OPERATIVE OUTCOME AND HOSPITAL COST

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Introduction: **Because of concern about increasing health care costs, we undertook a study to find patient risk factors associated with increased hospital costs and to evaluate the relationship between increased cost and in-hospital mortality and serious morbidity.** ***Methods:*** **More than 100 patient variables were screened in 1221 patients undergoing cardiac procedures. Simultaneously, patient hospital costs were computed from the cost-to-charge ratio. Univariate and multivariate statistics were used to explore the relationship between hospital cost and patient outcomes, including operative death, in-hospital morbidity, and length of stay.** ***Results:*** **The greatest costs were for 31 patients who did not survive operation ($74,466, 95% confidence interval $27,102 to $198,025), greater than the costs for 120 patients who had serious, nonfatal morbidity ($60,335, 95% confidence interval $28,381 to $130,897, $p = 0.02$) and those for 1070 patients who survived operation without complication ($31,459, 95% confidence interval $21,944 to $49,849, $p = 0.001$). Breakdown of the components of hospital costs in fatalities and in cases with nonfatal complications revealed that the greatest contributions were in anesthesia and operating room costs. Significant (by stepwise linear regression analysis) independent risks for increased hospital cost were as follows (in order of decreasing importance): (1) preoperative congestive heart failure, (2) serum creatinine level greater than 2.5 mg/dl, (3) New York state predicted mortality risk, (4), type of operation (coronary artery bypass grafting, valve, valve plus coronary artery bypass grafting, or other), (5) preoperative hematocrit, (6) need for reoperative procedure, (7) operative priority, and (8) sex. These risks were different than those for in-hospitality death or increased length of stay. Hospital cost correlated with length of stay ($r = 0.63, p < 0.001$), but there were many outliers at the high end of the hospital cost spectrum.** ***Conclusions:*** **We conclude that operative death is the most costly outcome; length of stay is an unreliable indicator of hospital cost, especially at the high end of the cost spectrum; risks of increased hospital cost are different than those for perioperative mortality or increased length of stay; and ventricular dysfunction in elderly patients undergoing urgent operations for other than coronary disease is associated with increased cost. Certain patient factors, such as preoperative anemia and congestive heart failure, are amenable to preoperative intervention to reduce costs, and a high-risk patient profile can serve as a target for cost-reduction strategies. (J Thorac Cardiovasc Surg 1998;115:593-603)**

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Health care costs accounted for only 2% of the gross domestic product in 1965, but 14% in 1994.[1] This dramatic rise in health care costs has prompted interest and concern about the allocation and use of health care dollars. Cardiac operations are a logical target for initiatives aimed at decreasing health care costs, because coronary artery bypass grafting (CABG) accounts for more health care dollars than any other surgical procedure in the United States.[2] Hospital costs for cardiac procedures have been evaluated,[3-5] and some of the risks

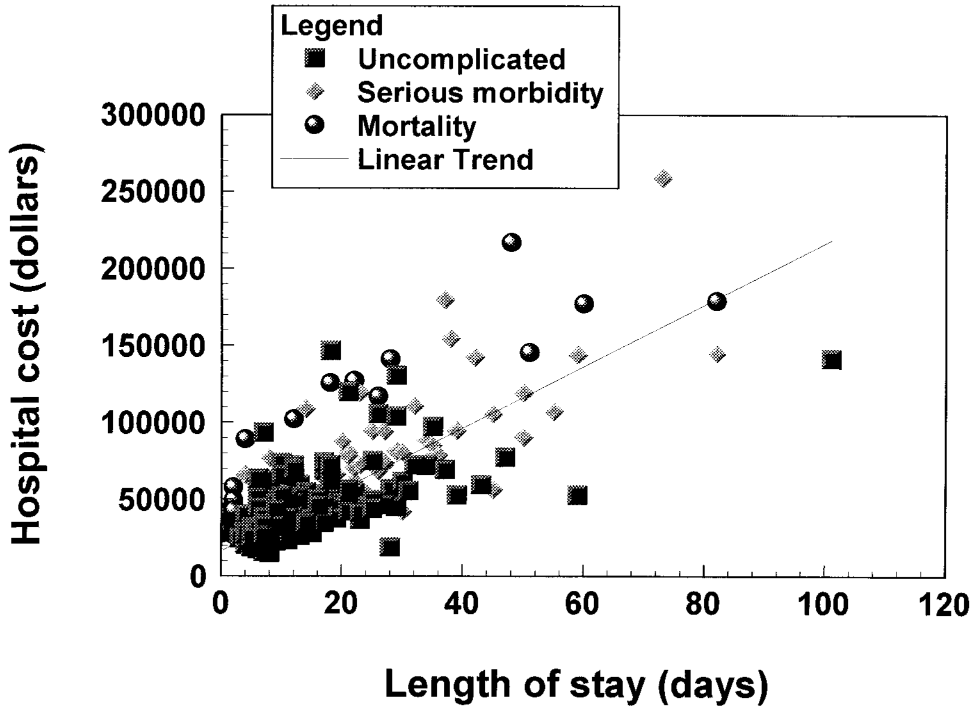


Fig. 1. Relationship between hospital costs and LOS.

associated with increased resource use have been identified.[6-11] However, the exact relationship of patient risk factors to hospital cost is poorly understood. This is alarming, because external forces may mandate cost limitation and ultimately deny care to patients at high risk. To determine which patients are at high risk for excessive hospital cost and to understand the relationship between hospital cost and other outcomes (morbidity and mortality), we undertook a study to evaluate the risks for high costs and to define the relationship between costs of cardiac operation and hospital outcome. Our ultimate goal is to generate a profile for patients at high risk for excessive hospital costs and to modify the patient risk factors and reduce hospital costs.

