (67.8)	
Priority III	1479 (8.2)	1075 (8.9)	
Number of diseased vessels	18,207 (100)	12,143 (100)	.0225
None	3432 (18.8)	2321 (19.1)	
1-2 vessels	3237 (17.8)	2298 (18.9)	
3 vessels	8037 (44.1)	5257 (43.3)	
Main left stenosis	3501 (19.2)	2267 (18.7)	
Ongoing myocardial infarction (MI $\leq$ 24 h)	360 (2.0)	199 (1.7)	.0322
Peripheral vascular disease	3034 (16.7)	1969 (16.2)	.2999
Cerebrovascular disease (CVA, TIA) recent $<$ 6 mo	269 (1.5)	192 (1.6)	.4628
Congestive heart failure	5858 (32.2)	3888 (32.0)	.7693
Malignant ventricular arrhythmia (preoperative arrhythmia)	2510 (13.8)	1599 (13.2)	.1314
Impaired pulmonary function (COPD, asthma, etc)	3679 (20.2)	2444 (20.1)	.8543
History of myocardial infarction	8781 (48.4)	5867 (48.5)	.8475
History of open heart surgery	1139 (6.3)	766 (6.3)	.8520
History of percutaneous coronary intervention	3309 (18.3)	2216 (18.4)	.8484
High-dose vassopressors postsurgery	206 (1.1)	118 (1.0)	.1848
Inotropes	11,803 (64.8)	7846 (64.6)	.7031
30-d operative mortality	492 (2.7)	298 (2.5)	.1834

SD, Standard deviation; EF, ejection fraction; NYHA, New York Heart Association; eGFR, estimated glomerular filtration rate; CABG, coronary artery bypass grafting; MI, myocardial infarction; CVA, cerebrovascular accident; TIA, transient ischemic attack; COPD, chronic obstructive pulmonary disease.

TABLE 2. Logistic regression model for 30-day mortality in the derivation cohort

Variables	Coefficient β	P value	Odds ratio	95% Wald CI
Intercept	$\beta_0 = -10.2028$	<.0001		
CABG only	0		1	
Ascending aortic procedure	0.7711	.001	2.162	1.366-3.422
CABG + single valve	0.3322	.0306	1.394	1.031-1.884
CABG + multiple valves	0.4669	.1061	1.595	0.905-2.81
Single valve	0.6825	.0012	1.979	1.31-2.988
Multiple valves	1.1051	<.0001	3.02	1.809-5.04
Age	0.5549	<.0001	1.742	1.551-1.956
Female sex	0.3704	.001	1.448	1.162-1.805
Emergency	1.4929	<.0001	4.45	3.275-6.047
Urgent	0.4966	<.0001	1.643	1.291-2.091
Left main stenosis/3-vessel disease	0.4198	.005	1.522	1.135-2.041
Pulmonary hypertension	0.4976	<.0001	1.645	1.294-2.09
Peripheral vascular disease	0.434	.0002	1.543	1.232-1.934
eGFR 15-59	0.2923	.0057	1.339	1.089-1.648
Renal failure (eGFR < 15)	0.4521	.0047	1.572	1.148-2.151
Diabetes mellitus	0.2732	.0122	1.314	1.061-1.627
Peptic ulcer, GI bleed history	0.5183	.0022	1.679	1.205-2.34
Alcohol abuse	0.5647	.0157	1.759	1.113-2.781
Refusal of blood products	1.8595	<.0001	6.421	2.673-15.426
Intraoperative IABP	0.977	<.0001	2.657	1.908-3.698
VAD/ECMO	1.6479	.0016	5.196	1.865-14.476
Intraoperative complication	0.9199	<.0001	2.509	1.936-3.251
Inotrope	0.5315	<.0001	1.701	1.348-2.147
High-dose vasopressors	0.6204	.004	1.86	1.219-2.838
Packed cells	0.3158	.0075	1.371	1.088-1.728
CPB time (in hours)	0.2442	<.0001	1.277	1.155-1.412

