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Development and Validation of a Multifactorial Risk Index for Predicting Postoperative Pneumonia after Major Noncardiac Surgery

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Background: Pneumonia is a common postoperative complication associated with substantial morbidity and mortality.

Objective: To develop and validate a preoperative risk index for predicting postoperative pneumonia.

Design: Prospective cohort study with outcome assessment based on chart review.

Setting: 100 Veterans Affairs Medical Centers performing major surgery.

Patients: The risk index was developed by using data on 160 805 patients undergoing major noncardiac surgery between 1 September 1997 and 31 August 1999 and was validated by using data on 155 266 patients undergoing surgery between 1 September 1995 and 31 August 1997. Patients with preoperative pneumonia, ventilator dependence, and pneumonia that developed after postoperative respiratory failure were excluded.

Measurements: Postoperative pneumonia was defined by using the Centers for Disease Control and Prevention definition of nosocomial pneumonia.

Results: A total of 2466 patients (1.5%) developed pneumonia, and the 30-day postoperative mortality rate was 21%. A postoperative pneumonia risk index was developed that included type of surgery (abdominal aortic aneurysm repair, thoracic, upper abdominal, neck, vascular, and neurosurgery), age, functional status, weight loss, chronic obstructive pulmonary disease, general anesthesia, impaired sensorium, cerebral vascular accident, blood urea nitrogen level, transfusion, emergency surgery, long-term steroid use, smoking, and alcohol use. Patients were divided into five risk classes by using risk index scores. Pneumonia rates were 0.2% among those with 0 to 15 risk points, 1.2% for those with 16 to 25 risk points, 4.0% for those with 26 to 40 risk points, 9.4% for those with 41 to 55 risk points, and 15.3% for those with more than 55 risk points. The C-statistic was 0.805 for the development cohort and 0.817 for the validation cohort.

Conclusions: The postoperative pneumonia risk index identifies patients at risk for postoperative pneumonia and may be useful in guiding perioperative respiratory care.

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Postoperative pulmonary complications are associated with substantial morbidity and mortality. It has been estimated that nearly one fourth of deaths occurring within 6 days of surgery are related to postoperative pulmonary complications (1). Postoperative infections are also a major source of the morbidity and mortality associated with undergoing surgery. Pneumonia is the most serious postoperative complication that is included in both of these categories. Pneumonia ranks as the third most common postoperative infection, behind urinary tract and wound infection (2). According to the National Nosocomial Infection Surveillance system, pneumonia occurred in 18% of patients after surgery (3). Postoperative pneumonia occurs in 9% to 40% of patients, and the associated mortality rate is 30% to 46%, depending on the type of surgery (1, 4).

Previous studies of risk factors used various definitions of postoperative pulmonary complications. Atelectasis (1, 4–7), postoperative pneumonia (1–2, 4–6, 8–11), the acute respiratory distress syndrome (9, 12), and postoperative respiratory failure (6, 9, 11, 13) have been classified as postoperative pulmonary complications. Although the clinical significance of each of these complications varies greatly, they were grouped together as a single outcome in previous studies (6). Some studies were limited to examination of risk factors in patients undergoing abdominal or thoracic procedures or in patients with specific medical conditions, such as chronic obstructive pulmonary disease (2, 4, 6, 10–12, 14). These studies were often based on a small sample from one institution, and studies of independent samples did not validate their findings (15, 16).

Although clinicians have used preoperative cardiac risk indexes for more than 20 years (17), previous studies have not produced a validated risk index that predicts risk for pneumonia (18). Our main objective was to develop and validate a multifactorial risk index for predicting postoperative pneumonia. Preoperative risk factors for postoperative pneumonia were determined in a large multicenter observational cohort of patients under-

Table 1. **Definition of Postoperative Pneumonia**

Patient met one of the following two criteria postoperatively:
1. Rales or dullness to percussion on physical examination of chest AND any of the following:
   - New onset of purulent sputum or change in character of sputum
   - Isolation of organism from blood culture
   - Isolation of pathogen from specimen obtained by transtracheal aspirate, bronchial brushing, or biopsy
2. Chest radiography showing new or progressive infiltrate, consolidation, cavitation, or pleural effusion AND any of the following:
   - New onset of purulent sputum or change in character of sputum.
   - Isolation of organism from blood culture.
   - Isolation of pathogen from specimen obtained by transtracheal aspirate, bronchial brushing, or biopsy
   - Isolation of virus or detection of viral antigen in respiratory secretions
   - Diagnostic single antibody titer (IgM) or fourfold increase in paired serum samples (IgG) for pathogen
   - Histopathologic evidence of pneumonia

going various major noncardiac operations. Specific goals included identification of predictors that are easily obtained and commonly accessible to care providers before surgery. Using these predictors, we developed and validated a risk assessment model and scoring system for predicting postoperative pneumonia, analogous to risk assessment models for predicting cardiac complications (17, 19, 20).

