PROGNOSTIC MODELS OF THIRTY-DAY MORTALITY AND MORBIDITY AFTER MAJOR PULMONARY RESECTION

David H. Harpole, Jr, MD
Malcolm M. DeCamp, Jr, MD
Jennifer Daley, MD
Kwan Hur, MS
Charles A. Oprian, PhD
William G. Henderson, PhD
Shukri F. Khuri, MD
Participants in the National Veterans
Affairs Surgical Quality Improvement
Program

Background: A part of the prospective, multi-institutional National Veterans Affairs Surgical Quality Improvement Program was developed to predict 30-day mortality and morbidity for patients undergoing a major pulmonary resection. **Methods:** Perioperative data were acquired from 194,319 noncardiac surgical operations at 123 Veterans Affairs Medical Centers between October 1, 1991, and August 31, 1995. Current Procedural Terminology code-based analysis was undertaken for major pulmonary resections (lobectomy and pneumonectomy). Preoperative, intraoperative, and outcome variables were collected. The 30-day mortality and morbidity models were developed by means of multivariable stepwise logistic regression with the preoperative and intraoperative variables used as independent predictors of outcome. **Results:** A total of 3516 patients (mean age 64 ± 9 years) underwent either lobectomy ($n = 2949$) or pneumonectomy ($n = 567$). Thirty-day mortality was 4.0% for lobectomy (119/2949) and 11.5% for pneumonectomy (65/567). The preoperative predictors of 30-day mortality were albumin, do not resuscitate status, transfusion of more than 4 units, age, disseminated cancer, impaired sensorium, prothrombin time more than 12 seconds, type of operation, and dyspnea. When the intraoperative variables were considered, intraoperative blood loss was added to the preoperative model. In the presence of these intraoperative variables in the model, do not resuscitate status and prothrombin time more than 12 seconds were only marginally significant. Thirty-day morbidity, defined as the presence of 1 or more of the 21 predefined complications, was 23.8% for lobectomy (703/2949) and 25.7% for pneumonectomy (146/567). In multivariable models, independent preoperative predictors ($P < .05$) of 30-day morbidity were age, weight loss greater than 10% in the 6 months before surgery, history of chronic obstructive pulmonary disease, transfusion of more than 4 units, albumin, hemiplegia, smoking, and dyspnea. When intraoperative variables were added to the preoperative model, the duration of operation time and intraoperative transfusions were included in the model and albumin became marginally significant. **Conclusions:** This analysis identifies independent patient risk factors that are associated with 30-day mortality and morbidity for patients undergoing a major pulmonary resection. This series provides an initial risk-adjustment model for major pulmonary resections. Future refinements will allow comparative assessment of surgical outcomes and quality of care at many institutions. (J Thorac Cardiovasc Surg 1999;117:969-79)

From the Veterans Affairs Medical Center/Harvard Medical School, Brockton/West Roxbury, Mass; the Veterans Affairs Medical Center/Duke University Medical Center, Durham, NC; and the Cooperative Studies Program Coordinating Center, Veterans Affairs Medical Center, Hines, Ill.

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Address for reprints: David H. Harpole, Jr, MD, Chief, Cardiothoracic Surgery, Durham VA Medical Center, 10 Fulton St, Durham, NC 27705.

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Several single-institution, retrospective series have been published that examine patient characteristics associated with an increased risk of mortality and morbidity after major pulmonary resection. Because series span several decades and are of limited size, multivariable analyses were not undertaken.¹⁻¹² The National Veterans Affairs (VA) Surgical Quality Improvement Program was designed to prospectively collect historical, laboratory, operative, and postoperative patient characteristics and clinical outcomes for many operative procedures from several surgical subspecialties. The goal of the study was to develop tools for future risk-adjusted models of mortality and morbidity that would allow for the comparative assessment of the quality of surgical care at various institutions.¹³⁻¹⁸ This project examined the subset of patients who had undergone a major pulmonary resection (lobectomy or pneumonectomy).

Methods

The methods of the National VA Surgical Quality Improvement Program have been described in detail elsewhere.¹³

Population. Data were acquired prospectively on 194,319 consecutive patients undergoing noncardiac surgical procedures from October 1, 1991, until August 31, 1995, in 123 Department of VA Medical Centers. The database included 10,008 patients who had undergone a lung operation, of which 3516 (35%) were for a major pulmonary resection (Current Procedural Terminology [CPT] codes 32440-32445 and 32480-32488). International Classification of Diseases—ninth revision—Clinical Modification (ICD-9-CM) diagnoses for these pulmonary resections included 3251 for cancer (non-small cell lung cancer = 3105, pulmonary metastatic cancer = 146), 34 benign lung masses (hamartoma or typical carcinoid), 156 infectious processes (*Mycobacterium tuberculosis* = 27, fungal = 36, bronchiectasis = 25, infectious massive hemoptysis = 19, inflammatory lung masses with pneumonia = 49), and 51 other lung masses (not otherwise stated).

