# Multivariable Predictors of Postoperative Respiratory Failure after General and Vascular Surgery: Results from the Patient Safety in Surgery Study

Robert G Johnson, MD, FACS, Ahsan M Arozullah, MD, MPH, Leigh Neumayer, MD, MS, FACS, William G Henderson, MPH, PhD, Patrick Hosokawa, MS, Shukri F Khuri, MD, FACS

**BACKGROUND:** Postoperative respiratory failure (RF) is associated with an increase in hospital morbidity, mortality, cost, and late mortality. We developed and tested a model to predict the risk of postoperative RF in patients undergoing major vascular and general surgical operations. This model is an extension of an earlier model that was derived and tested exclusively from a population of male patients from the Veterans Affairs National Surgical Quality Improvement Program.

**METHODS:** Patients undergoing vascular and general surgical procedures at 14 academic and 128 Veterans Affairs Medical Centers from October 2001 through September 2004 were used to develop and test a predictive model of postoperative RF using logistic regression analyses. RF was defined as postoperative mechanical ventilation for longer than 48 hours or unanticipated reintubation.

**RESULTS:** Of 180,359 patients, 5,389 (3.0%) experienced postoperative RF. Twenty-eight variables were found to be independently associated with RF. Current procedural terminology group, patients with a higher American Society of Anesthesiologists classification, emergency operations, more complex operation (work relative value units), preoperative sepsis, and elevated creatinine were more likely to experience RF. Older patients, male patients, smokers, and those with a history of congestive heart failure or COPD, or both, were also predisposed. The model's discrimination (c-statistic) was excellent, with no decrement from development (0.856) to validation (0.863) samples.

**CONCLUSIONS:** This model updates a previously validated one and is more broadly applicable. Its use to predict postoperative RF risk enables the study of preventative measures or preoperative risk adjustment and intervention to improve outcomes. (J Am Coll Surg 2007;204:1188–1198. © 2007 by the American College of Surgeons)

Respiratory failure (RF) after major operations occurs frequently and with serious consequences for hospital morbidity, mortality, and cost.[1-5] Beyond its early impact on perioperative outcomes, postoperative RF has also been associated with decreased longterm survival.[5] In 2000, Arozullah and colleagues[3] published the experience of the Department of Veterans Affairs (VA) National Surgical Quality Improvement Program (NSQIP) with respiratory failure after major noncardiac operations. Postoperative respiratory failure was defined as

**Competing Interests Declared:** None.

This article is part of a group of articles from the Patient Safety in Surgery Study, a demonstration project between the Department of Veterans Affairs National Surgical Quality Improvement Program and the American College of Surgeons in selected private-sector hospitals, funded by the Agency for Healthcare Research and Quality, grant number 5U18HS011913, entitled "Reporting System to Improve Patient Safety in Surgery." The Patient Safety in Surgery Study led to the successful formation of the American College of Surgeons National Surgical Quality Improvement Program. This article represents the personal viewpoints of the authors and cannot be construed as a statement of official policy of the American College of Surgeons, the Department of Veterans Affairs, or the US government.

Received February 27, 2007; Accepted February 28, 2007.

From Saint Louis University and the John Cochran VA Medical Center, St Louis, MO (Johnson); Section of General Internal Medicine, University of Illinois at Chicago and Jesse Brown VA Medical Center, Chicago, IL (Arozullah); George E Whalen Salt Lake City VA Healthcare System and the University of Utah, Salt Lake City, UT (Neumayer); University of Colorado Health Outcomes Program (Henderson) and National Surgical Quality Improvement Program, Office of Patient Care Services, Department of Veterans Affairs, Aurora, CO (Hosokowa); VA Boston Healthcare System, West Roxbury, MA (Khuri); Harvard Medical School, Boston, MA (Khuri); and the Brigham and Women's Hospital, Boston, MA (Khuri).

Correspondence address: Robert G Johnson, MD, Department of Surgery, Saint Louis University, 3635 Vista at Grand Blvd, St Louis, MO 63110. email: johnsorg@slu.edu


Published by Elsevier Inc.

ISSN 1072-7515/07/$32.00
doi:10.1016/j.jamcollsurg.2007.02.070

**Abbreviations and Acronyms**

| | |
|---|---|
| ASA | = American Society of Anesthesiologists |
| CHF | = congestive heart failure |
| CPT | = current procedural terminology |
| NSQIP | = National Surgical Quality Improvement Program |
| PSS | = Patient Safety in Surgery |
| RF | = respiratory failure |
| RRI | = respiratory risk index |
| RVU | = relative value unit |
| VA | = Veterans Affairs |

mechanical ventilation for longer than 48 hours or unplanned reintubation.[3] The generalizability of that predictive model can be limited, because it was derived from a VA-based population exclusive of female patients. The experience presented here updates the earlier study by combining a contemporary experience of both the VA sector and 14 private-sector academic centers that participated in the Patient Safety in Surgery (PSS) Study. The PSS Study was a collaborative effort between the VA-NSQIP and the American College of Surgeons. Funded by the Agency for Healthcare Research and Quality, it explored the applicability of the VA-NSQIP to the private sector. From this updated risk model, a respiratory failure risk index (RRI) is developed and validated for broad application to patients undergoing general and vascular surgery procedures.

## METHODS

This study, which was based on data collected during a 3-year period from 128 VA hospitals and 14 private-sector academic institutions, used the methods of the NSQIP and the PSS Study, which have been described in detail in other publications.[6-10] A brief description of the pertinent methodology is provided here.

