ORIGINAL ARTICLE

Multivariate Analysis of Factors Associated With Postoperative Pulmonary Complications Following General Elective Surgery

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Objective: To develop a predictive model identifying perioperative conditions associated with postoperative pulmonary complications (PPCs).

Design: A prospective survey of patients whose preoperative history and physical examination, spirometric, Pa_{O_2} and Pa_{CO_2} analysis, and operative results were recorded. These patients underwent postoperative cardiopulmonary examinations until they were discharged from the hospital; their medical records were also reviewed until they were discharged from the hospital.

Setting: The Louisville Veterans Administration Medical Center, Louisville, Ky.

Patients: A randomly chosen sample of patients aged 40 years or older who required elective, nonthoracic surgery under general or spinal anesthesia and who were hospitalized at least 24 hours postoperatively.

Main Outcome Measure: An analysis of risk factors associated with the development of 1 or more of the following conditions: acute bronchitis, bronchospasm, atelectasis, pneumonia, adult respiratory distress syndrome, pleural effusion, pneumothorax, prolonged mechanical ventilation, or death secondary to acute respiratory failure.

Results: Postoperative pulmonary complications developed in 16 (11%) of 148 patients. The risk factors found to be higher among those with PPCs compared with those without PPCs were postoperative nasogastric intubation (81% vs 16%, $P<.001$), preoperative sputum production (56% vs 21%, $P=.005$), and longer anesthesia duration (480 vs 309 minutes, $P<.001$). Upper abdominal surgery was performed in 11 (69%) of the 16 patients with PPCs and in 20 (15%) of the 132 patients without PPCs ($P<.001$); this difference lost significance in multivariate analysis. The final linear logistic model included postoperative nasogastric intubation (odds ratio [OR], 21.8), preoperative sputum production (OR, 4.6), and longer anesthesia duration (OR exp[0.01x] for an increase in x minutes) (1 minute of additional anesthesia time increases the OR to 1.01), resulting in 92% accuracy in predicting PPCs.

Conclusions: We identified 3 potentially modifiable risk factors for PPCs. If validated, our results may lead to modifications of perioperative care that will further reduce PPCs.

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PULMONARY complications following surgery are associated with significant morbidity[1-4] and have been shown to increase the length of hospitalization.[1,5,6] The identification of patient-related features associated with increased risk for postoperative pulmonary complications (PPCs) has been reported; however, the results have been conflicting.[1-20] Surgical features that increase risk include the performance of emergent procedures; longer anesthesia duration; and the surgical incision site, with thoracic and upper abdominal incisions having the highest rate of PPCs.[2,11,15,19] Efforts have been focused on the minimization of postoperative risk factors, such as prolonged bed rest[21] and inadequate pain control,[22] and on the routine use of incentive spirometry.[23] The identification and correction of modifiable perioperative risk factors in patients undergoing elective surgery should lead to further improvement in outcomes and reductions in lengths of hospital stay.

The interpretation of the English-language literature in this field is limited because older studies, although inclusive of diverse operative cases, did not fully define PPCs before the surgery or perform uniform preoperative evaluations.[2,3,11] Recent studies, including the few multivariate analyses available, are limited because of their focus on upper abdominal procedures[1,4,6] or on patients who have specific medical conditions.[8,15,17,19,20] To our knowledge, no report that includes multivariate analysis has been published about a group of patients undergoing elective general surgery without disease-specific inclusion criteria.

