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Risk-adjusted econometric model to estimate postoperative costs: An additional instrument for monitoring performance after major lung resection

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Objectives: The objectives of this study were to develop a risk-adjusted model to estimate individual postoperative costs after major lung resection and to use it for internal economic audit.

Methods: Variable and fixed hospital costs were collected for 679 consecutive patients who underwent major lung resection from January 2000 through October 2006 at our unit. Several preoperative variables were used to develop a risk-adjusted econometric model from all patients operated on during the period 2000 through 2003 by a stepwise multiple regression analysis (validated by bootstrap). The model was then used to estimate the postoperative costs in the patients operated on during the 3 subsequent periods (years 2004, 2005, and 2006). Observed and predicted costs were then compared within each period by the Wilcoxon signed rank test.

Results: Multiple regression and bootstrap analysis yielded the following model predicting postoperative cost: 11,078 + 1340.3X (age > 70 years) + 1927.8X cardiac comorbidity − 95X ppoFEV$_1$%. No differences between predicted and observed costs were noted in the first 2 periods analyzed (year 2004, \$6188.40 vs \$6241.40, $P = .3$; year 2005, \$6308.60 vs \$6483.60, $P = .4$), whereas in the most recent period (2006) observed costs were significantly lower than the predicted ones (\$3457.30 vs \$6162.70, $P < .0001$).

Conclusions: Greater precision in predicting outcome and costs after therapy may assist clinicians in the optimization of clinical pathways and allocation of resources. Our economic model may be used as a methodologic template for economic audit in our specialty and complement more traditional outcome measures in the assessment of performance.

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As a result of an increasing cost awareness and a relative scarcity of resources, it has become important to optimize and quality-assure medical interventions.

Ideally, the clinical care team would select and implement the strategy of care that maximizes patient outcomes without wasting scarce resources. Thus, both information regarding the patient's medical outcomes and the estimated relative resource use associated with a set of alternative therapies become important considerations in the clinical team's decision-making process.

In this regard, the identification of candidates for lung surgery at increased risk of higher costs may assist in the allocation of limited resources and in the economic optimization of clinical pathways.

Whereas some studies have tried to develop and apply models to monitor the medical outcomes with the aim to assess the internal clinical performance,[1-4] there is scant evidence in the thoracic surgery literature concerning the economic evaluation of the postoperative course used as a quality indicator.[5,6]

Abbreviations and Acronyms

$Paco_2$	= arterial carbon dioxide level
Pao_2	= arterial oxygen tension
FEV_1	= forced expiratory volume in 1 second
FVC	= forced vital capacity
ICU	= intensive care unit
ppoDLCO	= predicted postoperative carbon monoxide lung diffusion capacity
$ppoFEV_1$	= predicted postoperative forced expiratory volume in 1 second

Therefore, the objectives of this study were to develop a clinically risk-adjusted model to estimate individual postoperative costs after major lung resection and to use it to track the internal economic performance of our unit during successive periods of activity.

Patients and Methods

Variable and fixed hospital costs were individually and prospectively collected for 679 consecutive patients submitted to major lung resection (574 lobectomies and 105 pneumonectomies) from January 2000 through October 2006 at our unit. This is a retrospective analysis performed on a prospectively compiled electronic database. The study was approved by the local institutional review board, and all patients gave their consent to use their data in the dataset. As a rule, the operations were performed through a muscle-sparing thoracotomy by the same surgical team (composed of 4 certified staff general thoracic surgeons). Perioperative treatment was standardized and focused on the control of postthoracotomy chest pain, chest physiotherapy, early as possible mobilization, and antibiotic and antithrombotic prophylaxis.

Major lung resections were contraindicated in those patients with a predicted postoperative forced expiratory volume in 1 second ($ppoFEV_1$) and a predicted postoperative carbon monoxide lung diffusion capacity (ppoDLCO) less than 30% of predicted, in addition to an insufficient exercise tolerance (height reached at stair climbing test less than 12 m or a maximum volume of oxygen utilization < 10 mL $\cdot$ kg^{-1} $\cdot$ min^{-1}).

Perioperative mortality in this series occurred in 27 (4%) patients who were included in the analysis.

Fixed and variable costs were retrieved from the data systems of the Accounting and Pharmacy Departments of Umberto I Hospital. For the purpose of this study, the costs were collected in euros and converted in US dollars (conversion rate dollar/euro: 1.285) and corrected according to the current inflation rate (as of November 2006).