### Patient population

Patients from 128 VA medical centers and 14 private-sector hospitals who underwent major general or vascular procedures from fiscal years 2002 through 2004 were assessed as part of this study. Major operations as defined by the NSQIP included operations using general, spinal, or epidural anesthesia. Patients having carotid endarterectomy are included regardless of anesthetic type. A list of types of operations included in the study and their current procedural terminology (CPT) codes is shown in Table 1. Exclusions include those patients undergoing operations in the previous 30-day period, vascular patients having catheter-based operations outside the operating room, and selected CPT codes with known low postoperative mortality and morbidity. Transplantation procedures have also been excluded because they are performed rarely in the VA system. Certain very common operations, such as inguinal hernia repairs, breast lumpectomies, and transurethral resection of the prostate or bladder tumors, are limited to the first 5 consecutive cases in each 8-day cycle. For hospitals that perform more than 140 eligible operations per month, the operations included in the NSQIP are sampled as follows. The first 40 operations in each 8-day cycle are included, with each cycle beginning on a different day of the week. The VA-NSQIP includes nine surgical subspecialties: general, vascular, cardiac, noncardiac thoracic, orthopaedics, urological, otolaryngology, neurosurgery, and plastic surgery. The PSS study has been limited to general and vascular surgery, and the VA sample for this study was accordingly limited.

### Variable selection

The preoperative, operative, and postoperative variables available for analysis were described previously.[3] Because the intention of the NSQIP was to cover all major operations performed in a VA surgical service, the variables chosen were generic and not disease-specific or operation-specific. They were selected on the basis of clinical relevance, reliability of data collection, and availability and ease of data collection. Preoperative variables include demographics; some lifestyle variables; functional status; American Society of Anesthesiologists (ASA) classification; selected laboratory tests; and selected pulmonary, cardiac, hepatobiliary, renal, vascular, central nervous system, nutritional, and immunologic comorbidities. Operative data included CPT codes for the principal operation and any secondary operations, emergency status, wound classification, anesthesia method, operative times, blood loss, and blood transfused. Outcomes variables included 30-day mortality from any cause inside or outside the hospital; length of stay; return to the operating room; and 19 different postoperative complications, including respiratory failure, occurring in the 30-day postoperative period.

### Data-collection protocol

A surgical clinical nurse reviewer is assigned at each medical center to collect the NSQIP data. The nurses receive in-depth training on study protocol, patient selection,

**Table 1.** Respiratory Failure by Operation Type

| CPT range | Operations covered | No. of operations | % RF |
|---|---|---|---|
| 10000–29999 | Integumentary and musculoskeletal system | 21,447 | 1.86 |
| 30000–32999<br>38000–39999 | Respiratory system, hemic and lymphatic systems, mediastinum, and diaphragm | 2,782 | 4.31 |
| 33001–34900 | Thoracic and thoracoabdominal aneurysms, embolectomy/thrombectomy, venous reconstruction, and endovascular repair | 2,785 | 6.61 |
| 35001–37799 | Aneurysm, blood vessel repair, thromboendarterectomy, angioscopy, angioplasty and atherectomy, bypass and composite grafts, other artery, and vein | 29,511 | 4.22 |
| 40000–43499 | Mouth, palate, salivary glands, pharynx, adenoids, and esophagus | 2,570 | 6.89 |
| 43500–49429<br>49650–49999 | Stomach, intestines, appendix and mesentery, rectum and anus, liver, biliary tract, pancreas, abdomen, peritoneum, and omentum (nonhernia) | 69,996 | 4.31 |
| 49491–49611 | Hernioplasty, herniorrhaphy, herniotomy | 44,916 | 0.40 |
| 60000–60999 | Endocrine system | 6,105 | 0.90 |
| | CPT missing | 247 | 4.86 |

CPT, current procedural terminology; RF, respiratory failure.

definition of variables, and data-collection methods. An operations manual is also provided to each nurse that outlines these procedures in depth. Regular conference calls and annual nurse meetings are held to maintain data uniformity and accuracy. The nurses are coordinated by two national nurse clinical specialists, a national nurse data coordinator at the data analysis center, and by regional nurse team leaders. Interrater reliability site visits are conducted periodically, in which a nurse from the chairman's office visits a site, reviews the case selection, reabstracts a sample of charts, and compares results with the locally obtained variable values. The site nurse is expected to complete data collection on each patient within 45 days of the date of operation. After review by the local chief of surgery, the data are submitted for central data analysis.

### Statistical analysis

We used RF as the primary dependent variable. We defined RF as having mechanical ventilation longer than 48 hours postoperatively or unplanned postoperative reintubation for cardiac/respiratory failure, or both. Potential independent variables included preoperative demographic and medical risk factors, preoperative laboratory values, and the work relative value units (RVUs) of the operation, as a measure of complexity of the operation. Work RVUs for each operation were obtained from the Medicare Web site using resource based relative value unit (RBRVU) values.[11]

There were 184,120 cases assessed in the VA and PSS systems in the general and peripheral vascular subspecialties during fiscal 2002, 2003, and 2004. Of these records, 2,719 patients with preoperative pneumonia or ventilator dependence were excluded from the study sample. We also excluded 1,042 cases that are typically not performed by general or vascular surgeons (CPT 50000 to 59999: urinary, male genital, female genital systems; 61000 to 64999: nervous, eye and auditory systems). The remaining 180,359 records were randomly divided into 2 sets (90,223 in a development set and 90,136 in a validation set). The development set was used to develop a logistic risk model predicting respiratory failure. One hundred sixty-eight records were dropped from the development set because of missing values in the response or explanatory variables, and the remaining 90,055 were used to develop the model parameters. The logistic model estimates the probability of experiencing RF, defined as either 48 or more hours of ventilator dependence or unplanned reintubation for cardiac/respiratory failure in the postoperative period.

