European Heart Journal (2002) **23,** 574–578
doi:10.1053/euhj.2001.3031, available online at http://www.idealibrary.com on IDEAL®

Determinants of costs and resource utilization associated with open heart surgery

E. Sokolovic[1], D. Schmidlin[2], E. R. Schmid[2], M. Turina[3], C. Ruef[4], M. Schwenkglenks[1] and T. D. Szucs[1]

[1]*Department of Medical Economics,* [2]*Division of Cardiovascular Anaesthesia,* [3]*Clinic of Cardiovascular Surgery,* [4]*Department of Hospital Hygiene, University Hospital, Zurich, Switzerland*

Aims This study sought to determine the patient- and the therapy-related determinants of in-hospital costs for patients undergoing heart surgery at the University Hospital in Zurich.

Methods and Results We performed a retrospective analysis of all adult cardiac surgical patients from the canton St. Gallen who were covered by a fixed fee arrangement (29 500 Swiss francs (19 470 Euro)) and referred to our institution during 1998. A total of 201 patients (143 (71%) male) with basic insurance were hospitalized in 1998 under the fixed fee arrangement. The mean age of the patients was 61·4 years (95% confidence intervals (CI): 60; 63). With the help of univariate analysis, the following pre-operative characteristics were found to be significantly associated with cost: age ($P<0·001$), pre-operative cardiac diagnosis (coronary vs valvular heart disease) ($P<0·001$) and EuroSCORE ($P<0·0001$). A significant correlation was also found between intra-operative variables and costs ($P<0·0001$) as well as between postoperative variables and costs ($P<0·0001$). A linear regression model based on EuroSCORE, operation time and postoperative infection status is able to predict costs for patients (all P-values $<0·0001$, except for $P<0·05$ for operation time, $R^2=0·565$).

Conclusions These results suggest that both pre-operative (patient related) and intra-operative (therapy- and patient-related) variables are predictors of costs in cardiac surgical patients.

(Eur Heart J 2002; 23: 574–578, doi:10.1053/euhj.2001.3031)

Key Words: Economics, risk scores, insurance, infection, outcome.

Introduction

As health care costs continue to escalate, the extent of supply of medical technology, drugs and human resources has become increasingly important to providers, insurance companies and patients alike. The introduction of fixed reimbursement rates for adult cardiac surgery in Switzerland has shifted the financial risk from insurers to providers of medical care, namely hospitals. It is now established that the true costs of treatment and their inducing factors must be taken into consideration in decisions about health care provision[1]. To improve our ability to compare resource consumption across different regions and institutions, it is important to identify the impact of various non-clinical and clinical characteristics on subsequent cost. Understanding the underlying causes of wide variability in costs is important in determining optimum pricing.

There is a contractual agreement between the cantons St. Gallen and Zurich to treat patients who need open heart surgery at the University Hospital of Zurich. Reimbursements are regulated by a fixed fee arrangement (29 000 Swiss francs (19 470 Euro)) for patients with basic insurance, which excludes any variation based on individual patient characteristics. In the early days of this arrangement reimbursement was not greatly different from the costs of providing care, but now the costs of treatment far exceed the reimbursement level. It was therefore necessary to identify predictors of high costs and to search for ways to influence them.

Objectives

This study sought to determine which patient- and therapy-related determinants influence in-hospital costs and resource utilization for patients undergoing open heart surgery in a University Hospital setting.

Revision submitted 6 September 2001, accepted 12 September 2001, and published online 21 December 2001.

Correspondence: Emina Sokolovic MD, Georg Kempf-Str. 5, CH-8046 Zurich, Switzerland.

Methods

We performed a retrospective analysis of all adult cardiac surgical patients from the canton St. Gallen who were covered by a fixed fee arrangement (29 500 Swiss francs (19 470 Euro)) and referred to our institution during 1998. Excluded were patients who had heart transplantation. The primary data source for this analysis was the observational database established by the Division of Cardiovascular Anaesthesia, supplemented by medical chart review. Cost data were obtained by taking a relative value-based hospital tariff code[2] for physician services, including laboratory and in vivo diagnostic procedures. The intensive care unit, general ward and operating room were valued on the basis of charges, originating from the hospital's financial accounting system. Data from the observational database were: age, sex, body mass index, clinical characteristics known at the time of admission (co-morbidity), history of myocardial infarction, previous history of heart surgery, ASA status, the pre-operative risk scores (Parsonnet, EuroSCORE)[3,4], and urgency of the operation. Further intra-operative variables (time of anaesthesia, intubation, extracorporeal circulation, aortic cross-clamping and operation) and post-operative variables (APACHE II Score, SAPS II Score, resternotomy)[5,6] were also drawn from the anaesthesia database. Incidence of infection has been found by chart review. The types of infection which were taken into account were nosocomial pneumonia, wound infection, catheter related infection and blood stream infection. In order to predict the costs we developed several models based on significant pre-, intra- and postoperative variables.