Methods

Patient database. Patients undergoing cardiac procedures in 1994 were entered into the study group. A total of 1221 patients were studied. Data were gathered prospectively and concurrently during the patients' hospital stays. Data were obtained from patient records by research nurses who were given strict criteria to determine outcome variables (stroke, perioperative myocardial infarction, sepsis, respiratory failure, postoperative bleeding, low cardiac output necessitating intraaortic balloon counterpulsation, and renal failure) as well as to determine preoperative variables. A few patient records were incomplete, but more than 98% of all data elements for each patient were available for analysis. Incomplete records were not included in the study. More than 100 patient variables were evaluated for each patient undergoing operation. All database elements were gathered by an independent observer (a research nurse hired by the institution). These variables are included in a database maintained by the institution and used as part of the New York State cardiac surgery database. The New York State cardiac surgery database is used to generate hospital-specific and surgeon-specific risk-adjusted mortality rates, which are routinely published in the lay press. Appendix 1 lists significant variables and their definitions used to calculate predicted operative mortality rates for New York State risk adjustment methodology.

An estimated mortality risk for each patient was calculated according to the New York State risk adjustment system. This method of risk adjustment has only been validated for CABG procedures.[12-14] The study group included all patients undergoing cardiac procedures requiring cardiopulmonary bypass, not just patients undergoing CABG. Many of the risk factors for death in patients undergoing procedures other than coronary revascularization are similar to those in patients undergoing CABG (Appendix 2). Such variables as ventricular dysfunction, advanced age, and urgency of operation are important risk factors for death both in patients undergoing coronary revascularization and in those undergoing other cardiac procedures.[15] For comparison purposes, the New York State mortality risk score for CABG was therefore used as an approximation of predicted mortality rate for the study group, which underwent a variety of operations, not only CABG.

Determination of hospital costs from charges. Hospital costs were computed from the cost to charge ratio. There are a total of 32 cost centers in the institution, including operating room, anesthesia, room and board, pharmacy, microbiology, blood bank, chemistry, and hematology. Each person responsible for administration of an individual cost center identified the true direct and indirect costs within that cost center. The ratio for each cost center was used to compute the estimated true costs per patient undergoing cardiac surgery in 1994, and the cost estimates for each cost center were summed to obtain the total hospital costs per patient. To facilitate analysis, the different cost centers were grouped into seven different cost groups as follows: (1) pathology, costs including hematology, chemistry, blood bank; (2) cost of room and board; (3) anesthesia costs, including perfusion apparatus; (4) operating room costs, including disposables and personnel costs but not physician fees; (5) drugs and pharmacy costs; (6) cardiology costs, including telemetry, electrocardiograms, and postoperative diagnostic studies; and (7) miscellaneous costs, including radiologic, gastrointestinal, renal, physical medicine, emergency department, and noninvasive vascular studies. Professional fees were not included in the computed costs.

Statistical methods. Univariate and multivariate statistical methods were used for examination of the study group. Four outcomes were measured: (1) hospital cost, (2) length of stay (LOS), (3) in-hospital death, and (4) serious in-hospital morbidity (stroke, perioperative myocardial infarction, sepsis or deep sternal infection, low cardiac output necessitating intraaortic balloon counterpulsation or a left ventricular assist device, renal failure, or pulmonary failure). All variables in the database were screened for relevance to each of the outcomes and for variable interactions.[16]

Hospital costs in the various patient outcome groups (deaths, morbidities, and uncomplicated courses) were compared with one-way analysis of variance. Intergroup comparisons were made with adjusted *t* tests. Similar univariate statistical methods were used to analyze the relationship between LOS and outcome.

Linear regression analysis was used to determine the correlation between hospital cost and LOS. The Pearson correlation coefficient was calculated from the regression line, and an analysis of residuals was performed to determine the quality of the regression.

A stepwise multivariate linear regression model was used to find independent predictors of increased hospital cost (BMDP Statistical Software, Sepulveda, Calif.). Only preoperative variables were included in the multivariate models. Intraoperative or postoperative variables, such as ischemic time, chest tube drainage, amount of blood products consumed, or number of bypass grafts, were not entered into the multivariate models because it would be difficult to estimate the value of these variables before the operation for a predictive model. Variables were entered into the linear regression model in a stepwise manner, with a univariate contingent probability of 0.10 or less used to enter variables and a *p* value lower than 0.15 used to remove variables from the model. A Cox regression model was used to find independent risk factors for increased LOS. Postoperative deaths were considered censored events for the purposes of the Cox regression. For operative death, a logistic regression model 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.

