Clinical Investigation

Predicting Early Death after Cardiovascular Surgery

by Using the Texas Heart Institute Risk Scoring Technique (THIRST)

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Preoperative risk-prediction models are an important tool in contemporary surgical practice. We developed a risk-scoring technique for predicting in-hospital death for cardiovascular surgery patients. From our institutional database, we obtained data on 21,120 patients admitted from 1995 through 2007. The outcome of interest was early death (in-hospital or within 30 days of surgery). To identify mortality predictors, multivariate logistic regression was performed on data from 14,030 patients from 1995 through 2002 and risk scores were computed to stratify patients (low-, medium-, and high-risk). A recalibrated model was then created from the original risk scores and validated on data from 7,090 patients from 2003 through 2007. Significant predictors of death included urgent surgery within 48 hours of admission, advanced age, renal insufficiency, repeat coronary artery bypass grafting, repeat aortic aneurysm repair, concomitant aortic aneurysm or left ventricular aneurysm repair with coronary bypass or valvular surgery, and preoperative intra-aortic balloon pump support. Because the original model overpredicted death for operations performed from 2003 through 2007, this was adjusted for by applying the recalibrated model. Applying the recalibrated model to the validation set revealed predicted mortality rates of 1.7%, 4.2%, and 13.4% and observed rates of 1.1%, 5.1%, and 13%, respectively. Because our model discriminates risk groups by using preoperative clinical criteria alone, it can be a useful bedside tool for identifying patients at greater risk of early death after cardiovascular surgery, thereby facilitating clinical decision-making. The model can be recalibrated for use in other types of patient populations. ***(Tex Heart Inst J 2013;40(2):156-62)***

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A realistic evaluation of surgical risk is crucial to the decision-making process for patients considering a major cardiovascular procedure. Operative or in-hospital mortality rate after cardiovascular surgery is widely used as an indicator of quality of care and of the performance of surgeons and hospitals.[1] However, crude procedural mortality figures are no longer sufficient either for obtaining informed consent from patients or for evaluating the quality of care at institutions.[2] An important impetus for the development of risk scores has been the need to meaningfully compare outcomes among operators and institutions by adjusting outcome rates for differences in the prevalence of patient risk factors.[3] Because cardiac surgery is now possible in increasingly high-risk patients,[2] mortality data must be adjusted to the risk profiles of those patients.[4] Furthermore, it is essential to take into account differences in all patients' risk profiles in order to represent accurately the outcomes produced by surgeons who operate on higher-risk patients and to help eliminate bias against operating on high-risk patients.[1]

Preoperative risk-prediction models have become an integral part of contemporary surgical practice. They are used to counsel patients, evaluate procedure-related risk, perform cost-benefit analysis, and compare operator and institutional outcomes. Thus, these models have become important tools for hospitals, administrators, doctors, and patients in making decisions regarding surgery and surgical care. Preoperative risk stratification can be used to benchmark surgeons and institutions, aid the selection of a treatment method (surgical vs others), and help plan the delegation of hospital resources.[4,5]

During the last decade, many risk-prediction models have been developed to quantify the risks associated with cardiac surgery. These include the Society of Thoracic Surgeons (STS) mortality risk score,[6] the Bernstein-Parsonnet score,[7] the Higgins score,[8] and the European System for Cardiac Operative Risk Evaluation (EuroSCORE).[1,9] However, these models are either complex or not applicable to the patient population of the United States. The aim of this study was to develop a risk-scoring technique that would be more practical and user-friendly than the available scoring models. We wanted a scoring technique that would enable clinicians, through the use of readily available preoperative data, to accurately evaluate the early risk of death for prospective cardiovascular surgery patients.

