Preoperative Pulmonary Risk Stratification for Noncardiothoracic Surgery: Systematic Review for the American College of Physicians

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Background: The importance of clinical risk factors for postoperative pulmonary complications and the value of preoperative testing to stratify risk are the subject of debate.

Purpose: To systematically review the literature on preoperative pulmonary risk stratification before noncardiothoracic surgery.

Data Sources: MEDLINE search from 1 January 1980 through 30 June 2005 and hand search of the bibliographies of retrieved articles.

Study Selection: English-language studies that reported the effect of patient- and procedure-related risk factors and laboratory predictors on postoperative pulmonary complication rates after noncardiothoracic surgery and that met predefined inclusion criteria.

Data Extraction: The authors used standardized abstraction instruments to extract data on study characteristics, hierarchy of research design, study quality, risk factors, and laboratory predictors.

Data Synthesis: The authors determined random-effects pooled estimate odds ratios and, when appropriate, trim-and-fill estimates for patient- and procedure-related risk factors from studies that used multivariable analyses. They assigned summary strength of evidence scores for each factor. Good evidence supports patient-related risk factors for postoperative pulmonary complications, including advanced age, American Society of Anesthesiologists class 2 or higher, functional dependence, chronic obstructive pulmonary disease, and congestive heart failure. Good evidence supports procedure-related risk factors for postoperative pulmonary complications, including aortic aneurysm repair, nonresective thoracic surgery, abdominal surgery, neurosurgery, emergency surgery, general anesthesia, head and neck surgery, vascular surgery, and prolonged surgery. Among laboratory predictors, good evidence exists only for serum albumin level less than 30 g/L. Insufficient evidence supports preoperative spirometry as a tool to stratify risk.

Limitations: For certain risk factors and laboratory predictors, the literature provides only unadjusted estimates of risk. Prescreening, variable selection algorithms, and publication bias limited reporting of risk factors among studies using multivariable analysis.

Conclusions: Selected clinical and laboratory factors allow risk stratification for postoperative pulmonary complications after noncardiothoracic surgery.

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Postoperative pulmonary complications contribute importantly to the risk for surgery and anesthesia. The most important and morbid postoperative pulmonary complications are atelectasis, pneumonia, respiratory failure, and exacerbation of underlying chronic lung disease. Since the publication of the first cardiac risk index in 1977 (1), clinicians have been aware of the importance of, and the risk factors for, cardiac complications. Clinicians who care for patients in the perioperative period may be surprised to learn that postoperative pulmonary complications are equally prevalent and contribute similarly to morbidity, mortality, and length of stay. For example, in a large retrospective cohort study of 8930 patients undergoing hip fracture repair, 1737 (19%) patients had postoperative medical complications (2). Serious pulmonary complications occurred in 229 (2.6%) patients and serious cardiac complications occurred in 178 (2.0%) patients.

Similarly, in a study of 2964 patients undergoing elective noncardiac surgery, postoperative pulmonary and cardiac complications occurred in 53 patients and 64 patients, respectively (3). Rates of postoperative cardiac and pulmonary complications are similar in other large cohort studies of patients undergoing noncardiac surgery (4–6). Pulmonary complications may also be more likely than cardiac complications to predict long-term mortality after surgery. For example, among postoperative complications in a recent study of patients older than 70 years of age who were undergoing noncardiac surgery, only pulmonary and renal complications predicted long-term mortality (7). In another report of patients undergoing esophagectomy for cancer, postoperative pneumonia was second only to tumor stage in predicting long-term survival after surgery and predicted long-term mortality to a greater degree than postoperative cardiac, renal, or hepatic complications (8).

Office and hospital consultation for patients preparing for surgery is an important activity for internists. While guidelines and consensus statements for perioperative cardiac evaluation have been published (9, 10), no similar guideline is available to assist in perioperative pulmonary evaluation. The quality and number of studies that estimate perioperative pulmonary risk have increased in the past 2 decades, and this is no longer a neglected area of inquiry. We prepared this 2-part systematic review 1) to

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guide clinicians on clinical and laboratory predictors of perioperative pulmonary risk before noncardiothoracic surgery and 2) to evaluate the efficacy of strategies to reduce the risk for postoperative pulmonary complications (11). Risk factors for postoperative venous thromboembolism differ substantially from those for postoperative pulmonary complications, and they are not the subject of our review.

METHODS

Literature Search and Selection Criteria

The Appendix (available at www.annals.org) contains a detailed description of our methodology. We performed a MEDLINE search to identify relevant publications from 1 January 1980 through 30 June 2005. We used the following Medical Subject Heading (MeSH) terms and specified that they be the article's primary focus: *intraoperative complications*, *postoperative complications*, *preoperative care*, *intraoperative care*, and *postoperative care*, plus the text term *perioperative complications* in the title or abstract. We identified additional MeSH and text terms by a review of the MEDLINE indexing for the retrieved articles. These included terms for pulmonary, respiratory, or cardiopulmonary diseases, conditions, or complications and terms for oxygenation and chest roentgenography. We performed additional searches specific to preoperative chest radiography and preoperative spirometry. We identified additional references by reviewing bibliographies of retrieved studies.

We included only English-language publications and excluded publication types without primary data (that is, letters, editorials, case reports, conference proceedings, and narrative reviews). We excluded 1) studies with fewer than 25 participants per study group; 2) studies that used only administrative data (for example, International Classification of Diseases, Ninth Revision, Clinical Modification [ICD-9-CM] codes) or lacked explicit criteria or definitions for pulmonary complications; 3) studies from developing countries (because of potential differences in respiratory and intensive care technology); 4) studies of ambulatory surgery; 5) studies of physiologic (for example, lung volumes and flow, oximetry) rather than clinical outcomes; 6) studies of gastric pH manipulation; 7) studies of complications unique to a particular type of surgery (for example, upper airway obstruction after uvulectomy); 8) studies of cardiopulmonary or pediatric surgery; and 9) studies of organ transplantation surgery (because of profoundly immunosuppressive drugs).

Of 16 959 citations identified by the search, 1223 citations were duplicates and 14 793 citations were not relevant by title and abstract review (**Figure**). Of the remaining 943 potentially relevant citations, we excluded 626 citations after review of the full publication and abstracted 145 citations in detail.

Assessing Study Quality

We used the U.S. Preventive Services Task Force (USPSTF) criteria for assigning hierarchy of research design, grading a study's internal validity as our basis for assessing study quality, and assigning summary strength of recommendations for each risk factor and laboratory test (12).

Statistical Analysis

Our literature search yielded primarily unadjusted estimates for most laboratory factors of interest. Limited multivariable, adjusted studies were available for serum albumin level less than 30 g/L and elevated blood urea nitrogen level. However, rather than attempt to compute potentially biased summary estimates, we provided narrative descriptions of the pattern of results for these potential risk factors.

The eligible multivariable risk factor studies varied considerably in the number and type of competing risks and confounders included in the analyses. Extensive use of prescreening methods and variable selection algorithms often limited reporting to the subset of risk factors that were determined to be statistically significant in a given sample. The result is a subtle form of publication bias, which we verified by examination of the funnel plots and trim-and-fill estimates for each risk factor.

We extracted odds ratios from each study, along with their respective SEs, 95% confidence limits, or both. We used the I^2 statistic (13) and the Cochran Q statistic (14) to assess study heterogeneity. We also recomputed pooled estimates with and without studies that produced extreme results. An I^2 statistic of 50% or more indicates substantial heterogeneity among study estimates. We used the DerSimonian–Laird method to compute random-effects estimates when the set of studies was heterogeneous (15). In cases where 3 or more studies contributed estimates for a risk factor, we used the trim-and-fill method to adjust pooled estimates of a risk factor's effect on postoperative pulmonary complications for publication bias (16). Trim-and-fill estimates check the sensitivity of pooled estimates to potential publication bias (17). We used meta-analysis procedures available in Stata software, version 8 (Stata Corp., College Station, Texas), to conduct these analyses (18).