CI, Confidence interval; CABG, coronary artery bypass grafting; eGFR, estimated glomerular filtration rate; GI, gastrointestinal; IABP, intra-aortic balloon pump; VAD, ventricular assist device; ECMO, extracorporeal membrane oxygenation; CPB, cardiopulmonary bypass.

recognized as an important risk factor in the logistic model. Our risk model also identified renal function as a risk factor for mortality. In a study conducted on 843 patients undergoing cardiac surgery with CPB, postoperative renal function deterioration resulted not only to increased in-hospital mortality but also adversely affected long-term survival.¹⁹ Assessing renal function is therefore important in predicting ICU outcomes. Other factors such as use of inotropes, vasopressors and assist devices indicate severity

of patient condition postoperatively. These factors also have been identified in the risk model.

Risk factors with greatest impact on the score were patient's refusal of blood products (odds ratio [OR] 6.421) followed by VAD insertion and use of ECMO on leaving the operating room (OR 5.196). Emergency operative status (OR 4.45), multiple valves procedures (OR 3.02), insertion of intraoperative IABP (OR 2.657), and complications arising during the operation (OR 2.509), defined as any

TABLE 3. Variable definitions

Variable	Definition
Pulmonary hypertension	Mean pulmonary artery pressure >25 mm Hg
Intra-aortic balloon pump	Procedure performed or assistant device leaving operating room
Ventricular assist device/extracorporeal membrane oxygenation	Procedure performed or assistant device leaving operating room
Intraoperative complication (Table E3)	Any intraoperative complication reported by surgeon, such as resistant atrial fibrillation, low-output syndrome postcardiopulmonary bypass, prosthetic valve malfunction, CABG malfunction, coagulopathy, and others
Inotrope	Adrenaline, dobutamine, milrinone, or high-dose dopamine (>10 $\mu\text{g/kg/min}$) leaving the operating room
High-dose vasopressors	Norepinephrine >10 $\mu\text{g/min}$ or more than one vasopressor (norepinephrine and vasopressin) used in the same patient
Packed cells	Any packed red blood cell transfusion
Cardiopulmonary bypass time	Complete cardiopulmonary bypass pump time per minutes, off pump = 0

CABG, Coronary artery bypass grafting.

FIGURE 1. ROC curve for the logistic model in the derivation set. The C-statistic was 0.857. ROC, Receiver operating characteristic.

intraoperative complication reported by the surgeon, also were among high-impact risk factors.

Several predictive models have been developed to assess the risk of mortality after cardiac surgery.^{10,13,15} An important limitation of these models is that they fail to consider intraoperative variables and rely exclusively on

FIGURE 2. ROC curve for the logistic model in the validation set. The C-statistic was 0.856. ROC, Receiver operating characteristic.

preoperative risk factors. In contrast, the Cardiac Surgery ICU Score incorporates both preoperative and intraoperative risk factors. This allows for consideration of the patient's status at the end of the surgery.

Numerous studies have evaluated the predictive performance of existing preoperative risk models in different population cohorts. In one study,²⁰ the discriminative ability of the European System for Cardiac Operative Risk Evaluation (EuroSCORE) II, EuroSCORE I, and the Society of Thoracic Surgeons (STS) risk score was 0.844, 0.819, and 0.846, respectively, for operative mortality in a cohort of 11,788 cardiac surgery patients. The predictive value of those same scores in a cohort of 450 patients undergoing aortic valve replacement and/or CABG procedure was 0.587, 0.669, and 0.699 for the EuroSCORE I, EuroSCORE II, and STS score, respectively.²¹ In a Brazilian population of 659 patients submitted to isolated CABG surgery, the predictive performance of the STS score for postoperative mortality was 0.76.²² C-statistics for all those scores are inferior to that of our model (0.857). Similarly, the C-statistic of our model was lowered to 0.823 when rerun using only preoperative variables. Therefore, incorporation of intraoperative variables improved the predictive performance of our mortality risk model.