METHODS

Patients were selected from the Department of Veterans Affairs National Surgical Quality Improvement Program (NSQIP). A detailed description of the study methods is published elsewhere and is summarized briefly here (13, 21–23).

Participating Hospitals

Our study includes patients enrolled between 1 September 1995 and 31 August 1999 at 100 Veterans Affairs medical centers that perform major surgery. Patients enrolled at 97 medical centers between 1 September 1997 and 31 August 1999 were used to develop the model, and patients enrolled at 100 medical centers between 1 September 1995 and 31 August 1997 were used to validate the model.

Selection of Patients

All noncardiac operations performed under general, spinal, epidural, local, or monitored anesthesia were eligible for inclusion as index operations. All eligible operations were included at low-volume hospitals ($<$140 eligible operations per month). At 5 high-volume hospitals ($\geq$140 eligible operations per month), the first 36 consecutive eligible operations were entered in each consecutive 8-day period, beginning with a different day each period. On the basis of a review of operative mortality rates from the Veterans Affairs administrative discharge database for 1988 and 1989, selected operations with very low mortality rates were excluded from the NSQIP. Major transplantation procedures and patients entered into the study within the previous 30 days were also excluded.

Patients were defined as having postoperative pneumonia if they met the Centers for Disease Control and Prevention definition of nosocomial pneumonia after surgery (**Table 1**) (24). We excluded patients who were ventilator dependent before surgery and those who had preoperative pneumonia. Patients who experienced postoperative respiratory failure or unplanned intubation before postoperative pneumonia was diagnosed were also excluded.

Data Collection

A surgical risk-assessment nurse was assigned at each center to collect the data. All variables were defined before data collection (21). The nurses completed in-depth training on all study definitions and conduct of the protocol. Annual meetings and regular conference calls were conducted, and two traveling nurse coordinators performed site visits to maintain data reliability.

Generic preoperative, intraoperative, and postoperative variables were chosen on the basis of clinical relevance, reliability of data collection, and availability of data. Preoperative data were obtained by the study nurse from the medical chart or a surgical risk-assessment profile that was completed by the surgical resident caring for the patient and later verified by the study nurse from the medical record. Preoperative laboratory values within 30 days of the index operation and closest to the time of operation were acquired automatically from the laboratory software in each center's computer system. Intraoperative variables were collected from the operative log and anesthesia record for the index operation. The index operation was defined as the first eligible operation performed on the patient. Other operations performed under the same anesthetic by the same or different surgical team were also recorded. The type of surgery was primarily classified by the anatomic location of the surgical incision (13).

On the 30th postoperative day, the study nurse obtained outcome information by chart review, interviews with care providers, reports from morbidity and mortality conferences, and communication with each patient by letter or by telephone. Postoperative mortality was defined as death from any cause inside or outside the hospital within 30 days of surgery. The nurse entered all data into a surgical risk assessment module in each center's computer system. A summary of each patient data record was forwarded to the chief of the surgical service 30 days after surgery for inspection. No later than 45 days after surgery, the patient records were transmitted automatically to the statistical coordinating center for editing and analysis.

Missing Data

Data were more than 92% complete, except for preoperative laboratory variables; the completeness of these depended on whether the specific laboratory tests had been ordered. Patients with missing data for tests that were not ordered more than 8% of the time were excluded from the development and validation data sets. Twelve percent of blood urea nitrogen and 9% of creatinine values were missing; thus, patients for whom these values were missing were excluded from the development and validation data sets.

Statistical Analysis

Data were analyzed by using two software packages (SAS for UNIX [SAS Institute, Inc., Cary, North Carolina] and Stata statistical software, version 7.0 for Windows [Stata Corp., College Station, Texas]). Using patients from the development set (enrolled between 1 September 1997 and 31 August 1999), we used the chi-square test for categorical variables and the Student *t*-test for continuous variables to test the relationship between each potential risk factor and postoperative pneumonia. All potential risk factors were entered into a logistic regression model with postoperative pneumonia as the dependent variable and the potential risk factors as the independent variables. Blood urea nitrogen was categorized into ranges suggested by its U-shaped relationship to postoperative pneumonia in univariate analyses. Indicator variables created for each range were included in the logistic regression model. Potential risk factors that were not statistically significant ($P < 0.05$) were sequentially deleted from the full model. Excluded variables were reintroduced at various stages of model development until only statistically significant risk factors remained. Two-way interaction between recent smoking and history of chronic obstructive pulmonary disease was analyzed and found to be statistically nonsignificant. Robust variance estimates were calculated by using the Huber–White method to account for the effect of clustering of patients within hospitals (25).

Development of a Scoring System

By using the methods of Le Gall and colleagues (26), point values were assigned to each risk factor by multiplying the β-coefficients from the logistic regression model by 10 and rounding off to the nearest integer. The point total for each patient was designated the postoperative pneumonia risk index and was used in a multiple logistic regression equation designed to convert the risk index to the probability of developing postoperative pneumonia. Because the risk index scores were highly skewed, a shrinking power transformation, *ln* (postoperative pneumonia risk index score +25), where *ln* indicates the natural logarithm, was incorporated into the model for improved calibration (26).