This study determines whether a predictive model using clinical findings and perioperative conditions could be developed that would aid clinicians in identifying patients at greatest risk for developing PPCs during elective, general, nonthoracic surgi-

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PATIENTS AND METHODS

STUDY DEFINITIONS

Postoperative pulmonary complications were defined before patient enrollment as the development of 1 or more of the following conditions: acute bronchitis, bronchospasm, atelectasis, pneumonia, adult respiratory distress syndrome, pleural effusion, pneumothorax, prolonged mechanical ventilation (>48 hours), or death secondary to acute respiratory failure. Acute bronchitis was defined as the development of a productive cough, with a temperature less than 38°C, and no new chest signs except rhonchi or as an increased quantity of sputum with a change in color for patients with a productive cough preoperatively. Bronchospasm was defined as wheezing on auscultation that resulted in the initiation of therapy. Atelectasis was defined as new chest findings of reduced or absent breath sounds, localized breathing with a temperature lower than 38°C, with supporting chest roentgenogram findings, or both. Pneumonia was identified by a productive cough with new lung findings of coarse crepitations, large areas of bronchial breathing, or dullness to percussion (in the absence of an effusion) with supporting chest roentgenograms.[24] Adult respiratory distress syndrome was defined as a lung injury score[25] of 2.5 or greater. Pulmonary emboli and pulmonary edema were not included as PPCs. Standardized postoperative testing was not done to detect PPCs. Radiographic and laboratory studies were performed by the surgical team when clinically indicated. Chest radiographs were interpreted by a radiologist who was unaware of this clinical investigation.

STUDY PATIENTS

All patients aged 40 years or older who were scheduled for elective, nonthoracic surgical procedures at the Louisville Veterans Administration Medical Center, Louisville, Ky, were eligible to participate in the study. Patients were routinely admitted to the hospital at least 1 day prior to surgery. Patients were excluded from the study if emergent procedures were required, if they were not going to receive general or spinal anesthesia, if at least 24 hours of postoperative hospitalization were not anticipated, or if inadequate time was available preoperatively to complete the enrollment procedures. Typically, 7 to 8 patients listed on the operating room schedule met the eligibility criteria. The study coordinator would randomly draw eligible names from a hat for study enrollment. Because of staffing constraints and the limited time available to perform preoperative studies, only 2 to 3 of the eligible patients could be enrolled into the study daily. This study was approved by the Human Studies Committee at the Louisville Veterans Administration Medical Center, and informed consent was obtained from all participants.

Patient demographics, smoking history, current sputum production, and medical record diagnosis of chronic obstructive pulmonary disease (COPD) (including asthma) were determined preoperatively. A targeted physical examination done the day before surgery included the determination of height and weight and chest auscultation. The body mass index (calculated by dividing the weight [given in kilograms] by the height [given in meters, squared), with values of 30 or greater considered obese, was determined for each patient. The American Society of Anesthesiologists' (ASA) rating,[26] determined by an anesthesiologist independent of this study, was recorded as an indicator of general health. Pa_{O_2} and Pa_{CO_2} analysis and spirometric measurements were obtained on admission to the study. Operative data included the type and duration of anesthesia and the type of surgical procedure performed. An internist (C.K.M., S.H.S., M.K.P., P.J.D., or M.A.R.), blinded to the results of the initial preoperative evaluation, performed a cardiopulmonary examination and a medical record review daily during the first postoperative week and 3 to 4 times per week after that until the patient was discharged from the hospital. No communication occurred between the investigators (C.K.M., S.H.S., M.K.P., P.J.D., and M.A.R.) and the surgical team regarding the postoperative status of any patient.

STATISTICAL ANALYSIS

Statistical analysis was performed using the Student *t* test for an analysis of continuous variables and χ^2 testing for categorical variables. The results were considered significant at $P<.05$. Forward stepwise likelihood ratio methods were used for logistic regression modeling, which was performed using computer software (SPSS 6.0 for Windows, SPSS Inc, Chicago, Ill). An entry criterion was set at $P<.10$, and an exit criterion was set at $P<.05$. We also calculated an area under the receiver-operator characteristic curve for the model by nonparametric analysis (ROC Curve Analyzer 6.0, Richmond, Va, designed by R. M. Centor and J. Keightley).

cal procedures. Our goal was to identify specific risk factors amenable to modification that could reduce PPCs.