Available ICU scoring systems include a score developed at the Cleveland Clinic Foundation in 1997,¹³ which is calculated on admission to ICU and includes preoperative, operative, and postoperative values, predicting postoperative morbidity and mortality. A study by Wong and colleagues¹⁴ also permits the integration of pre-, intra-, and postoperative factors into prediction of mortality, prolonged ventilation, and prolonged ICU length of stay. Those studies, however, used data in an era in which surgical patients, intraoperative techniques and CPB technology, and ICU strategies differed significantly from the recent years. In fact, despite an increase in patient's risk factors over the years, operative mortality and morbidity have been decreasing significantly.²³⁻²⁷ Consequently, those scores have not been adopted widely. For example, in Canada, despite an increase in case complexity with older and sicker patients than in previous years, mortality rates after CABG decreased from 3.1% in 1992/1993 to 2.1% in 2000/2001.²⁸

According to data from the Canadian Institute for Health Information, cardiac procedures in Canada are performed at a rate of 144 per 100,000 population for percutaneous coronary intervention procedures, 94 per 100,000 population for CABG procedures, 16 per 100,000 population for isolated valve procedures, and 10 per 100,000 population for combined CABG and valve surgeries.^{29,30} Procedure costs of those surgeries are variable. One of the most significant determinants of surgical cost is the presence of postoperative

complications and prolonged stay in ICU.³¹ Many scoring systems can allow clinicians to estimate the risk of mortality, prolonged ICU stay, and morbidity in the preoperative period^{1,3,6,8,32-36}; however, although many scores are used every day in the general ICU, very few are designed to evaluate the risk of mortality after undergoing a cardiac operation.

More recently, 2 risk assessment scores after cardiac surgical ICU admission were developed: The Acute Physiology and Physical Health Evaluation IV score, which can be calculated from preoperative factors and some physiological values observed on admission to ICU,¹⁰ and the Cardiac Surgery Score system.¹⁵ Both of these scores can predict ICU mortality after admission and can be used during the ICU stay to allow a daily adjustment of the patients risk profile. Both scores, however, require a number of daily variables including some that might not be readily available or reliable at the time of admission to the ICU, such as laboratory values or level of consciousness. These scores are not specific for cardiac surgery or do not include variables from the intraoperative period.

Tools to assess postoperative care are necessary as our systems are imperfect, and approximately one third of in-hospital CABG deaths are deemed preventable.³⁷ Preoperative risk stratification is still important but needs to be reset after surgery. Ideally, a cardiac surgical ICU admission risk score would take into consideration known preoperative and intraoperative risk factors and could be calculated easily at the exit of the operating room or at ICU admission. It should not include actions or values measured after ICU admission. With such a score, a snapshot picture of the disease severity upon entrance to the ICU would permit comparison of patients from different units, similar to how preoperative assessments are used. This score can be useful to identify those patients at greatest risk of poor outcome and to counsel families on prognosis. In addition, by comparing estimated mortalities to observed mortalities, this score can be useful as a quality management tool for continuous monitoring of ICU outcomes and allow hospitals to evaluate the performance of their ICUs.

The database used in this study has the advantage of being a large database that completely captures all cardiac surgical procedures performed in this province. The 4 institutions were scrutinized yearly with compelling results. In addition, because institution cannot be separated completely from some risk factors, it was not used to estimate mortality. Although some institutions do more heart failure surgery, others might do more CABG surgery, and some more aortic procedures. Therefore, adding the institution would introduce a bias as those factors are already evaluated in the model. Furthermore, some surgeons may practice in more than one institution, which would as well introduce a bias. Because the study covers the database up to 2009 and that

no significant modification in the postoperative management or outcomes was observed, results were deemed representative of the current era.