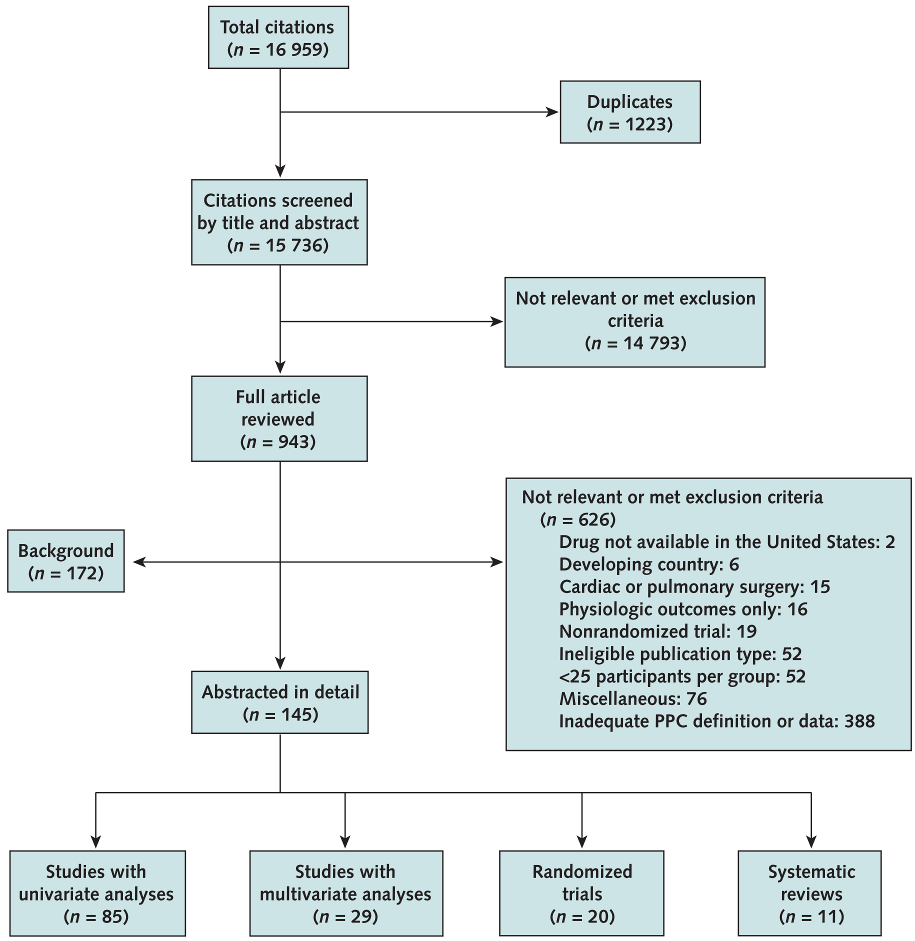
Role of the Funding Source

The Veterans Evidence-based Research, Dissemination, and Implementation Center (VERDICT) (Veterans Affairs Health Services Research and Development, HFP 98-002) provided the research librarian and administrative support for the study. The funding source had no role in the design, conduct, or reporting of the study or in the decision to submit the manuscript for publication.

RESULTS

Eighty-three publications provided univariate data on clinical predictors of postoperative pulmonary complications. **Appendix Table 1** (available at www.annals.org) summarizes the characteristics of these studies (2, 3, 19–

Figure 1. **Flow chart for article selection process.**



PPC = postoperative pulmonary complication.

99). Seventy-three (88.0%) publications were cohort studies; 3 (3.6%) were randomized, controlled trials; 2 (2.4%) were case–control studies; and the remaining 5 (6.0%) were case-series studies. Slightly less than half (45.8%) of the cohort studies used a prospective design. Ten studies were of good quality, 18 studies were of fair quality, and 55 studies were of poor quality. Eligible studies included 11 851 postoperative pulmonary complication events among 173 500 patients.

Twenty-seven studies reporting multivariable analyses (10 960 postoperative pulmonary complication events among 324 648 patients) met our inclusion criteria (**Appendix Table 2**, available at www.annals.org) (100–126). These studies form the principal basis of our review. Most studies (96%) were prospective cohort studies, and only 1 report was a case–control study. The 3 largest studies (118, 120, 123) used subsets of patients from the Veterans Affairs National Surgical Quality Improvement Project (NSQIP) (127). These 3 studies accounted for 89.8% of all patients included in the multivariable studies and 82.3% of the observed postoperative pulmonary complications. The crude postoperative pulmonary complication rate among the cohort studies was 3.4%.

The studies were heterogeneous with respect to study objectives, study samples, and criteria for defining a postoperative pulmonary complication. Seventeen of the 27 (63.0%) studies aimed to identify potential risk factors for postoperative pulmonary complications. The objective in 3 studies was to develop a risk index for postoperative pulmonary complications (113, 118, 120). The remaining studies focused on high-risk subgroups, such as patients undergoing aortic surgery (104, 125), patients with smoking histories (114), elderly patients (102, 117, 121), or patients with chronic obstructive pulmonary disease who required prolonged stays in the intensive care unit (108).

Postoperative pulmonary complication definitions varied considerably across studies. While 16 (59.3%) of the studies included some combination of pneumonia or respiratory infection along with respiratory insufficiency or failure, the studies varied in the inclusion of other complica-

Table 1. **Patient-Related Risk Factors for Postoperative Pulmonary Complications***

Risk Factor	Studies, *n*	Pooled Estimate Odds Ratio (95% CI)†	I^2, %†	Trim-and-Fill Estimate Odds Ratio (95% CI)‡
Age				
50–59 y	2	1.50 (1.31–1.71)	0.0	–
60–69 y	7	2.28 (1.86–2.80)	50.4	2.09 (1.65–2.64)
70–79 y	4	3.90 (2.70–5.65)	81.6	3.04 (2.11–4.39)
≥80 y	1	5.63 (4.63–6.85)	–	–
ASA class				
≥II§	6	4.87 (3.34–7.10)	0.0	4.87 (3.34–7.10)
≥III§	11	3.12 (2.17–4.48)	65.2	2.55 (1.73–3.76)
Abnormal chest radiograph	2	4.81 (2.43–9.55)	0.0	–
CHF	3	2.93 (1.02–8.43)	92.1	2.93 (1.02–8.03)
Arrhythmia	1	2.90 (1.10–7.50)	–	–
Functional dependence				
Partial	2	1.65 (1.36–2.01)	82.6	–
Total	2	2.51 (1.99–3.15)	67.9	–
COPD	8	2.36 (1.90–2.93)	82.0	1.79 (1.44–2.22)
Weight loss	2	1.62 (1.17–2.26)	91.7	–
Medical comorbid condition	1	1.48 (1.10–1.97)	–	–
Cigarette use	5	1.40 (1.17–1.68)	67.5	1.26 (1.01–1.56)
Impaired sensorium	2	1.39 (1.08–1.79)	63.0	–
Corticosteroid use	1	1.33 (1.12–1.58)	–	–
Alcohol use	2	1.21 (1.11–1.32)	0.0	–

* ASA = American Society of Anesthesiologists; CHF = congestive heart failure; COPD = chronic obstructive pulmonary disease.
† For I^2 definition and values, see the Appendix, available at www.annals.org.
‡ Estimates derived from meta-analysis of adjusted odds ratios from multivariable studies.
§ When compared with patients with lower ASA class values.

tions. Two studies included pulmonary edema (102, 121) and 2 studies included pulmonary embolus in addition to traditional postoperative pulmonary complication definitions (102, 125). Three studies used atelectasis as an exclusion criterion (110, 118, 120). One study explicitly excluded patients who required postoperative mechanical ventilation (128). The 2 largest studies derived from the NSQIP limited their analyses to either postoperative respiratory failure (118) or pneumonia (120). **Appendix Table 3** (available at www.annals.org) details the principal results of the studies that reported multivariable analyses.

Patient-Related Risk Factors

We considered patient- and procedure-related risk factors separately and divided the patient-related risk factors into the following general categories: age, chronic lung disease, cigarette use, congestive heart failure, comorbid condition measures, functional dependence, obesity, obstructive sleep apnea, impaired sensorium, and other factors. **Table 1** displays the DerSimonian–Laird pooled and trim-and-fill estimate odds ratios for the patient-related risk factors.

Age

The influence of age on postoperative pulmonary complication rates is not well established. Most previous reviews have considered age to be a minor risk factor for the development of postoperative pulmonary complications. Studies that reported postoperative pulmonary complications by age categories varied with respect to the cutoff ages used to define age strata (**Appendix Table 4**, available at www.annals.org). Ten studies reported unadjusted postoperative pulmonary complication rates by age strata for patients older than 65 years of age (5 studies) and for patients older than 70 years of age (5 studies). Unadjusted postoperative pulmonary complication estimates for patients older than 65 years of age ranged from 1% to 34%, with a median postoperative pulmonary complication rate of 14%. For patients 70 years of age and older, the unadjusted postoperative pulmonary complication estimates ranged from 4% to 45%, with a median postoperative pulmonary complication rate of 15%.

