Prediction of Outcome in Cardiac Surgery

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Abstract

There has been growing interest in defining and measuring outcomes for cardiac surgical patients. Outcomes measures have been used in many hospitals as tools for measuring the quality of care, although it is difficult to infer from them how care might be improved. Traditionally, the major outcome endpoints used in cardiac surgery have been the 30-day mortality and morbidity rates. Recently, more innovative intermediate outcomes, including health-related quality of life, functional status, and patient satisfaction 6 months to one year after surgery, have received more attention. Asignificant proportion of the variance in health care outcomes is affected by patient-related risk factors. By using outcome prediction tools and making conclusions based on preoperative risk factor information, surgeons and anesthesiologists are able to make better decisions about treatment strategies. Additionally, operating room and intensive care unit personnel can use these data to schedule cases and allocate resources more efficiently. These data are also very important for hospital administrators and insurance providers.

Key Words: Cardiac surgery, outcome prediction, risk factors, quality of life, morbidity, mortality.

Introduction

IN WESTERN SOCIETIES, health care costs have been increasing each year. Reasons for this growth include technical and biological advances in medicine and the relative freedom with which hospitals allocate resources to new areas. These costs have been borne by third parties: government, communities, insurance companies, and health maintenance organizations (1). Third parties have now assumed an active role in controlling hospital work, on a cost-benefit basis. As a result, health care systems are under economic pressure. One way of reducing costs in health care is to increase competition, but this raises concerns about reducing the quality of care. Critical and even comparative evaluations of alternative treatment strategies have gained increasing importance. New therapeutic practices have been critically evaluated and older therapies have been re-evaluated in terms of benefits and risks to individual patients. Thus, it is in the interest of patients, health care providers and third-party payers to measure and predict the outcome of different therapeutic approaches. Cardiac surgery has been one of the most intensive areas of research of this type. Patient outcomes between hospitals have been compared for some time. These comparisons may have significant consequences. Thus, the need for valid outcome measures is obvious (2).

All attempts to predict outcome must take into account the variability due to patient-related factors. On one hand, the average outcome of a certain therapeutic intervention depends on the patient population; patients who have high-risk profiles have less favorable outcomes. On the other hand, the same outcome may be viewed differently by different individuals. Ultimately, the measurement of patient outcome is a complex process in which the interests of society (e.g., ability to work) and the individual patient (e.g., quality of life) need to be balanced. The scope of this review is the prediction of outcomes in coronary artery bypass surgery. However, the principles are applicable to other surgical outcomes.

Outcome Dimensions

In cardiac surgery, outcome can be defined as the measurable result of an episode of health care, including all morbid events and mortalities that occur during the 6-month follow-up after cardiac surgery (3). Outcome can be divided into three sub-categories: short-term outcome, intermediate outcome, and long-term outcome. The term "short-term outcomes"

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refers to patient outcomes at discharge or within 30 days of surgery, and includes morbidity and mortality rates, length of hospital stay, resource utilization and patient satisfaction. Patient outcomes at 6 months after surgery are defined as being intermediate outcomes. These (intermediate) outcomes include morbidity and mortality rates, cardiac health status (functional status after treatment), health-related measures of quality of life, patient satisfaction and ability to work. Long-term outcome measurements include quality of life, patient satisfaction, and ability to work for a period of one year or longer (measured up to 10 years) after surgery (3).

Outcome Definitions

Outcomes that require definitions include mortality and morbidity rates, quality of life, patient satisfaction, resource utilization, economic outcome and cost-effectiveness. Mortality is an endpoint that is easy to define. Because patient mortality is a relatively rare event, it is not easy to predict on an individual level. In many institutions, mortality is used as a measure of the quality of care. For coronary bypass surgery, unadjusted mortality rates range from 2.0 – 4.6% (4). Since underlying diseases are factors contributing to mortality, an adjustment is necessary to compare the effects of treatments on mortality.

