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Risk Factors of Delayed Extubation, Prolonged Length of Stay in the Intensive Care Unit, and Mortality in Patients Undergoing Coronary Artery Bypass Graft with Fast-track Cardiac Anesthesia

A New Cardiac Risk Score

David T. Wong, M.D., Davy C. H. Cheng, M.D.,† Rafal Kustra, M.Sc.,‡ Robert Tibshirani, Ph.D.,§ Jacek Karski, M.D.,* Jo Carroll-Munro, R.N.,‖ Alan Sandler, M.D.#*

Background: **Risk factors of delayed extubation, prolonged intensive care unit (ICU) length of stay (LOS), and mortality have not been studied for patients administered fast-track cardiac anesthesia (FTCA). The authors' goals were to determine risk factors of outcomes and cardiac risk scores (CRS) for CABG patients undergoing FTCA.**

Methods: **Consecutive CABG patients undergoing FTCA were prospectively studied. Outcome variables were delayed extubation > 10 h, prolonged ICU LOS > 48 h, and mortality. Univariate analyses were performed followed by multiple logistic regression to derive risk factors of the three outcomes. Simplified integer-based CRS were derived from logistic models. Bootstrap validation was performed to assess and compare the predictive abilities of CRS and logistic models for the three outcomes.**

Results: **The authors studied 885 patients. Twenty-five percent had delayed extubation, 17% had prolonged ICU LOS, and 2.6% died. Risk factors of delayed extubation were increased age, female gender, postoperative use of intraaortic balloon pump, inotropes, bleeding, and atrial arrhythmia. Risk factors of prolonged ICU LOS were those of delayed extubation plus preoperative myocardial infarction and postoperative renal insufficiency. Risk factors of mortality were female gender, emergency surgery, and poor left ventricular function. CRSs were modeled for the three outcomes. The area under the receiver operating characteristic curve for the CRS–logistic models was not significantly different: 0.707/0.702 for delayed extubation, 0.851/0.855 for prolonged ICU LOS, and 0.657/0.699 for mortality.**

Conclusion: **In CABG patients undergoing FTCA, the authors derived and validated risk factors of delayed extubation, prolonged ICU LOS, and mortality. Furthermore, they developed a simplified CRS system with similar predictive abilities as the logistic models. (Key words: Coronary artery bypass graft; fast-track cardiac anesthesia; outcome; predictors; risk score.)**

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* Assistant Professor, Department of Anesthesia, University Health Network.

† Associate Professor, Department of Anesthesia, University Health Network.

‡ Graduate Student, Department of Public Health Sciences, University of Toronto.

§ Professor, Department of Public Health Sciences, University of Toronto.

‖ Research Nurse Coordinator, Department of Anesthesia, University Health Network.

#Professor, Department of Anesthesia, University Health Network.

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Address reprint requests to Dr. Cheng: Department of Anesthesia, Toronto General Hospital, 585 University Avenue, BW 4-646, Toronto, Ontario, Canada M5G 2C4. Address electronic mail to: dcheng@torhosp.toronto.on.ca

CORONARY artery bypass graft (CABG) surgery is one of the most expensive major surgical procedures in North America. There were 20,649 CABG surgeries performed in Canada in 1991 and an estimated 485,000 in the United States in 1993.[1,2] With constraints in health care resources and increasing demand for services, providers need to contain costs in CABG surgery. Cardiac surgical patients also want to know the risks involved, and physicians need outcome data for quality assurance. Predictive models for mortality, morbidity, and intensive care unit (ICU) length of stay (LOS) have been developed for

CABG patients to allow patient risk assessment and comparison of outcome between institutions.[3–13] To apply predictive models derived from elsewhere to an independent population, the patient characteristics and surgical and anesthesia management must be comparable between the two populations.[14]

In the 1990s, fast-track cardiac anesthesia (FTCA) technique, consisting of low-dose fentanyl (10–15 μg/kg) and propofol infusion, has been demonstrated to be generally safe for early tracheal extubation and mobilization of CABG patients.[15] FTCA allows extubation within 6 h of completion of surgery compared with 12–24 h for patients having conventional cardiac anesthesia. FTCA has resulted in significant reduction in ICU LOS, hospital LOS, resource utilization, and cost without adversely affecting mortality and morbidity.[16] Because of its safety and cost effectiveness, FTCA has been rapidly incorporated by cardiac centers worldwide. However, predictors of early extubation, ICU LOS and mortality for FTCA patients have not been fully defined. As well, there are currently no published reports on fast-track cardiac risk scoring systems. The objectives of this study were to identify perioperative risk factors of delayed extubation, prolonged ICU LOS, and mortality in CABG patients undergoing FTCA and to develop a simplified cardiac risk scoring system that can be used by clinicians.