RESULTS

During a period of 5 months, 148 patients (including only 3 women) were enrolled into the study. The mean (SD) age of the patients was 61.2 (10.4) years (range, 40-82 years). Sixty-three (42.6%) of the patients were current smokers, with a mean (SD) of 64.6 (30.7) pack-years; 65 (43.9%) of the patients were former smokers (they had not smoked for at least 8 weeks), with a mean (SD) of 57.0 (43.0) pack-years; and 20 (13.5%) of the patients had never smoked. A productive cough was present in 37 (25%) of the patients, and COPD or asthma had been diagnosed in 34 (23%) of the patients. The spirometric results were reliable for interpretation in 123 (83%) of the patients. Based on the spirometric results, 16 (11%) of the patients had severe COPD (forced expiratory volume in 1 second <50%), 9 (6%) had moderate COPD (forced expiratory volume in 1 second <60%), and 21 (14%) had mild COPD (forced expiratory volume in 1 second <70%). Only 4 (3%) of the patients had Pa_{O_2} concentrations lower than 60 mm Hg; 15 (10%) of the patients had Pa_{CO_2} concentrations higher than 45 mm Hg. The body mass index averaged 25.9 (range, 16.7-43.1); 29 (20%) of the 148 patients were considered obese. **Table 1** indicates the types of surgical procedures performed. General anesthesia was used in 124 (84%) of the patients. The mean (SD) anesthesia duration was 210 (108) minutes for the entire group.

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Table 1. Surgeries Performed in the Study Population (N=148)

Type of Surgery	No. (%) of Patients	Mean (SD) Duration of the Procedure, min
Upper abdominal*	31 (21)	218 (109)
Orthopedic (nonspinal)	25 (17)	191 (47)
Genitourinary	20 (14)	109 (57)
Inguinal herniorrhaphy	17 (11)	159 (61)
Lumbar spinal	13 (9)	334 (102)
Lower abdominal	9 (6)	216 (64)
Cervical spinal	9 (6)	303 (84)
Vascular (nonabdominal)	8 (5)	241 (76)
Ear, nose, and throat	6 (4)	240 (121)
Miscellaneous	10 (7)	357 (316)

*Thirteen patients had incisions extending below the umbilicus.

A total of 16 (11%) of the patients experienced PPCs. The preoperative characteristics affecting the development of PPCs are described in **Table 2**. The only preoperative variable associated with the development of PPCs was preoperative sputum production (P=.005).

The mean (SD) duration of anesthesia was longer for those patients with PPCs (300.0 [114.5] minutes) compared with those patients without PPCs (198.8 [102.6] minutes) (P<.001). Spinal anesthesia was given to 24 (16%) of the patients; PPCs did not develop in any of these patients. The average (SD) duration of anesthesia for patients receiving spinal anesthesia was 115.0 (36.7) minutes compared with 228.0 (108.0) minutes for those receiving general anesthesia (P<.001).

Upper abdominal incisions were performed in 11 (69%) of the 16 patients with PPCs (odds ratio [OR], 12.3; 95% confidence interval [CI], 3.4-46.9) and in 20 (15%) of the 132 patients without PPCs (P<.001). We also found complication rates to be common after cervical spine procedures (in 1 [11.0%] of the 9 patients undergoing these procedures) and after nonabdominal vascular procedures (in 1 [12.5%] of the 8 patients undergoing these procedures), although the absolute number of complications was few. Respiratory tract complications did not occur in patients undergoing genitourinary procedures, herniorrhaphies, nonspinal orthopedic surgical procedures, or ear, nose, and throat surgical procedures. The mean duration of the procedures is reported in Table 1.