Evaluation of Model Performance

Formal goodness-of-fit (Hosmer–Lemeshow) tests (27) were performed by using data on patients from the development cohort, the validation cohort, and 10 random sets of five hospitals to assess model calibration. The C-statistic was used to evaluate discrimination in model development and validation (28).

Results

Patient Characteristics and Postoperative Pneumonia Rates

Of the 206 434 patients enrolled between 1 September 1997 and 31 August 1999, 5395 patients (2.6%) with preoperative pneumonia or dependence on a ventilator were excluded. An additional 729 patients were excluded because postoperative pneumonia was diagnosed after development of respiratory failure or unplanned intubation. Of the remaining 200 310 patients, 18 448 were excluded because they had missing values for variables that were not recorded in more than 8% of cases. An additional 21 057 patients with missing values for blood urea nitrogen or creatinine were also excluded. The remaining 160 805 patients were used for development of the model.

Of the 195 046 patients enrolled between 1 September 1995 and 31 August 1997, 5246 (2.7%) with preoperative pneumonia or dependence on a ventilator were excluded. An additional 727 patients were excluded because postoperative pneumonia was diagnosed after development of respiratory failure or unplanned intubation. Of the 189 073 remaining patients, 15 916 were excluded because they had missing values for variables that were not recorded in more than 8% of cases. An additional 17 891 patients with missing values for blood urea nitrogen or creatinine were also excluded. The remaining 155 266 patients were used for model validation.

Table 2 shows baseline characteristics of patients with and without postoperative pneumonia in the development set. Overall, 2466 patients (1.5%) had postoperative pneumonia. Mean age (±SD) was 68.9 ± 10.9 years in patients with postoperative pneumonia and 61.2 ± 13.3 years in those without postoperative pneumonia ($P < 0.001$). Respiratory failure, systemic sepsis, cardiac arrest requiring cardiopulmonary resuscitation, prolonged ileus, and myocardial infarction were the most serious postoperative complications associated with pneumonia. Overall, the 30-day postoperative mortality rate was 21% in patients with postoperative pneumonia and 2% in patients without postoperative pneumonia ($P < 0.001$).

Multivariable Analysis

Potential risk factors that were excluded during model development because they were not statistically significant ($P > 0.05$) were preoperative serum creatinine concentration, history of diabetes mellitus, congestive heart failure, ascites, dialysis dependence, recent chemotherapy, preoperative renal failure, and dyspnea. **Table 3** shows the significant predictors of postoperative pneumonia found in logistic regression analysis. Risk factors were related to type of surgery, type of anesthesia, general health and immune status, respiratory status, neurologic status, and fluid status.

Patients undergoing abdominal aortic aneurysm repair; thoracic, upper abdominal, or neck surgery; neurosurgery; or peripheral vascular surgery had an increased likelihood of developing postoperative pneumonia. The reference group for type of surgery, designated as "other surgery," included ophthalmologic, ear, nose, mouth, lower abdominal, urogenital, extremity, peripheral vascular, dermatologic, spine, and back operations. These types were chosen as the reference category because they had the lowest associated rates of postoperative pneumonia in univariate analysis. Among types of surgery, abdominal aortic aneurysm repair and thoracic surgery had the highest odds ratios for development of postoperative pneumonia (4.29 [95% CI, 3.34 to 5.50] and 3.92 [CI, 3.46 to 4.67], respectively). Patients undergoing emergency surgery had an odds ratio of 1.33 (CI, 1.16 to 1.54) for developing pneumonia. Patients undergoing surgery using general anesthesia had an odds ratio of 1.56 (CI, 1.36 to 1.80) compared with patients in whom spinal, monitored, or other anesthesia was used.

Significant risk factors related to general health and immune status were age, functional status, weight loss, steroid use, and alcohol use. Compared with patients younger than 50 years of age, patients older than 80 years of age had an odds ratio of 5.63 (CI, 4.62 to 6.84), patients 70 to 79 years of age had an odds ratio of 3.58 (CI, 2.97 to 4.33), and patients 60 to 69 years of age had an odds ratio of 2.38 (CI, 1.98 to 2.87) for developing pneumonia. Patients with totally dependent functional status had an odds ratio of 2.83 (CI, 2.33 to 3.43) compared with those who had independent functional status. Patients with weight loss greater than 10% had an odds ratio of 1.92 (CI, 1.68 to 2.18), those using steroids for chronic conditions had an odds ratio of 1.33 (CI, 1.12 to 1.58), and those with a recent history of alcohol use had an odds ratio of 1.24 (CI, 1.08 to 1.42) for developing postoperative pneumonia.