Patient characteristics and clinical outcomes. A total of 122 separate variables were recorded for each operation by a dedicated surgical nurse reviewer who was independent of the various surgical teams, allowing unbiased data collection. Each reviewer was educated on the set of standard criteria for coding all collected variables. These variables were selected by a committee of expert advisors to the VA National Surgical Quality Improvement Program, and the data management manual was made available on the Internet in late 1998. A system of data audits was performed throughout the study interval to ensure data quality and completeness. In brief, after the data manager education process was completed, each center underwent periodic internal and external random audits for data quality. Whenever possible, data were directly downloaded to the statistical center from each VA Medical Center's computer (ie, laboratory results). A more complete description of the data collection and auditing process is

given in a manuscript presented at the 1998 meeting of the American Surgical Association.¹⁴

Preoperative patient characteristics included 4 demographic, 43 historical (divided among anatomic systems), and 17 preoperative laboratory values. Thirteen intraoperative and operation-specific variables were recorded. Follow-up 30-day postoperative mortality statistics and the presence of any one of 21 pre-defined postoperative complications occurring within 30 days of the index operation were recorded (Appendix 1).

Statistical analysis. Univariate analyses were performed on the preoperative, demographic, and laboratory variables, relating them to operative mortality and morbidity. In the case of continuous variables, an unpaired *t* test was used. For the categorical variables, a χ^2 test was used. The variables with a prevalence of greater than 0.5% that were univariately significant at $P < .20$ were considered as possible independent variables in a multivariable logistic regression. Stepwise logistic regression analysis with entry and exit criteria set at the $P = .05$ level was used with 30-day mortality as the dependent variable. For morbidity, the presence or absence of one or more complications was used as the dependent variable.

Subsequent mortality and morbidity models were developed to incorporate the type of operation (pneumonectomy or lobectomy) and then the intraoperative variables such as operation time and amount of blood loss. The modeling was done in a 2-stage process. The first-stage model consisted of preoperative variables and the type of operation. In the second stage the variables from the preoperative model were fixed and the intraoperative variables were added to these for possible inclusion in the stage 2 model. The second-stage model then consists of the first-stage model plus the intraoperative variables that were significant in the second model. Variables in the models are listed in Appendix 2.

All data were more than 99% complete, including the preoperative laboratory variables, except for serum albumin (78%), serum bilirubin (79%), alkaline phosphatase (77%), and serum aspartate aminotransferase (75%). A regression procedure was used to impute missing laboratory values.^{19,20} Some of the laboratory variables were not linearly related to the postoperative outcomes, but rather had U shapes or inverted J shapes. In these cases, the categorized laboratory variables based on clinical cutoff points were entered into the models.

To investigate the stability of the models, we used a bootstrap technique.^{21,22} In the bootstrap procedure, repeated samples of *n* observations are selected with replacement from the original set of *n* observations. For each sample, forward stepwise logistic regression was performed simultaneously entering the preoperative and intraoperative variables listed in Appendix 1. The stability of the final stepwise model can be assessed by identifying the variables that enter most frequently in 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.

Table I. Frequency distribution of selected patient characteristics and preoperative risk factors among 3516 patients undergoing lobectomy and pneumonectomy

Variable	No.	%
Male sex	3471	98.7
Smoking during the 2 weeks before admission	1806	51.4
Chronic obstructive pulmonary disease	1372	39.0
Hypertension requiring medication	1319	37.5
Moderate or severe dyspnea	1163	33.1
More than two alcoholic drinks per day during the 2 weeks before admission	657	18.7
Diabetes mellitus requiring insulin or oral agents	395	11.2
Weight loss > 10% in 6 months before surgery	383	10.9
Previous PTCA or coronary bypass	365	10.4
Previous stroke or transient ischemic attack	338	9.6
Below- or above-knee amputation	198	5.6
Long-term steroid use	139	4.0
Congestive heart failure	81	2.3
Drug addiction	80	2.3
Hemiplegia	39	1.1

