RISK FACTORS FOR POSTOPERATIVE MORBIDITY

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Objective: **Analysis of outcomes after coronary artery bypass grafting has focused on risk factors for operative mortality. Nonfatal perioperative morbidity is far more costly and more common after operation. To identify the risk factors that lead to postoperative morbidity, we evaluated 938 patients undergoing coronary artery bypass grafting at Albany Medical Center Hospital during 1993.** *Methods:* **Multivariate statistical analysis was performed on preoperative patient variables to identify risk factors for either serious postoperative morbidity or increased hospital length of stay. Variables were considered both individually and in combination. For example, age was considered individually or in combination with other variables, including parameters of blood volume (i.e., age divided by red blood cell volume or Age/RBCVOL). Similar multivariate analysis was performed to identify independent risk factors for hospital mortality.** *Results:* **In order of decreasing importance, the following patient variables were significantly associated with increased length of stay by stepwise Cox regression analysis: Age/RBCVOL, history of congestive heart failure, hypertension, femoral-popliteal peripheral vascular disease, chronic obstructive lung disease, and renal dysfunction. The combination variable, Age/RBCVOL, was an important risk factor for both increased length of stay and serious postoperative morbidity. Variables that were significant independent predictors of increased mortality, such as preoperative shock, and redo operation, were not risk factors for either serious morbidity or increased length of stay.** *Conclusions:* **We conclude that risk factors for postoperative morbidity are different from those for postoperative mortality. These results suggest that older patients with preoperative anemia and low blood volume who also have other comorbidities (congestive heart failure, stroke, chronic obstructive pulmonary disease, or hypertension) are at increased risk for postoperative complications. This allows identification of a high-risk cohort of patients who are likely candidates for interventions to lessen postoperative morbidity. (J THORAC CARDIOVASC SURG 1996;111:731-41)**

Analysis of outcomes after cardiac operations, especially coronary artery bypass grafting (CABG), has assumed new importance because of concerns about the cost of surgical interventions. Arguably, the most modifiable component of hospital cost in patients undergoing cardiac procedures is nonfatal perioperative morbidity. Before surgeons or health care organizations can make rational decisions regarding patients in whom risk is high, they must know what factors predispose patients to costly morbidity and increased hospital length of stay (LOS) after operation.

An analysis at our institution revealed that significant components of hospital cost in patients undergoing CABG were prolonged hospital LOS and serious postoperative morbidity. As much as 40% of the total cost of CABG during 1 year was accounted for by patients having serious postoperative morbidity with resultant prolonged hospital LOS. The first

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step in lowering costs associated with CABG was to identify risk factors that predispose patients to serious postoperative morbidity and increased LOS. Only after knowing what the risk factors are that predispose to increased morbidity can strategies be devised to limit morbidity and ultimately lower costs.

Numerous reports have catalogued the preoperative risk factors predictive of operative mortality,[1-4] and some others have identified risk factors for postoperative morbidity or hospital LOS.[5-11] Because of the need to better define factors that influence post-CABG morbidity and to implement strategies that limit costs of operation, we undertook a study to identify risk factors for serious hospital morbidity and increased LOS. We used the cohort of patients undergoing CABG at Albany Medical Center Hospital during 1993 as a study population to perform this risk analysis.

Methods and patient selection

Patient database. All patients undergoing CABG at Albany Medical Center in 1993 were evaluated. Only patients who were operated on and discharged in 1993 were entered into the study group. With these criteria, 938 patients were studied and records were available for each of the study patients. A few patient records were incomplete, but more than 98% of all data elements for each patient record were available for analysis. Two databases were combined to form the final database from which the numerical calculations were performed: (1) the New York State cardiac surgery database for Albany Medical Center and (2) the Albany Medical Center perfusion database. Combining these two databases provided a double check to ensure that no patients were inadvertently omitted from either database. Only patients having initial or reoperative CABG were included in the study group. Patients having CABG in conjunction with other procedures such as valve replacement or repair of a mechanical defect after myocardial infarction were excluded.

Risk factors. Preoperative variables that might be associated with increased LOS or morbidity were evaluated by multivariate statistical methods. A complete list of all the preoperative variables examined and their definitions are shown in Appendix 1. Variables were considered both individually and in combination if there was evidence that variable interaction existed. For example, patient age was considered individually or in combination with blood volume, renal function, cardiac function, and hematocrit value. For the multivariate analyses, composite variables were used in place of individual variables, whenever feasible, to minimize variable interactions and to improve the validity of the resultant multivariate models. An attempt was made to reduce this redundancy and variable interaction to a minimum.[12] In particular, two composite variables were used that greatly improved both the multivariate logistic regression and the Cox proportional hazards model. These two composite variables were Age/RBCVOL and PROBMORT. Age/RBCVOL is the ratio of age divided by the packed red blood cell volume (RBCVOL). The RBCVOL is defined as the patient's blood volume (calculated from height, weight, and gender) multiplied by the preoperative hematocrit value. The RBCVOL was approximated by means of a nomogram. No attempt was made to determine the true blood volume by quantitative methods. Similarly, PROBMORT is a composite variable that combines multiple patient risk factors into a single risk-adjusted probability of in-hospital mortality (see Appendix 2). The validity of PROBMORT has been confirmed by the use of large data series from patients undergoing CABG in New York State.[2] This composite variable has been a reliable indicator of mortality risk in this population.