Table I. *Independent risk factors for excessive hospital cost determined by stepwise linear regression model*

Predictor variables	*Stepwise regression coefficient*	*Change in* r^2	*t Test*
Preoperative CHF	1114	0.0947	126.90
Creatinine >2.5 mg/dl	25634	0.0564	80.50
New York State predicted mortality risk	99930	0.0436	65.49
Type of operation (CABG, valve, valve with CABG or other)	5731	0.0402	63.56
Preoperative hematocrit	706	0.0278	45.61
Reoperative procedure	5416	0.0068	11.33
Priority (elective, urgent, or emergency)	3117	0.0064	10.68
Sex	2650	0.0031	5.15

CHF, Congestive heart failure.

Results

Hospital cost and outcome. Hospital cost was compared for each of three different patient outcomes, operative death, serious postoperative morbidity, and uncomplicated postoperative course. Significant differences were found between costs in uncomplicated cases and those in fatalities (p = 0.001 by analysis of variance and adjusted *t* test) and patients with serious morbidity ($p = 0.004$). Hospital costs in uncomplicated cases averaged $31,579 (95% confidence interval [CI] $21,944 to $49,849). Costs in patients who had serious morbidity averaged $60,335 (95% CI $28,381 to $130,897), versus an average cost of $74,466 (95% CI $27,102 to $198,025) in patients who did not survive operation. In general the worse the outcome, the higher the hospital cost.

LOS and outcome. Hospital LOS is not related to surgical outcome in the same way as hospital cost; a similar direct relationship between the seriousness of the various outcomes and hospital LOS does not exist. Patients with uncomplicated courses remained hospitalized for a mean of 8.3 days (95% CI 0 to 71 days), whereas patients with morbid complications stayed in the hospital an average of 18.2 days (95%

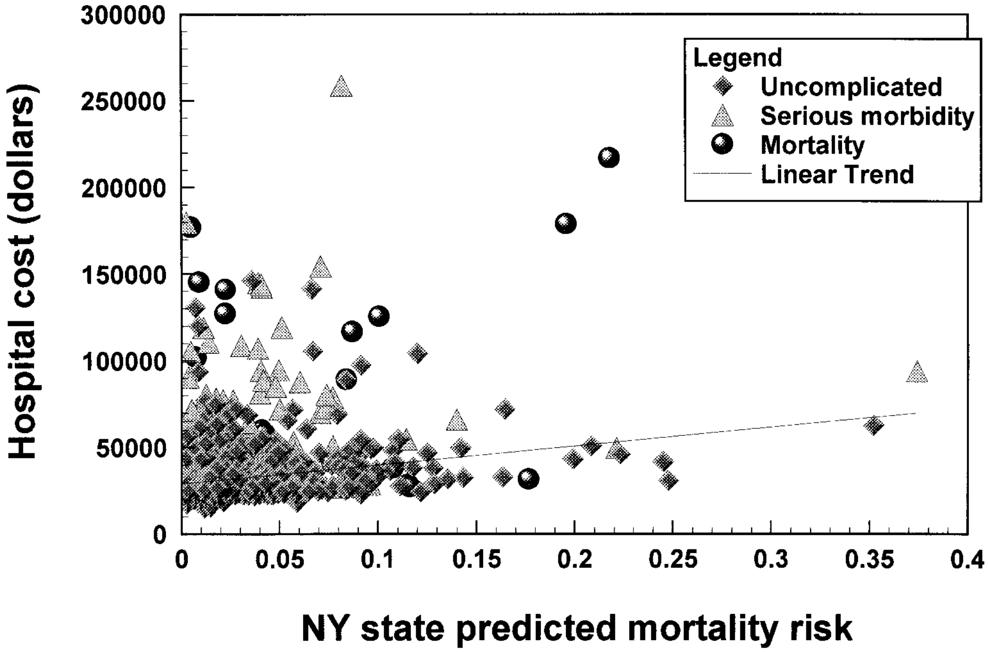


Fig. 2. Relationship between hospital cost and the New York State predicted mortality risk. There is poor direct correlation between these two variables. *NY,* New York.

CI 5.5 to 47.5 days) and patients who died did so an average of 14.2 days (95% CI 0 to 71 days) after operation. There was a significant difference in LOS between complicated and uncomplicated cases (p = 0.01 by analysis of variance with corrected t test), but not between fatalities and uncomplicated cases (p = 0.48 by analysis of variance).