Results

Patient characteristics and outcomes. The population for this project consisted of 3516 patients who underwent either an anatomic lobectomy ($n = 2949$) or a pneumonectomy ($n = 567$). The mean age for the study sample is 64 years with a standard deviation of 9 years and a range from 22 to 91 years. The majority of the population was male (98.7%). Other selected patient characteristics are listed in Table I. There were 119 deaths within 30 days for the patients undergoing lobectomy (4.0%) and 65 deaths for those undergoing pneumonectomy (11.5%), for an overall 30-day mortality of 5.2% in the 3516 patients. The postoperative morbidity for the lobectomy patients was 23.8% (703/2949) and for the pneumonectomy patients was 25.7% (146/567). The overall 30-day morbidity was 24.1% (849/3516). The most frequently occurring complications were pneumonia (11.7% for lobectomy and 9.7% for pneumonectomy) followed by unplanned reintubation (7.9% and 10.6%). Other individual complication rates are shown in Table II.

Univariate analyses. Patient characteristics associated with an increased risk of 30-day mortality ($P < .2$) included 24 preoperative clinical, 9 laboratory, and 4 intraoperative variables. Patient characteristics associated with an increased risk of 30-day morbidity included 24 preoperative, 9 laboratory, and 3 intraoperative variables. Eighteen preoperative and 6 laboratory vari-

Table II. Observed 30-day mortality and morbidity by primary operative procedure

Variable	Lobectomy ($n = 2949$)		Pneumonectomy ($n = 567$)	
	No.	%	No.	%
Thirty-day mortality	119	4.0	65	11.5
Thirty-day morbidity (1 or more complications)	703	23.8	146	25.7
Respiratory complications				
Pneumonia	344	11.7	55	9.7
Unplanned reintubation	234	7.9	60	10.6
Failure to wean more than 48 h	194	6.6	53	9.3
Pulmonary embolism	20	0.7	8	1.4
Cardiac complications				
Pulmonary edema	91	3.1	39	6.9
Cardiac arrest with CPR	76	2.6	39	6.9
Myocardial infarction	24	0.8	5	0.9
Wound complications				
Superficial wound infection	41	1.4	9	1.6
Deep wound infection	35	1.2	6	1.1
Wound dehiscence	8	0.3	5	0.9
CNS complications				
Coma more than 24 h	19	0.6	6	1.1
Stroke with neurologic deficit	17	0.6	6	1.1
Cerebral vascular accident	14	0.5	5	0.9
Urinary tract complications				
Urinary tract infection	77	2.6	9	1.6
Progressive renal insufficiency	31	1.0	10	1.8
Acute renal failure	20	0.7	8	1.4
Other complications				
Bleeding requiring > 4 units transfusion	85	2.9	17	3.0
Systemic sepsis	80	2.7	16	2.8
Ileus/bowel obstruction	49	1.7	6	1.1
Deep venous thrombosis	20	0.7	4	0.7
Graft/prosthesis failure	1	0.0	2	0.4

CPR, Cardiopulmonary resuscitation; CNS, central nervous system.

ables were commonly significant in the univariate analyses for both mortality and morbidity.

Multivariable analyses. All factors with a prevalence of greater than 0.5% of the sample and a univariate significance of $P < .2$ were placed into a multivariable stepwise logistic regression analysis to identify risk factors associated with mortality and morbidity. In the multivariable logistic regression model for mortality, the preoperative independent predictors ($P < .05$) were serum albumin, do not resuscitate status before the operation, transfusion of more than 4 units of red blood cells before the operation, age, disseminated cancer (defined as a resection for a pulmonary metastasis or for patients with clinical evidence of mediastinal lymph nodes in non-small cell lung cancer), impaired sensorium, prothrombin time of more than 12 seconds, operation type, and dyspnea. The β coefficients for

Table III-a. Multivariable logistic regression model of 30-day mortality (preoperative variables and type of operation)

Variable	β Coefficient	SE	P value	OR
Intercept	-2.1970	0.8726		
Higher serum albumin (g/dL)	-.6449	0.1537	.0001	0.525
Do not resuscitate status present	1.4606	0.4855	.0026	4.309
Preoperative transfusion > 4 RBC units present	1.9398	0.5685	.0006	6.957
Older age (y)	.0327	0.0099	.0010	1.033
Disseminated cancer present	.6959	0.2572	.0068	2.006
Impaired sensorium present	.9974	0.4050	.0138	2.711
Prothrombin time > 12 s present	.3627	0.1593	.0228	1.437
Dyspnea present	.3359	0.1586	.0342	1.399
Pneumonectomy operations (vs lobectomy)	-1.1103	0.1700	.0001	3.035
-2 LOG likelihood = 1317.1				
C-index = 0.729				
Hosmer-Lemeshow statistic = 4.74 ($P = .7851$)				