Fixed costs included capital, employee salaries, building maintenance, and utilities. Variable costs included patient care supplies, food, radiographic film, laboratory reagents, medications with their delivery systems (such as intravenous catheters or bottles), and the cost of other postoperative therapeutic procedures such as cardioversion, bronchoscopy, and blood transfusions.

Fixed costs derived from either service or support centers. Service centers were defined as those health care providers who directly care for patients such as physicians and nurses or departments that provide diagnostic or other measurable service to individual patients. Support center costs were of two types. The first type was nonsalary expenditures by the hospital for outside products (eg, cleaning supplies, utilities, or health insurance benefits) that contribute to the function of the hospital and its employees. The second type of support center cost was the salaries of employees in departments such as housekeeping, payroll, and administration. They perform functions throughout the facility for the entire organization.

Our hospital is a public tertiary referral institution, in which all employees, including physicians, are salaried, warranting the categorization of salaries among the fixed costs.

The total fixed costs for medical services (such as thoracic ward or intensive care unit [ICU]) include the salaries of employees working in the service centers providing the medical service plus all allocated support costs. So that the cost of medical services would be captured, all support center costs were allocated completely to the service centers. For example, housekeeping costs were allocated to each service and support center on the basis of each center's square footage. Likewise, payroll costs were allocated to each service and support center relative to each center's total number of full-time equivalent employees. Consequently, the calculation of fixed costs for 1 day of stay in the thoracic ward and in the ICU amounted to US $469 and US $1475.20, respectively.

All patients operated on during the period 2000 through 2003 (364 lobectomy, 71 pneumonectomy) were used to develop the risk-adjusted econometric model by a stepwise multiple regression analysis, which was subsequently validated by bootstrap analysis.

The following factors were used as independent variables in the regression analysis (dependent variable: total individual postoperative costs): age, arterial oxygen tension (Pao_2), arterial carbon dioxide level ($Paco_2$), smoking history (pack-years), preoperative hemoglobin concentration, serum albumin level, body mass index, type of operation (lobectomy vs pneumonectomy), presence of concomitant cardiac disease, diabetes, neoadjuvant chemotherapy, preoperative pulmonary function tests (ratio of forced expiratory volume in 1 second to forced vital capacity [FEV_1/FVC ratio], $ppoFEV_1$, ppoDLCO, and ratio of residual volume to total lung capacity), presence of concomitant cerebrovascular or symptomatic peripheral vascular diseases, presence of concomitant chronic renal insufficiency, Eastern Cooperative Oncology Group/Zubrod score, and Charlson Comorbidity index (see appendix for explanation of variables).

All data were at least 95% complete. Sporadic missing data were imputed by averaging the nonmissing values (numerical variables) or taking the most frequent category (categorical variables). So that multicollinearity could be avoided, only one variable in a set of variables with a correlation coefficient greater than 0.5 was selected (by bootstrap procedure) and used in the regression model.

A *P* value less than .05 was selected for retention of variables in the final model. The multivariate procedure was then validated by bootstrap bagging with 1000 samples. In the bootstrap procedure, repeated samples of the same number of observations as the original database were selected with replacement from the original set observations. For each sample, stepwise multivariate regression was performed. The stability of the final stepwise model can be assessed by identifying the variables that enter most frequently in

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the repeated bootstrap models and comparing those variables with the variables in the final stepwise model. If the final stepwise model variables occur in a majority (>50%) of the bootstrap models, the original final stepwise regression model can be judged to be stable.[7-9]

The model was then prospectively applied on all patients operated on during the 3 subsequent periods (years 2004, 2005, and 2006) to estimate the postoperative costs. Normality of the predicted and observed costs was assessed by the Shapiro–Wilk normality test. Observed and predicted costs were then compared within each period by the Wilcoxon matched-pairs signed rank test.

All the statistical tests were 2-tailed. The analysis was performed by the statistical softwares Statview 5.0 (SAS Institute, Inc, Cary, NC) and STATA 8.2 (Stata Corp, College Station, Tex).

Results

The characteristics of the patients in the derivation set (years 2000-2003) and of those operated on in the years monitored by the econometric model (years 2004–2006) are shown in Table 1.

Fixed costs accounted for 80% of the total observed postoperative costs.