Significant risk factors related to respiratory status included history of chronic obstructive pulmonary disease (odds ratio, 1.72 [CI, 1.55 to 1.91]) and smoking within 1 year of surgery (odds ratio, 1.28 [CI, 1.17 to 1.42). Two risk factors related to neurologic status were found to be significant in multivariable analysis: Patients with impaired sensorium had an odds ratio of 1.51 (CI, 1.26 to 1.82) and patients with a history of cerebrovascular accident with a residual neurologic deficit had an odds ratio of 1.47 (CI, 1.28 to 1.68) for developing pneumonia.

Table 2. **Demographic and Clinical Characteristics of Development Cohort Patients with and without Postoperative Pneumonia***

Patient Demographic and Clinical Characteristics	Patients with Postoperative Pneumonia (*n* = 2466)	Patients with No Postoperative Pneumonia (*n* = 158 339)	*P* Value
Mean age ± SD, *y*	68.9 ± 10.9	61.2 ± 13.3	<0.001
Men, *n (%)*	2411 (98)	150 803 (95)	<0.001
Mean blood urea nitrogen level ± SD, *mmol/L (mg/dL)*	7.3 ± 5.0 (20.6 ± 14.1)	6.2 ± 3.8 (17.3 ± 10.6)	<0.001
Creatinine concentration ± SD, *µmol/L (mg/dL)*	112 ± 85 (1.3 ± 1.0)	105 ± 89 (1.2 ± 1.0)	<0.001
Functional status, *n (%)*			<0.001
Independent	1647 (67)	137 043 (87)	
Partially dependent	591 (24)	17 817 (11)	
Totally dependent	228 (9)	3479 (2)	
Diabetes mellitus, *n (%)*			<0.001
No diabetes or diet controlled	1957 (79)	130 186 (82)	
Oral therapy	232 (9)	14 673 (9)	
Insulin therapy	277 (11)	13 480 (9)	
Weight loss > 10% in past 6 months, *n (%)*	338 (14)	5766 (4)	<0.001
Alcohol intake > 2 drinks/d in past 2 weeks, *n (%)*	337 (14)	17 623 (11)	<0.001
Steroid use for chronic condition, *n (%)*	160 (6)	4896 (3)	<0.001
Congestive heart failure within 1 month, *n (%)*	175 (7)	4311 (3)	<0.001
Transfusion > 4 units, *n (%)*	92 (4)	1579 (1)	<0.001
Ascites, *n (%)*	50 (2)	1152 (0.7)	<0.001
Dialysis dependent, *n (%)*	51 (2)	2217 (1)	0.005
Chemotherapy in past 30 days, *n (%)*	38 (2)	1286 (1)	<0.001
Preoperative renal failure, *n (%)*	31 (1)	930 (0.6)	<0.001
Respiratory status, *n (%)*			
Current smoker within 1 year	1005 (41)	60 172 (38)	0.005
History of chronic obstructive pulmonary disease	814 (33)	22 137 (14)	<0.001
Dyspnea			<0.001
No dyspnea	1696 (69)	133 849 (85)	
On minimal exertion	662 (27)	22 072 (14)	
At rest	108 (4)	2418 (2)	
Neurologic status, *n (%)*			
History of cerebrovascular accident	328 (13)	9010 (6)	<0.001
Impaired sensorium	226 (9)	3761 (2)	<0.001
Type of anesthesia, *n (%)*			<0.001
General anesthesia	2147 (87)	121 133 (77)	
Spinal anesthesia	272 (11)	30 262 (19)	
Monitored anesthesia care	37 (2)	3420 (2)	
Other, local, or no anesthesia	10 (0.4)	3524 (2)	
Type of surgery, *n (%)*			
Upper abdominal	692 (28)	20 310 (13)	<0.001
Extremity	514 (21)	35 432 (23)	0.129
Thoracic	382 (16)	8412 (5)	<0.001
Lower abdominal	260 (11)	46 804 (30)	<0.001
Peripheral vascular	223 (9)	15 146 (9)	0.461
Abdominal aortic aneurysm repair	99 (4)	1799 (1)	<0.001
Neck	75 (3)	3072 (2)	<0.001
Neurosurgery	69 (3)	2208 (1)	<0.001
Back and spine	57 (2)	11 154 (7)	<0.001
Dermatologic	49 (2)	6182 (4)	<0.001
Eye, nose, mouth, other	46 (2)	7820 (5)	<0.001
Total	2466 (100)	158 339 (100)	
Emergency surgery, *n (%)*	452 (18)	13 308 (8)	<0.001
Postoperative complications, *n (%)*			
Respiratory failure†	623 (25)	2482 (2)	<0.001
Systemic sepsis	327 (13)	920 (1)	<0.001
Cardiac arrest requiring cardiopulmonary resuscitation	172 (7)	911 (1)	<0.001
Prolonged ileus	168 (7)	1471 (1)	<0.001
Myocardial infarction	66 (3)	588 (0.4)	<0.001
30-day postoperative mortality, *n (%)*	512 (21)	3340 (2)	<0.001

* Development cohort patients enrolled between 1 September 1997 and 31 August 1999.
† Includes patients with postoperative respiratory failure or unplanned intubation.