The present/absent dichotomous risk variables were all coded as 0 = absent, 1 = present in the logistic regression analysis. Type of operation was coded as 0 = lobectomy, 1 = pneumonectomy. SE, Standard error; OR, odds ratio; RBC, red blood cell.

these variables along with their P values and associated odds ratios are contained in Table III-a. When the intraoperative variables are added for possible entry into this logistic model for mortality, the combined model contains the preoperative predictors and the intraoperative blood loss. This combined model is described in Table III-b.

In the multivariable morbidity model, the preoperative predictors significant at the .05 level were age, weight loss of more than 10%, history of chronic obstructive pulmonary disease, transfusion of more than 4 units of red blood cells, serum albumin, hemiplegia, smoking, and dyspnea. Table IV-a contains the β coefficients, P values, and odds ratios for this model. When the intraoperative variables are added, the resultant combined model includes the preoperative predictors with operation time and intraoperative red blood cell units transfused. Table IV-b lists the result of this model.

Model validation. The predictive validity (discrimination) of the model was measured by means of the c-index.^{23,24} The c-indexes for the mortality models were 0.729 for the preoperative model and 0.749 for the model including the intraoperative variables. The c-indexes for the respective morbidity models were 0.623 and 0.646. These indexes indicate a moderate level of predictability. The model fit was measured with the

Table III-b. Multivariable logistic regression model of 30-day mortality (preoperative variables, type of operation, and intraoperative variables)

Variable	β Coefficient	SE	P value	OR
Intercept	-3.2584	0.9073		
Higher serum albumin (g/dL)	-.5075	0.1592	.0014	0.602
Do not resuscitate status present	1.0205	0.5592	.0680	2.775
Preoperative transfusion > 4 RBC units present	1.9731	0.5704	.0005	7.193
Older age (y)	.0356	0.0100	.0004	1.036
Disseminated cancer present	.6848	0.2588	.0081	1.983
Impaired sensorium present	.9749	0.0452	.0161	2.651
Prothrombin time > 12 s present	.3007	0.1619	.0633	1.351
Dyspnea present	.3176	0.1610	.0485	1.374
Pneumonectomy (vs lobectomy)	-.9978	0.1737	.0001	2.712
Intraoperative blood loss (mL)	.0006	0.0001	.0001	1.001
-2 LOG likelihood = 1286.3				
C-index = 0.749				
Hosmer-Lemeshow statistic = 6.56 ($P = .5845$)				

The present/absent dichotomous risk variables were all coded as 0 = absent, 1 = present in the logistic regression analysis. Type of operation was coded as 0 = lobectomy, 1 = pneumonectomy. SE, Standard error; OR, odds ratio; RBC, red blood cell.

Hosmer-Lemeshow²⁵ statistic. The Hosmer-Lemeshow statistics for the mortality models were 4.74 ($P = .79$) and 6.56 ($P = .58$). The corresponding Hosmer-Lemeshow statistics for the morbidity models were 5.81 ($P = .67$) and 8.43 ($P = .39$). These Hosmer-Lemeshow statistics show a good level of fit for each of the models.

In addition, the stability of the mortality and morbidity models was verified with a bootstrap resampling method.^{26,27} The bootstrap resampling technique was performed on 200 random samples for both mortality and morbidity with the use of the preoperative and intraoperative variables that were univariately significant. All the variables in the final mortality model were included in a majority of the 200 bootstrap replications except for dyspnea and prothrombin time. For morbidity, all variables in the final model were included in at least 50% of the bootstrap replications, except for smoking and albumin (Table V).

Discussion

Purpose of study. Advances in surgery require prospectively collected, accurate, and reliable outcome data. The Department of VA Medical Centers is an excellent place to create an outcome database, because

Table IV-a. Multivariable logistic regression model of 30-day morbidity (preoperative variables and type of operation)

Variable	β coefficient	SE	P value	OR
Intercept	-2.3979	0.4981		
Older age (y)	.0291	0.0050	.0001	1.030
Weight loss > 10% present	.4762	0.1209	.0001	1.610
History of COPD present	.2830	0.0847	.0008	1.327
Preoperative transfusion > 4 RBC units present	1.7901	0.5254	.0007	5.990
Higher serum albumin (g/dL)	-0.2710	0.0896	.0025	0.763
Hemiplegia present	.9233	0.3307	.0052	2.518
Smoking present	.2114	0.0831	.0109	1.235
Dyspnea present	.2386	0.0866	.0059	1.269
-2 LOG likelihood = 3754.5				
C-index = 0.623				
Hosmer-Lemeshow statistic = 5.81 ($P = .6684$)				

The present/absent dichotomous risk variables were all coded as 0 = absent, 1 = present in the logistic regression analysis. SE, Standard error; OR, odds ratio; COPD, chronic obstructive pulmonary disease; RBC, red blood cell.