Outcome variables. Three outcome variables were measured: (1) hospital LOS, (2) serious postoperative morbidity, and (3) hospital mortality. Serious postoperative morbidity was defined as the occurrence of any of the following during the postoperative course: postoperative myocardial infarction (Q wave), stroke, pulmonary failure (more than 5 days on the ventilator), renal failure necessitating dialysis, postoperative cardiogenic shock necessitating left ventricular assist device or intraaortic balloon pump, sepsis, or mediastinitis. LOS was measured from the day of operation to the day of discharge or death. Hospital mortality was defined as any death during the postoperative stay, regardless of whether the cause of death was directly related to the operation or only remotely related.

Statistical modeling—multivariate testing. Only preoperative variables were included in the multivariate analyses as independent or predictor variables. Intraoperative or postoperative variables such as ischemic time, chest tube drainage, amount of blood products consumed, or number of CABGs were not entered into the multivariate models, because it would be difficult to estimate the value of these variables before the operation for the purpose of a predictive model.

For operative mortality, logistic regression analysis with stepwise addition of variables was used to determine independent predictors of operative death. A contingent probability of 0.10 or less was used to enter variables into the logistic model in a forward-stepping manner, and a contingent probability of 0.15 or less was used to remove variables from the model.

Similarly, stepwise logistic regression was used to evaluate serious postoperative morbidity using similar entry and removal criteria. Serious postoperative morbidity was considered a dichotomous variable with discrete values of zero if patients had an uncomplicated hospital course or one if the patient had one or more serious postoperative complications. Independent predictor variables that contributed to the final multivariate logistic regression model were screened for variable interactions and were excluded or combined if significant colinearity was found.[12] Independent predictor variables that contributed to the final multivariate model were considered significant risk factors for serious postoperative morbidity if the p value for improvement in χ^2 was 0.05 or less.

Cox proportional hazards regression with stepwise addition of variables was used to determine independent

Table I. *Logistic regression model for significant multivariate predictors of operative mortality*

Risk factor	*Observed percent mortality (95% CI)*	*Odds ratio (95% CI)*	χ^2 *improvement*
None* (348 patients)	0.3% (0.6%)	0.07 (0.009-0.53)	—
PROBMORT (683 patients with value ≤ mean of 0.025)	0.9% for patients with ≤ mean value (0.2%-1.6%)	8.0 (3.3-19.5)	21.279
Dialysis-dependent renal failure (7 patients)	28.6% (0%-73.6%)	13.2 (1.3-132)	6.938
CHF (91 patients)	12.1% (5.3%-18.9%)	8.8 (3.8-20.3)	11.097
LVH (78 patients)	7.7% (1.7%-13.7%)	3.9 (1.5-10.1)	5.111
Femoral-popliteal peripheral vascular disease (74 patients)	8.1% (1.7%-14.5%)	4.1 (1.6-10.8)	4.131

CI, Confidence interval; *CHF,* congestive heart failure; *PROBMORT,* risk-adjusted probability of in-hospital death as determined by New York State risk model for CABG mortality; *LVH,* left ventricular hypertrophy.

*For purposes of calculating zero risk factor scores, PROBMORT was assumed to be ≤0.01 (one standard deviation below the mean).

predictors of hospital LOS, because this outcome is a time-dependent continuous variable.[13, 14] Perioperative deaths were included in the Cox analysis, and the time from operation to discharge or death was considered the survival time for analysis of survival time data in the Cox proportional-hazards regression model. A probability of 0.10 or less was used to enter variables into the Cox model in a forward-stepping manner, and a probability of 0.15 or less was used to remove variables from the model. Independent predictor variables that contributed to the final multivariate model were considered significant risk factors for LOS if the p value for improvement in χ^2 was 0.05 or less.

Statistical calculations were carried out with BMDP statistical software (BMDP Software, Los Angeles, Calif.) programs on a personal computer. The adequacy of the final multivariate regression models (either logistic regression or Cox analysis) was judged by means of various regression diagnostics. For logistic regression, receiver operating curves were used to assess model performance. For Cox regression analysis, the final model derived from 1993 data at Albany Medical Center Hospital was used to develop multivariate risk factors and a risk scoring system (described later). The risk scoring system was cross-validated with 1994 data from the same institution to assess the predictive ability of the Cox model and the risk scoring system.