Limitations

Although the predictive accuracy of the model was high with an area under the ROC curve of 0.86, the score remains imperfect, with 14% of mortalities not accounted by this model. The accuracy of this model, however, is superior to other scores in cardiac surgery.²

Given that 30-day mortality was the chosen endpoint for this model, the small percentage of deaths occurring after more than 30 days of hospitalization were not considered. This is therefore a difference from the STS definition of operative mortality.

Another limitation of this study is the omission of ejection fraction as a risk factor in the final model. A significant proportion of patients had acute coronary syndromes during, which stunning or inotrope usage may lead to over and underestimation of the true left ventricular ejection fraction. These data were, therefore, not uniformly present or stable in all patient datasets. Furthermore, after many attempts at forcing ejection fraction in the model with no added benefit on predicting outcome, it was estimated that other factors in the equation accounted for ejection fraction and allowed adequate estimation of 30-day mortality. It is clear that ejection fraction has a significant impact on long term outcomes, however, factors such as CPB time, dose of inotropes and vasopressors, intraoperative IABP, intraoperative complications and ECMO/VAD leaving the operating room, might represent most of the early phase hazard of death for patients with reduced ejection fraction. Because the available data varied significantly among patients and because we could not find predictive value after multiple attempts at categorizing ejection fraction, we decided not to use it as a variable in modelling.

CONCLUSIONS

We have developed a new score to estimate 30-day mortality after cardiac surgery for patients who are admitted to cardiac surgery ICUs based on pre- and intraoperative risk factors. Although preoperative risk stratification is important, mortality risk also needs to be assessed immediately after surgery because the surgery represents a turning point for the patient and the beginning of the ICU care. This new score is, therefore, based on preoperative factors and operative information available when leaving the operating room or entering intensive care. Further assessment of this score should include external validation. The score is usable on the Canadian Cardiovascular Critical Care Society (CANCARE) Web site at <http://www.cancare-society.com/cardiac-surgery-icu-score/>. It can also be used on the QxMD mobile application at <https://www.qxmd.com/calculate/bc-cardiac-surgical-intensive-care-score>.

Conflict of Interest Statement

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Key Words: cardiac surgery, intensive cardiac care unit, risk score

TABLE E1. Candidate variables considered for modeling

Candidate variables
Demographic
Age
Body surface area
BMI
Sex
Clinical features
NYHA class
Number of diseased coronary arteries
Left ventricular ejection fraction
Creatinine clearance
Priority status for surgery
Previous cardiac surgery
Type of procedure
Intraoperative risk factors
Time in operating room
Cardiopulmonary bypass time
Aortic crossclamp time
Circulatory arrest time
Insertion of an IABP (intraoperative IABP)
Number of pump runs
Transfusions of packed red blood cells
Transfusions of pooled platelets or fresh-frozen plasma
Vasopressors and dosage leaving the operating room
Presence of inotropes leaving the operating room
Support with ECMO leaving the operating room
VAD - Impella
Postoperative status
Postoperative prognosis
Rhythm at crossclamp removal
Vasodilators postoperatively
Intraoperative complications
Single crossclamp
Comorbidities
Cerebrovascular disease
CVA/TIA remote >6 mo
CVA/TIA recent 6 mo
Peripheral arterial disease
Peripheral vascular disease
Left ventricular hypertrophy
Congestive heart failure (current or history)
Malignant ventricular arrhythmia (preoperative arrhythmia)
Impaired pulmonary function (COPD, asthma, etc)
Left main coronary disease (stenosis 50%)
Diabetes mellitus
Dialysis
Renal failure (acute/chronic)
Active endocarditis
Previous endocarditis
Systemic hypertension
Pulmonary hypertension
Family history of coronary artery disease
Valvular heart disease
Dilated cardiomyopathy
Cardiomegaly
Dyslipidemia