Table 3. **Logistic Regression Model of Preoperative Predictors of Postoperative Pneumonia***

Variable	Odds Ratio (95% CI)†
Type of surgery	
Abdominal aortic aneurysm repair	4.29 (3.34–5.50)
Thoracic	3.92 (3.36–4.57)
Upper abdominal	2.68 (2.38–3.03)
Neck	2.30 (1.73–3.05)
Neurosurgery	2.14 (1.66–2.75)
Vascular	1.29 (1.10–1.52)
Other surgery‡	1.00 (referent)
Age	
≥80 y	5.63 (4.62–6.84)
70–79 y	3.58 (2.97–4.33)
60–69 y	2.38 (1.98–2.87)
50–59 y	1.49 (1.23–1.81)
<50 y	1.00 (referent)
Functional status	
Totally dependent	2.83 (2.33–3.43)
Partially dependent	1.83 (1.63–2.06)
Independent	1.00 (referent)
Weight loss > 10% in last 6 months	1.92 (1.68–2.18)
History of chronic obstructive pulmonary disease	1.72 (1.55–1.91)
Type of anesthesia	
General anesthesia	1.56 (1.36–1.80)
Spinal, monitored anesthesia, or other	1.00 (referent)
Impaired sensorium	1.51 (1.26–1.82)
History of cerebrovascular accident	1.47 (1.28–1.68)
Blood urea nitrogen level	
<2.86 mmol/L (<8 mg/dL)	1.47 (1.26–1.72)
2.86–7.50 mmol/L (8–21 mg/dL)	1.00 (referent)
7.85–10.7 mmol/L (22–30 mg/dL)	1.24 (1.11–1.39)
≥10.7 mmol/L (≥30 mg/dL)	1.41 (1.22–1.64)
Transfusion > 4 units	1.35 (1.07–1.72)
Emergency surgery	1.33 (1.16–1.54)
Steroid use for chronic condition	1.33 (1.12–1.58)
Current smoker within 1 year	1.28 (1.17–1.42)
Alcohol intake > 2 drinks/d in past 2 weeks	1.24 (1.08–1.42)

* In the development model using patients enrolled from 1 September 1997 to 31 August 1999, the C-statistic was 0.805 and the Hosmer–Lemeshow goodness-of-fit statistic was 7.49 ($P > 0.2$). In the validation model using patients enrolled from 1 September 1995 to 31 August 1997, the C-statistic was 0.817 and the Hosmer–Lemeshow goodness-of-fit statistic was 12.9 ($P = 0.12$). The intercept parameter estimate (±SE) was −43.1 ± 3.3.
† The CIs were adjusted for patient clustering by hospital by using robust variance estimates based on the Huber–White method.
‡ Ophthalmologic, ear, nose, mouth, lower abdominal, urogenital, peripheral vascular, extremity, dermatological, spine, and back surgeries.

Two risk factors related to fluid status were significant predictors of postoperative pneumonia. Patients with low blood urea nitrogen levels (<2.86 mmol/L [<8 mg/dL]) and those with high blood urea nitrogen levels (≥7.85 mmol/L [≥22 mg/dL]) had increased odds of developing pneumonia. The reference group (2.86 to 7.50 mmol/L [8 to 21 mg/dL]) represents the normal range reported for blood urea nitrogen in Veterans Affairs medical center laboratories. Patients receiving more than 4 units of blood before surgery had an odds ratio of 1.35 (CI, 1.07 to 1.72) for developing postoperative pneumonia.

Model Calibration, Discrimination, and Validation

The model was applied to development cohort patients (1 September 1997 to 31 August 1999), resulting in a C-statistic of 0.805 and a Hosmer–Lemeshow goodness-of-fit statistic of 7.5 ($P > 0.2$); these values indicate good discrimination and calibration, respectively. The model was then applied to patients from the validation cohort (1 September 1995 to 31 August 1997), resulting in a C-statistic of 0.817 and a Hosmer-Lemeshow goodness-of-fit statistic of 12.9 ($P = 0.12$). Thus, discrimination was improved but calibration was poorer in a temporally independent data set.

To assess model performance across hospitals, the model was applied to all patients (1 September 1995 to 31 August 1999) from 10 separate sets of five randomly selected hospitals. The goodness-of-fit statistic P values ranged from 0.03 to 0.87. Only 3 of 10 hospital sets had goodness-of-fit statistic P values less than 0.2, indicating that the model had good fit in the majority of the randomly selected hospital sets. The C-statistic ranged from 0.78 to 0.83, indicating that the model had excellent discrimination across the 10 hospital sets.