Material and Methods

Design and Patient Population

This prospective observational study was performed at the Toronto Hospital, a university teaching hospital cardiac center. After institutional approval, from April 1995 to November 1995, consecutive patients undergoing CABG surgery were included in the study. All patients underwent a FTCA protocol.

Fast-track Cardiac Anesthesia Protocol

Preoperative, intraoperative, and postoperative management were as follows: CABG patients were admitted to the hospital on the day of surgery or day(s) before surgery. Lorazepam, 1–3 mg administered sublingually, was given 1.5 h before surgery. Monitoring consisted of electrocardiography, noninvasive blood pressure cuff, pulse oximetry, capnography, and arterial and pulmonary artery catheters. Anesthesia induction consisted of administration of intravenous midazolam, 1–3 mg, fentanyl, 10–15 μg/kg, with or without propofol, 50–100 mg. Pancuronium, 0.15 mg/kg, was given before tracheal intubation. Anesthesia was maintained with isoflurane, 0–2%, and oxygen before cardiopulmonary bypass (CPB). Propofol infusion, 2–6 mg $\cdot$ kg^{-1} $\cdot$ h^{-1}, was initiated during CPB and maintained for 1–4 h in the ICU. At completion of surgery, patients were directly admitted to the ICU. While in the ICU, postoperative sedation with propofol was adjusted to achieve a Ramsay sedation score of 3 or 4. The Ramsay sedation score was graded as follows: (1) anxious, agitated; (2) cooperative, oriented, accepting ventilation; (3) responding to verbal commands only; (4) responding to gentle shaking; (5) responding to noxious stimulation; and (6) no response to noxious stimulation. Shivering was treated with administration of intravenous meperidine, 25–50 mg. Persistent systemic hypertension (systolic blood pressure $>$ 140 mmHg) was treated with infusion of nitroglycerin or nitroprusside or both to a target systolic blood pressure of 90–130 mmHg. An intravenous bolus of esmolol, 20 mg, or propranolol, 1 mg, was used to maintain a heart rate of $<$ 110 beats/min. An indomethacin, 50–100 mg, suppository was given for pain control at arrival in the ICU unless the patient's creatinine level was more than 150 mM or if he or she had a history of bleeding peptic ulcer disease. Patients were assessed for tracheal extubation within 1–6 h of arrival to ICU (Appendix 1).[15,16] Analgesia was maintained after extubation by administration of intravenous morphine, 1–mg. When patients fulfilled ICU discharge criteria (Appendix 2)[15,16] and when ward beds were available, they were transferred to the surgical ward.

Surgical Procedure

Patients underwent a median sternotomy. Saphenous veins and internal thoracic (mammary) arteries were harvested as conduits. Aortic and right atrial cannulae were inserted. Myocardial protection was achieved with intermittent antegrade cold blood cardioplegic infusion through the aortic root. Systemic temperature was allowed to drift down to 33°C during CPB. Hematocrit was maintained above 18%. CPB pump flow was maintained at 2.0–2.5 l $\cdot$ min^{-1} $\cdot$ m^{-1}. The mean perfusion pressure was kept at 50–60 mmHg by administration of isoflurane, nitroprusside, or phenylephrine. Patients were actively rewarmed to 38°C (nasopharyngeal) before removal of the aortic cross-clamp and weaning from CPB.

Data Collection

Preoperative, intraoperative, postoperative, and outcome variables collected are listed below. Preoperative variables collected included age; sex; height; weight; any medical history of hypertension, diabetes, chronic obstructive pulmonary disease, cerebral vascular accident, transient ischemic attack, cirrhosis, or renal insufficiency (creatinine level > 150 mM); any cardiac history including timing of myocardial infarct (none, < 1 week, 1 week to 3 months, 3–6 months, > 6 months, timing unknown), left ventricular function (grades 1–4), history of congestive heart failure, arrhythmia, or atrial fibrillation; prescribed medications including inotropic use, antiarrhythmic use, β-adrenergic receptor blocker, calcium receptor antagonist, or nitrates; intraaortic balloon pump; timing of surgery (emergency, urgent, elective) or repeat surgery.