Eleven multivariable risk factor studies reported statistically significant effects for age. This was the second most commonly identified risk factor in our review. Seven of these studies—4 good-quality studies, 2 fair-quality studies, and 1 poor-quality study—provided odds ratios along with SEs or CIs. The remaining studies did not report values, used age as a continuous or ordered categorical variable, or reported results from a multivariate discriminant function analysis. Three studies reported age-related odds ratios in several strata. We organized study estimates into 4 age strata based on deciles (50 to 59 years, 60 to 69 years, 70 to 79 years, and ≥80 years). While several studies used this stratification scheme for age, some studies used 1 age category stratification, such as 65 years and older or 60 years and older. We grouped these study values within the 60 to 69 years of age stratification in our analyses. Two studies reported age strata as 50 to 69 years and 70 years and older. We assigned the 50 to 69 years of age category to the 60 to 69 years of age group and the 70 years and older age category to the 70 to 79 years of age group. Sensitivity analyses showed that reassigning the 50 to 69 years of age category to the 50 to 59 years of age group or reassigning the 70 years and older age category to the 80 years and older age group had little effect on the results. The odds that patients experienced a postoperative pulmonary complication increase systematically with age (**Table 1**), with older age categories conferring higher postoperative pulmonary complication risk, even after trim-and-fill correction for publication bias. Odds ratios for the 60 to 69 years of age group and 70 to 79 years of age group are 2.09 (95% CI, 1.66 to 2.64) and 3.04 (CI, 2.11 to 4.39), respectively.

While unadjusted risk due to increasing age was previously believed to be due to accumulating comorbid conditions, our review indicates that advanced age is an important independent predictor of postoperative pulmonary complications even after adjustment for comorbid conditions.

Chronic Lung Disease

Among studies reporting multivariable analyses, chronic obstructive pulmonary disease was the most frequently identified risk factor for postoperative pulmonary complications. Thirteen of 15 studies that entered this factor into a multivariate model reported it to be a statistically significant predictor of postoperative pulmonary complications. Eight studies—2 good-quality studies, 4 fair-quality studies, and 2 poor-quality studies—provided odds ratios with SEs, 95% CIs, or both. The trim-and-fill bias-corrected odds ratio for chronic obstructive pulmonary disease is 1.79 (CI, 1.44 to 2.22).

Two small, poor-quality studies reported unadjusted postoperative pulmonary complication rates for patients with and without abnormal findings on chest examination (40, 73). Postoperative pulmonary complications occurred in 35 of 57 patients with abnormal findings. Only 1 of these 2 studies reported postoperative pulmonary complication rates for patients with chronic obstructive pulmonary disease (40). One multivariable study reported that abnormal findings on chest examination (defined as decreased breath sounds, prolonged expiration, rales, wheezes, or rhonchi) were the strongest predictor of postoperative pulmonary complication rates (odds ratio, 5.8 [CI, 1.04 to 32.1]) (110). While the data indicate a higher postoperative pulmonary complication risk for patients with abnormal findings, the magnitude of this effect is uncertain because of the small number of studies. One study evaluated the cough test as a potential tool to stratify risk (126). To perform a cough test, the patient takes a deep breath and coughs once. A positive test result is recurrent coughing. The adjusted odds ratio for postoperative pulmonary complication was 3.8 ($P = 0.01$).

No eligible study determined the incremental postoperative pulmonary complication risk for patients with chronic restrictive lung disease or restrictive physiology due to neuromuscular disease or chest wall deformity, such as kyphoscoliosis.

Cigarette Use

Five multivariable studies (3 good-quality and 2 fair-quality studies) provided odds ratios, with SEs, 95% CIs, or both, of the effect of cigarette use on postoperative pulmonary complication rates. The trim-and-fill bias-adjusted odds ratio for cigarette use is 1.26 (CI, 1.01 to 1.56), suggesting a modest increase in postoperative pulmonary complication risk among patients with a smoking history.

Studies evaluating the effect of smoking cessation on postoperative pulmonary complication rates have generally evaluated patients undergoing pulmonary or cardiac surgery, which we excluded from our review. One multivariable study of 410 patients undergoing elective general, orthopedic, urologic, or cardiovascular surgery reported an adjusted odds ratio of 5.5 (CI, 1.9 to 16.2) for the risk for postoperative pulmonary complications in current smokers versus nonsmokers (114). Of interest, current smokers who attempted to reduce cigarette use shortly before surgery were more likely to develop a postoperative pulmonary complication than those who continued usual smoking habits. The adjusted odds ratio was 6.7 (CI, 2.6 to 17.1). Possible explanations include selection bias (patients who correctly perceived themselves as being at high risk for complications may have been more likely to attempt to reduce cigarette use before surgery) or a transient increase in cough and sputum production in the first 1 to 2 months after cigarette cessation. In a study of self-reported duration of smoking cessation before minor surgeries, 2 months of preoperative smoking cessation was necessary for intraoperative sputum volume to decrease to the baseline levels of nonsmokers (129).

Congestive Heart Failure

Three good-quality multivariable risk factor studies identified congestive heart failure as a statistically significant risk factor for postoperative pulmonary complications. While the estimates are variable ($I^2 = 91\%$), the DerSimonian–Laird random-effects estimate for the risk associated with congestive heart failure is 2.93 (CI, 1.02 to 8.43). Both the standard and trim-and-fill bias-adjusted methods produce similar estimates (**Table 1**).

Comorbid Condition Measures

Investigators have evaluated several integrated measures of comorbid conditions as potential predictors of postoperative pulmonary complications. The American Society of Anesthesiologists' (ASA) classification aims to predict perioperative mortality but has since been proven to predict both postoperative pulmonary and cardiac complications (102). The 5 ASA classes are 1) a normally healthy patient (class I), 2) a patient with mild systemic disease (class II), 3) a patient with systemic disease that is not incapacitating (class III), 4) a patient with an incapacitating systemic disease that is a constant threat to life (class IV), and 5) a moribund patient who is not expected to survive for 24 hours with or without operation (class V) (130). In our review, 12 studies (1 good-quality study, 2 fair-quality studies, and 9 poor-quality studies) stratified postoperative pulmonary complication rates by ASA class. Since ASA class is a subjective composite clinical judgment based on several risk factors, we organized the data according to 2 criteria, ASA class II or higher versus ASA class lower than II and ASA class III or higher versus ASA class lower than III, and we generated pooled odds ratios for each criterion (**Table 1** and **Appendix Table 5**, available at www.annals.org). Using either approach, higher ASA class is associated with a substantial increase in postoperative pulmonary complication risk (odds ratios, 4.87 [CI, 3.34 to 7.10] and 2.55 [CI, 1.73 to 3.76], respectively).

In 1 eligible nested case–control study of patients undergoing elective abdominal surgery, the authors studied the predictive value of the Charlson comorbidity index for postoperative pulmonary complications (110). This is a multidisease-specific (incorporating 19 medical conditions), weighted summary measure that considers both number and severity of diseases. Possible summary scores range from 0 to 37 (131). Among 82 patients with postoperative pulmonary complications and controls without postoperative pulmonary complications matched by operation type and age, the Charlson comorbidity index score was 1 of 4 independent, statistically significant risk factors in a multivariable analysis (odds ratio, 1.6 [CI, 1.0 to 2.6] per point).

Functional Dependence

The 2 largest eligible trials from the NSQIP evaluated functional dependence as a potential risk factor for postoperative pulmonary complications (118, 120). Total dependence was the inability to perform any activities of daily living (for example, a dependent patient in a nursing home). Partial dependence was the need for equipment or devices and assistance from another person for some activities of daily living. Our pooled estimates of odds ratios for total and partial dependence are 2.51 (CI, 1.99 to 3.15) and 1.65 (CI, 1.36 to 2.01), respectively.

Obesity

Decreased lung volumes after surgery is a principal cause of postoperative pulmonary complications. Obesity may lead to restrictive pulmonary physiology and may further reduce lung volumes and the ability to take a deep breath after surgery. However, studies evaluating clinically meaningful pulmonary complications after surgery have generally found no increased risk, even for patients with morbid obesity (132, 133). In our review, 9 studies (4 fair-quality and 5 poor-quality studies) reported only unadjusted data (7134 total patients [range, 114 patients to 2964 patients]) and 2 of 8 multivariable studies (1 good-quality study and 1 fair-quality study) determined postoperative pulmonary complication rates for obese patients (**Appendix Table 6**, available at www.annals.org). Definitions of obesity varied from a body mass index (BMI) of 25 kg/m^2 or greater to "morbid obesity." Of the 8 studies that reported multivariable models, obesity was an independent risk factor in only 1 study. In studies that reported only univariate results, postoperative pulmonary complication rates are similar in obese and nonobese patients (6.3% and 7.0%, respectively).