Nasogastric (NG) tubes were placed in 13 (81%) of the 16 patients with PPCs and in 21 (16%) of the 132 patients without PPCs (OR, 23; 95% CI, 5.3-112.3; P<.001). Only 3 (9%) of the 34 patients had documentation that the NG intubation was for symptoms occurring 24 to 48 hours postoperatively; PPCs did not develop in any of these patients. The mean (SD) duration of NG intubation was 4.5 (3.3) days for patients with PPCs and 3.0 (1.6) days for patients without PPCs (P=.08). Nasogastric intubation was used in 26 (83.9%) of the 31 patients undergoing upper abdominal procedures, 5 (55.6%) of the 9 patients undergoing lower abdominal procedures, 1 (16.7%) of the 6 patients undergoing ear, nose, and throat procedures, 1 (12.5%) of the 8 patients undergoing nonabdominal vascular procedures, and 1 (11.1%) of the 9 patients undergoing cervical spine procedures.

Table 2. Preoperative Characteristics and the Development of Postoperative Pulmonary Complications (PPCs)*

Preoperative Characteristics	Patients With PPCs (n=16)	Patients Without PPCs (n=132)	P†
Age, y‡	61.1 (9.3)	61.2 (10.6)	.97
Preoperative hospital stay, d‡	8.3 (4.6)	5.6 (8.4)	.21
BMI‡§	26.0 (4.8)	25.9 (5.1)	.91
BMI ≥30§	2 (12.5)	27 (20)	. . .
Smoking pack-years‡	66.0 (41)	58.1 (37.8)	.19
Smoking status			
Current	10 (63)	54 (41)	.25
Former	5 (31)	61 (46)	
Never	1 (6)	17 (13)	
Preoperative sputum production	9 (56)	28 (21)	.005
Pa_{O_2}, mm Hg	83.2	83.3	.99
Pa_{CO_2}, mm Hg	38.8	40.3	.15
FEV_1, % predicted‡	73.8 (22.7)	76.5 (21.1)	.65
FVC, % predicted‡	78.9 (15.1)	81.1 (17.9)	.65
ASA classification			
1	0 (0)	7 (5)	.45
2	11 (69)	64 (49)	
3	5 (31)	44 (33)	
4	0 (0)	7 (5)	
5	0 (0)	1 (1)	
Not recorded	0 (0)	9 (7)	

*Data are given as the number (percentage) of patients unless otherwise specified. BMI indicates body mass index; FEV_1, forced expiratory volume in 1 second; FVC, forced vital capacity; and ASA, American Society of Anesthesiologists.

†The student t test was used for continuous variables, and the χ^2 test was used for differences in proportions.

‡Data are given as the mean (SD).

§The BMI was calculated by dividing the weight (given in kilograms) by the height (given in meters, squared).

The mean (SD) length of hospital stay was more than double for those with PPCs (28.7 [26.0] days) compared with those without PPCs (13.0 [11.1] days) (P=.03). The median length of hospital stay was 18.5 days for those with PPCs and 10.0 days for those without PPCs (P<.001). The time (SD) spent in the surgical intensive care unit averaged 3.5 (3.9) days for patients with PPCs and 0.7 (1.5) days for those without PPCs (P<.001).

No case of a pneumothorax or death secondary to respiratory tract failure occurred in this study. There was 1 death due to cardiac disease in a 61-year-old patient, ASA class 2, in whom adult respiratory distress syndrome developed. The details of the patients in whom PPCs developed are given in **Table 3**.

Multivariate analysis resulted in a linear logistic model with a 92% total accuracy in predicting PPCs in our study. The variables remaining in the final model were postoperative NG intubation (OR, 21.8), preoperative sputum production (OR, 4.6), and longer anesthesia duration. The estimated OR for an increase of x minutes of anesthesia duration was $\exp(0.01x)$. Upper abdominal surgery did not maintain significance in this multivariate analysis. The data were also analyzed combining all abdominal surgeries, but this analysis did not change the final model. The area under the receiver-operator characteristic curve for the final model was 0.91 (95% CI, 0.85-0.97), indicating good model discrimination.