TABLE E1. Continued

Candidate variables
Preoperative IABP
History of myocardial infarction
Ongoing myocardial infarction
Recent myocardial infarction ≤ 6 wk
Myocardial infarction > 6 wk
Marfan syndrome
Preoperative ventilation/Intubation
Addison disease
Hypothyroidism
Chronic steroid use
Liver disease
Peptic ulcer, GI bleed history
Malignant disease
Controlled < 5 y
Controlled > 5 y
Anemia
HIV+/AIDS
Other immunosuppressed
Collagen disease
Depression, other mood disorders
Coagulopathy (hyper and hypo)
History of open-heart surgery
History of PCI
Smoking history
Remote (discontinued > 1 mo)
Smoker or discontinued < 1 mo
History of alcohol abuse
History of drug abuse
History of chemical dependence
Refusal of blood products

BMI, Body mass index; *NYHA*, New York Heart Association; *IABP*, intra-aortic balloon pump; *ECMO*, extracorporeal membrane oxygenation; *VAD*, ventricular assist device; *CVA*, cerebrovascular accident; *TIA*, transient ischemic attack; *COPD*, chronic obstructive pulmonary disease; *GI*, gastrointestinal; *PCI*, percutaneous coronary intervention.

(Continued)

TABLE E2. Univariate association between baseline, clinical and operative characteristics, and 30-day mortality in the derivation cohort

Variable	Occurrence of events				
	Death n (%)	Nondeath n (%)	OR	95% CI	P value
Number (%)	492 (2.7)	17,715 (97.3)			
Age, mean $\pm$ SD	71.8 $\pm$ 9.5	66.1 $\pm$ 10.8	1.06	(1.05-1.07)	<.0001
Sex					
Female	186 (4.2)	4262 (95.8)	1.92	(1.59-2.31)	<.0001
Male	306 (2.2)	13,453 (97.8)			
Body surface area, mean $\pm$ SD	1.9 $\pm$ 0.3	2.0 $\pm$ 0.2	0.32	(0.22-0.48)	<.0001
Body mass index, mean $\pm$ SD	27.4 $\pm$ 5.8	28.0 $\pm$ 5.2	0.98	(0.96-1.00)	.0271
NYHA class					
Class I (normal)	20 (1.48)	1331 (98.5)	1.12	(0.70-1.82)	.6334*
Class II (mild)	68 (2.4)	2734 (97.6)	1.86	(1.37-2.52)	<.0001*
Class III (moderate)	128 (4.0)	3070 (96.0)	3.12	(2.41-4.03)	<.0001*
Class IV (severe)	134 (11.5)	1034 (88.5)	9.69	(7.48-12.56)	<.0001*
Pulmonary hypertension					
Yes	190 (7.4)	2380 (92.6)	4.09	(3.39-4.93)	<.0001
No	298 (1.9)	15,270 (98.1)			
Diabetes mellitus					
Yes	177 (3.3)	5199 (96.7)	1.36	(1.13-1.64)	.0012
No	313 (2.4)	12,510 (97.6)			
Renal function, mL/min/1.73 m ²					
eGFR $\geq$ 59	177 (1.5)	11,725 (98.5)			
30 $\leq$ eGFR < 59	240 (4.7)	4892 (95.3)	3.25	(2.67-3.96)	<.0001†
15 $\leq$ eGFR < 30	25 (6.4)	367 (93.6)	4.51	(2.93-6.95)	<.00018†
0 < eGFR < 15 or dialysis	21 (12.3)	150 (87.7)	9.27	(5.74-14.99)	<.0001†
Peptic ulcer/GI bleed history					
Yes	50 (4.7)	1006 (95.3)	1.89	(1.40-2.55)	<.0001
No	438 (2.6)	16,644 (97.4)			
Alcohol abuse					
Yes	28 (4.0)	672 (96.0)	1.53	(1.04-2.27)	.0302
No	460 (2.6)	16,978 (97.4)			
Refusal of blood products					
Yes	6 (7.6)	73 (92.4)	3.00	(1.30-6.92)	.0102
No	482 (2.7)	17,577 (97.3)			
Surgery					
Aortic procedure	56 (6.4)	821 (93.6)	2.64	(1.98-3.52)	<.0001
CABG only	203 (1.7)	11,502 (98.3)	0.38	(0.32-0.46)	<.0001
CABG + single valve	111 (4.9)	2176 (95.2)	2.08	(1.68-2.58)	<.0001
CABG + multiple valves	23 (8.1)	260 (91.9)	3.29	(2.13-5.09)	<.0001
Single valve	57 (2.3)	2425 (97.7)	0.83	(0.63-1.09)	.1806
Multiple valves	42 (7.3)	531 (92.7)	3.02	(2.18-4.19)	<.0001
Priority status for surgery					
Emergency	122 (15.8)	648 (84.2)	13.07	(8.15-20.96)	<.0001‡
Priority I (urgent)	120 (3.4)	3461 (96.7)	2.41	(1.51-3.84)	.0002§
Priority II	228 (1.9)	12,082 (98.2)	1.31	(0.84-2.06)	.2397
Priority III	21 (1.4)	1458 (98.6)			
Number of diseased vessels					
1-2 vessels	69 (2.1)	3168 (97.9)	1.35	(0.99-1.84)	.0582¶
3 vessels	203 (2.5)	7834 (97.5)	1.19	(0.90-1.57)	.2179#
Main left stenosis	100 (2.9)	3401 (97.1)			
Ongoing myocardial infarction (MI $\leq$ 24 h)					
Yes	51 (14.2)	309 (85.8)	6.56	(4.81-8.96)	<.0001
No	436 (2.45)	17,338 (97.6)			