Even among obese patients, those with greater obesity did not seem to have an increased postoperative pulmonary complication risk. In a study of 197 morbidly obese patients undergoing gastric bypass surgery, authors stratified patients by BMI (99). Postoperative pulmonary complication rates were 10% for patients with a BMI of 43 kg/m^2 or less and 12% for those with a BMI greater than 43 kg/m^2. This difference was not statistically significant.

Obstructive Sleep Apnea

Obstructive sleep apnea increases the risk for airway management difficulties in the immediate postoperative period, but its influence on postoperative pulmonary complication rates has not been well studied. We identified 1 univariate study that evaluated the risk due to obstructive sleep apnea among patients undergoing hip or knee replacement (92). The case–control study (101 patients with obstructive sleep apnea and 101 matched controls) found non–statistically significant trends toward higher rates of reintubation, hypercapnia, and hypoxemia for patients with obstructive sleep apnea. The authors did not measure rates of postoperative pneumonia or respiratory failure. However, differences for unplanned intensive care unit transfers (20% vs. 6%), all serious complications (24% vs. 9%), and length of stay (6.8 days vs. 5.1 days) were statistically significant. While we await further research, these findings suggest that postoperative pulmonary complication rates may be higher among patients with obstructive sleep apnea.

Impaired Sensorium

Two large trials from the NSQIP evaluated the influence of impaired sensorium on respiratory failure (118) and pneumonia (120) after major noncardiac surgery. The authors defined impaired sensorium as 1) an acutely confused or delirious patient who can respond to verbal or mild tactile stimulation or both or 2) a patient with mental status changes, delirium, or both in the context of current illness. This definition excluded patients with stable chronic mental illness or dementia. Our pooled odds ratio estimate for impaired sensorium is 1.39 (CI, 1.08 to 1.79).

Table 2. **Procedure-Related Risk Factors for Postoperative Pulmonary Complications**

Risk Factor	Studies, *n*	Pooled Estimate Odds Ratio (95% CI)*	I^2, %†	Trim-and-Fill Estimate Odds Ratio (95% CI)*
Surgical site				
Aortic	2	6.90 (2.74–17.36)	97.30	–
Thoracic	3	4.24 (2.89–6.23)	89.70	4.24 (2.89–6.23)
Any abdominal	6	3.09 (2.54–3.77)	59.50	3.01 (2.43–3.72)
Upper abdominal	4	2.96 (2.40–3.63)	66.40	2.91 (2.35–3.60)
Neurosurgery	2	2.53 (1.84–3.47)	71.00	–
Head and neck	2	2.21 (1.82–2.68)	0.00	–
Vascular	2	2.10 (0.81–5.42)	98.70	–
Emergency surgery	6	2.52 (1.69–3.75)	93.80	2.21 (1.57–3.11)
Prolonged surgery	5	2.26 (1.47–3.47)	67.80	2.26 (1.47–3.47)
General anesthesia	6	2.35 (1.77–3.12)	81.70	1.83 (1.35–2.46)
Transfusion (>4 units)	2	1.47 (1.26–1.71)	0.00	–

* Estimates derived from meta-analysis of adjusted odds ratios from multivariable studies.
† For I^2 definition and values, see the Appendix, available at www.annals.org.

Other Patient-Related Factors

Among eligible studies in our review, diabetes and asthma did not influence postoperative pulmonary complication rates (see Appendix, available at www.annals.org, for details). Five studies (2 fair-quality and 3 poor-quality studies) provided unadjusted estimates for postoperative pulmonary complication rates among patients with diabetes. Postoperative pulmonary complication rates for diabetes varied from 6% to 40% among these studies, with a median rate of 21%. Among 4 studies that provided unadjusted data on postoperative pulmonary complication rates for patients with asthma ($n = 895$), the unadjusted postoperative pulmonary complication rate was 3.0%, which is similar to the crude adjusted postoperative pulmonary complication rate for all studies in our review (3.4%). For 2 additional patient-related factors, exercise capacity and HIV infection, the evidence (on the basis of 1 study each) was insufficient to determine the influence on postoperative pulmonary complication rates (see Appendix, available at www.annals.org).

Procedure-Related Risk Factors

Table 2 displays the unadjusted and adjusted summary estimates for procedure-related risk factors, including surgical site, duration of surgery, anesthetic technique, and emergency surgery.

Surgical Site

We obtained unadjusted postoperative pulmonary complication rates for upper abdominal, lower abdominal, and any abdominal surgery from 43 studies. These were 19.7%, 7.7% and 14.2%, respectively (**Appendix Table 7**, available at www.annals.org). The unadjusted postoperative pulmonary complication rate for 11 studies of patients undergoing esophagectomy was 18.9%. Among 16 studies of patients undergoing abdominal aortic aneurysm repair, the unadjusted postoperative pulmonary complication rate was 25.5%. Head and neck surgery (6 studies) carried an intermediate risk (unadjusted postoperative pulmonary complication rate, 10.3%). Low-risk procedures were hip surgery (5 studies) and gynecologic or urologic procedures (2 studies), and the unadjusted postoperative pulmonary complication rates were 5.1% and 1.8%, respectively.

The multivariable risk factor studies were heterogeneous in how each handled type of surgery, surgical site, or both. The I^2 index for surgical sites ranged from 66.4% to 98.7% for all surgical sites except head and neck surgeries. Seven studies included all noncardiac surgeries but provided only crude postoperative pulmonary complication rates for each type of surgery. Among the 14 studies providing information on abdominal surgeries, 5 studies restricted their sample to patients undergoing upper or lower abdominal surgery, 2 studies compared major abdominal surgery with minor abdominal surgery, 3 studies compared general abdominal surgery with other noncardiac surgeries, and 4 studies compared upper abdominal surgery with lower abdominal or other noncardiac surgeries. Two studies focused on specific high-risk surgical procedures, such as esophagectomy (124) and thoracoabdominal aortic (104) surgeries. Only the 2 largest good-quality NSQIP studies provided a comprehensive assessment of the effect of type of surgery on postoperative pulmonary complication rates (118, 120). These 2 studies are the only source of adjusted estimates for aortic, head and neck, neurologic, and peripheral vascular surgeries (**Appendix Table 3**, available at www.annals.org).

Patients undergoing open aortic surgeries are at the highest risk for postoperative pulmonary complications (odds ratio, 6.90 [CI, 2.74 to 17.36]). One cohort study compared postoperative pulmonary complication rates for open surgical repair of abdominal aortic aneurysms and endovascular repair (125). After multivariable adjustment for patient-related confounders, the hazard ratio for endovascular repair was 0.14 (CI, 0.04 to 0.47) compared with open surgery. Other high-risk surgeries include thoracic (odds ratio, 4.24 [CI, 2.89 to 6.23]) and upper abdominal operation (odds ratio, 2.91 [CI, 2.35 to 3.60]). Three good-quality and 3 fair-quality multivariable risk factor studies provided estimates of the effect of any abdominal surgery on postoperative pulmonary complication rates. The trim-and-fill bias-corrected odds ratio for any abdominal surgery is 3.01 (CI, 2.43 to 3.72). For surgical procedures with 3 or more studies, trim-and-fill estimates for the surgical procedures differ little from the original random-effects estimates. Much of the observed heterogeneity (I^2 = 59.5%) is attributable to differences in composition of the reference group or criteria for defining a postoperative pulmonary complication.

Duration of Surgery

Five fair-quality multivariable risk factor studies provided odds ratios, with SEs, CIs, or both, for prolonged surgery. The definition of prolonged surgery ranged from 2.5 hours to 4 hours. Publication bias for estimates of the effect of prolonged surgery on postoperative pulmonary complication rates was not very evident. The pooled odds ratio for prolonged surgery is 2.26 (CI, 1.47 to 3.47). This finding contrasts with data on postoperative cardiac complications, where duration of surgery is not an independent predictor and does not appear in any commonly used cardiac risk index (1, 134).