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Table 3. Patient Features in Postoperative Pulmonary Complication Cases

Age, y/ Sex	Preoperative Sputum Production	Pack-years Smoked	Surgical Site	Anesthesia Duration, min	Nasogastric Tube Placed	Pulmonary Complication	Length of Hospital Stay, d
40/M	No	50	Upper abdomen	225	Yes	Pneumonia	46
48/F	Yes	53	Upper abdomen	225	Yes	Bronchospasm	38
53/M	No	50	Lumbar spine	310	No	Acute bronchitis	17
55/M	No	60	Upper abdomen	370	Yes	Atelectasis	20
58/M	No	50	Cervical spine	350	No	Atelectasis	7
58/M	Yes	68	Cervical spine	430	Yes	Pneumonia, pleural effusion, and prolonged mechanical ventilation	110
60/M	Yes	112	Upper and lower abdomen	260	Yes	Atelectasis and bronchospasm	15
61/M	No	92	Upper and lower abdomen	520	Yes	Pneumonia, adult respiratory distress syndrome, and death due to cardiac disease	9
62/M	No	20	Upper abdomen	220	Yes	Atelectasis and pleural effusion	13
65/M	Yes	124	Upper and lower abdomen	300	Yes	Atelectasis	17
66/M	Yes	76	Vascular (nonabdominal)	76	No	Acute bronchitis	16
66/M	Yes	54	Upper and lower abdomen	545	Yes	Atelectasis, pneumonia, and pleural effusion	61
68/M	No	0	Upper and lower abdomen	210	Yes	Atelectasis and pleural effusion	30
68/M	Yes	156	Upper abdomen	195	Yes	Acute bronchitis and bronchospasm	24
74/M	Yes	9	Upper and lower abdomen	235	Yes	Atelectasis and pneumonia	15
76/M	Yes	25	Lower abdomen	170	Yes	Acute bronchitis	21

COMMENT

Our results reveal that postoperative NG intubation, preoperative sputum production, and longer anesthesia duration are factors associated with PPCs in a group of patients undergoing a range of general surgical elective procedures. In a multivariate analysis, these 3 factors predicted 92% of the complications. If validated, our results may lead to modifications of perioperative care that will further reduce PPCs.

The single most important variable associated with the development of PPCs was postoperative NG intubation. We found that while NG intubation was most frequently used in patients who underwent abdominal surgeries, it was also used in patients who underwent various nonabdominal procedures. Upper abdominal incisions were significantly ($P<.001$) related to the development of PPCs in our study by univariate analysis, as found in previous studies.[1,18] Mitchell and colleagues[18] found that postoperative NG intubation identified patients at risk more clearly than, and independently of, their next most important factor, upper abdominal surgery. Our study extends this finding and shows that the incision site loses significance after adjusting for postoperative NG intubation.

Routine NG decompression following gastrointestinal tract surgery can often be safely eliminated,[27-32] but the practice of gastric decompression remains common. In our patients, only 3 (9%) of the 34 patients had documentation that the NG intubation was for symptoms 1 to 2 days postoperatively. Postoperative pulmonary complications did not develop in any of the patients who underwent upper abdominal surgery whose NG intubation occurred after full recovery from their anesthesia. Savassi-Rocha and colleagues[31] found prospectively a significantly higher incidence of atelectasis in patients with prophylactic NG intubation following digestive surgery. They also found an equal occurrence of nausea, vomiting, and abdominal distention in patients regardless of postoperative NG intubation. Cheadle and colleagues[28] found that prophylactic gastric decompression was associated with increased morbidity, delayed return of gastrointestinal tract function, and increased number of postoperative days until discharge from the hospital. In our study, patients who underwent upper abdominal surgery and who were managed without postoperative NG intubation suffered no surgical complications.