Intraoperative variables collected included number of coronary grafts; the use of an arterial graft; duration of CPB, cross-clamp; CPB: degree of hypothermia, cardioplegia technique (intermittent, continuous, antegrade, retrograde), intraoperative systolic hypotension (> 80 mmHg for 5 min), tachycardia (> 100 beats/min for 5 min), cardiac ischemia (ST depression > 1 mm for 5 min); and post–CPB support: inotropes, intraaortic balloon pump, pacing, number of attempts coming off CPB.

Postoperative ICU variables collected included extubation time, ICU morbidity from stroke or myocardial infarction (creatine kinase [CK] MB > 50 U/l and > 8% of total CK), and 12-lead electrocardiographic changes from baseline in two or more leads. Cardiac enzymes were sampled 8, 16, and 24 h postoperatively, whereas electrocardiographs were done daily for 3 days. Variables also collected included atrial arrhythmia or ventricular arrhythmia requiring medication to treat, cardiac arrest, tracheal reintubation, pneumonia, pulmonary embolism, acute respiratory distress syndrome, renal insufficiency (increase in creatinine level of 100% or that requiring dialysis), excessive bleeding (> 750 ml in 6 h) and use of drugs or other support, including inotrope, pacing, or intraaortic balloon pump.

Outcome variables included delayed extubation defined *a priori* as extubation time > 10 h (which corresponded to 75th percentile of extubation time in our preliminary data), prolonged ICU LOS defined as stays more than 48 h (based on review of the literature and our clinical experience),[15,16] and mortality (death occurring within 30 days of surgery or during hospital stay).

The preoperative and intraoperative data were collected by staff anesthesiologists, and ICU and mortality data were collected by research nurses. Perioperative data were entered into a computer database (Microsoft ACCESS 7.0, Microsoft Corp, Roselle, IL).

Statistical Analyses

Statistical analyses were performed by the Department of Public Health Sciences at the University of Toronto.

Univariate analyses and multiple logistic regression analyses were performed to identify risk factors of delayed extubation, prolonged ICU LOS, and mortality. As mortality risks were primarily used for patient counseling before surgery, we assessed only preoperative variables as predictors of mortality. However, because preoperative, intraoperative, and postoperative factors were all associated with ICU LOS,[9] we included perioperative variables in determining risk factors of prolonged ICU LOS and delayed extubation.

Univariate Analyses

Univariate analyses were initially performed to identify perioperative risk factors associated with outcomes (delayed extubation, prolonged ICU LOS, and mortality) using chi-square analyses or Fisher exact test. Different cut-off points for continuous variables (*e.g.*, age, CPB time) were examined to determine the best association with outcome. A P value of < 0.05 was considered significant. Odds ratios were calculated to indicate the effect size of perioperative risk factors on outcome.

Multivariate Logistic Regression Analyses

Patients who died while still intubated were excluded from the development of delayed extubation and prolonged ICU LOS models. Variables associated with outcome with a P value < 0.05 in the univariate analyses and variables considered clinically significant were entered into separate multiple logistic regression models for delayed extubation, prolonged ICU LOS, and mortality to identify independent risk factors. This was performed using a stepwise logistic regression technique in Splus Environment[17](StatSci, MathSoft Inc, Seattle, WA). The odds ratios, 95% confidence intervals (CI), and P values were calculated for each risk factor in the final models. A P value of < 0.05 was considered statistically significant.

Development of Simplified Cardiac Risk Score

Calculation of probabilities of delayed extubation, prolonged ICU LOS, and mortality require computers or sophisticated calculators. To allow clinicians to use risk assessment in clinical settings, three simplified scoring systems were developed for mortality, prolonged ICU LOS, and delayed extubation. For each risk factor identified in the multiple logistic regression model for mortality, an integer score between 1 and 6 was given based