Statistical analysis

All data were analysed with SPSS (version 9.0) for Windows NT.

Descriptive statistics are presented as percentages for discrete variables and for continuous variables either as median and interquartile range (for non-normally distributed data) or as mean and confidence interval (for normally distributed data). Hospitalization costs are presented both as a mean (to represent the best estimate of the cost per patient) and as a median (to represent the best estimate of the cost of a typical patient).

Assessment of univariate associations between candidate predictors and costs was performed as follows: Pearson's and Spearman's correlation coefficients were calculated in the case of continuous independent variables; t-tests or ANOVA were used for categorical independent variables. Two-tailed $P=0{\cdot}05$ was used as the level of statistical significance. Independent variables showing a possible association with costs were treated as candidates for multivariate linear regression analysis. Regression analysis of costs was performed for pre-, intra- and postoperative variables separately and combined. Interaction terms combining pairs of influence variables were tried out during model construction. Highly correlated variables, e.g. anaesthesia time, operation time and aorta clamp time, were not combined in a single model, to avoid collinearity problems. Tolerance values and condition indexes were calculated to assess remaining collinearity. Influential points were identified by calculating Cook's distance and the covariance ratio.

Table 1 Baseline patient characteristics

Age in years, mean (95% CI)	61·4 (59·9/62·9)
BMI (kg . m^{-2}), mean (95% CI)	27·0 (26·5/27·6)
Males, n (%)	143 (71·1)
History of previous MI, n (%)	22 (10·9)
History of previous surgery, n (%)	13 (6·5)

BMI = body mass index, MI = myocardial infarction.

Table 2 Pre-operative and postoperative scores

Pre-operative	Mean (95% CI)	Postoperative	Mean (95% CI)
EuroSCORE	3·7 (3·3/4·1)	APACHE II	14·0 (13·3/14·7)
Parsonnet	8·0 (7·0/9·0)	SAPS II	26·2 (25·0/27·4)

Table 3 Intra-operative variables (in hours and minutes) and their correlation to average hospital costs

	Mean (95% CI)	Correlation coefficients
Operation time	4:50 (4:35/5:05)	0·354*
Anaesthesia time	6:50 (6:35/7:05)	0·416*
Extracorporal circulation time	2:05 (1:55/2:10)	0·298*
Aortic clamp time	1:10 (1:05/1:15)	0·148**

*$P<0{\cdot}0001$; **$P<0{\cdot}05$.

Results

We included in this study 201 consecutive patients referred from St. Gallen in 1998. The mean age of the patients was 61·4 years (95% CI: 60; 63) with 143 (71%) male patients. Coronary artery surgical patients represent the largest group with 145 patients (72·1%). Twenty one patients (10·4%) had valve replacement alone and 25 (12·8%) CABG including valve replacement. Baseline patient characteristics are shown in Table 1. Pre-operative and postoperative scores are shown in Table 2. Duration of operation, anaesthesia, extracorporal circulation and aortic clamping and their correlation to average cost is presented in Table 3. Thirteen patients (6·5%) underwent resternotomy. Table 4 shows the comorbidity data related to total costs.

The median length of stay was 1 day (IQR 1–3) in the intensive care unit (ICU) and 10 days (IQR 8–12) in the cardiac surgical ward. As might be expected, patients who stayed longer were also more likely to incur greater hospital costs ($r=0{\cdot}62$, $P<0{\cdot}0001$ for ICU stay;

Table 4 Univariate analysis of patient co-morbidity with total costs (in Euro)

Independent variables	n	Mean (SD)	Median (IQR)
Hypertension			
Absent	74	24 926 (14 291)	21 827 (9089)
Present	125	24 069 (10 105)	20 415 (9620)
Missing value	2		
P-value		0·62	
Diabetes mellitus			
Absent	167	23 883 (12 079)	20 843 (8748)
Present	32	27 023 (10 033)	22 689 (14 375)
Missing value	2		
P-value		0·17	
COPD			
Absent	184	24 108 (11 493)	20 986 (8856)
Present	15	27 831 (15 209)	25 401 (17 251)
Missing value	2		
P-value		0·24	
PVD			
Absent	173	24 547 (12 151)	20 843 (8707)
Present	26	23 326 (9334)	22 147 (14 165)
Missing value	2		
P-value		0·62	

COPD=chronic obstructive pulmonary disease; PVD=peripheral vascular disease.

r=0·48, $P<0·01$ for surgical ward). To avoid collinearity problems, these variables were excluded as candidates for multivariate analysis.