Postoperative Pneumonia Risk Index

Point values were assigned to each risk factor by multiplying the β-coefficients from the logistic regression model by 10 and rounding off to the nearest integer. **Table 4** shows the point values assigned to each preoperative risk factor used in calculating the postoperative pneumonia risk index score. Patients were categorized into five risk classes based on the predicted probability associated with various postoperative pneumonia risk index scores. **Table 5** shows the number of development cohort patients in each risk class, the average predicted probability of postoperative pneumonia based on the model, and the actual incidence of postoperative pneumonia in development cohort and validation cohort patients.

The postoperative pneumonia risk index predicted the incidence of postoperative pneumonia well in the development and validation cohorts across all risk classes. When applied to development cohort patients, the risk index yielded a C-statistic of 0.779 and a

Hosmer–Lemeshow goodness-of-fit statistic of 0.01 ($P > 0.2$), indicating good discrimination and excellent calibration. When applied to validation cohort patients, the risk index yielded a C-statistic of 0.792 and a Hosmer–Lemeshow goodness-of-fit statistic of 2.60 ($P > 0.2$), indicating good discrimination and good calibration in a temporally independent patient cohort. Overall, the incidence of postoperative pneumonia decreased from 1.7% in the validation cohort to 1.5% in the development cohort.

DISCUSSION

Our results confirm several previously described risk factors for postoperative pneumonia, including the type of surgery performed. The patient-specific risk factors were related to general health and immune status, respiratory status, neurologic status, and fluid status. These risk factors were used to develop a preoperative risk assessment model for predicting postoperative pneumonia, the postoperative pneumonia risk index.

We found that patients undergoing abdominal aortic aneurysm repair; thoracic, neck, upper abdominal, or peripheral vascular surgery; or neurosurgery had an increased likelihood of developing postoperative pneumonia. Previous studies focused on the increased incidence of postoperative pulmonary complications in patients undergoing these types of surgery (2, 4, 5, 8, 9, 11, 12, 14, 29). Impairment of normal swallowing and respiratory clearance mechanisms may be responsible for some of the increased risk in these patients.

Table 4. **Postoperative Pneumonia Risk Index**

Preoperative Risk Factor	Point Value
Type of surgery	
Abdominal aortic aneurysm repair	15
Thoracic	14
Upper abdominal	10
Neck	8
Neurosurgery	8
Vascular	3
Age	
≥80 y	17
70–79 y	13
60–69 y	9
50–59 y	4
Functional status	
Totally dependent	10
Partially dependent	6
Weight loss > 10% in past 6 months	7
History of chronic obstructive pulmonary disease	5
General anesthesia	4
Impaired sensorium	4
History of cerebrovascular accident	4
Blood urea nitrogen level	
<2.86 mmol/L (<8 mg/dL)	4
7.85–10.7 mmol/L (22–30 mg/dL)	2
≥10.7 mmol/L (≥30 mg/dL)	3
Transfusion > 4 units	3
Emergency surgery	3
Steroid use for chronic condition	3
Current smoker within 1 year	3
Alcohol intake > 2 drinks/d in past 2 weeks	2

We found several patient-specific risk factors for postoperative pneumonia related to general health and immune status. Long-term steroid use (30) and age older than 60 years (2, 4, 5, 11, 12) have previously been found to be risk factors for postoperative pneumo-

Table 5. **Distribution of Postoperative Pneumonia Risk Index Scores in Patients in the Development and Validation Cohorts***

Variable	Risk Class				
	1 (0–15 Points)	2 (16–25 Points)	3 (26–40 Points)	4 (41–55 Points)	5 (>55 Points)
Development cohort patients, *n (%)*	69 333 (43)	55 757 (35)	32 103 (20)	3517 (2)	95 (0.1)
Average predicted probability of postoperative pneumonia in development cohort patients (95% CI), %†	0.24 (0.24–0.25)	1.20 (1.19–1.20)	4.0 (3.98–4.01)	9.4 (9.34–9.42)	15.3 (15.1–15.5)
Rate of postoperative pneumonia in development cohort patients, %‡	0.24	1.19	4.0	9.4	15.8
Rate of postoperative pneumonia in validation cohort patients, %§	0.24	1.18	4.6	10.8	15.9

* Patients in the development cohort were enrolled from 1 September 1997 to 31 August 1999; patients in the validation cohort were enrolled from 1 September 1995 to 31 August 1997.
† Based on logistic regression model; 95% CI calculated as average predicted probability ± (1.96 × SE).
‡ The risk class model yielded a C-statistic of 0.779, a Hosmer–Lemeshow goodness-of-fit test statistic of 0.01 ($P > 0.2$), and a Pearson chi-square goodness-of-fit statistic of 0.02 ($P > 0.2$).
§ The risk class model yielded a C-statistic of 0.792, a Hosmer–Lemeshow goodness-of-fit test statistic of 2.60 ($P > 0.2$), and a Pearson chi-square goodness-of-fit statistic of 2.83 ($P > 0.2$).

nia. We discovered three additional risk factors: dependent functional status, weight loss greater than 10% of body mass in the previous 6 months, and recent alcohol use. Further studies are needed to assess the effect of interventions, such as preoperative optimization of nutritional status and perioperative physical therapy, in reducing the incidence of postoperative pneumonia.