Several mechanisms may account for the risk related to NG intubation. An NG tube may interfere with an effective cough postoperatively through incomplete closure of the glottis. Interference with coughing could lead to the accumulation of secretions that increase the risk of atelectasis and infection. Bacteria also may be more easily transferred from the oral pharynx to the lungs when an NG tube is present, increasing the risk for respiratory tract infections. Stimulation by the NG tube may also result in diaphragmatic dysfunction through reflex mechanisms.[27] Any of these mechanisms could promote the development of PPCs.

Our finding that preoperative sputum production is strongly related to postoperative respiratory tract morbidity confirms the results of other investigators.[5,10,18,20,33] Although smokers are more likely to produce sputum, not all smokers have productive coughs and smoking history is not a reliable predictor of PPCs. We found no association between spirometric results and PPCs, similar to the results of other studies.[5,6,20,34] Our results suggest that preoperative sputum production is a better indicator than spirometry in predicting PPCs in patients undergoing nonthoracic general surgery.

The duration of anesthesia has previously been noted to be an important risk factor for the development of PPCs.[8,9,17] Our findings also corroborate the effect of anesthesia duration. No episodes of PPCs occurred in the patients who received spinal anesthesia; however, the anesthesia duration was significantly ($P<.001$) shorter in these patients than in the patients who received general anesthesia. We, therefore, cannot comment on the differences in safety between the 2 types of anesthesia.

Pulmonary complications have been related to mild to moderate obesity in several studies,[8,12,17] but the pres-

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ence of additional pulmonary risk factors was not evaluated. Similar to the findings of other researchers,[9,11,13,35] we failed to detect an increase in postoperative respiratory tract complications in obese patients.

Age was not an independent variable contributing to PPCs in our elective surgical population. The elderly patients chosen for elective surgery may have been "healthier" than those not referred for elective procedures. However, when the ASA classification is used as an indicator of general health, we found no differences in the ratings received by those younger compared with those 65 years and older in this study. Our sample did not include many patients in the old-old (≥85 years) age range, and our findings may not extend to this group.

In a multivariate analysis of 1000 patients who underwent laparotomy, Hall and colleagues[4] found that the ASA classification was the single most important variable predictive of the development of PPCs. They also found that chronic bronchitis was a significant predictor by univariate analysis but not by multivariate analysis. In our study, the ASA score was not a significant (P=.45) predictor by either univariate or multivariate analysis; however, preoperative sputum production was a significant (P=.005) predictor by both analyses. Whether these differences occurred because the surgical procedures were not homogeneous in our population or because the ASA classification is based on a subjective evaluation of the conditions of patients and is subject to observer variability cannot be determined from this analysis.

Our results may not be generalizable to other populations. The patients were all enrolled at a veterans' hospital and were almost exclusively men. There was a high incidence of smoking in the patient population and of smoking-related conditions that did not increase our overall rate of PPCs. Despite these facts, preoperative Pa_{O_2} and Pa_{CO_2} analysis and spirometry did not aid in predicting patients at risk for PPCs. Such preoperative testing would only lead to increased cost for patients who were similar to those enrolled in our study. Inpatient diagnostic evaluations and medical clearance led to longer preoperative lengths of hospital stay than will be found in civilian hospitals. Also, the reported lengths of hospital stay were also affected by other complications (data not shown), such as cardiac or surgical complications, in the group with PPCs and in the group without PPCs.

The prevention of postoperative complications is an important task for the clinician. Efforts to reduce PPCs may help decrease the length of hospitalization. We have identified 3 factors, postoperative NG intubation, preoperative sputum production, and longer anesthesia duration, that are potentially modifiable. An increased duration of anesthesia was associated with the development of PPCs but may not be subject to modification as it is dependent on the type of procedure performed. Postponing elective procedures in patients with productive coughs until aggressive pulmonary management corrects the situation may reduce postoperative respiratory tract complications. The elimination of routine NG intubation has the potential for the greatest reduction in postoperative respiratory tract sequelae, and we strongly recommend that the use of prophylactic NG intubation be avoided.

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