A risk score for hospital LOS was determined for each patient by adding the weighted score for each significant risk factor in the final Cox model. The weights were obtained from the coefficients for each prognostic factor in the final model.[5, 11] Since the baseline survivor function is altered by the risk scores in an incremental way with increasing risk scores causing rightward shift of the baseline decay curve (i.e., shift toward increased LOS), it is possible to calculate a predicted LOS from a patient's preoperative risk score. For purposes of cross-validation, the predicted 50th percentile LOS was calculated by inverting the hazard function by means of the following equation:

$$\text{50th Percentile LOS} = 1/\text{Hazard function}$$
$$= 0.5^{\exp(\text{riskscore}/10)}$$

The predicted LOS in days was computed for patients operated on in 1994 at Albany Medical Center Hospital from this equation. To relate LOS to the risk score, one must calculate incremental values of LOS from the baseline Cox regression decay curve multiplied by conversion factors for each different risk score. These predicted values for LOS were compared with the observed values for each patient over the entire range of risk scores. By using the 1993 data as a "training" set and the 1994 data as the "cross-validation" set, we assessed the validity of the Cox model and the risk scoring system.

Results

Postoperative mortality. Among the 938 patients undergoing initial or reoperative CABG during 1993 at Albany Medical Center Hospital, there were 24 operative deaths (2.6%). The significant multivariate predictors of increased mortality by logistic regression are shown in Table I. The most important risk factor for operative mortality was the composite variable PROBMORT. This variable represents a compilation of variables found to be significantly associated with fatal outcome in the New York State cardiac surgery database (Appendix 2). The important components of PROBMORT include preoperative shock, left ventricular dysfunction, reoperative surgery, and preoperative renal failure.[2]

Serious postoperative morbidity. Eighty patients (8.5%) had a serious postoperative complication. The type and number of serious complications experienced after CABG are shown in Table II. Forty patients had a single serious complication, whereas 40 more had a combination of complications. Because the number of patients having two (23 patients), three (9 patients), four (7 patients), or five (1 patient) complications was relatively small, serious postoperative morbidity was considered a dichotomous (yes or no) variable.

Logistic regression analysis revealed four variables to be significantly associated with any serious postoperative morbidity. The relative magnitude of

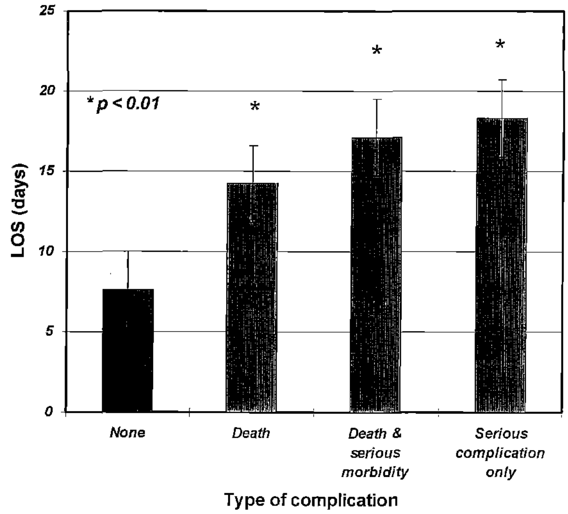

Fig. 1. Hospital LOS for patients with serious morbidity or mortality. *Error bars* represent standard error of the mean.

Table II. *Type and number of serious postoperative complications*

Morbidity or mortality	*Patients with additional complications associated with morbidity or mortality* 0	1	2	3	4	*Total patients with morbidity or mortality*
Death	9	10	2	3	0	24
Stroke	9	4	2	0	0	15
MI	2	0	1	0	0	3
IABP	9	3	1	0	0	13
Pulmonary failure	8	6	3	3	1	21
Renal failure	3	0	0	1	0	4
Total	40	23	9	7	1	80

MI, Q-wave perioperative myocardial infarction; *IABP,* intraaortic balloon counterpulsation required for weaning from cardiopulmonary bypass.

Table III. *Logistic regression model for significant multivariate predictors of serious postoperative morbidity*

Risk factor (patients with risk factor)	*Observed complication rate (95% CI)*	*Odds ratio (95% CI)*	χ^2 *improvement*
None (51 patients)*	0.02% (0%-26.1%)	0.2 (0.03-1.5)	—
CHF (91 patients)	22.0% (13.4%-30.6%)	3.1 (1.8-5.6)	25.857
Age/RBCVOL (385 patients with mean value ≥ 0.0390)	18.4% (12.4%-24.4%)	13.7 (6.7-27.7)	11.931
Hypertension (646 patients)	10.2% (7.9%-12.5%)	2.3 (1.2-4.1)	8.795
Previous stroke (51 patients)	19.6% (8.3%-30.9%)	2.8 (1.4-5.9)	4.686

CI, Confidence interval; *CHF,* congestive heart failure during admission and requiring CABG; *Age/RBCVOL,* age in years divided by red blood cell volume obtained from nomogram of patient height, weight, gender, and preoperative hematocrit value.