Table IV-b. Multivariable logistic regression model of 30-day morbidity (preoperative variables, type of operation, and intraoperative variables)

Variable	β coefficient	SE	P value	OR
Intercept	-3.4339	0.5253		
Older age (y)	.0314	0.0051	.0001	1.032
Weight loss > 10% present	.4719	0.1223	.0001	1.603
History of COPD present	.2621	0.0855	.0022	1.300
Preoperative transfusion > 4 RBC units present	1.6634	0.5355	.0019	5.277
Higher serum albumin (g/dL)	-0.1501	0.0929	.1062	0.861
Hemiplegia present	.9708	0.3326	.0035	2.640
Smoking present	.2363	0.0840	.0049	1.267
Dyspnea present	.2435	0.0875	.0054	1.276
Longer operation time (h)	.1013	0.0270	.0002	1.107
Intraoperative RBC unit transfusion	.2309	0.0449	.0001	1.260
-2 LOG likelihood = 3698.3				
C-index = 0.646				
Hosmer-Lemeshow statistic = 8.43 ($P = .3929$)				

The present/absent dichotomous risk variables were all coded as 0 = absent, 1 = present in the logistic regression analysis. SE, Standard error; OR, odds ratio; COPD, chronic obstructive pulmonary disease; RBC, red blood cell.

Table V. Morbidity and mortality bootstrap results

Mortality bootstrap			Morbidity bootstrap		
Variable	Frequency selected	%	Variable	Frequency selected	%
Age	200	100	Type of operation	200	100
Operation time	195	97.5	Age	185	92.5
Weight loss > 10%	190	95.0	Intraoperative blood loss	142	71.0
Intraoperative RBC unit transfusion	170	85.0	Disseminated cancer	134	67.0
History of COPD	164	82.0	Albumin	120	60.0
Transfusion > 4 units	160	80.0	Transfusion > 4 units	115	57.5
Hemiplegia	147	73.5	Impaired sensorium	108	54.0
Dyspnea	126	63.0	DNR	103	51.5

RBC, Red blood cell; COPD, chronic obstructive pulmonary disease; DNR, do not resuscitate.

of its nationally based patient population and easily retrieved computerized patient data. The National VA Surgical Quality Improvement Program was established in 1991 as a model of a multi-institutional outcomes study. Patient risk and postoperative data on more than 300,000 operative encounters have been collected, 184,319 of which were for noncardiac procedures.^{13,15} Variable definitions and data collection were standardized across surgical subspecialties so that aggregate analyses would be possible.

The purpose of this project was to use these data to construct a model of preoperative patient risk for mortality and morbidity within 30 days of major pulmonary resections. Data collection was prospective and

recent (1991-1995), eliminating any temporal bias that existed in previous single-institution reports that spanned decades and may not reflect current clinical practice. Because a dedicated surgical nurse reviewer acquired all of the data prospectively, its reproducibility and accuracy were assured. Interpretive test results, such as electrocardiography and spirometry, were not included in this study.

The 30-day mortality and morbidity rates (5.2% and 24.1%, respectively) from this multi-institution series are in the range of those published from single-institution retrospective series (mortality 3%-14%; morbidity 10%-25%).¹⁻⁹ The largest pneumonectomy series (n = 244) from the Mayo Clinic reported 11% deaths and

Fig 1. Statistical nomograms were constructed with 95% confidence intervals to demonstrate the results. *Top*, Probability of death for age in years. *Bottom*, Probability of a complication for patient by age. Note that risk increases with age.

24% major morbidity within 30 days. These procedures were performed for cancer and infection.¹⁰ Deslauriers and associates¹¹ reported a series of 1076 patients from several centers in Canada who had undergone elective lobectomy or pneumonectomy for cancer from 1978 until 1984. They observed an overall 3.2% mortality and a 19% morbidity rate, which are similar to our overall mortality and morbidity rates.