Anesthetic Technique

Two good-quality and 4 fair-quality studies provided estimates for postoperative pulmonary complication risk attributable to the use of general anesthesia. The studies were heterogeneous (I^2 = 81.7%). The trim-and-fill bias-corrected odds ratio is 1.83 (CI, 1.35 to 2.46).

Emergency Surgery

Six multivariable risk factor studies—2 good-quality, 2 fair-quality, and 2 poor-quality studies—provided odds ratios, with SEs and CIs, for emergency versus elective surgery. The trim-and-fill bias-corrected odds ratio for emergency surgery is 2.21 (CI, 1.57 to 3.11). Patients undergoing emergency surgery incur a modest risk for the development of postoperative pulmonary complications.

Laboratory Testing To Estimate Risk

Spirometry

The first systematic review of the predictive value of preoperative spirometry, published in 1989, concluded that its value was unproven (135). A subsequent economic evaluation found that estimated annual real costs for preoperative spirometry are $25 million to $45 million in 1991 U.S. dollars (136). If use of spirometry were reduced to meet current guidelines, potential savings to third-party payers would range from $29 million to $111 million.

We identified 14 additional eligible studies for our review that evaluated the ability of preoperative spirometry to stratify postoperative pulmonary complication risk (**Appendix Table 8**, available at www.annals.org) (28, 50, 52, 57, 60, 73, 102, 108, 112, 115, 137–140). Ten studies provided unadjusted univariate data for postoperative pulmonary complications on the basis of particular laboratory findings. In 1 study, 6 of 22 (27%) patients with abnormal results on spirometry had a postoperative pulmonary complication, while fewer patients with normal spirometry results (16 of 100 [16%] patients) had a postoperative pulmonary complication (28). In 3 of 4 studies that determined mean FEV_1 values and 3 studies that determined mean FVC values, the value was lower for patients who developed a postoperative pulmonary complication than for those who did not. These differences were, however, small and were unlikely to help clinicians undertake risk stratification.

Three studies (*n* = 505) provided categorical groupings of FEV_1 values. The postoperative pulmonary complication rates for patients in the highest and lowest FEV_1 categories were 14.6% and 31.4%, respectively. One study each (*n* = 324 total) performed a similar analysis by using either FVC or FEV_1–FVC ratio and reported similar results (52, 102). None of these studies compared the predictive value of abnormal spirometry results with that of abnormal findings on history or physical examination.

Only 4 eligible studies used multivariable analysis to adjust for potentially relevant clinical variables to determine the independent predictive value of spirometry. Wong and colleagues (108) studied 105 patients undergoing noncardiothoracic surgery who had severe chronic obstructive pulmonary disease (as defined by an $FEV_1 < 1.2$ L and FEV_1–FVC ratio < 75%). In their small, select cohort, FEV_1:FVC less than 50% was 1 of 5 independent risk factors. Three other factors (abdominal surgery, ASA class IV or V, and general anesthesia) conferred higher odds ratios in the multivariable model. In a study of 460 patients undergoing abdominal surgery, FEV_1 less than 61% predicted, Pa_{O_2} less than 9.33 kPa (70 mm Hg), FEV_1 of 61% to 79% predicted, ischemic heart disease, cancer operation, and age were each independent predictors (140). The single strongest factor was FEV_1 less than 61% predicted.

In a third study of 361 patients undergoing upper abdominal surgery, residual volume, diffusing capacity of carbon monoxide (% predicted), and FEV_1 (% predicted) were statistically significant independent predictors of postoperative pulmonary complications (112). Chronic mucus hypersecretion (sputum production for at least 3 months of each year) was the strongest factor and predicted risk to a greater degree than any spirometric value. Finally, the fourth study used a case–control design to study 116 patients undergoing elective abdominal surgery and matched controls (110). In this report, FEV_1 results were similar between case-patients and controls (2.4 L vs. 2.6 L, respectively) and FVC results were identical (3.6 L). Abnormal findings on chest examination, abnormal results on chest radiography, Goldman cardiac risk index, and Charlson comorbidity index were independent predictors of postoperative pulmonary complication. In contrast, spirometry results were not statistically significant in the final model.

No eligible studies provided data on the use of spirometry to stratify risk for patients with restrictive pulmonary disease or restrictive physiology due to chest wall or neuromuscular disease.

The available literature suggests that spirometry may identify patients at higher risk for development of postoperative pulmonary complications; however, the data are mixed. An additional problem is that while spirometry diagnoses obstructive lung disease, this diagnostic clarity does not translate into effective risk prediction for individual patients. Furthermore, the few studies that have compared spirometric data with clinical data have not consistently shown spirometry to be superior to history and physical examination. While consensus exists on the value of spirometry before lung resection and in determining candidacy for coronary artery bypass, its value before extrathoracic surgery remains unproven. Finally, the data do not suggest a prohibitive spirometric threshold below which the risk for surgery is unacceptable. For example, in a study of 107 operations in patients with severe chronic obstructive pulmonary disease ($FEV_1 < 50\%$ predicted and FEV_1–FVC ratio $< 70\%$), 6 deaths and 7 severe postoperative pulmonary complications occurred (50). While this risk is substantial, it may be acceptable when contemplating life-saving surgery.

Chest Radiography

Clinicians frequently order chest radiography as part of a routine preoperative evaluation. This practice is often due to local institutional guidelines requiring chest radiography for all patients older than a particular age. Only 2 univariate studies that met our inclusion criteria stratified postoperative pulmonary complication rates on the basis of the finding of a normal or abnormal preoperative chest radiograph (28, 139). In their small, pooled patient sample ($n = 150$), 46% of patients with an abnormal preoperative chest radiograph had a postoperative pulmonary complication, and the rate for patients with a normal preoperative study was 25%. Two eligible studies used multivariable analysis to determine the effect of an abnormal chest radiograph, and both reported that it was a statistically significant predictor of postoperative pulmonary complication rates (110, 114).

Most studies of the value of preoperative chest radiography, however, have not studied postoperative pulmonary complication as the primary outcome measure but have evaluated the frequency with which an abnormal study changes perioperative management. While these studies do not meet the inclusion criteria for our review, we discuss them in our report to provide additional insight into the value of this commonly ordered test. In a recent review of the value of routine preoperative testing, the authors identified 8 studies ($n = 14\,650$) published from 1980 to 2000 of the frequency with which preoperative chest radiography results influenced perioperative management (141). While 23.1% of preoperative chest radiographs in the sample were abnormal, only 3.0% of studies influenced management. Only 4.9% of chest radiographs among patients younger than 50 years of age were abnormal. In an earlier review of 21 studies ($n = 14\,390$) published between 1966 and 1993 (2 of the studies were included in both reviews), 10% of all routine preoperative chest radiographs were abnormal (142). However, only 1.3% of all studies showed unexpected abnormalities and only 0.1% of all studies influenced management.

From these observations, we conclude that clinicians may predict most abnormal preoperative chest radiographs on the basis of the history and physical examination and that chest radiography only rarely provides unexpected information that influences preoperative management. While existing data on clinical outcomes do not allow firm conclusions, the incremental value of the test in estimating postoperative pulmonary complication risk is small. Limited evidence from multivariable risk factor studies supports the use of preoperative chest radiography for patients with known cardiopulmonary disease and those older than 50 years of age who are undergoing upper abdominal, thoracic, or abdominal aortic aneurysm surgery.

Serum Measures of Renal Function

Two studies using NSQIP data identified a serum blood urea nitrogen level of 7.5 mmol/L or greater (≥ 21 mg/dL) as a statistically significant predictor after multivariable adjustment (118, 120). The risk increased with increasing blood urea nitrogen levels. One study identified serum creatinine level greater than 133 μmol/L (>1.5 mg/dL) as a risk factor after multivariable analysis (123).

Serum Albumin Measurement

Four studies that reported univariate analyses ($n = 56\,050$) stratified postoperative pulmonary complication rates by serum albumin level and used a threshold of 36 g/L to define low serum albumin level (62, 88, 143, 144). Unadjusted postoperative pulmonary complication rates for patients with low and normal serum albumin levels were 27.6% and 7.0%, respectively. Our review of studies reporting multivariable analyses confirms the value of a low serum albumin level as an important predictor of postoperative pulmonary complications. In 4 of 5 eligible studies that considered albumin level, it was an independent risk factor for postoperative pulmonary complications (low level values defined variably from 30 g/L to 39 g/L) (100, 101, 109, 118, 145). In the 1 study that provided an adjusted estimate of risk, the odds ratio was 2.53 (CI, 2.04 to 2.56) (118).