Postoperative morbidity is common, especially in cardiac surgery. Since it is a relatively frequent event, it is easier to predict on an individual basis. Morbidity rates vary from 2 – 43%. Morbidity correlates with length of stay (LOS) in the intensive care unit (ICU) (5), LOS in the hospital, and health care costs (6). Morbidity in cardiac surgery is usually defined as complications that will increase the length of stay postoperatively, either in the ICU or in other areas of the hospital. The most common postoperative morbid events include prolonged mechanical ventilation, ventricular failure, central nervous system complications (e.g., stroke), renal failure, serious infections (e.g., mediastinitis) and severe arrhythmia (7).

Quality of life (QOL) and patient satisfaction are outcomes that are highly valued but difficult to measure objectively. The health-related quality-of-life (HRQoL) instruments are normally categorized as generic or disease-specific, on the basis of their applicability to various conditions. Generic measures are necessary to compare outcomes across different populations and interventions, especially for cost-effectiveness studies. Disease-specific measures assess the special states and concerns of diagnostic groups. There are several commonly used and validated generic measures of QOL, such as the Nottingham Health Profile (NPH), SF-36 health survey, Sickness Impact Profile, Duke Activity Status Index, and RAND Mental Health Inventory. The advantage of generic QOL measurement is that one can compare the impact of various therapies across disease boundaries. The Duke Activity Status Index has been used to measure functional status after cardiac surgery, and the RAND Mental Health Inventory has been used to evaluate emotional health postoperatively (8). One disease-specific measure that has been used to determine HRQoL in coronary artery disease is the Seattle Angina Questionnaire (SAQ) (9).

Economic outcome/cost-effectiveness and resource utilization have generated increasing interest, especially among hospital administrators and insurance companies (10). The evaluation of costs may be based on cost-related events, such as LOS, or on real costs. However, it is not easy to calculate real costs, because the costs of an individual procedure and its possible complications are not always recorded. Moreover, hospital discharge costs may not reflect the costs of the treatment of an individual patient but rather an average of similar or even different procedures as well as the “overhead.” Resource utilization includes length of stay in the ICU and hospital, readmission to the ICU or hospital, operating room (OR) time and total hospital costs. Hospitals make comparisons between their operative results in cardiac surgery. The cost-effectiveness analysis should include information about patient satisfaction and quality of postoperative life (QALY) in individual patients. The full analysis should integrate data regarding morbidity and mortality, patient status and patient satisfaction measures, as well as data regarding costs of the care. Comparisons of the alternative modes of care (coronary artery bypass graft [CABG]; with sternotomy and cardiopulmonary bypass [CPB]; minimally invasive CABG; “off-pump” CABG; catheterization laboratory interventions; and medical therapy) (11, 12) can be made based on this information. However, a comparison of newer versus older methods should not be based solely on short-term results. The intermediate or even long-term outcome should be included in such analyses. Changes in the approaches to surgery and anesthesia can also be made based on cost-effectiveness results (13).

Outcome Prediction Tools

Patient risk factors are variables that affect outcome; they are defined as the preoperative patient characteristics that may place the patient at a disadvantage for a favorable outcome. These factors include severity of cardiac disease, co-morbidity factors, general heath status, demographics and socioeconomic factors.

Several risk stratification systems have been developed to predict the risk for mortality and/or morbidity from cardiac surgery. The Montreal Heart Model is one of the first published risk stratification methods (1983) used to determine mortality (14). It was created using data from 500 patients in a single institution. The Parsonnet Model was developed to predict mortality based on a database of 3,500 patients; it was prospectively validated on 1,332 additional patients (15). The Society of Thoracic Surgeons (STS) Database, with 80,000 cardiac surgical patients, was used to develop the STS Model for prediction of mortality and morbidity (16). The STS Model and Parsonnet score are still widely used in U.S. hospitals. The Cleveland Clinic Preoperative Model, developed from a database of 5051 patients and validated on 4069 patients at a single institution, was published in 1992 (17). It consists of 13 risk factors for mortality and morbidity and is also claimed to predict LOS, costs, and the likelihood of early ICU discharge for patient populations. However, none of these models has gained worldwide acceptance in routine clinical planning work, perhaps due to their regional basis and complexity.