Table 1. Univariate Risk Factors of Delayed Extubation

Factor	Occurrence (%)	Odds Ratio	*P* Value
Preoperative			
Age > 60 yr	57.1	1.86	0.0002
Female gender	23.9	1.84	0.0006
Emergency	6.5	2.49	0.002
MI < 1 week	6.1	1.95	0.04
Renal insufficiency	9.6	1.83	0.02
Inotrope use	4.1	2.81	0.007
Intraaortic balloon pump	2.1	6.90	0.0001
Intraoperative			
Inotrope use	6.8	3.49	<0.0001
Intraaortic balloon pump	6.4	6.94	<0.0001
Cardiac pacing	31.6	1.66	0.02
CPB > 120 min	8.0	1.95	0.02
Postoperative			
Inotrope use	11.6	3.80	<0.0001
Intraaortic balloon pump	4.8	13.11	<0.0001
Stroke	1.0	10.21	0.04
Atrial arrhythmia	12.3	2.82	<0.0001
Ventricular arrhythmia	15.8	1.75	0.0007
Renal insufficiency	3.7	3.05	0.007
Excessive bleeding	3.6	6.33	<0.0001

MI = myocardial infarction; CPB = cardiopulmonary bypass.

on the odds ratios and clinical considerations.[3,4] The total risk score were calculated by summation of scores of the individual factors. The same process was performed to arrive at scores from risk factors of prolonged ICU LOS and delayed extubation.

Bootstrap Validation of Models and Cardiac Risk Scores

The logistic regression models and the cardiac risk scores (CRSs) derived from them were validated with bootstrapping techniques.[18–20] The area under the receiver operating characteristic (ROC) curve was used to assess the predictive performance of the models and CRSs.[21]

Bootstrapping involved drawing, with replacement, a random sample of 885 cases from the original 885 cases. Some cases could be included more than once, whereas others would not be included in this process. On average, a bootstrap sample contains 63% of cases from the original sample.[18] Cases included in the bootstrap sample constituted the bootstrap-derivation set, whereas cases "left out" constituted the bootstrap-validation set. For each bootstrap sample of 885 cases, stepwise logistic modeling was performed on the bootstrap-derivation set and subsequently applied to the bootstrap-validation set. For each case in the bootstrap-validation set, the probability of outcome and the actual outcome were noted. A ROC curve was then derived by plotting true-positive rates against false-positive rates, while the threshold for prediction of outcome varied from zero to one.[21] The area under the ROC curve is a measure of the overall discriminatory power of the predictive model. An area under the ROC curve value of 0.5 indicates random prediction, whereas a value of 1.0 indicates perfect discrimination. This sampling process was repeated 300 times, resulting in 300 random bootstrap samples with corresponding ROCs. The mean area under the ROC derived from the 300 samples was used as an estimate of the predictive performance of the logistic models and CRS if applied to a new population.

The predictive abilities of the CRS and the logistic models for the three outcomes were compared using areas under the ROC by utilizing paired *t* test with bootstrap estimates of variance. The calibration of the CRS models were assessed by bar graphs of observed and predicted outcomes with 95% CIs across various ranges of CRS risks.

Table 2. Univariate Risk Factors of Prolonged Length of Stay in the Intensive Care Unit

Factor	Occurrence (%)	Odds Ratio	*P* Value
Preoperative			
Age > 60 yr	57.1	2.15	0.001
Female gender	23.9	2.54	<0.0001
Emergency	6.5	2.68	<0.003
MI < 1 week	6.1	4.32	<0.0001
LV grade 4	4.5	2.60	0.02
Renal insufficiency	9.6	2.75	0.0002
Inotrope use	4.1	4.35	<0.0001
Antiarrhythmic	10.8	2.45	0.0005
Intraaortic balloon pump	2.1	12.11	<0.0001
Intraoperative			
Hypotension	5.3	3.47	0.0002
Ischemia	1.6	5.77	0.003
Inotrope use	6.8	4.18	<0.0001
Intraaortic balloon pump	6.4	14.36	<0.0001
Cardiac pacing	31.6	1.90	0.001
CPB > 120 min	8.0	2.37	0.005
Postoperative			
Inotrope use	11.6	9.60	<0.0001
Intraaortic balloon pump	4.8	26.67	<0.0001
Stroke	1.0	22.87	<0.0001
MI	1.5	11.58	<0.0001
Atrial arrhythmia	12.3	6.09	<0.0001
Ventricular arrhythmia	15.8	3.99	<0.0001
Pneumonia	1.4	75.60	<0.0001
Renal insufficiency	3.7	17.45	<0.0001
Excessive bleeding	3.6	3.42	0.002
Reintubation	1.6	9.58	<0.001

MI = myocardial infarction; LV = left ventricle; CPB = cardiopulmonary bypass.