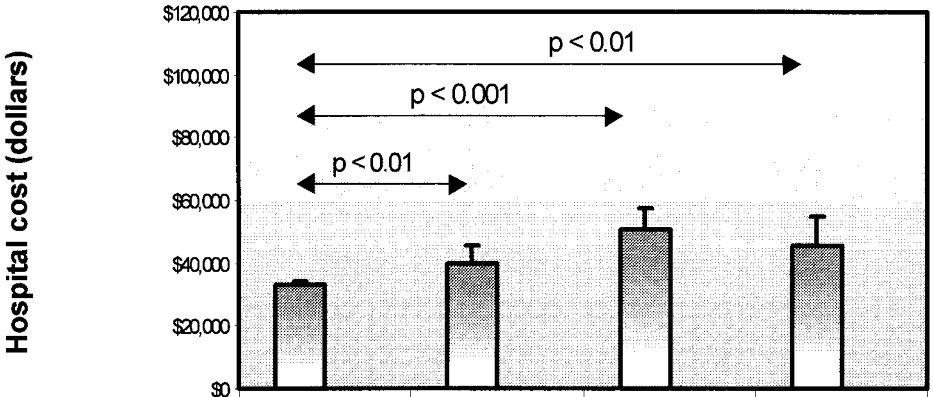
Relationship between cost and hospital LOS. The relationship between cost and LOS is depicted in Fig. 1. The Pearson correlation coefficient for this relationship is 0.63 ($p < 0.001$), Residual analysis of the regression in Fig. 1 suggests that outliers from the regression line are part of the natural variation of the two outcome variables, cost and LOS,

Multivariate analysis of risk factors for increased cost. Stepwise linear regression analysis was used to model independent preoperative risks for incurring increased hospital costs. Significant predictor variables in the model are shown in Table I. The variables are listed in order of their relative contribution to the linear regression equation.

Hospital cost and risk for operative death. The relationship of hospital cost to the operative mortality risk is shown in Fig. 2. There is a surprisingly poor correlation between cost and predicted mortality risk. Even though the mortality risk (as represented by the New York State predicted mortality risk scoring system) is a significant multivariate predictor of increased cost, there is poor direct correlation between these two variables. Many patients with a less than 2% predicted risk of death had hospital costs in excess of $100,000.

Hospital cost and type of operation. The type of operative procedure alters hospital cost. Fig. 3 shows the change in average hospital cost with the type of operation performed. Operations other than coronary revascularization are associated with significantly increased costs compared with isolated coronary revascularization.

Components of increased hospital cost. The hospital cost per patient was the summation of cost from each of the 32 different cost centers within the institution. The different cost centers were reduced into seven different groups to facilitate analysis (see Methods). Fig. 4 shows the contribution to total costs from each of the seven major groups for the various outcomes. More than 80% of hospital costs were from five cost centers: (1) pathology (including hematology, chemistry, and blood bank), (2) room and board, (3) anesthesia, (4) operating room expenses, and (5) pharmacy costs. The proportional contributions to costs for each of the cost centers were slightly different for patients who did not survive operation. For the group as a whole and for all patients who survived operation,



	CABG	Valve	Valve / CABG	Other
Average hospital cost	*$33,142.68*	*$39,912.72*	*$50,506.34*	*$45,512.51*
No. of patients	*989*	*102*	*89*	*41*

Fig. 3. Variation of hospital cost with type of operation performed. The more complex the operation, the greater the hospital cost. *Error bars* represent the 95th percentile CI for each type of operative procedure.

the anesthesia and operating room costs made up the largest single component of total cost. In the case of operative fatalities, however, the biggest single component of cost was not operating room expenses but pathology costs (including blood bank, chemistry, hematology, and other costs).

Risks for death and increased LOS. Multivariate risks associated with other postoperative outcomes (death and LOS) were determined for comparison with the risks associated with hospital cost. Table II summarizes the results of Cox proportional hazards regression analysis to determine risks for hospital LOS, and Table III summarizes logistic regression results to determine risks for increased operative mortality rate. The risk factors for both operative death (Table III) and prolonged hospital LOS (Table II) are different than those for increased hospital cost (Table I).

Some of the relative risks for significant variables associated with increased LOS (shown in Table II) are less than 1. This indicates that the presence of one or more of these risks in a case reduces the chance of minimizing hospital LOS before discharge or in-hospital death.

Conclusions

This study demonstrates the patient risk factors associated with increased hospital cost after cardiac operations. Consideration of these risk factors suggests that frail (anemic), elderly patients with ventricular dysfunction undergoing urgent operations other than coronary revascularization are at particularly high risk for incurring excessive hospital costs. This result is not surprising and appeals to the intuitive view of experienced surgeons, who use the "eyeball test" to estimate the risk of incurring high cost. A careful scrutiny of the risk factors associated with high cost suggests that only a few are amenable to preoperative intervention to reduce costs. Attempts to improve preoperative anemia (by increasing preoperative hematocrit) and to improve congestive heart failure will probably decrease cost, especially if the operation can be converted to an elective procedure. Although this is an intriguing hypothesis, it must be treated as such until tested in controlled trials.