*For purposes of calculating zero risk factor scores, Age/RBCVOL was assumed to be <0.025 (one standard deviation below the mean).

the effect of these risk factors on postoperative morbidity is shown in Table III. The combination variable Age/RBCVOL represents a semiquantitative measure of the preoperative anemia and body size and was an important risk factor associated with serious morbidity. The variables associated with serious morbidity shown in Table III are different from those associated with operative mortality shown in Table I.

Postoperative LOS. The mean LOS for patients undergoing CABG was 8.4 days (95% confidence interval = 0.45 days). The LOS was significantly longer in patients who had serious morbidity or who died than in those who had an uncomplicated procedure (Fig. 1).

Hospital LOS was considered to be a time-dependent, continuous variable and, as such, was evaluated by means of survival analysis techniques. Predictor variables that were significant independent predictors of the LOS are shown in Table IV. The most important risk factor for increased LOS was Age/RBCVOL. This suggests that risks for a global index of morbidity and resource use (i.e., LOS) are different from those for mortality.

By considering the Cox regression coefficients, it is possible to develop a set of weighted risk scores for each of the significant variables that contribute to the Cox regression. Table IV shows the odds ratios and the Cox regression coefficients obtained from the multivariate analysis.[5, 14] For computational purposes the regression coefficients were converted to "risk scores" by rounding off the regression coefficient values to the nearest integer. For example, the risk score for having preoperative renal dysfunction is 6 (rounded up from 5.64). In the case of the predictor variable Age/RBCVOL, the risk score is computed by multiplying the actual value of the variable by 181.3. As an example, a patient who is 75 years old and has a preoperative RBCVOL of 1800 ml would have a value of Age/RBCVOL of

Table IV. *Cox proportional hazards regression model for significant predictor variables associated with hospital LOS*

Risk factor (patients with risk factor)	*Observed LOS (95% CI)*	*Odds ratio for mean LOS ≥ 8.4 days (95% CI)*	*Cox regression coefficient*	*χ^2 improvement*
None (40 patients)*	5.9 days (5.2-6.6 days)	0.14 (−1.9-0.6)	1.00	—
Age/RBCVOL (385 patients with ≥ mean value of 0.0390)	10.0 days (9.0-11.0 days)	2.6 (1.9-3.4)	1.813 per 0.010 unit of Age/RBCVOL	72.907
CHF (91 patients)	11.6 days (9.3-13.9 days)	2.6 (1.7-4.1)	4.534	17.729
Hypertension (646 patients)	9.0 days (8.4-9.6 days)	2.1 (1.5-2.9)	2.312	12.296
Femoral-popliteal vascular disease (74 patients)	10.1 days (8.7-11.5 days)	2.7 (1.6-4.3)	3.0159	8.053
Renal dysfunction (17 patients)†	12.8 days (9.0-16.6 days)	5.4 (2.0-14.9)	5.64	6.904
COPD (213 patients)	9.4 days (8.5-10.3 days)	1.9 (1.3-2.6)	2.23	7.259
Previous stroke (51 patients)	11.1 days (8.9-13.3 days)	3.5 (2.0-6.2)	3.20	5.017

LOS, Length of stay; *CI,* confidence interval; *Age/RBCVOL,* age in years divided by red blood cell volume obtained from nomogram of patient height, weight, gender, and preoperative hematocrit value; *CHF,* congestive heart failure immediately preceding CABG; *COPD,* chronic obstructive pulmonary disease.
*For purposes of calculating zero risk factor scores, Age/RBCVOL was assumed to be <0.0250 (one standard deviation below the mean).
†Serum creatinine concentration ≥2.5 mg/dl but not dialysis-dependent.

0.042. The computed risk score for this patient for Age/RBCVOL would be 7.6, or 8 rounded to the nearest integer. The computed risk scores are related to the baseline decay curve for LOS in an incremental way, as shown in Fig. 2. This means that as one or more significant variables contribute to the decay curve function, the curve is shifted to the right (i.e., toward longer hospital stay). The mathematical relationship between risk score and LOS is shown in Fig. 3 for the 10th, 50th, and 90th percentiles of LOS. A patient's preoperative risk score can be calculated by adding the individual weighted scores that apply. For a given risk score, it is possible to estimate a 50th percentile value (or any other percentile) for LOS, and a graphic display of the 50th percentile of LOS is shown in Fig. 3.

Regression diagnostics. For the logistic regressions, it is possible to use model diagnostics to assess the quality of the regression model. For the two logistic regression models generated, the diagnostics suggest that the values of outcome (either serious morbidity or mortality) predicted by the regression equations fit the observed values well. For example, the area under the receiver operating characteristic curve for model prediction of operative mortality is 0.8004. For serious perioperative morbidity, the area under the receiver operating characteristic curve is 0.710.