Our definition of current smoking included patients who smoked up to 1 year before surgery. Before 1995, the NSQIP definition for "current smoking" was smoking in the 2 weeks before surgery. Using this definition, we found that smoking was not significantly associated with postoperative mortality or overall morbidity (22, 23). On closer examination, it appeared that sicker patients tended to quit smoking more than 2 weeks before surgery and were therefore being classified as nonsmokers. To capture the effect of recent smoking, the NSQIP definition was modified in September 1995 to include patients who smoked up to 1 year before surgery.

Recent smoking and history of chronic obstructive pulmonary disease were previously found to be pulmonary risk factors for postoperative pneumonia (2, 4, 9–12, 14). Chumillas and colleagues (31) found that preoperative and postoperative respiratory rehabilitation protected against postoperative pulmonary complications in moderate-risk and high-risk patients undergoing upper abdominal surgery. Use of an incentive spirometer or intermittent positive-pressure breathing and control of pain that interferes with coughing and deep breathing have been recommended for preventing postoperative pneumonia in high-risk patients (32).

We found two risk factors related to neurologic status: history of cerebral vascular accident with a residual deficit and impaired sensorium. Previously identified neurologic risk factors for postoperative pneumonia included impaired cognitive function (4). These risk factors are often associated with a decreased ability to protect one's airway and may increase the risk for aspiration. Other risk factors related to aspiration in previous studies included the use of nasogastric tubes and H_2 receptor antagonists (6).

Our postoperative pneumonia risk index overcomes several limitations of previous studies. Most studies have depended on retrospective review of administrative databases or medical chart review. Missing data, inconsistencies in definitions of variables, and lack of clinical detail are some limitations of retrospectively obtained or administrative data. An advantage of our study is that patient characteristics and outcomes were obtained prospectively and at a level of clinical detail not found in administrative databases. Previous studies had relatively small samples, which limited the number of potential risk factors that could be evaluated (29). The smaller number of variables included in previous models may have contributed to their relatively poor predictive ability (4, 29). Another weakness of previous studies was the lack of validation of the models in independent data sets (15, 16). The NSQIP provided a unique opportunity to develop a model from data on 160 000 patients and to validate the model in a separate set of more than 155 000 patients. The model that we developed maintained its explanatory power in validation testing over time and across hospitals.

Previous pulmonary risk indexes were often modified versions of risk indexes originally developed for predicting cardiac complications, wound infections, or mortality (18, 29, 33). These indexes were limited to patients undergoing specific types of surgery (18, 29, 33). The postoperative pneumonia risk index enables one to predict the risk for postoperative pneumonia in a wide range of noncardiac operations. Other advantages of the index are that the variables needed to calculate it are readily accessible for almost all patients undergoing major surgery and that it can be calculated at the bedside without expensive preoperative testing.

Our study has several limitations. Since veterans who receive care at Veterans Affairs medical centers have greater comorbid illness, these models may not be generalizable to other, healthier populations. Only 3.2% of patients were female because of the patient population served by the source hospitals. Patient-specific factors, such as age and functional status, are likely to be risk factors in women, but their associated odds ratios may differ from those obtained here. Studies are needed to validate these models in other groups, including women. Study nurses uniformly assessed all patients enrolled in the NSQIP for several postoperative outcomes, including postoperative pneumonia. However, bias in determining postoperative pneumonia may have occurred because postoperative chest radiographs and sputum cultures were not performed for all patients and were obtained on the basis of routine clinical care. The potential bias in ascertainment may have led to overestimation of the risk for postoperative pneumonia in older patients and patients with risk factors that lower the clinical threshold for obtaining studies whose results were used in the definition of postoperative pneumonia.

Another limitation is that the NSQIP did not obtain information about other potentially important risk factors for postoperative pneumonia. Although efforts are currently under way to include information about prophylactic use of antibiotics, information about this potential risk factor was not recorded for patients enrolled between 1 September 1995 and 31 August 1999. During the planning stages of the NSQIP, a pilot study examining the feasibility of including pulmonary function test results revealed that it would be difficult to obtain reliable information consistently across multiple institutions. The definition of chronic obstructive pulmonary disease used in the NSQIP was fairly broad and may have resulted in underestimation of the risk associated with severe chronic obstructive pulmonary disease (21). The lack of pulmonary function test data precluded assessment of the severity of underlying pulmonary diseases; however, a nested case–control study of patients undergoing abdominal surgery found that no component of spirometry predicted postoperative pulmonary complications (29). Body mass index, which has been shown to be associated with postoperative pneumonia, was not recorded in the NSQIP (4). Therefore, the postoperative pneumonia risk index does not include an assessment of the importance of obesity or increased body mass index as risk factors for postoperative pneumonia.