Multiple regression analysis showed that significant and reliable factors associated with postoperative costs were age older than 70 years (P = .05, bootstrap 51%), $ppoFEV_1$ (P < .0001, bootstrap 100%), and cardiac comorbidity (P = .005, bootstrap 92%) (Table 2). Consequently, the following model predicting postoperative costs (US$) was derived:

$$11{,}078 + 1340.3X\ (\text{age} > 70\ \text{years}) + 1927.8X\ \text{cardiac comorbidity} - 95X\ ppoFEV_1\%.$$

TABLE 1. Characteristics of the patients in the derivation set and in the periods under analysis

Variables	Derivation period (2000–2003, 435 patients)	Periods under analysis (2004–2006, 244 patients)
Age (y)	67 (9.3)	66.3 (10.8)
Diagnosis (n, %)		
Primary malignant	407 (93.6%)	227 (93%)
Metastatic	10 (2.3%)	7 (2.9%)
Infection	7 (1.6%)	6 (2.5%)
Benign, others	11 (2.5%)	4 (1.6%)
BMI (kg/m^2)	26.2 (4.3)	25.9 (3.8)
FEV_1 (%)	85.1 (19.1)	85.5 (18.5)
DLCO (%)	76.2 (19.6)	79.6 (17.9)
ECOG score	0.98 (0.8)	0.7 (0.8)
CCI	2 (1.7)	1.7 (1.6)
Pack-years	40 (27.5)	44.1 (33.5)
Cardiac disease (n, %)	212 (49%)	126 (52%)
Pneumonectomy (n, %)	71 (16%)	34 (14%)
Neoadjuvant chemotherapy (n, %)	67 (15%)	26 (11%)

Results are expressed as means ± standard deviations unless otherwise specified. *BMI,* Body mass index; *FEV_1,* forced expiratory volume in 1 second; *DLCO,* carbon monoxide lung diffusion capacity; *ECOG,* Eastern Cooperative Oncology Group; *CCI,* Charlson Comorbidity index.

TABLE 2. Results of the stepwise multiple regression analysis (dependent variable: postoperative costs); parsimonious model

Variables	Coefficients	SE	*P* value	Bootstrap %
Intercept	11,078	1,449		
Age > 70 y	1,340.3	686	.05	51%
Cardiac disease	1,927.8	679	.005	92%
$ppoFEV_1$ (%)	−95	20	<.0001	100%

SE, Standard error; *Bootstrap %,* percentage of bootstrap samples in which the variable was significant (P < .05); *$ppoFEV_1$,* predicted postoperative forced expiratory volume in 1 second.

The model showed satisfactory calibration in the derivation set after plotting the cumulative predicted costs against the observed ones (Figure 1).

The econometric model was then prospectively applied to predict individual postoperative costs in patients operated on during the following 3 years. The results of the comparisons between observed and predicted postoperative costs in each of the 3 successive years of activity showed no differences between predicted and observed costs in the first 2 periods analyzed (year 2004, $6188.40 ± $2180 vs $6241.40 ± $6884, P = .3; year 2005, $6308.60 ± $1971 vs. $6483.60 ± $11,569, P = .4), whereas in the most recent period (year 2006), observed costs were significantly lower than the predicted ones ($3457.30 ± $2079 vs $6162.70 ± $7748, P < .0001) with a mean saving per patient of $2705.40.

Only 7.6% of patients in 2006 had observed costs higher than 1 SD above the predicted costs, compared with 17% in 2004 and 16% in 2005.

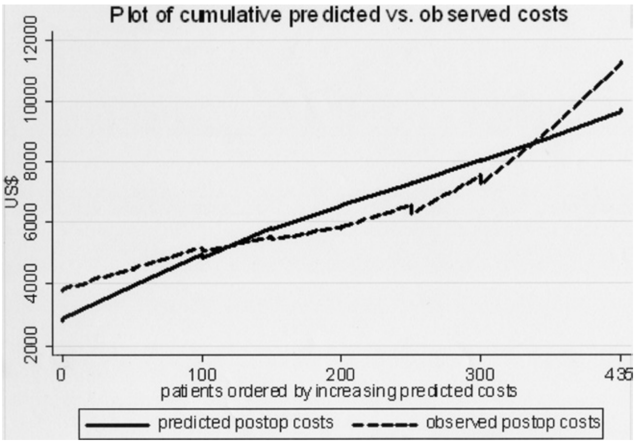

Figure 1. Plot of the cumulative predicted postoperative costs against the observed ones with the patients in the derivation set ordered by increasing predicted costs.

To rule out a possible effect of patient distribution on postoperative costs, we assessed the distribution of tertiles of predicted costs in each of the analyzed years (2004, 2005, and 2006), finding no significant difference (χ^2 1.9, $P = .8$).