Multi-institution, prospective data are available from

the Lung Cancer Study Group (1979-1981). Ginsberg and colleagues¹² reported a 2.6% mortality for a lobectomy ($n = 1058$) and a 6.2% mortality for a pneumonectomy ($n = 569$) for cancer. Silvestri and colleagues²⁸ published data from hospital discharges in the state of South Carolina from 1991 until 1995. This study observed a 30-day mortality of 11.8% for pneumonectomy and 3.0% for lobectomy performed by board-certified thoracic surgeons. Both of these series

Fig 2. Statistical nomograms were constructed with 95% confidence intervals to demonstrate the results. *Top*, Probability of death for serum albumin. *Bottom*, Probability of a complication for patient by serum albumin. Note that risk decreases with improved nutritional status.

included elective operations performed for cancer. Our VA data included 3516 consecutive patients who underwent a lobectomy or pneumonectomy for any cause, elective or emergency. There were 19 emergency procedures for infection or massive hemoptysis, and 11 urgent or emergency procedures were performed on patients who had previously asked not to be resuscitated in the event of a cardiac arrest. Significant comor-

bidity is common in this veteran population, including 39% of patients with chronic obstructive lung disease, 33% with moderate or severe dyspnea, 19% with chronic alcoholism, 11% with diabetes, and 10% with a history of a stroke or transient ischemic attack. These factors may explain the higher mortality rates observed in this population of male veterans. In fact, if the mortality models for lobectomy and pneumonectomy were

used to define a "low risk" subset of patients (expected mortality $\leq 5.0\%$), observed mortality was actually 2.5% for lobectomy and 7.0% for pneumonectomy.

Limitations of study. The study population is predominantly male. The 1997 cancer statistics demonstrate that 40% of newly diagnosed cases of lung cancer occur in women.²⁹ Clearly, the generalizability of this VA study will need to be verified in a more heterogeneous population. Early efforts by the Society of Thoracic Surgeons may accomplish this goal, and this VA study can act as a model for future analytical risk models. In an effort for data consistency and completeness, only easily quantifiable data were included and no subspecialty procedure-specific morbidity (ie, bronchopleural fistula instead of pneumonia) was collected, allowing consistent data collection throughout the VA system. Future studies are being designed to include procedure-specific variable collection, such as exercise oximetry, spirometry, and predicted postresection forced expiratory volume in 1 second.

Clinical relevance of models. Two separate analyses were undertaken after univariate analyses identified potential variables associated with mortality and morbidity. The first model consisted of preoperative variables that would be readily available to clinicians, as well as the type of resection planned (lobectomy or pneumonectomy). The mortality model demonstrated the significance of patient age, pulmonary reserve (dyspnea class), level of cognition, nutritional status (serum albumin), liver function (serum prothrombin time), clinical cancer stage, and need for a pneumonectomy on perioperative survival. If one added the intraoperative variables to this model, only the operative blood loss (a measure of the difficulty of the operation) added independent prognostic information.

The morbidity models included different variables. In addition to patient age, serum albumin, and dyspnea class, preoperative smoking, weight loss, and hemiplegia were significant predictors of a complicated postoperative course. Intraoperative variables that significantly predicted a complication included operative time and blood loss, both markers of a more difficult operation, whereas there was no difference in the risk of a complication between the two procedures once the model accounted for these other significant variables. Figs 1 and 2 demonstrate the results of two continuous variables (age in years and serum albumin level before operation) on mortality and morbidity.

Conclusion

This recent series of lobectomy and pneumonectomy in the Department of VA Medical Centers demonstrates

the feasibility of a prospective, national, multicenter perioperative study. The outcome results obtained were consistent with those published in the literature. The large size of the population allowed the creation and validation of a risk-adjusted model for patient selection for major pulmonary resections. Therefore, in addition to the clinically relevant assessment of the patient's health, one can use the β coefficients of the significant factors present in a specific patient to determine the probability of an adverse event in that patient. This is the largest data set of its type and therefore allowed construction of the most predictive model to date. Future prospective multicenter studies of patients undergoing major pulmonary resections may include other variables (ie, spirometry and exercise oximetry), thereby increasing the overall predictive validity of the models.