The adequacy of the Cox regression model in predicting hospital LOS was assessed by means of cross-validation techniques. For this analysis, the 1993 results at Albany Medical Center Hospital were used to predict the LOS of patients undergoing operation during 1994. Fig. 4 compares the observed 1994 LOS data with the predicted LOS developed from the 1993 "training" data set for each level of risk score. There is good agreement between predicted and observed values in the 1994 cross-validation data set, suggesting that the Cox model described in Table IV is a satisfactory representation of the observed findings.

Discussion

These results suggest that there is a difference between the risk factors associated with postoperative morbidity and those that lead to operative mortality. The multivariate results shown in Tables III and IV point out unique risk factors associated with postoperative morbidity (as measured by LOS and serious complications) that are not significantly related to operative mortality. For example, the composite variable PROBMORT is a significant predictor variable for postoperative mortality but does not contribute to the regression models for either LOS or serious morbidity. Likewise, Age/RBCVOL is an important determinant of postoperative morbidity (as measured by either LOS or serious complications) but does not contribute to the multivariate regression for mortality. This difference between predictors of mortality and morbidity has clinical implications. Important risk factors that predict mortality include measures of ventricular function, reoperative surgery, or hemodynamic instability (Appendix 2). As opposed to this, multivariate risk factors for morbidity emphasize measures of small body stature (as measured by blood

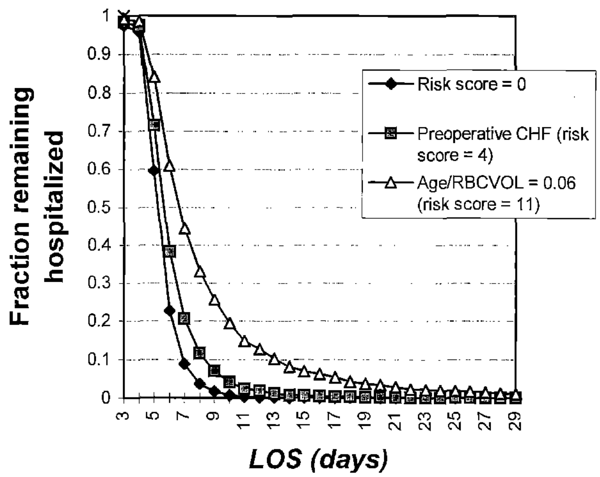

Fig. 2. Decay curves (fraction remaining hospitalized) for patients with varying risk scores. The values used to generate these curves are hypothetical, calculated values obtained from the baseline decay curve and from exponential conversion factors related to the relative risk for each significant variable in the Cox regression analysis. *CHF,* Congestive heart failure.

volume) and chronic illness or anemia. Indexes of chronic illness that are multivariate predictors of morbidity include anemia and small body stature (as measured by RBCVOL), as well as previous stroke, renal dysfunction, and hypertension. Although the variables overlap somewhat, these results suggest that risk factors for morbidity are different from those for mortality, with parameters of chronic illness being more commonly associated with prolonged hospital stay and serious postoperative complications.

Our data not only support the contention that LOS is a continuous variable that correlates with serious morbidity but also suggest that LOS can be used in a prospective manner to study postoperative morbidity. The risk scoring system developed from the Cox regression model can be used as a measure of risk for prolonged LOS and increased morbidity. The results of the calculations shown in Figs. 2 and 4 suggest at least three ways that these risk scores might be used in a prospective manner: First, computation of the risk score for a given patient before operation provides an objective estimate of the chance of prolonged hospitalization, serious postoperative morbidity, and presumably, increased cost. For example, a patient with a preoperative risk score of 15 has a greater than 50% chance of staying in the hospital more than 14 days (incidentally the limit of diagnosis-related group reimbursement for CABG) after operation. Physicians can benefit from this knowledge, both in the approach to the patient and in providing informed consent regarding high-risk procedures. Second, patients with the highest risk score values are candidates for more costly interventions that might reduce LOS. Such interventions as use of heparin-bonded oxygenator circuits[15, 16] or aprotinin therapy to limit blood transfusion[17] might be viewed as cost-saving measures in patients in whom the risk is high, rather than expensive interventions that are not justified for routine use in patients in whom the risk is average. Any investigation into the reduction of morbidity and limitation of hospital costs should focus on the patients at highest risk, and the risk-scoring system outlined here is an ideal way to identify a high-risk study population. Third, the risk-scoring system outlined here is an ideal way to study changes over time in the high-risk study population. Characteristics of the high-risk subset as measured by changes in the risk score patterns can serve as a gauge of success or failure in improving outcome by decreasing morbidity and LOS.