The most costly outcome in our study is operative death, and the biggest component of cost in fatalities is laboratory (not operating room) cost. This somewhat surprising result warrants comment. Of the 31 patients who did not survive operation, only three died in the operating room. Many of the others died after prolonged intensive care unit and hospital stays. This results in the variability of costs in these patients being spread across a wide range, as can be appreciated from the CIs. The contributions to hospital cost shown in Fig. 4 suggest that operating room and anesthesia costs are fairly constant regardless of outcome. However, the sickest patients who eventually die after operation consume significantly increased resources largely composed of laboratory costs, including blood bank expenses, and other non–operating room costs. Operative death is associated with increased cost, but the

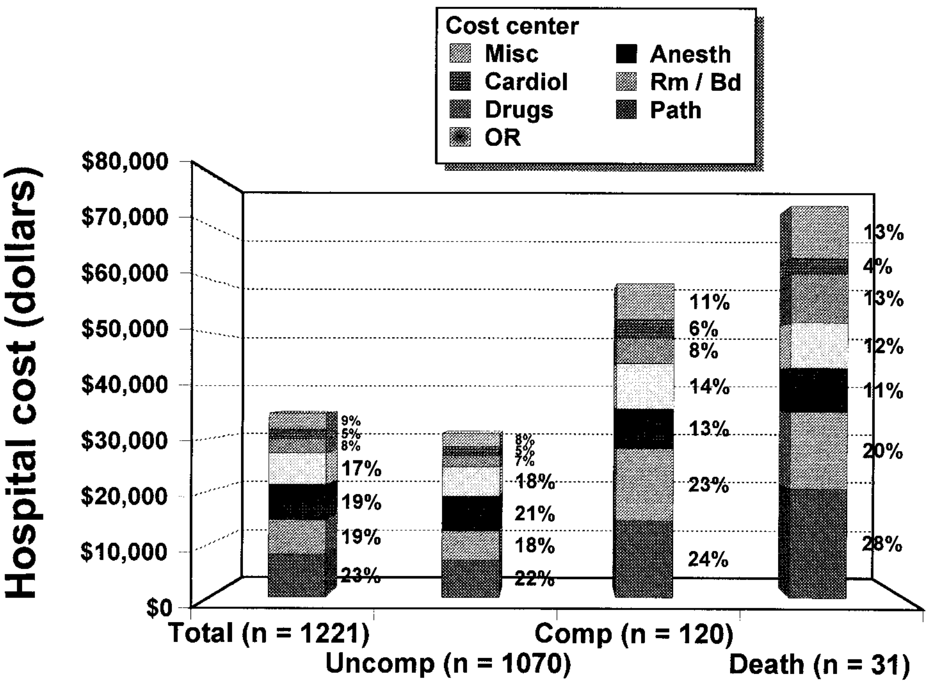


Fig. 4. Components of total hospital costs for each of the various outcomes. *Misc,* Miscellaneous; *Anesth,* anesthesia; *Cardiol,* cardiology; *Rm/Bd,* room and board; *Path,* pathology; *OR,* operating room; *Comp,* complicated course; *Uncomp,* uncomplicated course.

prognostic significance of this finding is uncertain. The variables that predict operative death in our study are few (Table III). A similar observation was made by Jones and coworkers,[17] who found that a relatively small number of clinical variables provide a large amount of prognostic information for operative death in patients undergoing CABG. Unfortunately, a high risk of operative death is not enough to suggest high cost. Many patients with high costs had relatively low risks of operative death; conversely, some patients with high predicted operative mortality risks did not have excessive hospital costs. Our results suggest that the preoperative predicted mortality risk is not the key item associated with high cost, but the care of the sickest patients after operation in the intensive care unit and elsewhere is an important component of increased cost for patients who do not survive operation. The difficulty in predicting which patients will die and have high costs makes it unwise and inappropriate to limit access to care solely on the basis of predicted operative mortality risk.

The exact relationship between hospital operative costs and in-hospital morbidity and mortality is not clear. If mandated limitation of health care resources becomes a reality, one cost-cutting maneuver may be to limit spending on patients with highest predicted operative mortality risks. There is, however, no clear-cut documentation that the patients with high postoperative morbidity or mortality risks have the worst cost-benefit relationship. No conclusive evidence exists that patients at high risk who consume the most hospital resources benefit the least from high-cost care. In fact, some preliminary evidence suggests that patients at very high risk surviving third operations for coronary artery disease have surprisingly limited hospital costs and good long-term benefits from reoperation.[18] On the other end of the spectrum, we found that many patients with a less than 2% predicted operative mortality risk have increased hospital costs, in excess of $100,000 (Fig. 5). Even though mortality risk is an independent, multivariate factor associated with increased cost, there is poor direct correlation between cost and predicted operative mortality risk. Before difficult decisions about limitation of care can be made, adequate information about the relationship between hospital cost and morbidity or mortality must be available.

Many patients with a less than 2% predicted mortality risk have hospital costs in excess of $100,000. Mortality risk is an independent predictor

Table II. *Results of Cox regression model to determine independent risks of hospital LOS in 1221 patients undergoing cardiac procedures during 1994*

Variable	*Relative risk (standard error)*	χ^2 *Improvement*	*p Value*
New York State predicted mortality risk (per 1% increased mortality risk)	−2.9274 (1.1280)	65.947	<0.001
Type of operation (not CABG)	0.2777 (0.0428)	48.646	<0.001
Age (per 1-year increase in age)	−0.0154 (0.0028)	26.682	<0.001
Preoperative hematocrit (per 1% increase in hematocrit)	0.0258 (0.0057)	25.204	<0.001
Creatinine greater than 2.5 mg/dl	−0.7013 (0.02085)	21.337	<0.001
CHF	−0.1798 (0.0787)	9.102	0.003
Hypertension	−0.1653 (0.0640)	5.935	0.015
Ejection fraction (per 1% change in ejection fraction)	0.0042 (0.0021)	3.839	0.050
Previous stroke	−0.2320 (0.1245)	3.454	0.063
COPD	−0.2583 (0.0867)	3.460	0.063

CHF, Congestive heart failure.

