Coronary artery bypass grafting: Are risk models developed from on-pump surgery valid for off-pump surgery?

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Objective: This study was undertaken to test whether risk models developed from on-pump coronary artery bypass grafting are valid for assessing the risk for off-pump coronary artery bypass grafting.

Methods: From January 1997 through June 2002, a total of 12,845 patients underwent isolated coronary artery bypass grafting procedures in Providence Health System hospitals. Of these, 1782 operations (14%) were performed without cardiopulmonary bypass. An operative mortality risk model was derived from on-pump data with logistic regression. This model and two other external risk models developed from on-pump data were then applied to patients undergoing off-pump coronary artery bypass grafting to test the model adequacy.

Results: Good model discrimination and calibration were obtained from all three models.

Conclusion: Operative mortality risk models developed from on-pump coronary artery bypass grafting can be used to assess the risk for off-pump coronary artery bypass grafting.

In a recent editorial on coronary artery bypass grafting (CABG), accompanying an article by Mack and colleagues¹ that presented the results of off-pump CABG (OPCAB), Bonchek² posed an interesting question: "Are the risk models in the Society of Thoracic Surgeons (STS) National Database, which are derived from experience with on-pump CABG, valid for assessing risk for patients undergoing OPCAB?" We tried to find the answer from an analysis of 5 years' experience with 12,845 isolated CABG surgeries in the Providence Health System (PHS) collaborative cardiac database.

Methods

Patients

From January 1997 through June 2002, a total of 12,845 patients underwent isolated CABG procedures in 9 PHS hospitals. Of these, 1782 operations (14%) were performed without cardiopulmonary bypass. Table 1 compares the major features of the on-pump CABG and OPCAB groups. All nine PHS hospitals participating in the cardiac surgery programs collected the data according to the same definitions, and the data were merged into the PHS collaborative cardiac database (see Appendix Table 1 for details).

Statistical Methods

To test whether risk models derived from on-pump CABG surgery are valid for assessing the risk of OPCAB, the PHS data were split into two subsets. The patients who underwent on-pump CABG were used as the training set for model development, and the OPCAB group was used as the test set for model validation. An operative mortality risk model was developed by logistic regression with the training set only. Model entry criteria were set at $P < .20$, and removal criteria were set at $P \geq .20$. The resulting model was then applied to the test set to test the model adequacy for OPCAB. Two other risk models, the Northern New

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TABLE 1. Clinical characteristics of on-pump CABG and OPCAB groups

	On-pump CABG	OPCAB
Age (y, mean $\pm$ SD)	65 $\pm$ 11	67 $\pm$ 11
Ejection fraction (%; mean $\pm$ SD)	57 $\pm$ 15	58 $\pm$ 14
Body surface area (m ² , mean $\pm$ SD)	2.0 $\pm$ 0.2	2.0 $\pm$ 0.2
No. of diseased vessels (mean $\pm$ SD)	2.2 $\pm$ 0.9	2.1 $\pm$ 1.0
Female (%)	24%	28%
Surgical urgency (%)		
Elective	55%	62%
Urgent	39%	35%
Emergency	6%	3%
Salvage	0.3%	0.1%
History of cerebrovascular disease (%)	11%	13%
History of peripheral vascular disease (%)	15%	15%
History of renal failure (%)	4%	6%
Diabetes (%)	31%	31%
History of chronic lung disease (%)	15%	11%
Systemic hypertension (%)	30%	30%
Pulmonary hypertension (%)	3%	2%
Mitral insufficiency (%)		
Mild	7%	8%
Moderate	15%	4%
Severe	0.2%	0.1%
History of congestive heart failure (%)	18%	12%
Left main stenosis >50% (%)	20%	26%
New York Heart Association functional class (%)		
I	38%	52%
II	16%	10%
III	24%	23%
IV	22%	15%
Canadian Cardiovascular Society class IV (%)	32%	31%
Preoperative intra-aortic balloon pump (%)	4%	4%
Previous cardiac surgery (%)	8%	5%
Operative mortality (%)	2.3%	2.5%

England (NNE) risk model (unpublished model, provided by courtesy of Dr Pamela Jenkins) and the logistic EuroSCORE model,³ (<http://www.euroscore.org/logisticEuroSCORE.htm>), both of which were developed from on-pump surgery only, were also applied to the patients undergoing OPCAB. We did not apply the Society of Thoracic Surgeons (STS) CABG risk model because not all the risk factors in STS CABG risk model were collected in the PHS collaborative cardiac database.

For both the training and test sets, the area under the receiver operating characteristic curve, also called the *C-statistic*,⁴ which evaluates the ability of a model to correctly classify dead and alive, was used to measure model discrimination. The Hosmer-Lemeshow test⁵ was used to measure model calibration, the agreement between estimated and actual mortality.