This is consistent with the NSQIP report that a low serum albumin level was also the most important predictor of 30-day perioperative morbidity and mortality (88). In the report, the relationship between serum albumin levels

Table 3. **Summary Strength of the Evidence for the Association of Patient, Procedure, and Laboratory Factors with Postoperative Pulmonary Complications***

Factor	Strength of Recommendation†	Odds Ratio‡
Potential patient-related risk factor		
Advanced age	A	2.09–3.04
ASA class ≥ II	A	2.55–4.87
CHF	A	2.93
Functionally dependent	A	1.65–2.51
COPD	A	1.79
Weight loss	B	1.62
Impaired sensorium	B	1.39
Cigarette use	B	1.26
Alcohol use	B	1.21
Abnormal findings on chest examination	B	NA
Diabetes	C	
Obesity	D	
Asthma	D	
Obstructive sleep apnea	I	
Corticosteroid use	I	
HIV infection	I	
Arrhythmia	I	
Poor exercise capacity	I	
Potential procedure-related risk factor		
Aortic aneurysm repair	A	6.90
Thoracic surgery	A	4.24
Abdominal surgery	A	3.01
Upper abdominal surgery	A	2.91
Neurosurgery	A	2.53
Prolonged surgery	A	2.26
Head and neck surgery	A	2.21
Emergency surgery	A	2.21
Vascular surgery	A	2.10
General anesthesia	A	1.83
Perioperative transfusion	B	1.47
Hip surgery	D	
Gynecologic or urologic surgery	D	
Esophageal surgery	I	
Laboratory tests		
Albumin level < 35 g/L	A	2.53
Chest radiography	B	4.81
BUN level > 7.5 mmol/L (>21 mg/dL)	B	NA
Spirometry	I	

* ASA = American Society of Anesthesiologists; BUN = blood urea nitrogen; CHF = congestive heart failure; COPD = chronic obstructive pulmonary disease; NA = not available.
† Recommendations: A = good evidence to support the particular risk factor or laboratory predictor; B = at least fair evidence to support the particular risk factor or laboratory predictor; C = at least fair evidence to suggest that the particular factor is not a risk factor or that the laboratory test does not predict risk; D = good evidence to suggest that the particular factor is not a risk factor or that the laboratory test does not predict risk; I = insufficient evidence to determine whether the factor increases risk or whether the laboratory test predicts risk, and evidence is lacking, is of poor quality, or is conflicting. From reference 12.
‡ For factors with A or B ratings. Odds ratios are trim-and-fill estimates. When these estimates were not possible, we provide the pooled estimate.

and mortality was continuous for values less than approximately 35 g/L without a clear threshold value.

Oropharyngeal Culture

One eligible univariate study evaluated the value of preoperative oropharyngeal culture to predict postoperative pulmonary complication risk before upper abdominal surgery (51). The evidence is insufficient to determine the influence of this test on postoperative pulmonary complication rates (see Appendix, available at www.annals.org, for details).

Pulmonary Risk Indices

While clinicians have used preoperative cardiac indices for more than 3 decades (1), early efforts to develop perioperative pulmonary risk indices for pulmonary and nonpulmonary surgery were limited by conflicting results in validation cohorts (113, 146–148). More recently, Arozullah and colleagues (118, 120) developed 2 indices on the basis of NSQIP data. In the multifactorial postoperative respiratory failure index, Arozullah and colleagues (118) identified statistically significant risk factors in a multivariable analysis of 81 719 male veterans undergoing major noncardiac surgery and validated the index in an additional cohort. The definition of respiratory failure was mechanical ventilation for more than 48 hours or unplanned intubation. The final weighted index included 7 factors. Procedure-related factors dominated the index, which included type of surgery (abdominal aortic aneurysm [27 points]; thoracic [21 points]; neurosurgery, upper abdominal, or peripheral vascular [14 points]; neck [11 points]), emergency surgery (11 points), albumin level less than 30 g/L (9 points), blood urea nitrogen level greater than 10.71 mmol/L (>30 mg/dL) (8 points), partially or fully dependent functional status (7 points), chronic obstructive pulmonary disease (6 points), and age (≥70 years [6 points] or 60 to 69 years [4 points]).

A similarly derived postoperative pneumonia index differed by greater relative weight to age and the inclusion of weight loss, general anesthesia, impaired sensorium, history of cerebrovascular accident, transfusion of more than 4 units, emergency surgery, steroid use for chronic condition, current smoker within 1 year, and alcohol intake of more than 2 drinks per day in the past 2 weeks (120).

These rigorously derived indices from a large cohort advance the field of pulmonary risk stratification. The prominence of unmodifiable risk factors was notable in both indices. These indices, however, allow clinicians to reconsider the indications for surgery in a high-risk patient and suggest patients who will most benefit from strategies to reduce the risk for postoperative pulmonary complications.

DISCUSSION

Postoperative pulmonary complications are common and are an important cause of perioperative morbidity. We present data from a systematic review of the literature on preoperative risk stratification for postoperative pulmonary complications after noncardiothoracic surgery. **Table 3** provides the summary strength of the evidence and odds ratios for the association of patient, procedure, and laboratory factors with postoperative pulmonary complications. Among patient-related risk factors, good evidence supports advanced age, ASA class II or greater, functional dependence, chronic obstructive pulmonary disease, and congestive heart failure. Fair evidence, based on fewer studies or a lower odds ratio, supports impaired sensorium, abnormal findings on chest examination, cigarette use, alcohol use, and weight loss. Good evidence suggests that obesity and well-controlled asthma are not risk factors. Fair evidence, based on a single large study, suggests that poorly controlled asthma confers an increased risk. Evidence is insufficient to estimate risk due to obstructive sleep apnea, corticosteroid use, or poor exercise capacity.

The surgical site is an important factor for predicting postoperative pulmonary complication risk. Surgeons and medical consultants have recognized for decades that certain procedures incur inherently higher risk for postoperative pulmonary complications. Our review confirms this observation. The major procedure-related risk factors confer higher risk for pulmonary complications than that of patient-related risk factors. Good evidence supports aortic aneurysm repair, thoracic surgery, abdominal surgery, neurosurgery, vascular surgery, and head and neck surgery. Good evidence also supports the procedure-related risk factors of emergency surgery and prolonged surgery. While good evidence supports general anesthesia as a risk factor on the basis of adjusted observational data, randomized, controlled trials have not consistently reported an effect of anesthetic type on postoperative pulmonary complication rates (see accompanying review [11]). Fair evidence supports esophageal surgery and perioperative transfusion as risk factors.

The value of preoperative testing to estimate pulmonary risk is perhaps the most controversial area in the field of preoperative pulmonary evaluation. While some reports have suggested that certain tests, such as spirometry, identify a subset of high-risk patients, few studies have systematically compared the incremental risk attributable to abnormal preoperative testing with that obtained by history and physical examination. Among potential laboratory tests to stratify risk, a serum albumin level less than 35 g/L is the most powerful predictor and predicts risk to a similar degree as the most important patient-related risk factors. Fair evidence supports a serum blood urea nitrogen level of 7.5 mmol/L or greater ($\geq$21 mg/dL) as a risk factor, but the magnitude of the risk seems to be less than that for low serum albumin level.

While spirometry may provide some risk stratification, most patients identified as high risk by spirometry can be identified equally well by clinical evaluation. Evidence is insufficient to determine whether spirometry provides incremental value as a tool to estimate postoperative pulmonary complication risk. The evidence does not support the use of routine spirometry to stratify risk before noncardiothoracic surgery. Reasonable, although untested, indications include the evaluation of dyspnea when the cause is not apparent by history and physical examination (that is, cardiac causes, pulmonary causes, and deconditioning are all considerations) and in the patient with chronic obstructive pulmonary disease or asthma only if it is uncertain whether airflow obstruction has been maximally reduced before elective surgery. No eligible study in our review provided data on the predictive value of arterial blood gas analyses. Clinicians may anticipate most abnormal preoperative chest radiographs on clinical grounds, and the test infrequently changes preoperative management. Fair evidence supports that an abnormal chest radiograph identifies a cohort of patients with an increased risk for postoperative pulmonary complications.

Research methods in the literature have improved over the past 2 decades, but substantial problems remain. Notable limitations include study sample sizes that are too small to measure clinically relevant pulmonary outcomes, unblinded outcome assessment, inconsistencies in definitions of postoperative pulmonary complication, dependence on observational studies, and statistical issues. The preponderance of the literature consists of observational studies that focus on the discovery of potential risk factors rather than direct hypothesis testing.