Recently, the Parsonnet Model has been tested in several European cardiac surgical centers. Based on the results of these studies, a new modified "Parsonnet" model called "EuroSCORE" has been developed, to predict mortality for both CABG and valve replacement patients (18). The predictive power of this modified index is better for the European patient population than that of the Parsonnet Model. Another new model for use in isolated CABG surgery was developed and validated in 1999 by the Northern New England Cardiovascular Disease Study Group. This model was included in the ACC/AHA practice guidelines for bypass surgery (19, 20).

Accuracy of Outcome Prediction Models

Measurement of Accuracy

Before the risk assessment models are applied to larger populations, the models must be calibrated. We must be able to measure how closely the predicted and observed outcome results match one another. The Hosmer-Lemeshow goodness-of-fit test (chi-square test) has been used to measure calibration (21). Low chi-square values reflect good performance of the model. Another important measurement of the accuracy of the model is how well the model discriminates between ill and healthy patients. A common test to measure discrimination is the C-statistic (22). This statistic is the integral of the receiver-operator characteristic curve (sensitivity versus 1-specificity). A C-statistic of 0.5 indicates that 50% of the outcome could be predicted in the same manner as flipping a coin (which would not be particularly helpful or useful). A perfect test would have a C-statistic of 1.0. Most preoperative risk models have C-statistics of 0.70–0.85.

Statistical Methods

Various statistical methods have been used to predict outcome in cardiac surgery, such as univariate analysis, the Bayesian approach, multiple logistic regression, additive analyses and neural networks. Univariate analysis simply asks whether or not a single risk factor has an association with the outcome under study. These analyses include chi-squares, t-tests, and linear regressions. The results are expressed as p-values. A p-value less than 0.05 means that there is a 95% likelihood that the association between the factor and the outcome is not due to chance.

The Bayesian approach assumes that inferences can be made about future events based upon analyses of past events. It states how posterior probability is calculated using the prior probabilities (23, 24). Bayes' models require some computing and they adjust more easily for rare risk factors and missing data. Bayes' models have been used to predict surgical and nonsurgical outcomes in health care.

The logistic regression model, also known as multivariate analysis, is widely used in predictive models. Univariate analyses are first performed to consider the significant risk factors. Then the choice of backward or forward stepwise methods must be made. In the backward method, one factor at a time is removed, and in the forward method one factor at a time is added. After each removal or addition, a beta coefficient or relative weight for that factor is defined. Odds ratios and risk ratios can then be calculated. These ratios are very helpful for decision making. However, the analyses are quite complex and require a computer program to process the data (25).

Neural networks are nonparametric pattern recognition techniques. They use artificial intelligence to determine the probability of a relationship among multiple factors. Studies have been done using neural networks to predict CABG preoperative risks (26).

Additive methods that can be used at the bedside to calculate risk may be developed from logistic regression and Bayesian models. These additive scoring systems are easy to use and provide a rough estimate of the proposed risk. Each significant risk factor is assigned a score corresponding to its influence in the model. The CABDEAL index is an example of an additive model (27).

Development and Application of a Risk Stratification Method

The development of risk indices for cardiac surgery sometimes resembles a search for treasure at the end of the rainbow. While it may not be possible to develop one method that is applicable for all purposes, the methods that attempt to predict the same outcome usually are based on several common factors. Some of our work is summarized to illustrate this approach.

We have previously developed a preoperative risk index for predicting morbidity in coronary bypass patients (27). Data were retrospectively collected from 386 patients who underwent coronary bypass surgery in a single institution. The advantage of using a single institution is that it minimizes variability due to local treatment practices. The relationship between the preoperative risk factors and postoperative morbidity was analyzed using the Bayesian approach. The definition of increased morbidity was a prolonged postoperative hospital stay (greater than 12 days) due to adverse events. The most predictive preoperative risk factors were emergency operation, diabetes, arrhythmia or unstable angina, recent myocardial infarction with low ejection fraction, age greater than 70 years, decreased renal function, chronic pulmonary disease, obesity and cerebrovascular disease. Two types of indices were developed for the prediction of the morbidity. One was a computed model and the other was a manual, additive model with seven risk factors (the CABDEAL). The manual risk index is very easy to use, this ease being a prerequisite for its use in the initial screening of the patients. The risk factors have scores from 1–2, and the sum of the total score ranges from 0–10 (see Table). If the sum of the score is 2 or less, the risk for postoperative morbidity is minimal. If the score is 3 or more, the risk of postoperative morbidity will increase in a fashion that is nearly linear.