(Continued)

TABLE E2. Continued

Variable	Occurrence of events				
	Death n (%)	Nondeath n (%)	OR	95% CI	P value
Peripheral vascular disease					
Yes	146 (4.8)	2888 (95.2)	2.18	(1.79-2.65)	<.0001
No	344 (2.3)	14,821 (97.7)			
Cerebrovascular disease (CVA, TIA) remote <6 mo					
Yes	15 (5.6)	254 (94.4)	2.17	(1.28-3.69)	.004
No	473 (2.7)	17,396 (97.4)			
Congestive heart failure					
Yes	299 (5.1)	5559 (94.9)	3.42	(2.85-4.11)	<.0001
No	191 (1.55)	12,151 (98.5)			
Preoperative arrhythmia					
Yes	159 (6.3)	2351 (93.7)	3.15	(2.59-3.82)	<.0001
No	329 (2.1)	15,299 (97.9)			
Impaired pulmonary function (COPD, asthma, etc)					
Yes	152 (4.1)	3527 (95.9)	1.81	(1.49-2.20)	<.0001
No	338 (2.3)	14,181 (97.7)			
History of myocardial infarction					
Yes	283 (3.2)	8498 (96.8)	1.49	(1.24-1.79)	<.0001
No	204 (2.2)	9149 (97.8)			
History of open heart surgery					
Yes	73 (6.4)	1066 (93.6)	2.72	(2.11-3.52)	<.0001
No	418 (2.5)	16,625 (97.6)			
History of percutaneous coronary intervention					
Yes	103 (3.1)	3206 (96.9)	1.23	(0.99-1.53)	.067
No	377 (2.6)	14,429 (97.5)			
Preoperative IABP					
Yes	107 (23.9)	341 (76.1)	6.701	(4.92-9.13)	<.0001
No	385 (2.2)	17,374 (97.8)			
Intraoperative complications					
Yes	154 (13.9)	956 (86.1)	7.989	(6.53-9.77)	<.0001
No	338 (2.0)	16,759 (98.0)			
Time in operating room	343.9 (100.2)	291.1 (75.4)	1.007	(1.01-1.01)	<.0001
Cardiopulmonary bypass time, mean $\pm$ SD	2.8 (1.5)	1.9 (0.9)	1.829	(1.72-1.95)	<.0001
Transfusion of packed red blood cells					
Yes	293 (6.83)	3996 (93.2)	5.055	(4.21-6.07)	<.0001
No	199 (1.4)	13,719 (98.6)			
Transfusion of pooled platelets or fresh-frozen plasma					
Platelets					
Yes	172 (10.2)	1522 (89.9)	5.719	(4.72-6.93)	<.0001
No	320 (1.9)	16,193 (98.1)			
Fresh-frozen plasma					
Yes	176 (11.0)	1419 (89.0)	6.396	(5.28-7.75)	<.0001
No	316 (1.9)	16,296 (98.1)			
High-dose vasopressors postsurgery					
Yes	48 (23.3)	158 (76.7)	12.013	(8.58-16.82)	<.0001
No	444 (2.47)	17,557 (97.5)			
Inotropes					
Yes	425 (3.6)	11,378 (96.4)	3.533	(2.73-4.58)	<.0001
No	67 (1.1)	6337 (99.0)			
ECMO					
Yes	6 (66.7)	3 (33.3)	72.885	(18.18-292.28)	<.0001
No	486 (2.7)	17,712 (97.3)			