Bivariate analyses were performed to screen out potential predictor variables that did not differ ($p > 0.20$) between patients with and without respiratory failure. In this case, all variables differed significantly between the two groups. Race, pack-years of cigarette use, and dependent functional status were removed from consideration because of a high number of missing values. All missing laboratory values were imputed to ensure a sufficient sample size.

### Development of a scoring system

Using a modification of the methods of Le Gall and colleagues,[12] point values were assigned to each risk factor by rounding off the odds ratio associated with each factor to the nearest integer (eg, an odds ratio of 1.254 would add +1 to the final risk score). Adding these totals for each patient, point totals for each patient were calculated. To determine the risk index score associated with low, medium, and high rates of RF, we divided the patients into discrete risk index score ranges based on the predicted rates of RF first using the development data set. We then tested these ranges of risk index scores with the validation data set. For each range, the predicted RF rate produced from the development model logistic regression equation was calculated. These rates were then compared with the observed RF rates in each range of the risk index using a chi-square goodness-of-fit test. A similar analysis was performed with the validation data set.

### Evaluation of model performance

Discrimination and calibration of logistic regression models were determined using the c-statistic and Hosmer-Lemeshow goodness-of-fit[13] tests in both development and validation data sets.

## RESULTS

RF occurred in 5,389 of 180,359 patients (3.0%). It was observed most frequently after operations on the upper airway and esophagus (Table 1). The baseline characteristics of the population studied are shown in Table 2. RF tended to develop in older male patients. Patients with comorbidities (inclusive of dyspnea, COPD, diabetes, wound infection, renal failure, recent weight loss, congestive heart failure [CHF], CNS, alcohol use, smoking, poorer functional status, ascites) had an increased incidence of RF, and distribution of ASA classification among the RF patients was skewed to the 4/5 end of the spectrum and away from the 1/2 classification. Likewise, a higher proportion of patients with abnormal laboratory values were in the group experiencing RF.

Intra- and postoperative data are shown in Table 3. Patients with RF were more likely to have inpatient procedures and general anesthesia than were non-RF patients. More than one-third of patients with postoperative RF underwent emergency operations, and the majority had operations of high complexity (work RVUs > 17) compared with less than one-third of non-RF patients. Mean operative time was longer among RF patients (3.53 hours versus 2.11 hours) as well.

The 30-day mortality of 26.5% among those with RF versus 1.4% among patients without RF illustrates the gravity of the RF as a postoperative complication (Table 3). Of the 17 complications tracked, each one had a higher incidence of RF. The 3 complications with the largest percentage difference between the RF and non-RF patients were pneumonia (35.4% versus 1.2%), systemic sepsis (23.2% versus 0.9%), and cardiac arrest (13.3% versus 0.3%).

Twenty-eight variables were found to be independently associated with RF in the logistic regression analysis (Table 4). Each of these conferred increased risk of a respiratory complication. Seventeen of the 45 variables listed in Table 2 were not selected for the model. Patients with a higher ASA classification, emergency operation, elevated work RVU, preoperative sepsis, and elevated creatinine were more likely to experience RF. Compared with hernia operations (selected as reference group because of its lowest risk of RF), stomach and intestinal operations had a twofold increase in the risk of RF. Older patients, male patients, and smokers were also at higher risk for postoperative RF.

### Respiratory Risk Index (RRI)

The RRI score was divided into 3 discrete ranges based on the rate of RF: low (risk score < 8; RF 0.1% to 0.2%), medium (risk score 8 to 12; RF 0.8% to 1.0%), and high (risk score > 12; RF 6.5% to 6.8%). The scores accurately predicted the RF rate in each category, as shown in Table 5. The c-indices (reflecting "discrimination," a measure of how well the scoring predicts the outcomes of RF) ranged from 0.8498 for the development set to 0.8594 for the validation data set, indicating good stability of the model.

RRI score for an individual patient can be calculated by summing the appropriate point values for each applicable risk variable (Table 4). Patients with RRI > 12 have a relatively high risk (> 6%) of RF. For example, consider a 70-year-old male smoker with dyspnea, a > 10% weight loss, and a preoperative albumin of 3.4