Reduction of observed costs compared with that of predicted costs in 2006 was mostly attributable to a shortened hospital stay and ICU stay. In fact, whereas in 2004 the median hospital stay was 7 days (range 5–40 days) with only 11% of patients discharged before the sixth postoperative day, and in 2005 the median stay was 7 days (range 4–52 days) with 16% of patients discharged before the sixth postoperative day, in 2006 the median stay was 6 days (range 4–16) and 42% of patients were discharged before the sixth postoperative day. In 2006 we observed also a shortened mean ICU stay for those patients admitted to advanced care management (2004, 7.4 days ± 4; 2005, 11.8 ± 11; 2006, 4 ± 3.2) with no mortality in the ICU. The use of blood transfusion was also reduced in 2006 and contributed to the reduction of observed costs (mean blood units per patient: 2004, 1.8 units; 2005, 1.4 units; 2006, 0.6 units).

Discussion

The most basic tenet of any industrial process is a clear assessment of operating costs. 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 are the single most important piece of information almost uniformly lacking in hospital administration today.

Optimization and quality assurance of medical interventions have become an important part of our clinical practice, owing to the relative scarcity of resources.

Risk modeling is an essential element in quality monitoring and improving processes and has been used for internal and external evaluation of performance through the assessment of traditional outcome measures such as morbidity and mortality.[1-4] On the other hand, cost-based economic evaluation of thoracic surgical care has rarely been taken into consideration as a possible performance indicator.[5,6] Indeed, predicting individual costs in a population of surgical patients and tracking the agreement between predicted and observed costs during different periods of activity may be of great importance in optimizing pathways of care and for a more accurate allocation of resources.

Although no statistical risk model can replace clinical judgment, good decision-making must begin with good information. In this regard, greater precision in predicting outcome and costs after therapy may provide clinicians with reference points to augment decision-making by increasing the level of information and communication.[10]

Therefore, this study aimed to develop a clinically risk-adjusted model to estimate individual postoperative costs after major lung resection and to use it to track the internal economic performance of our unit during successive periods of activity. The main intent was not to develop an econometric model that could be generalized to other settings but to prove that economic parameters can be risk-modeled by using clinical data and that risk-adjusted econometric analysis can be used to evaluate the quality of our practice in addition to other more common outcome indicators (such as morbidity and mortality).

The most relevant characteristics of this study are that we used clinical factors and not administrative variable to risk-adjust the economic data and that the model is based on true individual costs and not on charge-based accounting.

Although administrative data provide one of the most used sources for observational studies, because they are readily available and relatively inexpensive[11,12] they have been collected primarily for billing purposes rather than for clinical studies, and critical variables such as $ppoFEV_1$ or ppoDLCO may be unavailable. In addition, differentiation of comorbidities from complications may be problematic. Administrative databases may limit the number of secondary diagnoses and generally have poor flexibility to properly classify certain comorbidities.[12] For all these reasons, claims data should be avoided whenever possible if the aim of the analysis is to assess the clinical performance of the provider.

The gold standard for data should be a specialty-specific, procedure-specific, prospectively maintained, periodically audited electronic clinical database.[4]

Relative comparisons with charge-based accounting may be 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.

Our model was developed from a set of patients operated on during an earlier period (2000–2003) with respect to those in whom we assessed the economic performance (2004–2006). This represents an example of temporal quality benchmark. The model was generated by multiple regression analysis and validated by bootstrap procedure by using the entire dataset (2000–2003), without resorting to the traditional training and test method. In fact, we and others have shown that bootstrap is superior to the training and test splitting of the dataset, inasmuch as more reliable and reproducible predictive equations are generated.[7,9]

When the model was then prospectively applied to compare the observed and predicted postoperative costs, we found that, whereas during the years 2004 and 2005 the observed costs were in line with the predicted ones, in 2006 the observed costs were significantly lower than expected.

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The mean saving per patient with respect to the predicted costs amounted to US $2705, with a savings in the total population of patients of approximately US $181,282. As expected by the distribution of fixed versus variable costs, which was in agreement with previous investigations performed in other settings,[13] most of the savings were attributable to reduced fixed costs by a shortening of postoperative hospital stay and a reduction in ICU stay for those patients admitted to the ICU. These improvements in postoperative management care are the results of a fast-tracking policy that was instituted in 2006 for major lung resections. Moreover, as of January 2006, maximum volume of oxygen utilization measurement was added in the preoperative workup of all lung resection candidates, which allowed a more accurate selection of patients that could be safely fast-tracked.

If they are to be reliably used as performance indicators, costs should always complement traditional clinical outcome indicators. In fact, after clinical risk-adjustment, costs can represent a measure against which morbidity and mortality could be weighed on a level playing field.