Table 3. Univariate Risk Factors of Mortality

Factor	Occurrence (%)	Odds Ratio	*P* Value
Age > 60 yr	58.1	1.70	0.004
Female gender	23.9	3.91	0.002
Emergency	6.5	9.56	<0.0001
MI < 1 week	6.1	9.61	<0.0001
LV grade 4	4.5	6.6	0.0004
Arrhythmia	7.5	3.58	0.03
Renal insufficiency	9.6	3.50	0.02
Stroke	4.1	1.76	0.006
Inotrope use	4.1	2.60	0.0001
Intraaortic balloon pump	2.4	7.80	0.004

MI = myocardial infarction; LV = left ventricle.

Results

There were 885 consecutive CABG patients studied from April 1995 to November 1995. Seventy-six percent of patients were male and 24% were female. The mean ± SD age was 60.8 ± 11.3 yr. Fifty patients (5.6%) had repeat surgery performed. Twenty-three patients (2.6%) died.

Extubation time had a highly skewed distribution. The median extubation time was 7 h, with a range of 1–306 h. Seventy-five percent of patients were extubated by 10 h, 80.8% by 14 h, and 90.4% by 20 h. The ICU LOS also had a skewed frequency distribution. The median ICU LOS was 1 day, with a range of 1–37 days. By 48 h, 83.3% of patients were discharged from ICU; by 72 h, 91.8%.

From univariate analyses, 18 perioperative risk factors for delayed extubation were identified. The individual risk factors, occurrence, odds ratios, and *P* values are shown in table 1. Twenty-five perioperative risk factors for prolonged ICU LOS and 10 preoperative risk factors for mortality were found. They are shown in tables 2 and 3. From multiple logistic regression analyses, six risk factors of delayed extubation, eight risk factors of prolonged ICU LOS, and three risk factors of mortality were identified. The risk factors, occurrence, odds ratios, 95% CI, and *P* values are shown in tables 4, 5, and 6. The CRS for delayed extubation, prolonged ICU LOS, and mortality are shown in table 7.

Table 4. Risk Factors Associated with Delayed Extubation from Multiple Logistic Regression Analyses

Factor	Odds Ratio	95% CI	*P* Value
Preoperative			
Age (yr)			
>75	2.77	1.48–5.17	0.001
61–75	1.68	1.17–2.41	0.005
Female gender	1.59	1.09–2.33	0.02
Postoperative			
Excessive Bleeding	6.06	2.55–14.45	<0.0001
Intraaortic balloon pump	5.98	3.06–11.66	<0.0001
Inotropes	2.28	1.63–3.18	<0.0001
Atrial arrhythmia	1.63	1.10–2.42	0.01

CI = confidence interval.

Table 5. Risk Factors Associated with Prolonged Length of Stay in the Intensive Care Unit from Multiple Logistic Regression Analyses

Factor	Odds Ratio	95% CI	*P* Value
Preoperative			
Age (yr)			
>75	4.00	1.74–9.23	0.001
61–75	1.58	1.10–2.79	0.03
MI < 1 week	3.13	1.34–7.34	0.008
Female gender	2.60	1.53–4.44	0.0004
Postoperative			
Renal insufficiency	18.90	6.28–56.91	<0.0001
Intraaortic balloon pump	14.43	6.65–31.29	0.008
Inotropes	4.22	2.44–7.33	0.0001
Atrial arrhythmia	4.04	2.39–6.83	0.0001
Excessive bleeding	3.47	1.24–9.74	0.02

MI = myocardial infarction; CI = confidence interval.

Bootstrap validation was used for internal validation of the logistic models and CRS. The area under the ROC values from logistic regression models and CRS, for both the derivation data and bootstrap analyses, are shown for predictions of delayed extubation, prolonged ICU LOS, and mortality (table 8). There were no significant differences in area under the ROC values between the logistic regression models and CRS in comparison of the six paired numbers. The observed and predicted outcomes with 95% CI for the three outcomes are shown in figure 1. There were no significant differences between the observed and predicted outcomes at various CRS ranges.

Discussion

In our prospective study of 885 consecutive CABG patients undergoing FTCA, multiple logistic regression

Table 6. Risk Factors Associated with Mortality from Multiple Logistic Regression Analyses

Factor	Odds Ratio	95% CI	*P* Value
Left ventricle grade 4	5.34	1.69–16.89	0.007
Emergency surgery	4.64	1.60–13.42	0.001
Female	3.42	1.42–8.21	0.01

CI = confidence interval.