Pneumonia was a common postoperative complication, occurring in 1.5% of patients enrolled in the NSQIP. The 30-day mortality rate in patients with postoperative pneumonia was 21% compared with 2% in patients without postoperative pneumonia. In contrast, cardiac arrest requiring cardiopulmonary resuscitation occurred in 0.7% of patients and myocardial infarction occurred in only 0.4% of patients. The clinical use of preoperative cardiac risk assessment models (17, 19, 20) may direct greater attention to maximization of cardiac status before surgery and to possible cancellation of surgery in high-risk patients. Our results indicate that similar attention should be given to preoperative assessment of postoperative pneumonia risk.

In conclusion, we used a combination of risk factors to develop and validate a postoperative pneumonia risk index for predicting pneumonia after major noncardiac surgery. Many potential intraoperative and postoperative factors influence the development of postoperative pneumonia as well. Our model may be used to control for preoperative patient-specific and operation-specific risk factors in future studies of interventions designed to modify intraoperative and postoperative risk factors. The risk index may be useful for patient-mix adjustment in studies exploring hospital variation in postoperative pneumonia rates and evaluation of hospital-level interventions designed to reduce the incidence of postoperative pneumonia. The Postoperative Pneumonia Risk Index may also be useful to clinicians in estimating patient risk for postoperative pneumonia and in targeting perioperative testing and respiratory care to high-risk patients. We hope that awareness of pneumonia as a significant, potentially preventable postoperative complication will increase as a result of the clinical use of the Postoperative Pneumonia Risk Index.

APPENDIX: DEFINITIONS OF RISK FACTORS IN THE POSTOPERATIVE PNEUMONIA RISK INDEX

Type of Surgery

Abdominal aortic aneurysm repair: Surgeries to repair ruptured or unruptured aortic aneurysm involving only abdominal incisions.

Neck surgery: Surgeries related to the thyroid, parathyroid, and larynx; tracheostomy; cervical and axillary lymph node excision; and cervical and axillary lymphadenectomy.

Neurosurgery: Application of a halo, central nervous system injection, central nervous system drainage, creation of a bur hole, craniectomy, craniotomy, arteriovenous malformation or aneurysm repair, stereotaxis, neurostimulator placement, skull repair, and cerebral spinal fluid shunt.

Thoracic surgery: Esophageal resection, esophageal repair, mediastinoscopy, pleural biopsy, pneumocentesis, chest wall excision, incision and drainage of neck and thorax, excision of neck and thorax, repair of fractured ribs, diaphragmatic hernia repair, bronchoscopy, catheterization of trachea, trachea repair, thoracotomy, pericardium, pacemaker placement, heart wound repair, valve repair, thoracic or abdominothoracic aortic aneurysm repair, and pulmonary artery procedures.

Upper abdominal surgery: Gastrectomy; vagotomy; intestinal surgery; partial hepatectomy; subfascial abdominal excision; splenectomy; excision of abdominal masses; laparoscopic appendectomy and cholecystectomy; shunt insertion; ventral, umbilical and spigelian hernia repair; and liver, gallbladder, and pancreas surgery.

Vascular surgery: Any surgery related to the arteries or veins except central nervous system aneurysm or abdominal aortic aneurysm repair.

Functional Status

Functional status: The level of self-care demonstrated by the patient on admission to the hospital, reflecting his or her prehospitalization functional status.

Totally dependent: The patient cannot perform any activities of daily living for himself or herself; includes patients who are totally dependent on nursing care, such as a dependent nursing home patient.

Partially dependent: The patient requires use of equipment or devices plus assistance from another person for some activities of daily living. Patients admitted from a nursing home setting who are not totally dependent would fall into this category, as would any patient who requires kidney dialysis or home ventilator support yet maintains some independent function.

Independent: The patient is independent in activities of daily living; includes those who are able to function independently with a prosthesis, equipment, or devices.

Other

History of chronic obstructive pulmonary disease: The patient has chronic obstructive pulmonary disease resulting in functional disability, hospitalization in the past to treat chronic obstructive pulmonary disease, need for bronchodilator therapy with oral or inhaled agents, or FEV_1 of less than 75% of predicted value. Patients excluded from this category were those in whom the only pulmonary disease was acute asthma, an acute and chronic inflammatory disease of the airways resulting in bronchospasm.

History of cerebrovascular accident: The patient has a history of cerebrovascular accident (embolic, thrombotic, or hemorrhagic) with persistent motor, sensory, or cognitive dysfunction.

Impaired sensorium: The patient is acutely confused or delirious and responds to verbal or mild tactile stimulation; patient with mental status changes or delirium in the context of the current illness. Patients with chronic mental status changes secondary to chronic mental illness or chronic dementing illnesses were excluded from this category.

Steroid use for chronic condition: The patient has required the regular administration of parenteral or oral corticosteroid medication in the month before admission. Patients using only topical, rectal, or inhalational corticosteroids were excluded from this category.

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