In this regard, we did not find any differences between observed and predicted (by using previously validated models[4]) morbidity and mortality within each of the periods of activity. This confirmed that the reduction of postoperative costs was achieved without compromising the clinical outcomes and was the result of the institution of a fast-track policy in patients treated with major lung resections.

We showed that a clinically risk-adjusted econometric model was able to detect a successful cost-containment policy. For this reason, we think it may represent a common instrument that can be used both by the administrators and by the clinicians for performance evaluation and budgetary reasons.

A reduction in the observed costs does not automatically translate into improved efficiency unless corrective measures based on the reduction of resources caring for the patients or on the increase of operations performed are applied. We anticipate that, should our results be confirmed during the next year, corrective measures on resources utilization will be elaborated and discussed during annual budget negotiations. The most important result of this study was that we were able to provide clinicians and administrators with a reliable instrument for monitoring the costs after major lung resections so that they could adopt appropriate measures to improve clinical cost-effectiveness. In our practice, the number of operations is dependent either on the number of referrals or on the availability of postoperative beds and personnel that limit to cycle more patients in the perioperative setting. In this context, a reliable econometric instrument may allow a more accurate allocation of resources to improve efficiency.

In fact, potential applications of econometric risk-modeling may include reinvestment of potentially saved economic resources to further implement quality-improving strategies, appropriate allocation of resources during annual budget discussion, and negotiation of prospective charges with financing institutions.

This analysis may have potential limitations. First, only postoperative costs were assessed. Preoperative workup, intraoperative, and primary care postoperative costs were not the objects of this study. Therefore, our work cannot be interpreted as an assessment of the total expenditure of the health care system for a lung resection patient.

Second, our hospital has a high patient volume, allowing economies of scale. We negotiate low rates for consumables by large volume purchasing. Moreover, our public hospital works with a restricted budget. Expenditures for supplies such as pharmaceuticals are kept as low as possible. Physicians are expected to order medications available on the formulary and more expensive patent medications are purchased only if clear benefit or special need is demonstrated. This may partly explain the low proportion of variable costs, which may not be reproducible at other settings.

As for other more traditional indicators of performance, even this economic model was intended for quality purposes only and not for patient selection, a process that should be based on clinical judgment and not on statistical models.[1,3,4]

In conclusion, we as physicians should assume complete responsibility in selecting the evaluation instruments and end points, not only for evaluating our clinical performance but even for the economic assessment of our practice.

Although the costs are hospital- and system-specific, our economic model may serve as a methodologic template for clinical cost analysis in our specialty and may complement other more traditional outcome measures (ie, morbidity and mortality) in the performance monitoring process.

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Appendix

The following variables were tested for a possible association with postoperative costs: age, $\mathrm{Pa{\scriptstyle O}_2}$, arterial carbon dioxide level ($\mathrm{Pa{\scriptstyle CO}_2}$), smoking history (pack-years), preoperative hemoglobin concentration, serum albumin level, body mass index, type of operation (lobectomy vs pneumonectomy), presence of concomitant cardiac disease, diabetes, neoadjuvant chemotherapy, preoperative pulmonary function tests (FEV_1/FVC ratio, $ppoFEV_1$, ppoDLCO, ratio of residual volume to total lung capacity), presence of concomitant cerebrovascular or symptomatic peripheral vascular diseases, and presence of concomitant chronic renal insufficiency.

We computed the number of pack-years of smoking as the total number of years smoked multiplied by the average number of cigarettes smoked per day, divided by 20.

Pulmonary function tests were performed according to the American Thoracic Society criteria. Results of spirometry were collected after bronchodilator administration. DLCO was measured by the single breath method.

The $ppoFEV_1$ and ppoDLCO were expressed as percentages of predicted for age, sex, and height and were calculated by estimating the amount of functioning parenchyma removed during the operations by bronchoscopy, computed tomographic scan, and quantitative lung perfusion scan.

For the purpose of the present study and in accordance with previous investigations,[2-4] a concomitant cardiac disease was defined as follows: previous cardiac surgery, previous myocardial infarction, history of coronary artery disease, and current treatment for arrhythmia, cardiac failure, or hypertension. We chose to use this definition of cardiac comorbidity for the sake of comparison with previous studies and for numerical reasons. In fact, breaking down the variable in the single cardiac diseases would have resulted in too many cofactors with limited representation. Although not weighed, all cardiac conditions included in the variable are widely recognized cardiac risk factors for noncardiac surgery.

Eastern Cooperative Oncology Group score was calculated according to Oken and associates.[14] Charlson Comorbidity index was calculated according to Birim and associates.[15]

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