Most studies use univariate prescreening and multivariable selection methods to identify a subset of statistically significant risk factors. The net effect is the introduction of a subtle form of publication bias into effect estimates. We used the random-effects trim-and-fill estimates to adjust for publication bias. The trim-and-fill estimates provide an assessment of the sensitivity of our results to the effects of publication bias. Recent methodologic studies, however, suggest that the trim-and-fill method may inappropriately adjust for publication bias where none exists, particularly when study estimates are heterogeneous (149). The net result may be an overcorrection for publication bias; therefore, the reader must exercise care in interpreting the meaning of the actual values.

The literature has developed to a point that we have, in our review, identified a set of potentially important risk factors. Future studies should be large enough to adjust for most, if not all, of these factors to move from exploratory studies to hypothesis testing and confirmatory studies. Investigators should strive to use outcome assessment that is blinded to preoperative risk status.

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References

1. **Goldman L, Caldera DL, Nussbaum SR, Southwick FS, Krogstad D, Murray B, et al.** Multifactorial index of cardiac risk in noncardiac surgical procedures. N Engl J Med. 1977;297:845-50. [PMID: 904659]
2. **Lawrence VA, Hilsenbeck SG, Noveck H, Poses RM, Carson JL.** Medical complications and outcomes after hip fracture repair. Arch Intern Med. 2002; 162:2053-7. [PMID: 12374513]
3. **Thomas EJ, Goldman L, Mangione CM, Marcantonio ER, Cook EF, Ludwig L, et al.** Body mass index as a correlate of postoperative complications and resource utilization. Am J Med. 1997;102:277-83. [PMID: 9217597]
4. **Rosen AK, Geraci JM, Ash AS, McNiff KJ, Moskowitz MA.** Postoperative adverse events of common surgical procedures in the Medicare population. Med Care. 1992;30:753-65. [PMID: 1518309]
5. **Escarce JJ, Shea JA, Chen W, Qian Z, Schwartz JS.** Outcomes of open cholecystectomy in the elderly: a longitudinal analysis of 21,000 cases in the prelaparoscopic era. Surgery. 1995;117:156-64. [PMID: 7846619]
6. **Pedersen T.** Complications and death following anaesthesia. A prospective study with special reference to the influence of patient-, anaesthesia-, and surgery-related risk factors. Dan Med Bull. 1994;41:319-31. [PMID: 7924461]
7. **Manku K, Bacchetti P, Leung JM.** Prognostic significance of postoperative in-hospital complications in elderly patients. I. Long-term survival. Anesth Analg. 2003;96:583-9. [PMID: 12538216]
8. **Kinugasa S, Tachibana M, Yoshimura H, Ueda S, Fujii T, Dhar DK, et al.** Postoperative pulmonary complications are associated with worse short- and long-term outcomes after extended esophagectomy. J Surg Oncol. 2004;88:71-7. [PMID: 15499604]
9. Guidelines for assessing and managing the perioperative risk from coronary artery disease associated with major noncardiac surgery. American College of Physicians. Ann Intern Med. 1997;127:309-12. [PMID: 9265433]
10. **Eagle KA, Berger PB, Calkins H, Chaitman BR, Ewy GA, Fleischmann KE, et al.** ACC/AHA guideline update for perioperative cardiovascular evaluation for noncardiac surgery—executive summary. A report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (Committee to Update the 1996 Guidelines on Perioperative Cardiovascular Evaluation for Noncardiac Surgery). Circulation. 2002;105:1257-67. [PMID: 11889023]
11. **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.
12. **Harris RP, Helfand M, Woolf SH, Lohr KN, Mulrow CD, Teutsch SM, et al.** Current methods of the US Preventive Services Task Force: a review of the process. Am J Prev Med. 2001;20:21-35. [PMID: 11306229]
13. **Higgins JP, Thompson SG.** Quantifying heterogeneity in a meta-analysis. Stat Med. 2002;21:1539-58. [PMID: 12111919]
14. **Cochran WG.** The combination of estimates from different experiments. Biometrics. 1954;10:101-29.
15. **DerSimonian R, Laird N.** Meta-analysis in clinical trials. Control Clin Trials. 1986;7:177-88. [PMID: 3802833]
16. **Duval S, Tweedie R.** A nonparametric "trim and fill" method of accounting for publication bias in meta-analysis. J Am Stat Assoc. 2000;95:89-98.
17. **Sutton AJ, Duval SJ, Tweedie RL, Abrams KR, Jones DR.** Empirical assessment of effect of publication bias on meta-analyses. BMJ. 2000;320:1574-7. [PMID: 10845965]
18. Stata User's Guide. Release 8. College Station, TX: Stata Pr; 2003.
19. **Fasth S, Hellberg R, Hultén L, Magnusson O.** Early complications after surgical treatment for Crohn's disease with particular reference to factors affecting their development. Acta Chir Scand. 1980;146:519-26. [PMID: 7223290]
20. **Warren CP, Grimwood M.** Pulmonary disorders and physiotherapy in patients who undergo cholecystectomy. Can J Surg. 1980;23:384-6. [PMID: 7417902]
21. **Wirén JE, Janzon L.** Respiratory complications following surgery. Improved prediction with preoperative spirometry. Acta Anaesthesiol Scand. 1983;27:476-9. [PMID: 6666525]
22. **Seymour DG, Pringle R.** Post-operative complications in the elderly surgical patient. Gerontology. 1983;29:262-70. [PMID: 6873640]
23. **Diehl JT, Cali RF, Hertzer NR, Beven EG.** Complications of abdominal aortic reconstruction. An analysis of perioperative risk factors in 557 patients. Ann Surg. 1983;197:49-56. [PMID: 6848054]
24. **Buckwalter JA, Herbst CA Jr.** Perioperative complications of gastric restrictive operations. Am J Surg. 1983;146:613-8. [PMID: 6638266]
25. **Galicier C, Richet H.** A prospective study of postoperative fever in a general surgery department. Infect Control. 1985;6:487-90. [PMID: 3852797]
26. **Beard K, Jick H, Walker AM.** Adverse respiratory events occurring in the recovery room after general anesthesia. Anesthesiology. 1986;64:269-72. [PMID: 3946814]
27. **Matsumata T, Kanematsu T, Okudaira Y, Sugimachi K, Zaitsu A, Hirabayashi M.** Postoperative mechanical ventilation preventing the occurrence of pleural effusion after hepatectomy. Surgery. 1987;102:493-7. [PMID: 3629477]
28. **Fogh J, Willie-Jørgensen P, Brynjolf I, Thorup J, Jørgensen T, Bording L, et al.** The predictive value of preoperative perfusion/ventilation scintigraphy, spirometry and x-ray of the lungs on postoperative pulmonary complications. A prospective study. Acta Anaesthesiol Scand. 1987;31:717-21. [PMID: 3501664]
29. **Zelcer J, Wells DG.** Anaesthetic-related recovery room complications. Anaesth Intensive Care. 1987;15:168-74. [PMID: 3605566]
30. **Fasth S, Hultén L, Magnusson O, Nordgren S, Warnold I.** Postoperative complications in colorectal surgery in relation to preoperative clinical and nutritional state and postoperative nutritional treatment. Int J Colorectal Dis. 1987; 2:87-92. [PMID: 3114397]
31. **Hollier LH, Symmonds JB, Pairolero PC, Cherry KJ, Hallett JW, Gloviczki P.** Thoracoabdominal aortic aneurysm repair. Analysis of postoperative morbidity. Arch Surg. 1988;123:871-5. [PMID: 3382354]
32. **Poe RH, Kallay MC, Dass T, Celebic A.** Can postoperative pulmonary complications after elective cholecystectomy be predicted? Am J Med Sci. 1988; 295:29-34. [PMID: 3122567]
33. **Jørgensen FS, Sørensen CG, Kjaergaard J.** Postoperative fever after major abdominal surgery. Ann Chir Gynaecol. 1988;77:47-50. [PMID: 3232947]
34. **Roberts J, Barnes W, Pennock M, Browne G.** Diagnostic accuracy of fever as a measure of postoperative pulmonary complications. Heart Lung. 1988;17: 166-70. [PMID: 3350683]
35. **Tartter PI.** Blood transfusion and infectious complications following colorectal cancer surgery. Br J Surg. 1988;75:789-92. [PMID: 3167530]
36. **Mellors JW, Kelly JJ, Gusberg RJ, Horwitz SM, Horwitz RI.** A simple index to estimate the likelihood of bacterial infection in patients developing fever after abdominal surgery. Am Surg. 1988;54:558-64. [PMID: 3415099]
37. **Pien LC, Grammer LC, Patterson R.** Minimal complications in a surgical population with severe asthma receiving prophylactic corticosteroids. J Allergy Clin Immunol. 1988;82:696-700. [PMID: 3171010]
38. **Nielsen PH, Jepsen SB, Olsen AD.** Postoperative pleural effusion following upper abdominal surgery. Chest. 1989;96:1133-5. [PMID: 2805843]
39. **Ejlertsen T, Nielsen PH, Jepsen S, Olsen A.** Early diagnosis of postoperative pneumonia following upper abdominal surgery. A study in patients without cardiopulmonary disorder at operation. Acta Chir Scand. 1989;155:93-8. [PMID: 2741621]
40. **Vodinh J, Bonnet F, Touboul C, Lefloch JP, Becquemin JP, Harf A.** Risk factors of postoperative pulmonary complications after vascular surgery. Surgery. 1989;105:360-5. [PMID: 2922676]
41. **Seymour DG, Vaz FG.** A prospective study of elderly general surgical patients: II. Post-operative complications. Age Ageing. 1989;18:316-26. [PMID: 2603840]
42. **Koness RJ, Cutitar M, Burchard KW.** Perforated peptic ulcer. Determinants of morbidity and mortality. Am Surg. 1990;56:280-4. [PMID: 2334066]
43. **Patrick JA, Meyer-Witting M, Reynolds F, Spencer GT.** Peri-operative care in restrictive respiratory disease. Anaesthesia. 1990;45:390-5. [PMID: 2356935]
44. **Verdeil X, Bossavy JP, Roche R, Barret A, Pouns J.** Nosocomial infection surveillance in a vascular surgery unit. Ann Vasc Surg. 1990;4:553-7. [PMID: 2261323]
45. **Arriaga MA, Kanel KT, Johnson JT, Myers EN.** Medical complications in total laryngectomy: incidence and risk factors. Ann Otol Rhinol Laryngol. 1990; 99:611-5. [PMID: 2382932]
46. **Pinto V, Baldonedo R, Nicolas C, Barez A, Perez A, Aza J.** Relationship of