Patients and Methods

The Texas Heart Institute Research Database (THIRDbase) is a comprehensive database that contains clinical, laboratory, surgical, procedural, and outcome data on more than 200,000 patients who have undergone surgical or cardiologic procedures at the Texas Heart Institute (THI). The database is part of our quality evaluation and improvement program. The definitions of variables included in this study were comparable to those used by the STS and American College of Cardiology. Congestive heart failure, renal insufficiency (including end-stage renal disease and other forms of renal dysfunction), and unstable angina were documented by a physician on admission. A history of acute myocardial infarction (MI) was defined as any acute MI (ST-elevation or non–ST-elevation) in the 4 weeks before admission. Peripheral vascular disease included both past and present cerebrovascular and peripheral disease.

Using data from THIRDbase, we analyzed outcomes of all patients admitted to THI from 1995 through 2007 for coronary artery bypass grafting (CABG), valve repair or replacement, aortic aneurysm repair (of the arch, the ascending, descending, or abdominal segments, or any combination thereof), left ventricular aneurysm repair, or any combination of these procedures. Our outcome of interest was early death, defined as death in the hospital or within 30 days of surgery. For patients transferred to other institutions in the state of Texas within 30 days of surgery, vital status was obtained from the Texas Bureau of Vital Statistics. In addition, for all patients, we used information collected from the U.S. Social Security Index, U.S. vital statistics, follow-up letters, and telephone calls. This study was approved by the institutional review board at St. Luke's Episcopal Hospital, where THI is based. The board waived the requirement for informed consent for this database study.

The 21,120 patients were divided into 2 sets (Table I). The 14,030 patients who underwent cardiovascular surgery from 1995 through 2002 were included in the derivation set; their data were used to develop the risk-scoring model. The 7,090 patients who underwent surgery from 2003 through 2007 were included in the validation set, on whose data the risk-scoring model was tested. We chose this method of dividing the sample because the EuroSCORE was constructed on the basis of data from one series and then validated on data from a subsequent series.

To develop the risk-scoring model, we first analyzed the association between each variable and death to generate odds ratios and 95% confidence intervals. Multivariate stepwise forward logistic regression analysis was then used to identify those variables that were independently associated with death. Cardiogenic shock was eliminated as an independent variable because our institution did not begin collecting data on it until partway through the study period. Including cardiogenic shock as an independent variable would have heavily biased the results. Predictors were chosen for use in the scoring system by means of a forward stepwise selection procedure to fit the logistic regression model, provided that P was less than 0.05.

Risk scores were computed by multiplying the β coefficient of each predictor by a constant (10) and rounding to the nearest integer. Use of the β coefficient enabled us to balance the impact of each risk factor on the model and to eliminate any variability in risk within variables. Accordingly, all individuals with a certain risk factor were assumed to have the same risk as indicated by the value of the β coefficient or its multiple (the calculated risk score). For example, the risk of MI differs in patients depending upon when a previous MI occurred; the risk of aortic aneurysm differs depending upon the location and type of aneurysm. By using the β coefficient, we were able to eliminate this variability in risk. For each patient, the computed risk scores were added together to produce that patient's THI Risk Scoring Technique (THIRST) score. Using these scores, we stratified the 14,030 derivation-set patients into 3 groups: low-risk (risk score, <15), medium-risk (risk score, 15–25), and high-risk (risk score, >25).

We then tested our model on the data from the validation set of 7,090 patients who underwent cardiovascular surgery from 2003 through 2007. We generated receiver operating characteristic (ROC) curves to describe the predictive accuracy, or discrimination, of the model.[10,11] The recalibrated model was developed by modeling the original risk scores obtained from the derivation set, a technique that fits a secondary logistic regression model to a population and uses the original risk score as the only predictor variable in the new model.[12] The new coefficient was obtained by multiplying each of the original model coefficients by a constant (β × 10) to recalibrate the old risk score; the new intercept corrected for baseline differences in risk. This single-variable model was then used to calculate revised probabilities. The area under the ROC curve was computed to evaluate the discrimination of the new model, and robust regression analysis (a form of weighted and reweighted least-squares regression) was performed to evaluate the relationship between the observed and predicted mortality rates. A slope of unity and intercept of