Using the above-described risk scores to identify a high-risk subset of patients who are likely candidates for interventions to limit morbidity is exactly analogous to application of "total quality management" principles to an industrial process or to any other complex process. For example, only 8% of the patients having CABG stay longer that 14 days after operation, but this minority account for more than 25% of the total hospital cost of patients undergoing CABG. A logical starting point for efforts to decrease costs of CABG should be to focus on this high-risk subset of patients who consume a disproportionate amount of resources. The observation that a few factors account for the majority of the outcomes of a complex process has been termed the *pareto principle* in the jargon of total quality management and has proved to be a valuable tool in improving quality.[18] The risk-scoring system outlined herein could serve both as a starting point to identify patients at high risk and as a means of monitoring success or failure in influencing outcome in this high-risk subset. An analogous approach has been used in the National Demonstration Project on Quality Improvement in Health Care.[19]

It is noteworthy that the composite variable, Age/RBCVOL, is a significant independent predictor of both serious morbidity and LOS. Age/RBCVOL is a semiquantitative measure of body size and anemia. The RBCVOL is not calculated

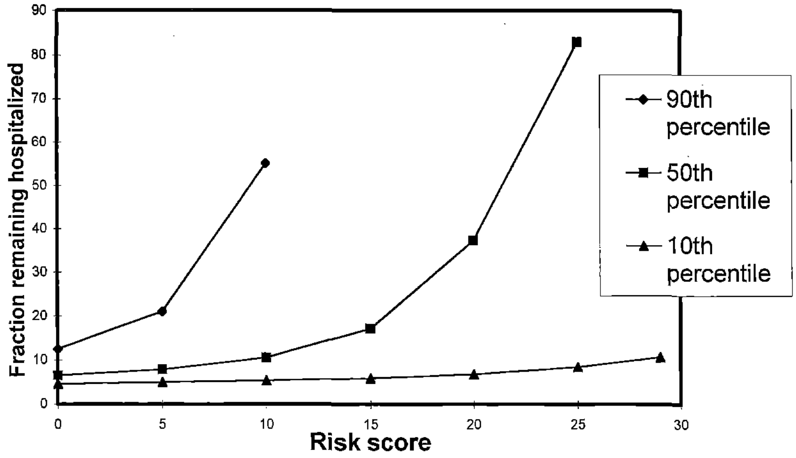

Fig. 3. Relationship between weighted risk scores and percentiles of hospital length of stay.

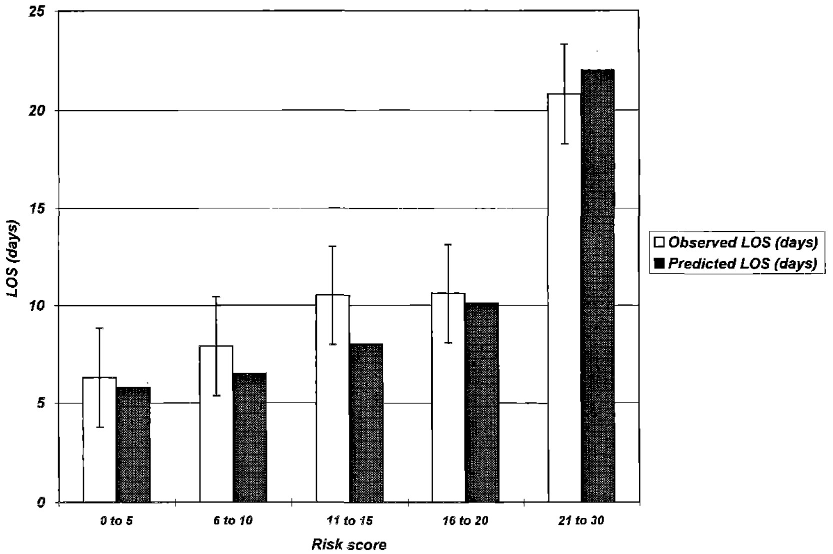

Fig. 4. Comparisons of predicted LOS from 1993 data to actual LOS from 1994 data. *Error bars* represent standard error of the mean for 1993 data.

from exact blood volume measurements but from estimates of blood volume. Despite the approximations used in estimating this variable, the results are both reproducible and important predictors of increased morbidity. We[20, 21] have found that RBCVOL is also an independent variable significantly associated with excessive postoperative blood transfusion. It is more than just coincidental that excessive blood transfusion is significantly associated with increased postoperative morbidity. Our study does not identify whether excessive blood transfusion is a cause or effect of increased LOS, but there is no doubt that the two variables are related. It is tempting to speculate that limitation of postoperative blood product use will result in decreased LOS and morbidity. Further studies are required to test this hypothesis.

There are some limitations of the studies presented. Even though the regression diagnostics suggest that the methods used to describe serious morbidity and mortality are appropriate and yield good results, it remains for the regression models presented to be tested in larger groups of patients and at multiple institutions. Because all of these results were obtained at one institution, it is not clear how generally applicable they will be to other smaller or larger facilities. Likewise, these results encompass only CABG operations, and the applicability of the regression analysis to other types of cardiac operations is uncertain. A more serious shortcoming involves selection bias. Only surgical patients were included in the study. An important unstudied feature of the population with coronary disease is the morbidity risks associated with nonoperative therapy. Prolonged hospitalization and increased cost may be greater with nonoperative therapy than with operative therapy in patients at high risk. Our results do not address this issue and further studies are required to unravel the morbidity risks of operative versus nonoperative therapy of coronary artery disease.