**Table 2.** Baseline Characteristics of the Patient Population

| Variable | No RF | RF | p Value |
|---|---|---|---|
| Sample size (n) | 174,970 | 5,389 | |
| Specialty code (%) | | | < 0.0001 |
| General | 79.04 | 69.33 | |
| Peripheral vascular | 20.96 | 30.67 | |
| Race (%) | | | < 0.0001 |
| Hispanic | 4.36 | 4.79 | |
| American Indian | 0.28 | 0.17 | |
| African American, not Hispanic | 12.17 | 15.70 | |
| Asian | 0.79 | 0.72 | |
| Caucasian, not Hispanic | 64.66 | 65.97 | |
| Unknown | 9.37 | 6.25 | |
| Missing | 8.37 | 6.40 | |
| Gender (%) | | | < 0.0001 |
| Male | 80.05 | 85.47 | |
| Female | 19.95 | 14.53 | |
| Age (y), mean ± SD | 60.04 ± 14.34 | 67.49 ± 12.12 | < 0.0001 |
| Cardiac, history of CHF (%) | 1.83 | 7.96 | < 0.0001 |
| Central nervous system (%) | | | |
| Impaired sensorium | 1.00 | 6.36 | < 0.0001 |
| Coma | 0.02 | 0.09 | 0.0140 |
| CVA with neurologic deficit | 4.32 | 9.43 | < 0.0001 |
| CVA without neurologic deficit | 2.88 | 5.23 | < 0.0001 |
| Hemiplegia | 2.35 | 5.55 | < 0.0001 |
| History of TIA | 3.87 | 5.46 | < 0.0001 |
| CNS tumor | 0.14 | 0.35 | < 0.0001 |
| General (%) | | | |
| ASA class | | | < 0.0001 |
| 1–2 | 41.09 | 7.64 | |
| 3 | 50.28 | 54.63 | |
| 4–5 | 8.64 | 37.72 | |
| DNR status | 0.74 | 2.32 | < 0.0001 |
| > 2 alcoholic drinks/day | 7.48 | 11.63 | < 0.0001 |
| Dependent functional status | 7.60 | 23.28 | < 0.0001 |
| Smoker | 31.92 | 36.89 | < 0.0001 |
| Pack-years | 24.73 (33.54) | 37.73 (39.13) | < 0.0001 |
| Hepatobiliary, ascites (%) | 0.88 | 5.36 | < 0.0001 |
| Laboratory (%) | | | |
| Albumin ≤ 3.5 g/dL | 29.83 | 60.91 | < 0.0001 |
| Alkaline phosphatase > 125 U/L | 14.40 | 24.86 | < 0.0001 |
| Bilirubin > 1.0 mg/dL | 13.42 | 22.79 | < 0.0001 |
| BUN > 60 mg/dL | 1.16 | 5.60 | < 0.0001 |
| Creatinine > 1.5 mg/dL | 12.49 | 31.76 | < 0.0001 |
| HCT ≤ 38% | 32.40 | 56.68 | < 0.0001 |
| HCT > 45% | 18.25 | 11.22 | < 0.0001 |
| Platelets ≤ 150,000/cumm | 6.87 | 14.60 | < 0.0001 |
| Platelets > 400,000/cumm | 7.06 | 11.12 | < 0.0001 |
| SGOT > 40 U/L | 12.19 | 20.25 | < 0.0001 |
| Sodium < 135 mmol/L | 14.66 | 26.49 | < 0.0001 |

**Table 2.** Continued

| Variable | No RF | RF | p Value |
|---|---|---|---|
| Sodium > 145 mmol/L | 1.18 | 3.39 | < 0.0001 |
| WBC | | | < 0.0001 |
| < 2,500/μm | 0.23 | 0.91 | |
| 2,500–10,000/μm | 79.60 | 59.67 | |
| > 10,000/μm | 20.17 | 39.43 | |
| Nutritional/immune/other (%) | | | |
| Diabetes | 18.38 | 27.28 | < 0.0001 |
| Disseminated cancer | 2.30 | 5.40 | < 0.0001 |
| Wound infection | 8.47 | 13.79 | < 0.0001 |
| Steroid use | 2.86 | 6.27 | < 0.0001 |
| Weight loss > 10% | 4.08 | 12.10 | < 0.0001 |
| Bleeding disorder | 2.84 | 10.69 | < 0.0001 |
| Transfusion > 4 U | 0.44 | 3.73 | < 0.0001 |
| Chemotherapy | 1.28 | 2.13 | < 0.0001 |
| Radiotherapy | 0.89 | 1.67 | < 0.0001 |
| Sepsis | 1.73 | 13.09 | < 0.0001 |
| Pulmonary (%) | | | |
| Dyspnea (minimal or at rest) | 13.30 | 31.95 | < 0.0001 |
| History of COPD | 10.39 | 25.64 | < 0.0001 |
| Renal (%) | | | |
| Acute renal failure | 0.54 | 4.43 | < 0.0001 |
| On dialysis | 2.01 | 4.01 | < 0.0001 |

ASA, American Society of Anesthesiologists; BUN, blood urea nitrogen; CHF, congestive heart failure; CNS, central nervous system; COPD, chronic obstructive pulmonary disease; CVA, cerebrovascular accident; HCT, hematocrit; RF, respiratory failure (postoperative ventilation longer than 48 hours or unplanned reintubation); SGOT, serum glutamic-oxalacetic transaminase; TIA, transient ischemic attack; WBC, white blood cell.

mg/dL, who is classified as ASA class 3 before undergoing an emergency colectomy. His RRI is 14 (3 points for ASA class; and 2 each for an emergency operation and colectomy; and age 70, male gender, dyspnea, smoking, albumin < 3.5 g/100 mL, and weight loss with 1 point), which is associated with a high risk of developing RF.

## DISCUSSION

The importance of respiratory failure as a postoperative complication is evident from its associated early mortality,[3] cost,[2] and longterm mortality.[5] Dimick and colleagues[2] found respiratory complications to be the most costly of four major postoperative complication categories: respiratory, thromboembolic, cardiovascular, and infections—with median hospital cost/patient of $62,704, $33,589, $18,496, and $13,083, respectively. Median hospital cost for patients without respiratory complications in their study was $5,015. Khuri and colleagues found the 5- and 10-year mortality among patients experiencing postoperative respiratory failure to be > 50% and 70%, respectively.[5] They also reported that the occurrence of a pulmonary complication (inclusive of respiratory complications and pneumonia) in the first 30 days postoperatively reduced median longterm survival by 87%.[5]

The present study, using private-sector and VA data found a similar incidence of postoperative RF compared with the risk model reported by Arozullah and coworkers[3] that used VA data exclusively (3.0% versus 3.4%). In addition, 30-day mortality of RF in the current experience (26.5%) is similar to that reported previously (27%).[3] Female patients, excluded from the earlier study, make up nearly 20% of the current sample. Overall, the preoperative risk factors for respiratory failure are similar to those reported previously. The prevalence of some risk factors, such as alcohol use and smoking, is lower in the current sample, but their association with RF remains (RF versus non-RF: 11.6% versus 7.5% and 36.9% versus 31.9%, $p < 0.0001$). In contrast, the prevalence of diabetes (oral and insulin-dependent) has increased during the past 10 years among patients with and without RF (diabetics with RF versus non-RF, previous study: 18% versus 14%, current study: 27.3% versus 18.4%, $p < 0.0001$). Operation site (upper ab-