Table III. *Summary of logistic regression model to determine independent risks of operative death in 1221 patients undergoing cardiac procedures during 1994*

Variable	*Relative risk (95% CI)*	χ^2 *Improvement*	*p Value*
CHF	9.20 (6.02–14.0)	43.743	<0.001
Emergency transfer to OR after catheterization	18.6 (7.42–46.6)	11.029	0.001
Type of operation (not CABG)	6.04 (3.48–10.5)	15.939	0.001
New York State predicted mortality rate	1.28 (1.16–1.41)	4.563	0.033

CHF, Congestive heart failure; *OR,* operating room.

of increased hospital cost; however, as Fig. 2 suggests, predicted operative mortality risk does not correlate directly with hospital cost. How can a variable such as mortality risk be both an important independent multivariate predictor of increased cost and a poor direct predictor of hospital cost? There are several possible explanations of this finding. One possibility is that the New York State mortality risk scoring system used to predict operative mortality risk for patients undergoing CABG is not an accurate reflection of operative risk for patients undergoing procedures other than coronary revascularization. Another possibility is related to the principles of multivariate statistical techniques and of variable interaction. For example, hospital costs for a patient with a low predicted operative mortality risk may turn out to be unexpectedly greater if the patient also has congestive heart failure and requires a complex operation (a procedure other than simple valve replacement or first-time coronary revascularization). Variable interactions of this sort are adjusted for by the regression model presented here, and resultant regression models are more likely to reflect the true state of nature than simple comparison of the predicted operative risk with hospital cost as in Fig. 2.

The results presented here can be used to infer details of the relationship between costs of operation and LOS. The correlation coefficient for the regression line between LOS and cost is 0.63, suggesting that LOS is a moderately good predictor of cost. In statistical parlance, the results shown in Fig. 1 suggest that cost, especially at the high end of the cost spectrum, is not totally accounted for by LOS. An example can be seen by considering some of the details shown in Fig. 1. Two patients had a total hospital cost of $150,000 each and stayed in the hospital less than 20 days, whereas two other patients had similar hospital costs but stayed in the hospital more than 80 days each. This example suggests that the relationship between LOS and cost is least predictable for patients who consume the greatest share of resources.

The profile of a patient at high risk for excessive hospital cost suggests a patient with advanced cardiac disease (e.g., congestive heart failure, high mortality score, reoperative procedure, and a combination of valvular and coronary artery disease). The only significant noncardiac comorbidities that contribute to increased hospital cost are preoperative renal dysfunction and anemia. Sex is also a significant factor. This profile differs from that of a patient at high risk for prolonged LOS. The risk profile for LOS contains more comorbidities, such as chronic obstructive pulmonary failure, hypertension, renal dysfunction, and previous stroke. This difference between LOS and hospital costs suggests that surviving patients with multiple risks for prolonged LOS do not necessarily have proportionately higher costs. Others have noticed a dichotomy between LOS and hospital cost. Kay and coworkers[19] found that hospital costs were roughly proportional to preoperative ejection fraction but LOS was not. The exact relationship between LOS and hospital cost is complex and is least predictable at the extremes of the hospital cost spectrum. Care should be taken in using improvement in LOS to infer reduced hospital costs.

In addition, because variable profiles that predict prolonged LOS are more likely to contain noncardiac comorbidities than are profiles that predict hospital cost and because cost and LOS share a complex relationship, limiting care for patients with multiple noncardiac comorbidities may not have as profound an effect on cost-containment as intuitively expected. Similar conclusions were reached by Parsonnet and coworkers,[20] who evaluated hospital costs of patients stratified according to risk of operative death. These authors found that exclusion of high-risk cases from operation will result in only a minimal cost saving, perhaps as low as 2% of the total hospital costs for coronary revascularization.

Our study uses adjusted patient charge data to infer costs. Others have used patient charges to make conclusions about hospital cost.[3, 8, 21-23] A discrepancy between cost-based and charge-based hospital costs has been noted.[24, 25] Hlatky and coworkers[25] suggest that methods used to compute cost (e.g., inclusion or exclusion of estimated hospital overhead cost) can have significant impact on cost analysis and that economic cost savings can be overestimated by using charge data. Similarly Cohen and associates[24] found significant difference between cost-based and charge-based accounting methods and therefore recommend caution in using charge-based data to judge and implement cost-effectiveness strategies.