In summary, we have shown that preoperative variables that predict operative mortality are different from those that predict serious morbidity or increased LOS. A particularly sensitive indicator of morbidity is the composite variable, Age/RBCVOL. This variable and others that reflect chronic health status and older age seem to be more predictive of increased morbidity, whereas parameters of myocardial dysfunction are predictive of mortality. Understanding and analysis of the multivariate regressions presented in this study allow identification of a high-risk subset of patients undergoing CABG who are candidates for interventions to reduce morbidity. Further studies will use the statistical modeling presented here to identify the high-risk cohort and to test efficacy of interventions aimed at reducing postoperative morbidity in this high-risk group.

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Discussion

Dr. Fred H. Edwards *(Jacksonville, Fla.)*. Up to this point, virtually all reported risk models have focused on operative mortality as the outcome variable. Dr. Ferraris has pushed out the envelope a bit by modeling morbidity rather than mortality. This is clearly more challenging, and in the past there has been some question as to whether one could reliably predict postoperative morbidity.

The Society of Thoracic Surgeons Database Committee has been interested in this concept for some time. To emphasize the point that morbidity can be reliably predicted, I would like to describe some representative results from more than 40,000 patients undergoing coronary bypass surgery in 1993. The models were based on a Bayesian algorithm and show good agreement between our predicted and observed results. In our LOS model, there is no deviation between the two curves until you reach the range of 2 weeks and greater. This is also true for our model of prolonged postoperative ventilation and for our model of postoperative stroke.

So we can do this. Logic dictates that it should be able to help us minimize our postoperative morbidity. But do we have any clinical evidence that these predictive models really help? Dr. Ferraris, have you seen any real reduction in your postoperative morbidity as a result of this study?

I wonder whether managed care groups should have access to this kind of analysis. It is obvious that these groups will impose restrictions on patient care and the restrictions will be based on their own arbitrary and sometimes hopelessly superficial criteria. Should we encourage managed care groups to use risk-adjusted analyses like the one you have presented, or should these risk models stay with the surgeon for purely clinical considerations?

Dr. Ferraris. Thank you, Dr. Edwards, for your comments. We are all aware of your efforts involved in risk stratification and risk identification, especially related to the Society of Thoracic Surgeons database.

The answer to your questions probably will be a little bit philosophic. First of all, these studies were formulated and designed as part of a process of improving patient outcomes, not decreasing costs. Of course, cost inevitably creeps in when managed care discussions come up, and we certainly hope that by decreasing morbidity we will also decrease costs. This seems likely, but, as yet, that is an unproved hypothesis. Organizations that pay for health care are interested in cost, probably more than in outcomes. I think for physicians to get involved in this process is very important. We are not at the point where we have to limit care based on costs, and we have to be involved in the risk identification and stratification process to provide optimal cost-effective care.

Clinically, we are still at the point where we are identifying risks. We have not applied this in a prospective manner yet, although we certainly intend to do that. The sought-after goal would be to reduce risks on the basis of this risk stratification, identifying high-risk patients who are likely to benefit from some intervention. Perhaps next year we can talk more about clinical applications.

Dr. Robert A. Guyton *(Atlanta, Ga.).* I have a question related to the use of composite variables. I have no difficulty with a composite variable when two variables are physiologically related, such as red cell volume and age, but I do have some concern with the probability of a mortality composite variable in which unrelated variables are pulled together. Do you think that the inclusion of probability of mortality is the reason, for example, that age was not a predictor of mortality but was a predictor of morbidity and that is the reason that you have different risk factors for mortality than you have for morbidity?

Dr. Ferraris. The issue of the composite variables is a little bit sticky. The PROBMORT variable is actually a variable that is generated by a New York State database. It has 12 or 15 variables within it, one of which is age. Thus there is some overlap among the variables that were used in the equation. From the point of view of constructing a model that you apply to the statistics, you want to minimize these variable interactions. As long as you can come up with a meaningful model, then I think it is reasonable to do this. The reason for including the PROBMORT variable was that this is something that has been proved in a large number of patients to correlate with mortality. We thought that by showing that it does indeed predict mortality, we have some validation of our statistical methods in our model.

Dr. Bruce A. Reitz *(Stanford, Calif.).* Dr. Ferraris, I wonder if you would comment on what additional information is gained from your database as opposed to the Society of Thoracic Surgeons or the New York State database.

Dr. Ferraris. Our database is smaller than the other two. Our method would have to be applied in larger databases to really validate the method. We would hope to show that it is possible to identify risk factors from a set of variables and from statistical modeling. It remains for this model to be tested in larger databases, such as the Society of Thoracic Surgeons or the New York State database.