The in-hospital mortality rate was 2% and there was no significant association between death and the higher cost of hospitalization. No death occurred within 48 h of admission. The median cost per patient was 21 183 Euro (IQR 17 744–26 800), whereas the mean was 24 440 (95% CI: 23 382; 26 369).

With the help of univariate analysis, the following pre-operative characteristics were found to be significantly associated with cost: age ($P<0·001$), pre-operative cardiac diagnosis (isolated coronary vs valvular heart disease) ($P<0·001$) and EuroSCORE values ($P<0·0001$). Table 5 relates these pre-operative patient characteristics to average hospital costs. A significant correlation was also found between intra-operative variables and costs ($P<0·0001$) (Table 3) as well as between postoperative variables and costs ($P<0·0001$) (Table 6).

The results of univariate analysis led to the following first regression models which included: age, diagnosis group, and EuroSCORE as pre-operative variables, time of operation, anaesthesia, extracorporal circulation and aortic cross clamping as intra-operative variables, the presence of infection, rethoracotomy and APACHE II score as postoperative variables.

In the presence of the EuroSCORE variable no other pre-operative variable was significant. The use of EuroSCORE alone ($P<0·0001$) led to a significant regression model (n=189, F=42·4, $P<0·0001$) with an R^2 of 0·185 and a coefficient of 1801 Euro (95% CI: 1314; 2346) per EuroSCORE point.

Table 5 Univariate analysis of pre-operative variables and total costs (in Euro)

	n	Mean (SD)	Median (IQR)
Pre-operative cardiac diagnosis*			
CAD	134	24 305 (10 448)	20 147 (8828)
Valvular disease	28	26 267 (10 719)	23 865 (8510)
CAD and valvular	31	29 867 (17 496)	26 062 (14 151)
Other	8	20 542 (10 310)	23 465 (15 504)
EuroSCORE**			
Low risk	55	20 809 (5973)	19 502 (5271)
Medium risk	84	26 142 (9476)	24 141 (12 431)
High risk	59	31 496 (16 266)	26 554 (17 439)
Missing	3		
		Spearman's correlation coefficient	
Age*	201	0·246	

*$P<0·001$; **$P<0·0001$.
CAD=coronary artery disease.

Table 6 Univariate analysis of postoperative variables (in Euro)

	n	Mean (SD)	Median (IQR)
Infection			
Yes	31	40 848 (17 268)	38 892 (19 792)
No	170	22 621 (8107)	20 174 (8210)
Resternotomy			
Yes	11	39 172 (15 854)	39 671 (29 485)
No	190	24 243 (11 053)	21 364 (9997)
		Correlation coefficient	
SAPS II score	201	0·302*	
APACHE II score	201	0·255*	

*$P<0·0001$.

Candidate parameters for the intra-operative model were characterized by a high degree of autocorrelation and could not be combined. The use of operation time ($P<0·0001$) alone led to the best available model (n=198, F=78·5, $P<0·0001$) with an R^2 of 0·29 and a coefficient of 3472 Euro (95% CI: 2699; 4245) per hour.

The final postoperative model reached an R^2 0·32 and included the following variables: presence of infection and APACHE II score. Details are given in Table 7. The combined linear regression model, which predicts hospital costs for patients undergoing cardiosurgery based on EuroSCORE, operation time, operation time squared and postoperative infection status, reached an R^2 0·57 (see Table 8 for details). All influence factors were checked for a non-linear effect, which resulted in the inclusion of operation time squared in the model. The APACHE II risk score was excluded due to its high correlation with EuroSCORE. Interaction terms were not statistically significant. Residual analysis (based on scatterplots of residuals vs predicted values and continuous influence variables, boxplots of residuals

Table 7 Parameter estimates of postoperative linear regression model on costs

	Standardized coefficient (β)	Coefficient (B)	Standard error	95% CI for B	*P*
APACHE II	174·54	396·46	174·54	51·89/741·02	0·024
Infection	2240·57	17674·78	2240·57	13251·48/22098·09	0·0001
Intercept		16911·26	2494·25	11987·16/21835·37	0·0001

n=171, R-square: 0·31; adjusted R-square: 0·31, F-value: 39·6; P=0·0001.