Table 7. Cardiac Risk Scores for Delayed Extubation, Prolonged Length of Stay in the Intensive Care Unit, and Mortality

Factor	CRS
Delayed extubation	
Preoperative	
Age > 75 yr	3
Age 61–75 yr	2
Female gender	2
Postoperative	
Excessive bleeding	6
Intraaortic balloon pump	6
Inotropes	2
Atrial arrhythmia	2
Prolonged ICU LOS	
Preoperative	
Age > 75 yr	4
Age 61–75 yr	2
Myocardial infarction	3
Female gender	3
Postoperative	
Renal insufficiency	6
Intraaortic balloon pump	6
Inotropes	4
Atrial arrhythmia	4
Excessive bleeding	3
Mortality	
Left ventricle grade 4	5
Emergency surgery	4
Female gender	3

CRS = cardiac risk score; ICU = intensive care unit; LOS = length of stay.

models were developed to identify risk factors associated with delayed extubation, prolonged ICU LOS, and mortality. To our knowledge, this is the first study to derive such risk factors and CRS in CABG patients undergoing FTCA.

Risk Factors of Delayed Extubation

We found that two preoperative variables (increased age and female gender) and four postoperative variables (usage of intraaortic balloon pump, inotropes, excessive bleeding, and atrial arrhythmia) were associated with delayed extubation. There are more postoperative factors with higher weights associated with delayed extubation than preoperative factors.

In a retrospective study by London *et al.*[22,23] involving 304 cardiac surgical patients on a "fast-track clinical pathway" wherein early extubation was defined as extubation in ≤ 10 h; one preoperative factor (age) and five intraoperative factors (sufentanil dose, fentanyl dose, inotrope use, platelet transfusion, use of arterial graft) were identified as independent predictors of delayed extubation. One confounding variable was that patients were rarely extubated between 12:00 AM and 5:00 AM because of limited nursing and housestaff coverage, even if they met extubation criteria. Only 48.3% of patients were successfully extubated early.

In a retrospective review of CABG patients by Arom *et al.*[24] wherein early extubation was defined as < 12 h, 269 early extubated and 376 late extubated patients were identified. Age, gender, preoperative diuretic use, and unstable angina were found to be associated with delayed extubation by logistic regression analysis. However, in Arom's study, patients were not treated in a fast-track protocol with the intent of early extubation. The cut-off criterion of 12 h was formulated *post hoc,* resulting in stratification of early and late extubation groups in review of cases.

In our study, all CABG patients underwent standardized FTCA with the intent to extubate 1–6 h postoperatively. We defined *a priori* extubation time > 10 h as delayed extubation, and 75% of patients were successfully extubated early. At our institution, anesthesia coverage was provided 24 h a day, and the medical and nursing staff in the cardiovascular ICU (CVICU) were instructed to extubate patients when extubation criteria were met, regardless of the time of the day. Our study design was a prospective observational study. The conclusion of London *et al.*[22] was consistent with ours: perioperative variables were more closely associated with delayed extubation than preoperative variables alone.

Risk Factors of Prolonged ICU LOS

We found that three preoperative variables (increased age, female gender, and myocardial infarction < 1 week) and five postoperative variables (usage of intraaortic balloon pump, inotropes, excessive bleeding, renal insufficiency, and atrial arrhythmia) were associated with

Table 8. Areas under the ROC Curves from Logistic Regression Models and Cardiac Risk Score for Predictions of Delayed Extubation, Prolonged ICU LOS, and Mortality

	Derivation		Bootstrap	
	Logistic	CRS	Logistic	CRS
Delayed extubation	0.742	0.728	0.702	0.707
Prolonged ICU LOS	0.894	0.889	0.855	0.851
Mortality	0.776	0.725	0.699	0.657

P value between areas under the ROC of logistic regression models and CRS were nonsignificant for all six comparisons.

ROC = receiver operating characteristic; ICU = intensive care unit; LOS = length of stay; CRS = cardiac risk score.