Appendixes 1 and 2 are on pages 740 and 741.

Appendix 1. *Definitions and values of variables used in multivariate analyses*

Variable	*Definition*	*Mean or % with variable*	*95% CI*
Outcome variables			
Mortality	In-hospital death	2.6%	1.0%
LOS	Days from operation to discharge or death	8.40 days	0.45 days
Morbidity	One or more of the following: stroke, MI, sepsis, low cardiac output requiring IABP or LVAD, renal failure, or pulmonary failure	8.5%	1.8%
Continuous predictor variables			
Age	Age in years	64.6 years	0.68 years
Age/RBCVOL	Age in years divided by red blood cell volume estimated from nomogram	0.0390 yr/ml	0.0009 yr/ml
Preop. hematocrit value	Hematocrit measured 24 hours before operation	39.4%	0.3%
Preop. platelet count	Platelet count measured 24 hours before operation (number/liter)	250	5
BSA	Body surface area estimated from nomogram of body weight, height, and gender	1.93 m^2	0.02 m^2
Ejection fraction	Ejection fraction measured from preoperative catheterization	50.1%	1.0%
PROBMORT	Predicted probability of death estimated from the NY State risk-adjusted mortality score (see Appendix 2)	0.0250	0.003
Discrete predictor variables			
Females	Percent of patients who were female	29.2%	2.9%
Left main disease	Left main obstruction ≥ 90%	4.9%	1.4%
Fresh MI	MI within 7 days before operation	8.0%	1.7%
Emergency OR	Operation performed in next available OR after diagnosis made	5.8%	3.7%
Reop. 1	First reoperative procedure	4.8%	1.4%
Reop. 2	Second reoperative procedure	0.1%	0.2%
Previous stroke	Stroke resulting in permanent deficit	5.4%	1.5%
Femoral popliteal disease	Arterial obstruction of >50% in the femoral popliteal distribution documented by arteriogram or noninvasive diagnostic study	7.9%	1.7%
Preop. shock	Hypotension requiring pressor therapy or IABP for maintainance of blood pressure	5.7%	1.2%
Hypertension	Diastolic hypertension requiring medication for control	68.9%	3.0%
Unstable angina	Rest angina requiring intravenous nitroglycerin for control	19.3%	2.5%
LVH	Ventricular hypertrophy documented by preoperative electrocardiogram	8.3%	1.8%
CHF	Preop. heart failure requiring treatment during the same admission that CABG was performed	9.7%	1.9%
Ventricular arrhythmias	VT or VF requiring cardioversion or documented episode of sudden death	1.9%	0.7%
COPD	Chronic lung disease requiring bronchodilator or steroid therapy	22.7%	2.7%
Diabetes	Glucose intolerance requiring oral or injectable medication	24.1%	2.7%
Hepatic failure	Elevation of bilirubin > 3.0	0.20%	0.28%
Renal failure	Dialysis-dependent	0.7%	0.6%
Renal dysfunction	Creatinine > 2.5 but not on dialysis	1.8%	0.8%
Immune deficit	AIDS or drug-induced immune deficit	1.4%	0.7%
Cath crash	Emergency transfer to OR after diagnostic catheterization	1.2%	0.7%
PTCA crash	Emergency transfer to OR after failed PTCA	2.1%	0.9%

CI, Confidence interval; *LOS,* length of stay; *MI,* myocardial infarction; *IABP,* intraaortic balloon pump; *LVAD,* left ventricular assist device; *RBCVOL,* red blood cell volume; *BSA,* body surface area; *PROBMORT,* probability of death; *NY,* New York; *OR,* operating room; *LVH,* left ventricular hypertrophy; *CHF,* congestive heart failure; *CABG,* coronary artery bypass grafting; *VT,* ventricular tachycardia; *VF,* ventricular fibrillation; *COPD,* chronic obstructive pulmonary disease; *AIDS,* acquired immunodeficiency syndrome; *PTCA,* percutaneous transluminal coronary angioplasty.

Appendix 2. *Risk factors and relative risk for variables that contribute to PROBMORT (from the New York State risk-adjusted mortality score for surgeons and hospitals)*[2]

Risk factor	*Relative risk*
None	1.000
Age	0.480
Body surface area	−11.816
Myocardial infarction within 6 hours of operation	8.093
Persistent ventricular arrhythmias	5.777
Ejection fraction < 0.20	9.558
Ejection fraction between 0.20 and 0.39	4.705
Unstable hemodynamic state (intraaortic balloon pumping or pressors)	12.158
Shock	20.032
Chronic obstructive pulmonary disease	3.822
Diabetes	4.821
Dialysis-dependent renal failure	9.890
Previous stroke	5.928
Canadian Coronary Score (class IV only)	5.960
Femoral/popliteal vascular disease	6.171
Previous cardiac operation	10.949