**Table 3.** Perioperative Processes of Care and Postoperative Complications

| Perioperative variable | No RF (n = 174,970) | RF (n = 5,389) | p Value |
|---|---|---|---|
| Operative data | | | |
| Work RVU (%) | | | < 0.0001 |
| < 10 | 37.88 | 7.22 | |
| 10–17 | 30.25 | 30.34 | |
| > 17 | 31.87 | 62.05 | |
| Emergency (%) | 9.33 | 35.76 | < 0.0001 |
| Anesthesia (%) | | | < 0.0001 |
| General | 84.24 | 96.68 | |
| Spinal | 1.13 | 0.89 | |
| Epidural | 7.99 | 1.99 | |
| Monitored | 0.75 | 0.19 | |
| Local | 0.53 | 0.07 | |
| Other | 5.35 | 0.17 | |
| Inpatient (%) | 60.84 | 96.08 | < 0.0001 |
| Operation time (h), mean ± SD | 2.11(1.62) | 3.53(2.47) | < 0.0001 |
| Wound class (%) | | | < 0.0001 |
| Clean | 61.96 | 38.99 | |
| Clean/contaminated | 29.17 | 39.08 | |
| Contaminated | 4.65 | 11.86 | |
| Dirty/infected | 4.22 | 10.08 | |
| PGY (%) | | | < 0.0001 |
| 0 | 24.70 | 17.51 | |
| 1−2 | 17.27 | 7.09 | |
| 3 | 13.01 | 10.65 | |
| 4 | 9.96 | 12.95 | |
| 5 | 27.04 | 39.99 | |
| ≥ 6 | 8.02 | 11.81 | |
| Postoperative complication data | | | |
| Cardiac complications (%) | | | |
| Cardiac arrest | 0.34 | 13.27 | < 0.0001 |
| Myocardial infarction | 0.34 | 6.46 | < 0.0001 |
| Central nervous system complications (%) | | | |
| Coma > 24 h | 0.02 | 2.62 | < 0.0001 |
| CVA | 0.23 | 3.21 | < 0.0001 |
| Peripheral nerve injury | 0.08 | 0.30 | < 0.0001 |
| Other surgical complications | | | |
| DVT/thrombophlebitis | 0.34 | 2.54 | < 0.0001 |
| Bleeding requiring > 4 U packed RBCs | 0.32 | 6.37 | < 0.0001 |
| Graft/prosthesis failure | 0.39 | 1.35 | < 0.0001 |
| Systemic sepsis | 0.88 | 23.25 | < 0.0001 |
| Respiratory complications (%) | | | |
| Pneumonia | 1.20 | 35.41 | < 0.0001 |
| Pulmonary embolism | 0.17 | 1.89 | < 0.0001 |
| Urinary tract complications (%) | | | |
| Acute renal failure | 0.20 | 10.41 | < 0.0001 |
| Renal insufficiency | 0.32 | 7.35 | < 0.0001 |
| Urinary tract infection | 1.87 | 11.99 | < 0.0001 |
| Wound complications (%) | | | |
| Dehiscence | 0.97 | 5.77 | < 0.0001 |
| Superficial infection | 3.21 | 5.27 | < 0.0001 |
| Deep wound infection | 1.28 | 6.35 | < 0.00001 |
| 30-d mortality rate (%) | 1.39 | 26.48 | < 0.0001 |

CVA, cerebrovascular accident; DVT, deep vein thrombosis; PGY, post-graduate year of surgeon; RBC, red blood cell; RF, respiratory failure; RVU, relative value unit.