The CABDEAL index was also validated using a sample of 15,383 patients drawn from the New York State Database (28). The method may be used to generate a score that predicts the risk for an individual patient, or for the "normalization" of risk in patient populations. Risk stratification methods may also be useful tools for planning hospital resource allocation, and even pricing. Using the preoperative risk factors of CABDEAL, we have developed a preliminary cost index using the New York State Database. This index predicts increased hospital costs related to postoperative morbidity (6). Work is continuing, to see if the preliminary model is applicable to another type of health care system, specifically in the community-owned and state-subsidized hospitals of Finland.

Clinical Value of Outcome Prediction

Comparisons of the true (observed) and the predicted (risk adjustment) outcomes are used to compare operative results. Hospitals can better allocate their resources if they know their patients' risk profiles preoperatively. They can optimize the scheduling of high-risk patients so as to be prepared for more demanding postoperative care. Currently, surgeons must select different modes of surgical therapy (e.g., CABG with cardiopulmonary bypass, minimally invasive CABG, "off-pump" CABG, etc.), using limited data. By comparing predicted outcomes with observed results, physicians and hospitals can better judge the value of newer and older therapies, and define the patient groups that

TABLE
Preoperative Risk Factor Model (CABDEAL) with Weighted Scores.

C =	creatinine > 110 μmol/L	(score 2)
A =	age over 70 years	(score 1)
B =	BMI > 0.28 or morbid obesity	(score 1)
D =	diabetes	(score 2)
E =	emergency operation	(score 2)
A =	arrhythmia preoperatively or unstable angina	(score 1)
L =	chronic lung disease	(score 1)

Total possible score: 10

should receive them. Thus, risk assessment should be part of everyday medical practice (19, 20, 29).

Conclusion

As part of modern “evidence-based medicine,” outcome prediction tools, especially risk stratification models, will become widely used in everyday clinical practice. Outcome prediction models will allow a systematic evaluation of preoperative risk among individual patients scheduled for cardiac surgery. In a single institution, outcome prediction will help in selecting the optimal treatment for individual patients, allocating resources, assessing the quality of care on a risk-adjusted basis, and predicting costs. Risk stratification models can also be applied for national or international comparisons of the results of cardiac surgery. Suitable instruments have been developed for the prediction of the outcome in cardiac surgery. Further work is needed to evaluate their accuracy and usefulness in operative planning and financial aspects of operating room management.