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Appendix 1

National Surgical Quality Improvement Program Program Worksheet

A. PREOPERATIVE INFORMATION

1. GENERAL

- a. Diabetes mellitus
 1. No
 2. Oral
 3. Insulin

- b. Current smoker within 2 weeks before admission
 1. Yes
 2. No
- c. Alcohol > 2 drinks/day within 2 weeks before admission
 1. Yes
 2. No
- d. Drug addiction
 1. Yes
 2. No
- e. Dyspnea
 1. No
 2. Minimal exertion
 3. Rest
- f. Do not resuscitate status—this admission
 1. Yes
 2. No
- g. Functional status
 1. Independent
 2. Partially dependent
 3. Total dependent

2. PULMONARY

- a. Ventilator dependent > 48 hours
 1. Yes
 2. No
- b. History of severe chronic obstructive pulmonary disease
 1. Yes
 2. No
- c. Current pneumonia
 1. Yes
 2. No

3. HEPATOBILIARY

- a. Hepatomegaly
 1. Yes
 2. No
- b. Ascites
 1. Yes
 2. No
- c. Esophageal varices
 1. Yes
 2. No
- d. Active hepatitis
 1. Yes
 2. No

4. CARDIAC

- a. History of myocardial infarction within past 6 months
 1. Yes
 2. No
- b. Previous percutaneous transluminal coronary angioplasty
 1. Yes
 2. No
- c. Previous operation with cardiopulmonary bypass
 1. Yes
 2. No
- d. History of angina within month before the operation
 1. Yes

- 2. No
- e. Congestive heart failure within 1 month before the operation
 - 1. Yes
 - 2. No
- f. Hypertension requiring medication
 - 1. Yes
 - 2. No

5. RENAL

- a. Acute renal failure (change in creatinine > 2.0 mg/dL)
 - 1. Yes
 - 2. No
- b. Currently requiring dialysis
 - 1. Yes
 - 2. No

6. VASCULAR

- a. History of revascularization/amputation for peripheral vascular disease
 - 1. Yes
 - 2. No
- b. Rest pain/gangrene
 - 1. Yes
 - 2. No
- c. Absent peripheral pulses
 - 1. Yes
 - 2. No

7. CENTRAL NERVOUS SYSTEM

- a. Impaired sensorium
 - 1. Yes
 - 2. No
- b. Severe head trauma
 - 1. Yes
 - 2. No
- c. History of coma
 - 1. Yes
 - 2. No
- d. Quadriplegia
 - 1. Yes
 - 2. No
- e. Paraplegia
 - 1. Yes
 - 2. No
- f. Hemiplegia
 - 1. Yes
 - 2. No
- g. History of transient ischemic attacks
 - 1. Yes
 - 2. No
- h. Cerebrovascular accident residual neurologic deficit
 - 1. Yes
 - 2. No
- i. Cerebrovascular accident/no neurologic deficit
 - 1. Yes
 - 2. No
- j. Neuromuscular degenerative disease
 - 1. Yes

- 2. No
- k. Tumor involving the central nervous system
 - 1. Yes
 - 2. No

8. NUTRITIONAL/IMMUNE/OTHER

- a. Disseminated cancer (stage IV)
 - 1. Yes
 - 2. No
- b. Open wound or infection
 - 1. Yes
 - 2. No
- c. Chronic steroid use
 - 1. Yes
 - 2. No
- d. >10% loss of body weight within last 6 months
 - 1. Yes
 - 2. No
- e. Bleeding disorders
 - 1. Yes
 - 2. No
- f. Transfusion > 4 red blood cell units this admission
 - 1. Yes
 - 2. No
- g. Number of prior operations this admission

B. OPERATIVE INFORMATION

- 1. Surgical specialty: (code)
- 2. Principal operation: (CPT code)
- 3. Other procedures: (CPT code)
- 4. Concomitant procedures: (code)
- 5. Postgraduate-year primary surgeon
- 6. Emergency case
 - a. Yes
 - b. No
- 7. Wound classification
 - a. Clean
 - b. Clean/contaminated
 - c. Contaminated
 - d. Infected
- 8. Redo
 - a. Yes
 - b. No
- 9. American Society of Anesthesiology class
- 10. Principal anesthesia technique
 - a. General
 - b. Spinal
 - c. Epidural
 - d. Regular/local
- 11. Time operation began (24-hour clock)_____
- 12. Intraoperative blood loss (mL) (minimal = 100)_____
- 13. Number of red blood cell units transfused_____

C. OUTCOME INFORMATION

- 1. Postoperative diagnosis (ICD-9-Code)
- 2. Length of postoperative hospital stay (days)_____
- 3. Thirty-day postoperative status
- 4. Date of death _____