**Table 4.** Independent Predictors of Respiratory Complications (Development Set)

| Step no. | Effect entered | Parameter estimate | Pr > chi-square | Odds ratio (95% Wald CI) | Score |
|---|---|---|---|---|---|
| 1 | ASA class (3 versus 1−2) | 1.057 | < 0.0001 | 2.878 (2.463−3.362) | +3 |
| 1 | ASA class (4−5 versus 1−2) | 1.5892 | < 0.0001 | 4.900 (4.105−5.849) | +5 |
| 2 | Emergency | 0.8821 | < 0.0001 | 2.416 (2.170−2.690) | +2 |
| 3 | Work RVU (10−17 versus < 10) | 0.8323 | < 0.0001 | 2.299 (1.937−2.728) | +2 |
| 3 | Work RVU (> 17 versus < 10) | 1.4918 | < 0.0001 | 4.445 (3.720−5.312) | +4 |
| 4 | Preoperative albumin (≤ 3.5 versus > 3.5) | 0.3955 | < 0.0001 | 1.485 (1.344−1.641) | +1 |
| 5 | Integumentary versus hernia | 0.1345 | 0.3369 | 1.144 (0.869−1.505) | +1 |
| 5 | Respiratory and hemic versus hernia | 1.1366 | < 0.0001 | 3.116 (2.175−4.466) | +3 |
| 5 | Heart versus hernia | 0.8372 | < 0.0001 | 2.310 (1.670−3.196) | +2 |
| 5 | Aneurysm versus hernia | 0.4394 | 0.0007 | 1.552 (1.203−2.002) | +2 |
| 5 | Mouth, palate versus hernia | 1.8924 | < 0.0001 | 6.635 (4.782−9.206) | +7 |
| 5 | Stomach, intestines versus hernia | 0.7541 | < 0.0001 | 2.126 (1.658−2.726) | +2 |
| 5 | Endocrine versus hernia | 0.4298 | 0.0546 | 1.537 (0.992−2.382) | +2 |
| 6 | Preoperative sepsis | 0.6927 | < 0.0001 | 1.999 (1.707−2.341) | +2 |
| 7 | Preoperative creatinine ≥ 1.5 | 0.5013 | < 0.0001 | 1.651 (1.493−1.826) | +2 |
| 8 | History of severe COPD | 0.4167 | < 0.0001 | 1.517 (1.362−1.689) | +2 |
| 9 | Ascites | 0.6131 | < 0.0001 | 1.846 (1.496−2.278) | +2 |
| 10 | Dyspnea (yes versus no) | 0.2759 | < 0.0001 | 1.318 (1.192−1.457) | +1 |
| 11 | Impaired sensorium | 0.4039 | 0.0001 | 1.498 (1.220−1.839) | +1 |
| 12 | Preoperative bilirubin > 1.0 | 0.1862 | 0.0011 | 1.205 (1.078−1.347) | +1 |
| 13 | > 2 alcoholic drinks/d in 2 wk before admission | 0.2639 | 0.0002 | 1.302 (1.135−1.494) | +1 |
| 14 | Bleeding disorders | 0.2255 | 0.0041 | 1.253 (1.074−1.462) | +1 |
| 15 | Age (40−65 y versus < 40 y) | 0.5327 | 0.1253 | 1.704 (0.862−3.367) | +2 |
| 15 | Age (> 65 y versus < 40 y) | 0.7235 | < 0.0001 | 2.062 (1.537−2.765) | +2 |
| 16 | Preoperative white blood count (< 2.5 versus 2.5−10) | 0.392 | 0.1323 | 1.480 (0.888−2.465) | +1 |
| 16 | Preoperative white blood count (> 10 versus 2.5−10) | 0.1858 | 0.0002 | 1.204 (1.093−1.327) | +1 |
| 17 | Preoperative serum sodium > 145 | 0.4471 | 0.0008 | 1.564 (1.205−2.030) | +2 |
| 18 | Weight loss > 10% | 0.2268 | 0.0010 | 1.255 (1.096−1.436) | +1 |
| 19 | Preoperative acute renal failure | 0.4099 | 0.0015 | 1.507 (1.171−1.939) | +2 |
| 20 | Gender (male versus female) | 0.1762 | 0.0041 | 1.193 (1.057−1.345) | +1 |
| 21 | Congestive heart failure < 30 d before operation | 0.2607 | 0.0037 | 1.298 (1.089−1.547) | +1 |
| 22 | Smoker | 0.1375 | 0.0026 | 1.147 (1.049−1.255) | +1 |
| 23 | Preoperative platelet count ≤ 150 | 0.1913 | 0.0047 | 1.211 (1.060−1.383) | +1 |
| 24 | CVA/stroke with neurologic deficit | 0.2383 | 0.0015 | 1.269 (1.095−1.471) | +1 |
| 25 | Wound class (clean/contaminated versus clean) | 0.1449 | 0.0189 | 1.156 (1.024−1.304) | +1 |
| 25 | Wound class (contaminated versus clean) | 0.3084 | 0.0003 | 1.361 (1.150−1.612) | +1 |
| 25 | Wound class (infected versus clean) | 0.2222 | 0.0154 | 1.249 (1.043−1.495) | +1 |
| 26 | Preoperative SGOT > 40 | 0.1515 | 0.0078 | 1.164 (1.041−1.301) | +1 |
| 27 | Preoperative hematocrit ≤ 38 | 0.1083 | 0.0253 | 1.114 (1.014−1.225) | +1 |
| 28 | CVA/stroke without neurologic deficit | 0.2054 | 0.0300 | 1.228 (1.020−1.478) | +1 |

C-index = 0.856; Hosmer-Lemeshow chi-square, 15.4539; p = 0.0509; no. of records used = 90,055.
ASA, American Society of Anesthesiologists; COPD, chronic obstructive pulmonary disease; CVA, cerebrovascular accident; RVU, relative value unit; SGOT, serum glutamic-oxalacetic transaminase.

**Table 5.** Respiratory Risk Index in Development and Validation Sets

| | | Development | | | Validation | | |
|---|---|---|---|---|---|---|---|
| **Risk level** | **Score range*** | **n** | **Predicted RF (%)** | **Actual RF (%)** | **n** | **Predicted RF (%)** | **Actual RF (%)** |
| Low | < 8 | 26,583 | 0.20 | 0.10 | 26,543 | 0.20 | 0.08 |
| Medium | 8–12 | 27,221 | 1.00 | 0.96 | 27,256 | 1.01 | 0.84 |
| High | > 12 | 36,251 | 6.50 | 6.62 | 36,149 | 6.64 | 6.75 |

Development model goodness-of-fit chi-square test: p value = 0.0046; c-index (model) = 0.8562; c-index (scale) = 0.8498; c-index (scale_class) = 0.7663.
Validation model goodness-of-fit chi-square test: p value = 0.0001; c-index (model) = 0.8634; c-index (scale) = 0.8594; c-index (scale_class) = 0.7719.
*Score derived from independent predictors of respiratory failure (Table 4).
RF, respiratory failure.

domen, chest) clearly contributed to the RF risk in the earlier study, as reflected by the high associated point values. Similarly, the current model found that CPT procedure codings and preoperative ASA classification are among the most important determinants of RF risk, as reflected in their relatively high point values in the RRI (Table 4). The respiratory risk index (Table 5) developed from this model has similar c-statistics to that of the Arozullah model, suggesting equivalent discrimination ability. In the interest of clinical parsimony, our respiratory risk prediction scores are divided into 3 classes (low, medium, and high risk), but, as seen in Figure 1, there is a steady increase in the incidence of RF as the score rises above 12, up to the point of a 40% incidence for a patient with > 25 points.