Applying external risk models (eg, NNE or EuroSCORE) may lead to overestimation or underestimation of the predicted risk, because perfect matching of risk factors from one system to another is unlikely. Unlike poor discrimination, however, poor calibration can be improved by secondary logistic regression (us-

TABLE 2. C-Statistics and Hosmer-Lemeshow test

	C-statistic	Hosmer-Lemeshow test
OPCAB		
On-pump PHS	0.781	0.511
Calibrated NNE	0.827	0.708
Calibrated EuroSCORE	0.802	0.453
All CABG		
Final PHS	0.806	0.376
Calibrated NNE	0.786	0.669
Calibrated EuroSCORE	0.780	0.456

ing the original logit as an independent risk factor)⁶. We calibrated the two external models so that the overall predicted operative mortality would be equal to the observed.⁷ The discrimination was unchanged by recalibration.

Results

The demographic and clinical characteristics were similar for the on-pump and OPCAB groups (Table 1). *P* values are not given because *P* < .05 does not necessarily mean the difference has clinical significance, especially when the sample sizes are large.

The risk model developed from the on-pump training set is described in Appendix Table 2. Twelve variables were found to be risk factors for operative death. The C-statistic for this model was 0.810, which indicated good discrimination, and the *P* value for the Hosmer-Lemeshow test was .937, which indicated good calibration. For the test set, the C-statistic was 0.781 and the Hosmer-Lemeshow test *P* value was .511, which also indicated good discrimination and calibration, respectively. Good model discrimination and calibration were also obtained when applying NNE and EuroSCORE risk models to the test set (Table 2). Because the PHS risk model derived from on-pump data works efficiently in predicting operative death for patients undergoing OPCAB, we combined the training set and the test set and produced a final PHS model (Appendix Table 2). We also applied the NNE and the EuroSCORE risk models to the entire set of patients. The C-statistic and the Hosmer-Lemeshow test showed that all the three models performed well (Table 2). We compared the final PHS-predicted risks with the calibrated NNE-predicted risks (Figure 1) and the calibrated EuroSCORE (Figure 2) for all patients undergoing CABG, on and off pump, and good agreement was found between PHS and the two external models.

Discussion

The 1996 STS CABG risk model was developed from a cohort of patients who underwent on-pump CABG from 1990 through 1996.⁸ Bonchek² asked whether the STS risk models for on-pump CABG were valid to assess the risk of OPCAB, because some variables unique to OPCAB that

Figure 1. Scattergram of calibrated NNE predicted risk versus PHS predicted risk. Small gray dots indicate patients alive; large black dots indicate patients dead. Horizontal and vertical axes are in logit scale. Diagonal line is 45° line of perfect agreement. Both gray and black dots are almost equally distributed around diagonal line, which indicates good agreement between calibrated NNE predicted risk and PHS predicted risk. Black dots get denser as logits get larger on both risk scales, which means larger predicted risk is associated with higher mortality.

could affect mortality, morbidity, and the selection of patients for OPCAB were not being collected (eg, intramyocardial coronary arteries, diffuse coronary disease, small and poor-quality target vessels, aortic atherosclerosis, left ventricular hypertrophy). With regard to mortality, we tried to answer the question by using a simple model validation method, data splitting. The risk model for operative mortality derived from our PHS on-pump data performed well with our OPCAB data. This was confirmed when two external risk models that also had been derived from on-pump data were applied. It is true that not all the potential risk factors are always available for selection, and no risk model can identify all the risk factors. The PHS, NNE, and EuroSCORE risk models may have not considered all of the potentially important risk factors for OPCAB (and perhaps not even for on-pump CABG), but although none are ideal, they all worked well in assessing the operative mortality among patients undergoing OPCAB. Sergeant and associates⁹ used the EuroSCORE risk model¹⁰ to evaluate their OPCAB experience and obtained good model discrimination. The NNE risk model used in this study was based on on-pump data only, but the NNE Cardiovascular Disease Study Group has recently compared the risk-adjusted mortality and morbidity between on-pump CABG and OPCAB, and all the patients undergoing CABG were used to develop the logistic regression models¹¹. Though the OPCAB group was excluded from the published 1996 STS risk model, the

same set of risk factors for the STS mortality and morbidity risk models have been used to develop the risk models for all patients undergoing CABG; these models were thereafter used to compare risk-adjusted mortality and morbidity between on-pump CABG and OPCAB.¹²

This study has some technical limitations. We have not validated the comparability of these risk models within the STS Database. Furthermore, our database assigned patients to the on-pump or OPCAB groups solely on the basis of the operation they finally underwent and did not assess the incidence or influence of intraoperative conversion from OPCAB to on-pump CABG. We also did not assess the potential influence of differences in mortality among different surgeons. As pointed out in Bonchek's editorial,² the report of OPCAB results by Mack and colleagues¹ revealed marked differences in mortality among surgeons, and those with the lowest operative mortality rates performed the vast majority of OPCAB procedures. This phenomenon may have influenced the observation of Cleveland and colleagues¹² that operative mortality in the STS Database was lower for OPCAB than for on-pump CABG. The influence of the surgeon's skill and experience on the on-pump versus OPCAB operative risk for any individual patient requires further study. Subject to these limitations, however, we conclude that risk model for operative mortality in the PHS Database that was developed from on-pump data can be used for assessing the risk for patients undergoing OPCAB.