5. Return to operating room within 30 days after index procedure
 - a. Yes
 - b. No
6. Number of returns related to index procedure _____
7. CPT code _____
8. CPT code _____
9. CPT code _____
10. Number of returns unrelated to index procedure _____
11. CPT code _____
12. CPT code _____
13. CPT code _____

D. COMPLICATIONS (See Table II)

E. LABORATORY VALUES

1. Preoperative (nearest to operation date)

- a. Sodium _____ Month _____ Day _____ Year _____
- b. Potassium _____ Month _____ Day _____ Year _____
- c. Glucose _____ Month _____ Day _____ Year _____
- d. BUN _____ Month _____ Day _____ Year _____
- e. Creatinine _____ Month _____ Day _____ Year _____
- f. CK _____ Month _____ Day _____ Year _____
- g. CK-MB _____ Month _____ Day _____ Year _____
- h. Albumin _____ Month _____ Day _____ Year _____
- i. Total bilirubin _____ Month _____ Day _____ Year _____
- j. ALT _____ Month _____ Day _____ Year _____
- k. AST _____ Month _____ Day _____ Year _____
- l. AP _____ Month _____ Day _____ Year _____
- m. WBC _____ Month _____ Day _____ Year _____
- n. Hct _____ Month _____ Day _____ Year _____
- o. Platelets _____ Month _____ Day _____ Year _____
- p. PTT _____ Month _____ Day _____ Year _____
- q. PT _____ Month _____ Day _____ Year _____

2. Postoperative laboratory values (record highest and lowest levels)

- a. Sodium _____ Month _____ Day _____ Year _____
- b. Sodium _____ Month _____ Day _____ Year _____
- c. Potassium _____ Month _____ Day _____ Year _____
- d. Potassium _____ Month _____ Day _____ Year _____
- e. Glucose _____ Month _____ Day _____ Year _____
- f. Creatinine _____ Month _____ Day _____ Year _____
- g. CK _____ Month _____ Day _____ Year _____
- h. CK-MB _____ Month _____ Day _____ Year _____
- i. Albumin _____ Month _____ Day _____ Year _____
- j. Total bilirubin _____ Month _____ Day _____ Year _____
- k. WBC _____ Month _____ Day _____ Year _____
- l. Hct _____ Month _____ Day _____ Year _____

Where *BUN* is blood urea nitrogen, *CK* is creatine kinase, *AP* is alkaline phosphatase, *ALT* is alanine aminotransferase, *AST* is aspartate aminotransferase, *WBC* is white blood cell count, *Hct* is hematocrit, *PTT* is partial thromboplastin time, and *PT* is prothrombin time.

Appendix 2

List of variables used in mortality and/or morbidity modeling (univariate $P < .2$ and prevalence $\geq 0.5\%$)

Mortality and morbidity

DRUGAD	Drug addiction
DYSP	Dyspnea (no vs minimal exertion or at rest)
DNR	Do not resuscitate status
FNSTATUS	Functional status
HXCOPD	History of severe chronic obstructive pulmonary disease
CPNEUMON	Current pneumonia
HXCHF	Congestive heart failure within 1 month preceding surgery
HXPVD	History of revascularization/amputation for peripheral vascular disease
ABPULSE	Absent peripheral pulse
IMPSENS	Impaired sensorium
HEMI	Hemiplegia
CVANEURO	Cerebrovascular accident/residual neurologic deficit
WTLOSS	>10% loss in body weight within last 6 months
BLEEDDIS	Bleeding disorders
TRANSFUS	Transfusion > 4 red blood cell units this admission
EMERGNCY	Emergency case
ASACLAS	American Society of Anesthesiology class
AGE	Age
PRALBUM	Serum albumin
PRSODM	Sodium
PRBUN	Blood urea nitrogen
PRALKPH	Alkaline phosphatase
PRHCT	Hematocrit
PRPTT	Partial thromboplastin time

Mortality only

SEX	Gender
ETOH	Alcohol > 2 drinks/day within 2 weeks before admission
DISCANCR	Disseminated cancer
STEROID	Long-term steroid use
NOPER	Number of returns related to index procedure
XSCORE	Complexity score of operation
PRPTAS	Potassium
PRSGOT	Aspartate aminotransferase
PRPT	Prothrombin time

Morbidity only

DIABETES	Diabetes
SMOKE	Current smoker within 2 weeks of admission
HYPERMED	Hypertension requiring medication
HXTIA	History of transient ischemic attack
CVANO	Cerebrovascular accident/no neurologic deficit
WNDCLASS	Wound classification
PRWBC	White blood cell count
PRPLAT	Platelet counts