It is of clinical interest to note that this model uses some preoperative risk parameters that can have apparent overlap in a given patient. For example, acute renal failure and a creatinine level ≥ 1.5 mL/dL, dyspnea and CHF in the past 30 days, CHF and a history of COPD, and perhaps weight loss > 10% and albumin < 3.5 g/dL. Additionally, although we considered CPT code groups and operative work RVUs as distinct risk factors, there is a direct link between a specific procedure and its work RVUs (this varies widely within the group of numerically clustered CPT codes[11]). Despite the potential association between these risk factors, we include them as distinct risk factors because each one contributed additional, stepwise improvement to the model's discrimination, suggesting that each one distinctly influenced the outcomes, postoperative RF. Any such overlap is salutary, because it guards against important determinants that are missed.

Risk factors identified in this study are consistent with those identified by others that have examined postoperative pulmonary complications in other distinct populations. Canver and Chanda[14] reported that respiratory failure after cardiac operations (defined as mechanical ventilation > 72 hours) occurred in 5.6% of patients studied and was predicted by both cardiac-specific factors (eg, endocarditis and cardiopulmonary bypass) and factors predictive of postoperative RF in noncardiac patients: emergency operation, age, CHF, and a history of CHF. Beyond respiratory failure (defined by some period of postoperative mechanical ventilator dependence) pulmonary complications after operations include pneumonia and atelectasis. A prospective study of 1,055 elective, nonthoracic surgical patients revealed pulmonary complications in 2.7% and respiratory failure in only 1.3%. Independently predictive factors included age, operative time (closely associated with work RVUs), perioperative nasogastric tube use, and preoperative "cough test."[15] A metaanalysis of studies examining postoperative pulmonary complications, which drew heavily on the large VA-NSQIP experience,[3] concluded that good evidence exists supporting advanced age, ASA class > 2, COPD, CHF, functional dependence, and serum albumin < 3.0 mg/dL as predictors of pulmonary complications. Among the operative factors for which good evidence existed were: operative type, prolonged operations, and emergency operation.[1] Arozullah specifically looked at postoperative pneumonia in the VA-NSQIP noncardiac surgical population previously studied for RF and found an incidence of 1.5% (among > 155,000 patients). In that study he identified predictors of postoperative pneumonia that were similar to those predictive for RF (inclusive of operation type: abdominal aortic aneurysm, thoracic, upper abdominal, age, functional status, COPD, smoker, CHF, and emergency operation).[16]

The current model is similar to that reported previously by Arozullah in its predictive factors, predictability, and discrimination.[3] Nevertheless, the current model's inclusion of a more broadly representative surgical population (inclusive of female patients and patients operated in the private sector) directly addresses concerns

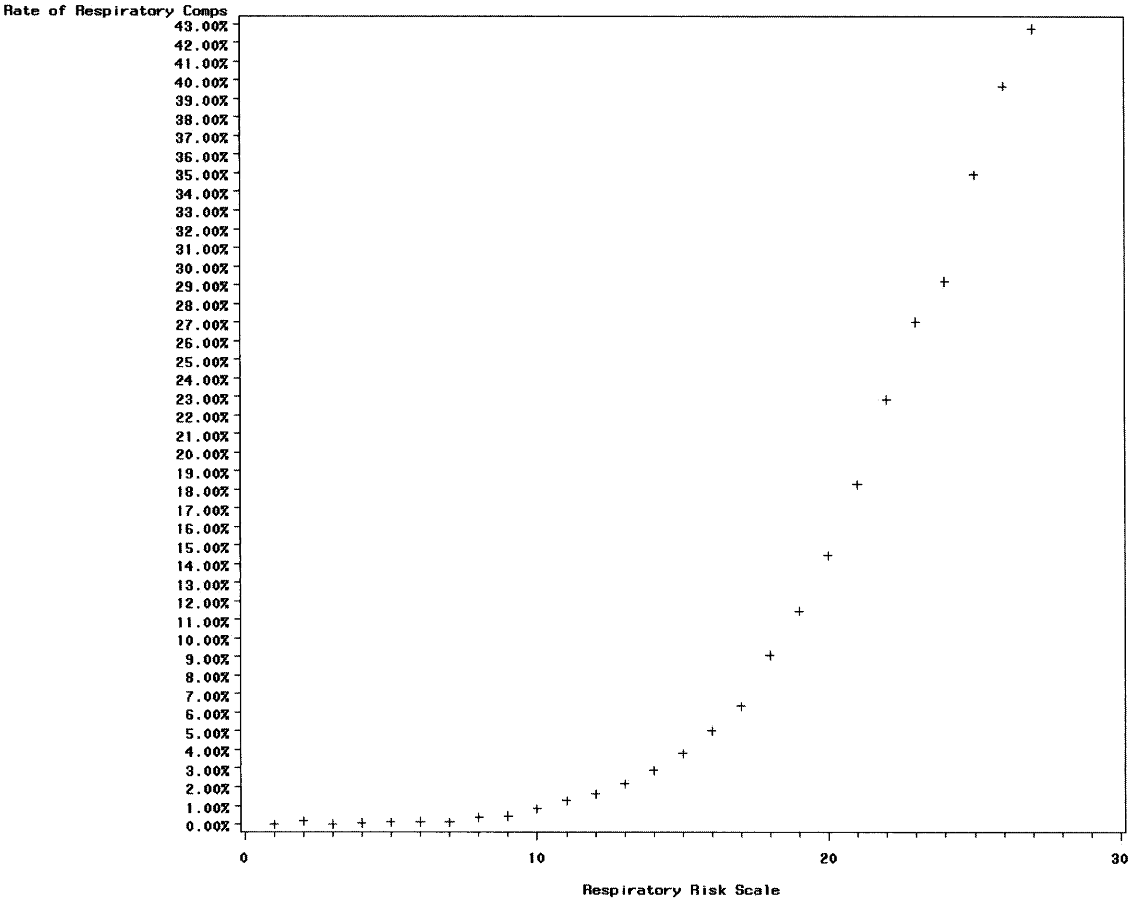


**Figure 1.** This graph plots the incidence of respiratory failure on the y axis against the respiratory risk score on the x axis.