TABLE I. Demographic, Clinical, and Angiographic Characteristics of the Derivation and Validation Sets

Characteristic	Derivation Set (n=14,030)	Validation Set (n=7,090)	*P* Value
Clinical and demographic			
Age, yr			
50–59	23.8	21.8	0.0009
60–69	30.6	31.5	NS
70–79	26.5	26.3	NS
80–89	6.6	8.5	<0.0001
Overweight (body mass index, >25 kg/m^2)	16.3	21.5	<0.0001
Known coronary artery disease	32.0	25.3	<0.0001
Hypertension	69.8	78.9	<0.0001
Dyslipidemia	49.6	61.6	<0.0001
Unstable angina	43.6	28.7	<0.0001
Prior myocardial infarction	38.2	28.4	<0.0001
Valvular disease	21.3	36.1	<0.0001
Renal insufficiency	12.5	20.8	<0.0001
Pulmonary disease	26.9	35.7	<0.0001
Prior transient ischemic attack	4.0	3.9	NS
Prior stroke	6.9	7.6	NS
Congestive heart failure	22.7	29.3	<0.0001
Low LV ejection fraction (<0.40)	16.2	13.2	<0.0001
NYHA functional class III or IV	83.3	61.4	<0.0001
Peripheral vascular disease	20.1	20.3	NS
Diabetes mellitus	8.0	6.8	0.0013
History of tobacco smoking	49.1	50.5	—
Prior revascularization	26.7	21.8	<0.0001
Prior valvular surgery	3.2	3.7	NS
Prior aortic aneurysm repair	1.6	3.1	<0.0001
Prior LV aneurysm repair	0.2	0	0.0025
Angiographic			
Number of diseased coronary vessels			
2	18.7	17.1	0.0051
3	54.1	43.2	<0.0001
Left main coronary disease	18.0	18.0	NS
Surgical			
Urgent operation within 48 hr	13.8	18.7	<0.0001
Repeat CABG	9.2	4.7	<0.0001
Repeat valvular surgery	2.6	2.9	NS
Aortic valve surgery	15.2	25.3	<0.0001
Mitral valve surgery	10.7	11.9	0.0001
Concomitant aortic aneurysm repair	8.7	17.7	<0.0001
Concomitant LV aneurysm repair	1.5	1.2	0.0282
Concomitant vascular procedure	4.2	5.7	<0.0001
Preoperative use of IABP	4.2	3.6	0.0363

CABG = coronary artery bypass grafting; IABP = intra-aortic balloon pump; LV = left ventricular; NS = not significant; NYHA = New York Heart Association

All data are reported as percentages.

0 indicated a perfect fit. Differences in slopes and intercepts for the regression equation were evaluated by the *t* test. All analysis was done using SAS software, version 9.1 (SAS Institute; Cary, NC).

Results

Nineteen variables (Table II) were selected from the regression analysis for use in calculating risk-prediction scores, which were used to stratify the patients in each data set into low-, medium-, and high-risk groups. The overall mortality rates were 5.8% in the derivation set and 4.8% in the validation set. In the derivation set, the observed mortality rates were 1.4% in the low-risk patients, 3.6% in the medium-risk patients, and 14.2% in the high-risk patients. In the validation set, the predicted mortality was 2.5%, 6.1%, and 21.3%; and the observed mortality was 0.8%, 2.8%, and 9.9% in the low-, medium-, and high-risk patients, respectively. When the recalibrated model was applied to the validation set, the predicted mortality was 1.7%, 4.2%, and 13.4%; and the observed mortality was 1.1%, 5.1%, and 13% in the low-, medium-, and high-risk patients, respectively (Table III).

The area under the ROC curve was 0.81 for the derivation set and 0.77 for the validation set, indicating that the model had excellent discrimination (Fig. 1). After recalibration, the area under the ROC curve for the validation set was again 0.77. Robust regression analysis was performed to evaluate the relationship between the observed and predicted mortality rates. The difference in slopes and intercepts for the regression equation was evaluated with the *t* test and was not statistically significant ($P=0.17$ for slopes and $P=0.25$ for intercepts). There was a positive correlation between the THIRST score and predicted death (Fig. 2).