(Continued)

TABLE E2. Continued

Variable	Occurrence of events				
	Death n (%)	Nondeath n (%)	OR	95% CI	P value
Ventricular assist device					
LVAD					
Yes	2 (6.9)	27 (93.1)	2.674	(0.63-11.28)	.1804
No	490 (2.7)	17,688 (97.3)			
RVAD					
Yes	1 (25.0)	3 (75.0)	12.040	(1.25-115.87)	.0313
No	491 (2.7)	17,712 (97.3)			
Rhythm at crossclamp removal					
Sinus	363 (2.3)	15,451 (97.7)	1.215	(0.72-2.05)	.4634**
VT/VF	1 (3.6)	27 (96.4)	1.916	(0.24-15.04)	.5362**
Other	113 (7.2)	1461 (92.8)	4.001	(2.32-6.91)	<.0001**
Missing	15 (1.9)	776 (98.1)			
Single crossclamp					
Yes	211 (2.6)	7789 (97.4)	0.957	(0.80-1.15)	.6333
No	281 (2.8)	9926 (97.3)			

OR, Odds ratio; CI, confidence interval; SD, standard deviation; NYHA, New York Heart Association; eGFR, estimated glomerular filtration rate; GI, gastrointestinal; CABG, coronary artery bypass grafting; MI, myocardial infarction; CVA, cerebrovascular accident; TIA, transient ischemic attack; COPD, chronic obstructive pulmonary disease; IABP, intra-aortic balloon pump; ECMO, extracorporeal membrane oxygenation; LVAD, left ventricular assist device; RVAD, right ventricular assist device; VT, ventricular tachycardia; VF, ventricular fibrillation. *Compared with class 0 patients with no functional limitations. †Compared with eGFR ≥ 59 . ‡Compared with Priority III status. §Compared with Priority II status. ||Compared with Priority III status. ¶Compared with left main stenosis. #Compared with 1-2 vessels. **Compared with missing.

TABLE E3. Intraoperative complications

Intraoperative complications
Bleeding
Tamponade
Arrhythmia
Foreign body
Graft problem
Valve problem
Mediastinitis
Intraoperative death
Patient deterioration requiring STAT cardiopulmonary bypass
Aortic dissection
A-V disruption post-MVR
Resistant ventricular fibrillation
Other ventricular arrhythmias
Hemorrhage
Resistant atrial fibrillation
Low-output syndrome postcardiopulmonary bypass
Prosthetic valve malfunction
CABG malfunction
Coagulopathy
Other

A-V, Atrioventricular; MVR, mitral valve replacement; CABG, coronary artery bypass grafting.