about the limited applicability of Arozullah's model, which was based on the VA male patient population only. The congruence between the predictive model developed in our study and that developed previously by Arozullah is yet another manifestation of the applicability of the NSQIP methodology to the private sector, which was the primary objective of the PSS Study.[6]

Given the high mortality and associated morbidity of postoperative respiratory failure, interventions or processes of care that can effectively reduce its incidence are highly desirable. Preventative measures for postoperative pulmonary complications were the subject of a meta-analysis that found a paucity of strong evidence for any measure other than "volume expansion" measures.[17] The validated predictive model and RRI scoring tool that are provided by our study allow for the preoperative identification of patients at risk of developing postoperative RF and prompt the development of prophylactic processes of care that can prevent the occurrence of this complication. The RRI can be used to select high-risk patients for research protocols or for analysis of risk reduction by rapid-cycle clinical interventions directed at decreasing the morbidity of postoperative respiratory failure.

## Author Contributions

Study conception and design: Johnson, Arozullah, Neumayer, Henderson, Khuri

Acquisition of data: Johnson, Neumayer, Henderson, Khuri, Hosokawa

Analysis and interpretation of data: Johnson, Henderson, Khuri, Hosokawa

Drafting of manuscript: Johnson, Arozullah

Critical revision: Johnson, Arozullah, Neumayer, Henderson, Khuri, Hosokawa

## REFERENCES

1. Smetana GW, Lawrence VA, Cornell JE. Preoperative pulmonary risk stratification for noncardiac surgery: systemic review

for the American College of Physicians. Ann Intern Med 2006;144:581–595.

2. Dimick JB, Chen SL, Taheri PA, et al. Hospital costs associated with surgical complications: a report from the private-sector National Surgical Quality Improvement Program. J Am Coll Surg 2004;199:531–537.
3. Arozullah AM, Daley J, Henderson WM, Khuri SF for the National Veterans Administration Surgical Quality Improvement Program. Multifactorial risk index for predicting postoperative respiratory failure in men after major noncardiac surgery. Ann Surg 2000;232:242–253.
4. Taylor GJ, Mikell FL, Moses HW, et al. Determinants of hospital charges for coronary artery bypass surgery: the economic consequences of postoperative complications. Am J Cardiol 1990;65:309–313.
5. Khuri SF, Henderson WG, DePalma RG, et al. Determinants of long-term survival after major surgery and the adverse effect of postoperative complications. Ann Surg 2005;242:326–341.
6. Khuri SF, Daley J, Henderson W, et al. The National Veterans Administration Surgical Risk Study: risk adjustment for the comparative assessment of the quality of surgical care. J Am Coll Surg 1995;180:519–531.
7. Khuri SF, Daley J, Henderson W, et al. Risk adjustment of the postoperative mortality rate for the comparative assessment of the quality of surgical care: results of the National Veterans Affairs Surgical Risk Study. J Am Coll Surg 1997;185:315–327.
8. Daley J, Khuri SF, Henderson W, et al. Risk adjustment of the postoperative morbidity rate for the comparative assessment of the quality of surgical care: results of the National Veterans Affairs Surgical Risk Study. J Am Coll Surg 1997;185:328–340.
9. Daley J, Forbes MG, Young GJ, et al. Validating risk-adjusted surgical outcomes: site visit assessment of process and structure. National VA Surgical Risk Study. J Am Coll Surg 1997;185:341–351.
10. Khuri SF, Henderson W, Daley J, et al. The Patient Safety in Surgery study: background, study design, and patient populations. J Am Coll Surg 2007;204:1089–1102.
11. US Department of Health and Human Services, Centers for Medicare and Medicaid Services. Available at: http://www.cms.hhs.gov/physicianfeesched/pfsrvf/list.asp. Accessed April 17, 2007.
12. Le Gall JR, Lemeshow S, Saulnier F. A new simplified acute physiology score (SAPS II) based on a European/North American multicenter study. JAMA 1993;270:2957–2963.
13. Lemeshow S, Hosmer DW. A review of goodness of fit statistics for use in the development of logistic regression models. Am J Epidemiol 1982;115:92–106.
14. Canver CC, Chanda J. Intraoperative and postoperative risk factors for respiratory failure after coronary bypass. Ann Thorac Surg 2003;75:853–858.
15. McAlister FA, Bertsch K, Man J, et al. Incidence of and risk factors for pulmonary complications after nonthoracic surgery. Am J Respir Crit Care Med 2005;171:514–517.
16. Arozullah AM, Khuri SF, Henderson WG, Daley J, for the Participants in the National Veterans Affairs Surgical Quality Improvement Program. Development and validation of a multifactorial risk index for predicting postoperative pneumonia after non-cardiac surgery. Ann Intern Med 2001;135:847–857.
17. Lawrence VA, Cornell JE, Smetana GW. Strategies to reduce postoperative pulmonary complications after noncardiothoracic surgery: systematic review for the American College of Physicians. Ann Intern Med 2006;144:596–608.