TABLE II. Predictors of In-Hospital Death after Cardiovascular Surgical Procedures, and Risk Scores Assigned to Variables Used in the Texas Heart Institute Risk Scoring Technique (THIRST)

Variable	β	Risk Score	Recalibrated Risk Score	*P* Value	OR	95% CI
Age, yr						
50–59	0.4	4	3	0.0224	1.5	1.1–2.2
60–69	0.8	8	6	<0.0001	2.2	1.6–3.1
70–79	1.1	11	9	<0.0001	3.2	2.1–4.3
80–89	1.5	15	12	<0.0001	4.5	3.1–6.7
LV ejection fraction <0.40	0.2	2	2	<0.0119	1.3	1.1–1.5
Congestive heart failure	0.4	4	4	<0.0001	1.6	1.3–1.9
Renal insufficiency	0.7	7	6	<0.0001	2.0	1.7–2.4
Urgent surgery (within 48 hr)	1.1	11	9	<0.0001	3.1	2.6–3.7
Aortic valve surgery	0.6	6	5	<0.0001	1.9	1.5–2.3
Mitral valve surgery	0.6	6	5	<0.0001	1.9	1.5–2.4
Repeat procedures						
Valve surgery	0.5	5	4	0.005	1.7	1.2–2.5
CABG	1.1	11	9	<0.0001	3.0	2.4–3.6
Aortic aneurysm repair	1.9	19	15	<0.0001	6.6	4.0–10.8
Concomitant procedures						
Aortic aneurysm repair	1.1	11	9	<0.0001	3.0	2.4–4.0
LV aneurysm repair	0.9	9	7	<0.0001	2.4	1.6–3.6
Preoperative IABP support	0.9	9	7	<0.0001	2.4	1.9–3.1
History of TIA	0.4	4	3	0.0154	1.4	1.1–1.9
History of acute MI	0.4	4	3	0.0004	1.4	1.2–1.8
Unstable angina	0.3	3	2	0.0011	1.3	1.1–1.6
Peripheral vascular disease	0.3	3	2	0.0014	1.3	1.1–1.6
Diabetes mellitus	0.3	3	2	0.0341	1.3	1.0–1.7
3-vessel disease	0.3	3	2	0.0025	1.3	1.1–1.6

β coefficient = the weight given to each variable when the THIRST score is calculated; CABG = coronary artery bypass grafting; CI = confidence interval; IABP = intra-aortic balloon pump; LV = left ventricular; MI = myocardial infarction; OR = odds ratio; TIA = transient ischemic attack

TABLE III. Comparison of Predicted and Observed Mortality Rates in the Derivation and Validation Data Sets

	Risk Group (according to THIRST score)		
	Low (<15)	**Medium** (15–25)	**High** (>25)
Derivation set			
No. patients	5,418	4,827	3,785
Predicted mortality rate, %	1.4	3.5	13.8
Observed mortality rate, %	1.1	3.6	14.2
Validation set			
No. patients	2,075	2,397	2,618
Predicted mortality rate, %	2.5	6.1	21.3
Observed mortality rate, %	0.8	2.8	9.9
Recalibrated model applied to validation set			
No. patients	3,010	2,754	1,326
Predicted mortality rate, %	1.7	4.2	13.4
Observed mortality rate, %	1.1	5.1	13.0