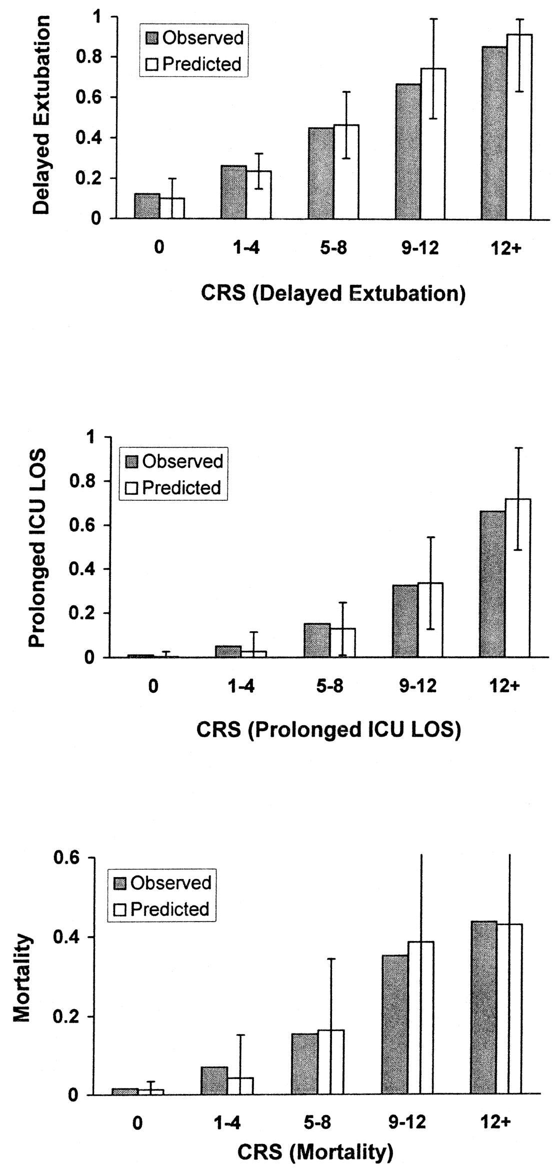

Fig. 1. The observed and predicted outcomes of delayed extubation (*top*), prolonged intensive care unit length of stay (*middle*) and mortality (*bottom*) across various CRS ranges are shown. The 95% confidence interval of the predicted outcomes are indicated by vertical bars superimposed on the predicted bars.

prolonged ICU LOS of > 48 h. Perioperative variables were more closely associated with prolonged ICU LOS than preoperative variables alone.

Although there were several studies comparing the ICU LOS between patients in the FTCA and non–FTCA protocol,[15,16,25–27] none had identified independent predictors of prolonged ICU LOS in FTCA patients.

Two studies assessed predictors of ICU LOS in cardiac patients undergoing non–FTCA. In cardiac surgery patients, Tu *et al.*[4] derived six predictors of ICU LOS ≥ 6 days and validated these predictors in an independent data set. The area under the ROC value was 0.66 in the validation data set. In our study, the area under the ROC value was 0.85 with bootstrap validation. In CABG patients, Becker *et al.*[9] identified acute physiology score component of APACHE III, age, sex, number of grafts, emergency surgery, and repeat surgery as predictors of ICU LOS. Among all factors, the postoperative acute physiology score was the most significant predictor. Becker stated that the predictive equation for ICU LOS was validated using group jackknife statistical technique. However, the area under the ROC value was not provided.

Risk Factors of Mortality

We found that female gender, emergency surgery, and poor left ventricular function were risk factors of mortality.

Among the FTCA literature,[15,16,25–30] none identified predictors of mortality. Among the non–FTCA literature,[3–10] age, gender, type of surgery, emergency surgery, repeat surgery, left ventricular function, previous myocardial infarction, cerebral vascular disease, and diabetes mellitus were identified by three or more references as independent predictors of mortality. The three preoperative risk factors of mortality we identified were consistent with the risk factors derived from the non–FTCA literature.

Mortality predictive figures are most useful for risk stratification for patient counseling and for comparison of performance between and within institutions. For preoperative patient counseling, intraoperative and postoperative factors are not available. Therefore, although intraoperative and postoperative factors are available at our disposal, we have chosen to use preoperative factors exclusively to identify risk factors of mortality.

Derivation and Validation of Cardiac Risk Scores

Risk factors of delayed extubation, prolonged ICU LOS, and mortality derived from logistic models were simplified into integer- valued CRS for the three outcomes. The rationale for formulation of the CRS is to equip clinicians with a simple integer-based additive cardiac scoring system, which allows bedside estimations of these three outcomes. Risk estimations cannot be made from predictors from logistic models unless computers are available. Are the predictive values from the CRS as good as those from the logistic models from which they are derived?