Unfortunately, most hospitals do not have a well-established cost-accounting system in place and cannot evaluate true hospital costs. This is astonishing, given the importance of escalating medical costs. The most basic tenet of any industrial process is a clear assessment of operating cost. This is necessary to judge outcome (profits) and to implement cost-effective strategies. Hospitals in particular, and health care providers in general, have been remiss in avoiding this concept that industry uses as a fundamental starting point for successful outcome. Accurate cost data provide the single most important piece of information that is almost uniformly lacking in hospitals today. More than anything else, the take-home message from our study is that accurate cost data are necessary before any cost-cutting strategies can be implemented. Relative comparisons with charge-based accounting, such as we used, are useful as a first approximation, but interventions aimed at cost saving should be based on true cost-accounting methods. This is particularly true because charges are changing at a rapid rate and are basically mandated without much concern for true costs. This situation is made worse because true costs are not usually known and are only estimated.

We found a set of multivariate risk factors associated with increased hospital cost. These risk factors allow definition of a high-risk profile that can serve as a target for cost-cutting strategies. Preoperative risk factors that may be amenable to intervention to limit hospital cost include preoperative anemia and congestive heart failure. Multivariate risks for increased hospital cost are different than those for increased LOS and for operative death. The relationship between hospital cost and outcome suggests that the greatest cost occurs for patients who do not survive operation, but the exact relationship between cost and outcome is complex. The relationship between hospital cost and LOS is also complex, so much so that improvements in LOS may not necessarily be associated with decreased cost. The components that make up hospital costs seem to be different for patients who do not survive operation than for those who do. Future refinements in deriving true hospital costs (from cost-accounting techniques) will be an important step toward implementing cost-cutting strategies.

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Appendix 1. *Variables and definitions used in the study group*

Variable	*Definition*	*Mean or % with variable*	*95% CI*
Outcome variables			
Mortality	In-hospital death	2.54%	0.008%
LOS (days)	Days from operation to discharge or death	9.43	0.46
Hospital cost (dollars)	Estimated per-patient hospital cost computed from cost to charge ratio validated by cost-accounting assessment	$35,389	$1153
Morbidity	One or more of the following: stroke, MI, sepsis, low cardiac output necessitating IABP or LVAD, renal failure, or pulmonary failure	11.6%	1.8%
Continuous variables			
Age (yr)	Age in years	64.5	0.6
Preoperative hematocrit	Hematocrit measured 24 hours before operation	39.7%	0.3%
Preoperative platelet count	Plate count measured 24 hours before operation (number/liter)	241	4
BSA (m^2)	BSA estimated from nomogram of body weight, height and gender	1.97	0.02
Ejection fraction	Ejection fraction measured from preoperative catheterization	49.9%	0.8%
New York State mortality risk	Predicted probability of death estimated from the New York State risk-adjusted mortality score (see Appendix 2)	2.46%	0.2%
Discrete variables			
Female	Percentage of patients who were female	31.6%	2.6%
Left main coronary artery disease	Left main coronary artery obstruction ≥90%	5.2%	1.2%
Fresh MI	MI within 7 days before operation	50%	2.8%
Emergency OR	Operation performed in next available OR after diagnosis made	4.8%	1.2%

Appendix 1. *Cont'd*

Variable	*Definition*	*Mean or % with variable*	*95% CI*
Re-op 1	First reoperative procedure	8.5%	1.6%
Re-op 2	Second reoperative procedure	0.98%	0.55%
Previous stroke	Stroke resulting in permanent deficit	6.7%	1.4%
Femoral popliteal disease	Arterial obstruction of >50% in the femoral popliteal distribution documented by arteriogram or noninvasive diagnostic study	22.5%	2.5%
Type of operation	Classified into one of four categories: (1) CABG, (2) valve, (3) valve/CABG, (4) other	81.0%	2.2%
Preoperative shock	Hypotension necessitating pressor therapy or IABP for maintenance of blood pressure	0.32%	0.2%
Hypertension	Diastolic hypertension necessitating medication for control	65.5%	2.7%
Unstable angina	Rest angina necessitating intravenous nitroglycerine for control	11.7%	1.8%
LVH	LVH documented by preoperative electrocardiogram	12.1%	1.8%
CHF	Preoperative heart failure necessitating treatment during the same admission that CABG was performed	9.7%	1.7%
Ventricular arrhythmias	V-tack or V-fib requiring cardioversion or documented episode of sudden death	1.3%	0.7%
COPD	Chronic lung disease necessitating bronchodilator or steroid therapy	13.6%	1.9%
Diabetes	Glucose intolerance necessitating oral or injectable medication	23.8%	2.4%
Renal failure	Dialysis dependence	1.4%	0.7%
Renal dysfunction	Creatinine >2.5 but without dialysis	2.6%	0.9%
Immune deficit	AIDS or drug-induced immune deficit	2.2%	0.8%
Cath crash	Emergency transfer to OR after diagnostic catheterization	0.9%	0.5%
PTCA crash	Emergency transfer to OR after failed PTCA	1.2%	0.6%

MI, Myocaridal infarction; *IABP,* intraaortic balloon pulsation; *LVAD,* left ventricular assist device; *BSA,* body surface area; *OR,* operating room; *Re-op,* reoperation; *LVH,* left ventricular hypertrophy; *CHF,* congestive heart failure; *V-tack,* ventricular tachycardia; *V-fib,* ventricular fibrillation; *COPD,* chronic obstructive pulmonary disease; *AIDS,* acquired immunodeficiency syndrome; *Cath,* catheterization; *PTCA,* percutaneous transluminal coronary angioplasty.