THIRST = Texas Heart Institute Risk Scoring Technique

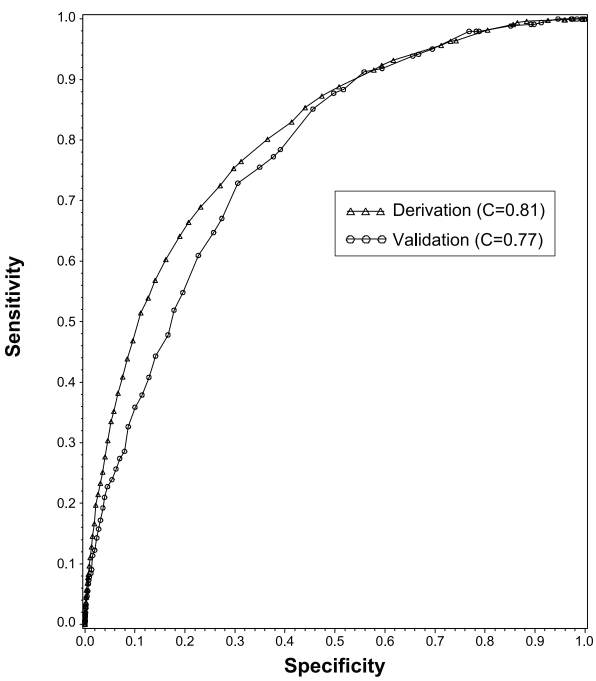

Fig. 1 *Receiver operating characteristic (ROC) curves for the derivation and validation sets.*

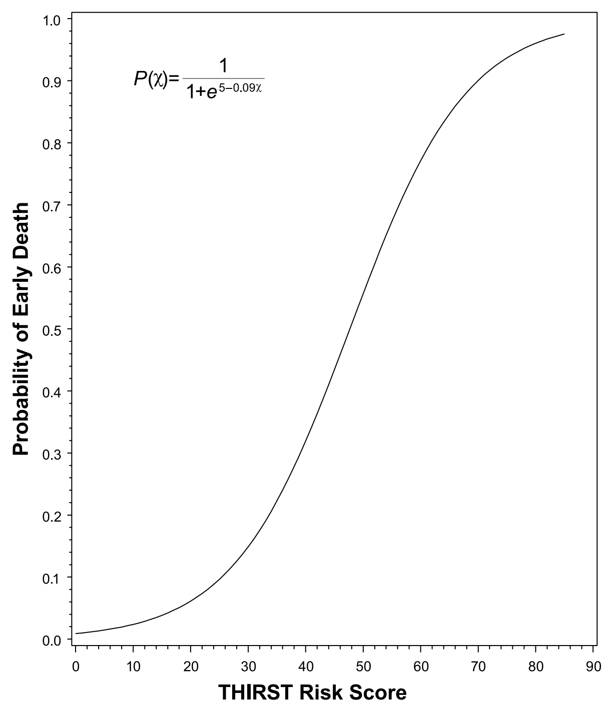

Fig. 2 *Correlation between early death and risk score.*

P = predicted death; THIRST = Texas Heart Institute Risk Scoring Technique; χ = risk score

Discussion

We have developed a risk score (THIRST) for predicting a patient's risk of in-hospital death after CABG, valvular surgery, aortic aneurysm repair, left ventricular aneurysm surgery, or a combination of these in a large tertiary care center with a high-risk surgical population. The THIRST score, which is calculated from preoperative clinical data and the results of basic tests, promises greater accuracy and ease of use than other available risk scores. An earlier (developmental) state of THIRST has been used successfully in our institution. Now we will use the most recent state and compare outcome predictions with those of the STS database for the years that we have been submitting to the STS.

The EuroSCORE and the STS are the 2 most frequently used risk-profile systems in the United States and Europe.[13] The EuroSCORE was developed from and validated on data collected from 128 European surgical centers in 1995; results were published in 1999.[1,9] Although Nashef and colleagues[14] validated the use of this scoring technique in North American patients in

2002, its use in the contemporary surgery population is less than ideal, for a variety of reasons. First, the epidemiology of ischemic heart disease and comorbid conditions in the United States is different from that in Europe, and studies have shown that risk-stratification models are less accurate when applied to populations different from the ones in which they were formulated.[15] For example, Yap and colleagues[3] reported in 2006 that the EuroSCORE did not accurately predict outcomes in their cohort of Australian patients. Likewise, the study group that developed the EuroSCORE stated that it did so because scoring systems derived from North American cardiac surgery patients were not necessarily applicable to European practice.[2] Hence, caution needs to be applied when one is using a risk-scoring system outside its place of origin or in a different patient population.