Bootstrap analyses and the area under the ROC values that we obtained indicated that there were no differences in predictive abilities between the CRS and the logistic models for the three outcomes.

There are no reported CRS in the FTCA literature. Among studies in the non–FTCA literature, four[3,4,7,10] developed integer- based CRS for mortality, morbidity, or ICU LOS. Higgins[3] evaluated the predictive accuracy of a CRS for mortality in a prospective independent data set. The CRS was found to be well calibrated, but the area under the ROC value was not stated. Tu[4] evaluated the predictive ability for mortality and ICU LOS $\geq$ 6 days of an integer-based risk scoring system in a validation data set. The area under the ROC values were 0.75 and 0.66, respectively. Parsonnet[7] attempted to validate the predictive ability of an additive integer-based CRS for mortality. He reported a $r = 0.99$ from linear regression analysis of observed *versus* predicted mortality. However, calibration and ROC analysis were not performed. Tuman[10] formulated and evaluated the predictive ability of a CRS for morbidity but not for mortality.

For risk factors of delayed extubation, prolonged ICU LOS, and mortality, we showed that the predictive ability was the same between the logistic and the CRS models. We recommend use of the CRS because we found the additive integer-based CRS easier to comprehend and to use for clinicians compared with the logistic models. They may be used for patient counseling, quality assessment, and allocation of ICU resources.

Limitations of the Study

First, our risk factors were derived from 885 CABG patients undergoing FTCA. Although the numbers are not large, they represent the largest series in the FTCA literature. Our series consisted of consecutive CABG patients without the bias of preselection of patients.

Second, our data were collected from a single tertiary referral cardiac center. The logistic and CRS models need to be validated in a prospective multicenter data set before its widespread application. On the other hand, in gathering data from one institution, we do not have vast interinstitutional variation in patient selection, quality of anesthesia and surgical care, and interpretation of definition in data collection.

Third, our logistic and CRS models were validated using a bootstrapping technique, not external validation using an independent data set. Bootstrapping had been used in clinical investigations as a statistical instrument to internally validate models derived from logistic regression analyses.[31,32] Harrell *et al.* stated that "bootstrapping provides nearly unbiased estimates of predictive accuracy that are of relatively low variance, and fewer model fits are required than cross-validation."[19] It was also stated that bootstrapping is more efficient in estimation of model predictive accuracy than split-sample validation or cross-validation.[19] However, because of the differences in patient case-mix in other cardiac centers, external validation of our CRS models in independent data sets is still recommended before application in other populations.

Fourth, in a statistical sense, the total score in CRS should be derived from multiplication of weighted scores of individual components, not their addition. However, as addition of weighted scores of individual factors is much easier to perform than the multiplication and as the performance of the CRS using the addition of individual weighted scores was similar to the logistic model,[33] we have elected to keep the additive integer-based CRS models for clinical purpose.

Conclusion

In 885 consecutive CABG patients undergoing FTCA, we derived risk factors associated with delayed extubation, prolonged ICU LOS, and mortality. Furthermore, we developed a simplified integer-based CRS, which performed just as well as the more complicated logistic models in prediction of the three outcomes. External validation of these CRS models in an independent data set is recommended before widespread use in fast-track cardiac surgical patients.

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Appendix 1: Trachea Extubation Criteria

- Patient responsive and cooperative
- Negative inspiratory force > -20 cm water
- Vital capacity > 10 ml/kg
- Arterial oxygen tension > 80 mmHg
- $F_{I_{O_2}} < 0.50$
- Cardiac index $> 2.0\ l \cdot min^{-1} \cdot m^{-2}$
- Oropharyngeal temperature $> 36.0°C$
- $pH > 7.30$
- Chest tube drainage < 100 ml/h $\times$ 2 h
- Absence of uncontrolled arrhythmia

Appendix 2: ICU Discharge Criteria

- Alert and cooperative patient
- No inotropic support and no significant arrhythmia
- Adequate ventilation and oxygenation (arterial oxygen tension > 80 mmHg, arterial carbon dioxide tension < 60 mmHg, arterial oxygen saturation $> 90\%$, $F_{I_{O_2}} < 0.50$)
- Chest tube drainage < 50 ml/h $\times$ 2 h
- Urinary output $> 0.5\ ml \cdot kg^{-1} \cdot h^{-1}$
- No active seizures