Table 8 Parameter estimates of prediction model of costs

	Standardized coefficient (β)	Coefficient	Standard error	95% CI for B	*P*
EuroSCORE	0·254	1099·98	238·85	631·83/1568·13	0·0001
Operation time	− 0·436	− 2897·58	1344·87	− 5532·46/ − 262·52	0·05
Operation time square	0·867	1344·87	104·43	239·46/648·80	0·0001
Infection	0·306	10848·45	2073·72	6783·96/14912·94	0·0001
Intercept		21825·70	4018·60	13889·73/29761·65	0·0001

n=166, R-square: 0·576; adjusted R-square: 0·565; F-value: 54·6; P<0·0001.

grouped by infection status, and a normality plot of residuals) leads to satisfactory results, confirming the underlying assumptions of least squares linear regression as reasonably fulfilled. A problem of collinearity seems unlikely, as there are significant individual regression coefficients, no β coefficients reaching 1, tolerance values >0·07 and condition indexes <25. Less optimal values are observed in operation time squared, which is expected due to this variable's link with linear operation time. All other independent variables perform better by far. Exclusion of influential points identified by Cook's distance and the covariance ratio (resulting n=147) does not affect significance, while R^2 is slightly lowered to 0·54. Changes of coefficient estimates are in the range of up to 20% of the original values, without changing the general pattern.

A logistic regression model using the same independent variables and a cut-off point of 26 400 Euro (n=166, log likelihood= − 57·6, P<0·0001, pseudo R^2=0·42) has significant coefficients throughout and allows for a correct prediction in 82% of cases (91% of patients with costs of 26 400 Euro or lower, 60% of patients with higher costs).

Discussion

In this study on the determinants of hospital cost, we have demonstrated that a series of clinical characteristics significantly contribute to the cost of surgery. With the help of established pre-operative risk scoring systems a subset of patients with lower hospital costs could be identified. Scoring may predict total ICU days of cardiac surgical patients and costs, knowing that prolonged intensive care unit treatment (>3 days) contributes to increased health costs and resource utilization[7–9].

The main finding of our study was that hospital costs are indeed closely related to pre-operative risk scores, operation time and the occurrence of early postoperative complications. This means it can identify patients at risk for excess costs prior to surgery and in the early post-operative period. We could not develop a model explaining a reasonable proportion of costs on the basis of pre-operative parameters alone. A model restricted to parameters known at the end of the first postoperative day enables the 57% of variance observed in the total hospitalization costs to be explained.

Previous studies have emphasized the importance of pre-operative factors in the prediction of costs. Magovern *et al*.[10] analysed pre-operative patient variables to predict patients at increased risk of morbidity, which results in higher costs. Haehnel *et al*.[11] suggested that costs are closely related to the pre-operative condition of a patient, implying that surgery in high-risk patients may result in financial losses for the operating institution.

Contrary to our expectations and findings in other studies, selected isolated co-morbidity factors (arterial hypertension, diabetes, chronic obstructive pulmonary disease, peripheral vascular disease) were not significantly associated with costs[12].

Taylor *et al*.[13] emphasized that the recognition of the powerful influence of complications on costs suggests that a low average cost can only be achieved by programmes with a low complication rate. The occurrence of infection had the most significant effect on cost in our study. Therefore, a high complication rate would make it impossible for a programme to have low charges. Costs related to a specific complication take into account not only the increased length of hospitalization but also the particular expenses incurred with treatment of that complication[14,15].

The major limitation of this study is in the area of cost analysis. Reliable data on the actual cost for each patient are difficult to determine. Hospital charges have therefore been used as a surrogate for cost. This however, has also been the case in other studies on this subject[1,16]. Operating room charges were based on operation time, which raises the possibility of circularity. As these charges were not the major determinant factor for costs, this fact was not of central importance. In addition, the statistical significance of the operation time squared term gives evidence that the influence of operation time on costs cannot exclusively be explained by a higher resource use during the operation itself. Long operations probably induce a more critical and more expensive postoperative phase.

Another limitation of this study is its observational design combined with the retrospective analysis of postoperative infections. The design of our study, though, also has some advantages. It more closely reflects real practice, and retrospective chart review methodology avoids the problem of selective use of certain resources which can result from a prospective approach.

Data from the present analysis show that both preoperative (patient-related) and intra-operative (therapy- and patient-related) variables are a predictor of costs in cardiac surgical patients and provide implications for health policy. In addition, the advent of postoperative complications, such as rethoracotomy or infectious problems, further increase cost.