Second, the improved logistic EuroSCORE model is now 7 years old and is based on data from patients who underwent cardiac surgery in 1995. After the original EuroSCORE was developed, the use of off-pump CABG gained considerable popularity, especially between 1997 and 2000. Advances in medical treatment, thrombolytic therapy, and percutaneous interventions in recent years have also altered the profile of patients referred for cardiac surgery.[16] Not only has surgical practice changed, but so has the patient population, which is now older and at substantially higher risk.[17-19] Because older models such as the EuroSCORE[19] and the STS score take into account patient age and comorbidities, but not advances in surgical technique, these models are likely to overpredict mortality risk. This problem necessitates recalibrating old models or creating new ones from new data. THIRST is based on a contemporary U.S. population, so it currently does not suffer from temporal variability, although it will require recalibration every 3 to 5 years.

The EuroSCORE is computed from 17 risk factors, some of which require invasive testing to accurately determine risk, such as right heart catheterization to determine pulmonary artery pressure.[1] The STS score is based on more than 40 clinical values, making it a complex tool to implement at the bedside.[6] The inclusion of large numbers of variables also can cause such scoring systems to overcapture or suppress results, and it makes them more vulnerable to “gaming” or “upcoding,” that is, the increased reporting of risk factors in order to improve risk-adjusted mortality rates.[20] We believe that THIRST is likely to strike a better balance between sample size and parsimony and is less amenable to gaming than are the STS score[6,21] and the EuroSCORE.[1]

Limitations. Our findings should be viewed in light of the limitations of this study. The data for the validation set were collected at the same single, high-volume referral center where the initial derivation data were collected. Hence, our model’s applicability to other cardiovascular surgery populations or to patients at lower-volume centers is uncertain. Also, because of the constant evolution of surgical techniques and perioperative care, our model will need recalibration every few years to maintain its discriminatory accuracy. Our recalibration data were from patients who underwent surgery from 2003 through 2007, so the model already is in need of recalibration with more contemporary data. In addition, centers with populations unlike ours would need to recalibrate the model before using it.

In order to create a simple bedside tool for the evaluation of mortality risk, we trimmed the number of recorded preoperative variables to 19. It might be argued that some important risk factors were omitted in the process, such as cardiogenic shock, acute MI within the past 6 hours, and emergent and “salvage” resuscitation procedures.[22] The inclusion of additional variables has been shown to strengthen risk evaluation in high-risk patients who have cardiogenic shock or acute MI.[23,24] In addition, the combination of a broad range of diverse procedures in one risk model might not impart sufficient specificity for risk evaluation in, for example, a heterogeneous group of patients with thoracic aneurysms. More accurate risk models have been validated for patients with thoracic aneurysms by using more specific data regarding the extent of the aneurysm, aortic dissection, acute presentation, rupture, and renal insufficiency.[25] Nevertheless, the object of our study was to produce a simplified method for bedside risk evaluation for most patients who undergo elective cardiac surgery at a single institution.

Conclusions

The THIRST score is an easy-to-use, practical bedside tool for evaluating a patient’s risk of in-hospital death after CABG, valvular surgery, aortic aneurysm repair, left ventricular aneurysm surgery, or a combination of these. The score can be calculated from preoperative clinical data and the results of basic tests; it does not use any variables that involve additional invasive testing. Developed from a large database of contemporary cardiac surgery patients, our score promises greater accuracy and ease of use than do the risk scores developed previously. We recommend its widespread validation and use in similar patient populations and its temporal and center-specific recalibration as a simple risk-prediction model for use with different patient populations.

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