Figure 2. Scattergram of calibrated logistic EuroSCORE vs. Providence Health System (PHS) predicted risk. Small gray dots indicate patients alive; large black dots indicate patients dead. Horizontal and vertical axes are in logit scale. Diagonal line is 45° line of perfect agreement. Both gray and black dots are almost equally distributed around diagonal line, which indicates good agreement between calibrated logistic EuroSCORE and PHS predicted risk. Black dots get denser as logits get larger on both risk scales, which means larger predicted risk is associated with higher mortality.

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See appendixes on page 178.

Appendix TABLE 1. Preoperative risk factors

Risk factor	Definition	Codes in regression
Age	Age in years	(Age - 60)/10
Female gender	Female gender	1, Female; 0, male
Ejection fraction	Last calculated ejection fraction; percent of blood emptied from left ventricle at end of contraction	Exact value or midpoint of range
Urgency	Status at entry to operating room	0, Elective; 1, urgent; 3, emergency; 6, salvage
History of cerebrovascular disease	History of cerebrovascular disease, documented by any of following: cerebrovascular accident, reversible ischemic neurologic deficit, transient ischemic attack, unresponsive coma >24 h, noninvasive or invasive carotid test with >75% occlusion	0, No; 1, yes
History of peripheral vascular disease	Peripheral vascular disease diagnosis from history of claudication, absent pedal pulses, positive noninvasive test result, abnormal arteriogram, previous vascular operations or amputation for nontraumatic arterial insufficiency; does <i>not</i> include carotid disease	0, No; 1, yes
History of renal insufficiency	History of acute or chronic renal insufficiency or dialysis, or history of creatinine >2.0 mg/dL	0, No; 1, yes
Previous cardiac surgery	Previous CABG, valve replacement or repair, aortic root replacement or reconstruction, or congenital heart surgery	0, No; 1, yes
Left main	Categorized percentage of stenosis	0, ≤50%; 1, >50%
New York Heart Association functional class	New York Heart Association functional class of congestive heart failure	1, Class I; 2, class II; 3, class III; 4, class IV
History of chronic lung disease	Any documented history of chronic lung disease (chronic obstructive pulmonary disease, asthma, bronchitis) or current treatment with pharmacologic therapy	0, No; 1, yes
Canadian Cardiovascular Society class	Canadian Cardiovascular Society classification of angina	0, Class 0-III; 1, class IV

Appendix TABLE 2. PHS CABG operative mortality risk model

	Training model (on-pump patients only)			Final model (all CABG patients)		
	B	Odds ratio	95% Confidence interval	B	Odds ratio	95% Confidence interval
Transformed age*	0.331	1.39	1.15-1.68	0.322	1.38	1.16-1.64
(Transformed age*) ²	0.158	1.17	1.07-1.28	0.181	1.20	1.10-1.30
Female gender	0.259	1.30	0.97-1.72	0.278	1.32	1.02-1.72
Ejection fraction	-0.024	0.98	0.97-0.99	-0.021	0.98	0.97-0.99
Urgency	0.447	1.56	1.40-1.75	0.441	1.55	1.40-1.73
History of cerebrovascular disease	0.433	1.54	1.11-2.14	0.302	1.35	0.99-1.84
History of peripheral vascular disease	0.350	1.42	1.05-1.93	0.380	1.46	1.10-1.94
History of renal insufficiency	0.897	2.45	1.65-3.65	0.925	2.52	1.76-3.60
Previous cardiac surgery	1.050	2.86	2.01-4.06	0.995	2.70	1.94-3.77
Left main stenosis >50%	0.189	1.21	0.91-1.61	0.200	1.22	0.94-1.59
New York Heart Association functional class	0.148	1.16	1.03-1.30	0.155	1.17	1.05-1.30
History of chronic lung disease	0.534	1.71	1.26-2.32	0.519	1.68	1.26-2.24
Canadian Cardiovascular Society class IV	0.307	1.36	1.03-1.80	0.248	1.28	0.99-1.66
Constant	-4.431			-4.554		

B, Coefficient.

*Transformed age, (age - 60)/10.