The findings of the present study have not yet led to a change in the reimbursement policy for cardiac surgery patients. However, discussions between providers of care (University Hospital of Zurich and thus, the Canton of Zurich) and the insurers as well as the patient-referring Cantons (in the presented study the Canton of St. Gallen) about the financing modalities, have been established. Due to the increasing percentage of high risk (namely older) patients during the last 3 years, particular attention will have to be paid to pre-operative risk-adjusted financing. Although no formal validation analysis was conducted, the parameters from our prediction model are considered cost-drivers.

Whether the situation in Switzerland can be generalized to other West-European healthcare systems is debatable. Ratios of expected to observed morbidity and mortality are dependent on a variety of parameters[17] even within one region in Europe. Therefore, any established model needs to be validated locally and is not necessarily transferable without modifications to other providers of care, especially to different healthcare systems in different countries. The use of models similar to that described here could explain the cost variability. Cost reduction in clinical practice should use different strategies for patients depending on risk level. The potential for risk reduction is greatest in high risk patients, but this requires a reduction of postoperative morbidity.

These findings will not only be important in developing contracting strategies and modifying national methods of reimbursement, but also in increased efforts to avoid early postoperative complications.

References

[1] Denton TA, Luevanos J, Matloff JM. Clinical and nonclinical predictors of the cost of coronary bypass surgery. Arch Int Med 1998; 158: 886–91.
[2] Spitalleistungs-Katalog, Schweiz 1997.
[3] Parsonnet V, Dean D, Bernstein AD. A method of uniform stratification of risk for evaluating the results of surgery in acquired adult heart disease. Circulation 1989; 79 (Suppl I): 3–12.
[4] Nashef SAM, Roques F, Michel P, Gauducheau E, Lemeshow S, Salamon R, the EuroSCORE study group. European system for cardiac operative risk evaluation (EuroSCORE). Eur J Cardiothorac Surg 1999; 16: 9–13.
[5] Knaus WA, Draper EA, Wagner DP. Apache II: A severity of disease classification system. Crit Care Med 1985; 13: 975–7.
[6] Le Gall JR, Lemeshow S, Saulnier F. A new simplified acute physiology score (SAPS II) based on a European/north American multicenter study. JAMA 1993; 270: 2957–63.
[7] Doering L, Esmailian F, Laks H. Perioperative predictors of ICU and hospital costs in coronary artery bypass graft surgery. Chest 2000; 118: 736–43.
[8] Christakis GT, Fremes SE, Naylor CD, Chen E, Rao V, Goldman BS. Impact of preoperative risk and perioperative morbidity on ICU stay following coronary bypass surgery. Cardiovasc Surg 1996; 4: 29–35.
[9] Mounsey JP, Griffith MJ, Heaviside DW, Hedley A, Reid S. Determinants of the length of stay in intensive care and hospital after coronary artery surgery. Br Heart J 1995; 73: 92–8.
[10] Magovern JA, Sakert T, Magovern GJ Jr. *et al.* A model that predicts morbidity and mortality after coronary artery bypass graft surgery. J Am Coll Cardiol 1996; 28: 1147–53.
[11] Haehnel JC, Roth P, Lohmann E, Meisner H, Hehrlein FW. Implications of the introduction of fixed reimbursement rates in Germany. Thorac Cardiovasc Surg 1996; 44: 97–102.
[12] Finkler SA. The distinction between cost and charges. Ann Intern Med 1982; 96: 102–9.
[13] Taylor GJ, Mikell FL, Moses HW *et al.* Determinants of hospital charges for coronary artery bypass surgery: the economic consequences of postoperative complications. Am J Cardiol 1990; 65: 309–13.
[14] Ghali WA, Hall RE, Ash AS, Moskowitz MA. Identifying pre- and postoperative predictors of cost and length of stay for coronary artery bypass surgery. Am J Med Qual 1999; 14: 248–54.
[15] Mauldin PD, Weintraub WS, Becker ER. Predicting hospital costs for first time coronary artery bypass grafting from preoperative and postoperative variables. Am J Cardiol 1994; 74: 772–5.
[16] Smith LR, Milano CA, Molter BS, Elbeery JR, Sabiston DC, Smith PK. Preoperative determinants of postoperative costs associated with coronary artery bypass surgery. Circulation 1994; 90 (Suppl): II 124–8.
[17] Wynne-Jones K, Jackson M, Grotte G, Bridgewater B. Limitations of the Parsonnet score for measuring risk stratified mortality in the north west of England. The North West Regional Cardiac Surgery Audit Steering Group. Heart 2000; 84: 71–8.