Appendix 2. *Risk factors and relative risks for variables that contribute to mortality risk, computed from the New York State risk-adjusted mortality score for surgeons and hospitals [486, 612, 621]*

Risk factor	*Relative risk of operative death*
None	1.000
Age	0.480
Body surface area	−11.816
MI 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 (IABP or pressors)	12.158
Shock	20.032
COPD	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 heart operation	10.949

MI, Myocardial infarction; *IABP,* intraaortic balloon pulsation; *COPD,* chronic obstructive pulmonary disease.

Discussion

Dr. Floyd D. Loop *(Cleveland, Ohio).* This article is germane to all thoracic surgeons because of several shifts in the medical market. We have shifts from supply to demand, from public to private, and from labor-intensive to capital-intensive health care. Physicians have assumed the economic risk, but there is one important principle that physicians are still reluctant to accept: price drives cost. Cost is simply a derivative of use.

The methodology, as Dr. Ferraris pointed out, is not the most precise estimate of cost because it assumes consistent pricing and markup policies. It is much better to have a real-time cost-accounting system, which is available today.

The authors' contentions that cost does not correlate well with LOS and that for certain subsets of patients laboratory costs and other costs are greater than surgery costs seem counterintuitive, and they certainly defy the conclusions presented by most in the literature on the subject. In fairness to the authors, however, they describe a very heterogeneous population.

The principal cost variables include disease severity, staffing, overhead, supplies, and time. In coronary artery surgery, the variables affecting severity are age, emergency procedures, reoperations, and renal status. There are others, but these four generally turn up in most analyses.

Staffing has to be flexible and responsive to volume; overhead mainly relates to square footage; supply costs are best affected through consortium purchasing and standardization; and time is a surrogate for complications.

We can reduce costs by educating ourselves and using good judgment. The most important strategies are these: (1) outpatient diagnostics and same-day admissions for all patients; (2) stratification of preoperative risk for appropriate selection and preparation; (3) minimization of intensive care unit time; (4) formulation of pathways of care and use of flexible staffing; and (5) development and use of a cost-accounting system to understand individual costs. Understanding each surgeon's cost will allow education of the staff and lead to further savings.

In my experience, costs cannot effectively be slashed arbitrarily. Cost reduction has to be accomplished thoughtfully and methodically. Try to gain savings in all areas of inpatient and outpatient care as new technology becomes available. The worst mistake we can make in a hospital is to cut irreplaceable employees who could have been reorganized to work more efficiently. It used to be said that the greatest saving in medical care was death. The authors point out that death can actually be very expensive.

Dr. Ferraris, one of your main conclusions was to focus future cost-containment strategies on this high-risk subset of patients. Often these patients are elderly and have fixed comorbidities, except for heart failure and anemia. Would you comment further on how cost might be reduced, other than by patient selection?

Dr. Jeffrey P. Gold *(Bronx, N.Y.).* Outcome, obviously, is a lot more than just what occurs in the hospital. And operative mortality and perioperative morbidity do not necessarily provide the standard for long-term outcome and quality of life. In our research, we found that perioperative neurologic morbidity, particularly stroke and lesser degrees of neurologic injury, not only are major predictors for hospital LOS and cost but also are the major predictor for long-term quality of life and outcome. Did your data reflect these same observations?

Dr. Javier Fernandez *(Browns Mills, N.J.).* We did a similar study, which has been accepted for publication by the *European Journal of Cardio-Thoracic Surgery,* involving more than 5000 patients. Half of those patients were younger than 65 years and half were older. Our purpose was to compare preoperative risk factors, complication rate, and charges as a function of age. We found a significant increase in morbidity in the elderly population, older than 65 years. Among the most important morbidities were pulmonary complications that resulted in increased LOS. Did you find pulmonary complications to be an important factor that increases the LOS and costs?

Dr. Ferraris. As Dr. Loop points out, this is a complex topic. One of the things that we learned early on is that costs are hospital specific. I will try to answer some of the discussants' questions in sort of a global way.

First is the issue of how we might reduce costs. It is true that there is a prototype of patient at whom you can look, as an experienced surgeon, and say that this patient is going to require increased time in the intensive care unit and increased cost. There are a limited number of things that may be done to intervene. One approach we have taken has to do with modification of the inflammatory response after bypass. Things that we have thought of that might reduce this inflammatory response are serum protease inhibitors and more biocompatible oxygenator circuits. We are in the process of trying to organize clinical trials that may affect patients at high risk.

The other questions about stroke and pulmonary complications and how they affect cost are difficult to answer. For example, in our study, stroke was not a particularly high-cost item. I have a feeling that this is a hospital-specific finding. Many of our patients with stroke may move out of the hospital rather rapidly compared with other hospitals. That they are discharged and go to a rehabilitation center means that their costs are decreased for our hospital's purposes, but does not necessarily mean that the costs are decreased for the system as a whole. I think it is very difficult to answer, in a global way, questions about stroke and pulmonary complications because many factors are hospital specific or surgeon specific. I hope this answers some of the discussants' questions.