References

1. Weintraub W, Craver JM, Jones EL, et al. Improving cost and outcome of coronary surgery. Circulation 1998; 98(19 Suppl):II23–II28.
2. Ferraris VA, Ferraris SP, Singh A. Operative outcome and hospital cost. J Thorac Cardiovasc Surg 1998; 115:593 – 603.
3. Schroyer A, London M, Sethi G, et al. Relationship between patient-related risk factors, processes, structures and outcomes of cardiac surgical care. Conceptual models. Med Care 1995; 33:OS26 –OS34.
4. Higgins TL. Quantifying risk and assessing outcome in cardiac surgery. J Cardiothorac Vasc Anesth 1998; 3:330– 340.
5. Petros AJ, Marshall JC, van Saene HKF. Should morbidity replace mortality as an endpoint for clinical trials in intensive care? Lancet 1995; 345:369– 371.
6. Kurki TS, Kataja M, Reich D. Predicting and modeling of hospital costs for the first-time coronary bypass patients [abstract]. Anesthesiology 1998; 89:A1176.
7. Silber JH, Rosenbaum PR, Schwartz JS, et al. Evaluation of the complication rate as a measure of quality of care in coronary artery bypass graft surgery. JAMA1995; 274:317– 323.
8. Hlatky MA, Rogers WJ, Johnstone I. Medical care costs and quality of life after randomization to coronary angioplasty or coronary bypass surgery. N Engl J Med 1997; 336:92– 99.
9. Spertus JA, Winder JA, Dewhurst TA, et al. Monitoring the quality of life in patients with coronary artery disease. Am J Cardiol 1994; 74:1240– 1244.
10. Denton TA, Luevanos J, Matloff JM. Clinical and nonclinical predictors of the cost of coronary bypass surgery: Potential effects on health care delivery and reimbursement. Arch Intern Med 1998; 158:886– 891.
11. Borst C, Grundeman PF. Minimally invasive coronary artery bypass grafting. An experimental perspective. Circulation 1999; 99:1400– 1403.
12. Wong DT, Cheng DC, Kustra R, et al. 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. Anesthesiology 1999; 91:936– 944.
13. Lahey SJ, Campos CT, Jennings B, et al. Hospital readmission after cardiac surgery. Does “fast track” cardiac surgery result in cost saving or cost shifting? Circulation 1998; 98(19 Suppl):II35–II40.
14. Paiement B, Pelletier C, Dyrda I. A simple classification of the risk in cardiac surgery. Can Anaesth Soc J 1983; 30:61– 68.
15. Parsonnet V, Dean D, Bernstein AD. Amethod of uniform stratification of risk for evaluating the results of surgery in acquired adult heart disease. Circulation 1989; 79(Suppl):3 – 12.
16. Edwards FH, Clark RE, Schwartz M. Coronary artery bypass grafting: The Society of Thoracic Surgeons National Database Experience. Ann Thorac Surg 1994; 57:12– 19.
17. Higgins TL, Estafanous FG, Loop FD, et al. Stratification of morbidity and mortality outcome by preoperative risk factors in coronary artery bypass patients. JAMA 1992; 267:2344 – 2348.
18. Nashef SA, Roques F, Michel P, et al. European system for cardiac operative risk evaluation (EuroSCORE). Eur J Cardiothorac Surg 1999; 16:9– 13.
19. Eagle KA, Guyton RA, Davidoff R, et al. ACC/AHA guidelines for coronary artery bypass graft surgery: Executive summary and recommendations: A report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (Committee to revise the 1991 guidelines for coronary artery bypass graft surgery). Circulation 1999; 100:1464 – 1480.
20. Eagle KA, Guyton RA, Davidoff R, et al. ACC/AHA guidelines for coronary artery bypass graft surgery: A report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (Committee to Revise the 1991 Guidelines for Coronary Artery Bypass Graft Surgery). American College of Cardiology/American Heart Association. J Am Coll Cardiol 1999; 34:1262– 1347.
21. Lemeshow S, Hosmer DW. Areview of goodness of fit statistics for use in the development of logistic regression models. Am J Epidemiol 1982; 115(1):92 – 106.
22. Hanley JA, McNeil BJ. The meaning and use of the area under a receiver operating characteristic (ROC) curve. Radiology 1982; 143:29– 36.
23. Marshall G, Shroyer AL, Grover FL, Hammermeister KE. Bayesian-logit model for risk assessment in coronary artery bypass grafting. Ann Thorac Surg 1994; 57:1492– 1500.
24. Schulman P. Bayes’ theorem — a review. Cardiol Clin 1984; 2:319 – 327.
25. Wright JG, Pifarre R, Sullivan HJ, et al. Multivariate discriminant analysis of risk factors for operative mortality following isolated coronary artery bypass graft. Chest 1987; 91:394 – 399.
26. Lippmann RP, Shahian DM. Coronary artery bypass risk prediction using neural networks. Ann Thorac Surg 1997; 63:1635 – 1643.
27. Kurki TSO, Kataja M. Preoperative prediction of postoperative morbidity in coronary artery bypass grafting. Ann Thorac Surg 1996; 61:1740– 1745.
28. Kurki TS, Kataja M, Reich D. Prediction of morbidity in coronary bypass surgery. Validation of the “CABDEAL” — model [abstract]. Anesthesiology 1998; 89:A283.
29. Ferraris VA, Ferraris SP. Risk factors for postoperative morbidity. J Thorac Cardiovasc Surg 1996; 111:731 – 741.