transfusion and infectious complications after gastric carcinoma operations. Transfusion. 1991;31:114-8. [PMID: 1996479]
47. **Hall JC, Tarala RA, Hall JL, Mander J.** A multivariate analysis of the risk of pulmonary complications after laparotomy. Chest. 1991;99:923-7. [PMID: 2009796]
48. **Greco D, Moro ML, Tozzi AE, De Giacomi GV.** Effectiveness of an intervention program in reducing postoperative infections. Italian PRINOS Study Group. Am J Med. 1991;91:164S-169S. [PMID: 1928159]
49. **Katz S, Reiten P, Kohl R.** The use of epidural anesthesia and analgesia in aortic surgery. Am Surg. 1992;58:470-3. [PMID: 1642382]
50. **Kroenke K, Lawrence VA, Theroux JF, Tuley MR.** Operative risk in patients with severe obstructive pulmonary disease. Arch Intern Med. 1992;152:967-71. [PMID: 1580723]
51. **Dilworth JP, White RJ, Brown EM.** Oropharyngeal flora and chest infection after upper abdominal surgery. Thorax. 1991;46:165-7. [PMID: 2028430]
52. **Kispert JF, Kazmers A, Roitman L.** Preoperative spirometry predicts perioperative pulmonary complications after major vascular surgery. Am Surg. 1992;58:491-5. [PMID: 1642387]
53. **Brooks-Brunn JA.** Development of a predictive model for postoperative pulmonary complications after cholecystectomy. Clin Nurs Res. 1992;1:180-95. [PMID: 1301861]
54. **Braga M, Vignali A, Radaelli G, Gianotti L, Di Carlo V.** Association between perioperative blood transfusion and postoperative infection in patients having elective operations for gastrointestinal cancer. Eur J Surg. 1992;158:531-6. [PMID: 1360824]
55. **Evaldson GR, Frederici H, Jullig C, Mannerquist K, Nyström B.** Hospital-associated infections in obstetrics and gynecology. Effects of surveillance. Acta Obstet Gynecol Scand. 1992;71:54-8. [PMID: 1315099]
56. **Iwamoto K, Ichiyama S, Shimokata K, Nakashima N.** Postoperative pneumonia in elderly patients: incidence and mortality in comparison with younger patients. Intern Med. 1993;32:274-7. [PMID: 8358115]
57. **Jayr C, Matthay MA, Goldstone J, Gold WM, Wiener-Kronish JP.** Preoperative and intraoperative factors associated with prolonged mechanical ventilation. A study in patients following major abdominal vascular surgery. Chest. 1993;103:1231-6. [PMID: 8131471]
58. **Kroenke K, Lawrence VA, Theroux JF, Tuley MR, Hilsenbeck S.** Postoperative complications after thoracic and major abdominal surgery in patients with and without obstructive lung disease. Chest. 1993;104:1445-51. [PMID: 8222804]
59. **Ephgrave KS, Kleiman-Wexler R, Pfaller M, Booth B, Werkmeister L, Young S.** Postoperative pneumonia: a prospective study of risk factors and morbidity. Surgery. 1993;114:815-9; discussion 819-21. [PMID: 8211699]
60. **Calligaro KD, Azurin DJ, Dougherty MJ, Dandora R, Bajgier SM, Simper S, et al.** Pulmonary risk factors of elective abdominal aortic surgery. J Vasc Surg. 1993;18:914-20; discussion 920-1. [PMID: 8264047]
61. **Heiss MM, Mempel W, Jauch KW, Delanoff C, Mayer G, Mempel M, et al.** Beneficial effect of autologous blood transfusion on infectious complications after colorectal cancer surgery. Lancet. 1993;342:1328-33. [PMID: 7901637]
62. **Weber RS, Hankins P, Rosenbaum B, Raad I.** Nonwound infections following head and neck oncologic surgery. Laryngoscope. 1993;103:22-7. [PMID: 8421415]
63. **Money SR, Rice K, Crockett D, Becker M, Abdoh A, Wisselink W, et al.** Risk of respiratory failure after repair of thoracoabdominal aortic aneurysms. Am J Surg. 1994;168:152-5. [PMID: 8053516]
64. **Charash WE, Fabian TC, Croce MA.** Delayed surgical fixation of femur fractures is a risk factor for pulmonary failure independent of thoracic trauma. J Trauma. 1994;37:667-72. [PMID: 7932901]
65. **Gefke K, Schroeder TV, Thisted B, Olsen PS, Perko MJ, Agerskov K, et al.** Abdominal aortic aneurysm surgery: survival and quality of life in patients requiring prolonged postoperative intensive therapy. Ann Vasc Surg. 1994;8:137-43. [PMID: 8198946]
66. **Arvidsson S, Ouchterlony J, Nilsson S, Sjöstedt L, Svärdsudd K.** The Gothenburg study of perioperative risk. I. Preoperative findings, postoperative complications. Acta Anaesthesiol Scand. 1994;38:679-90. [PMID: 7839777]
67. **Lawrence VA, Hilsenbeck SG, Mulrow CD, Dhanda R, Sapp J, Page CP.** Incidence and hospital stay for cardiac and pulmonary complications after abdominal surgery. J Gen Intern Med. 1995;10:671-8. [PMID: 8770719]
68. **Kabalin CS, Yarnold PR, Grammer LC.** Low complication rate of corticosteroid-treated asthmatics undergoing surgical procedures. Arch Intern Med. 1995;155:1379-84. [PMID: 7794086]
69. **Gilling-Smith GL, Worswick L, Knight PF, Wolfe JH, Mansfield AO.** Surgical repair of thoracoabdominal aortic aneurysm: 10 years' experience. Br J Surg. 1995;82:624-9. [PMID: 7613932]
70. **Liedman BL, Bennegård K, Olbe LC, Lundell LR.** Predictors of postoperative morbidity and mortality after surgery for gastro-oesophageal carcinomas. Eur J Surg. 1995;161:173-80. [PMID: 7599295]
71. **Choban PS, Heckler R, Burge JC, Flancbaum L.** Increased incidence of nosocomial infections in obese surgical patients. Am Surg. 1995;61:1001-5. [PMID: 7486411]
72. **Hall JC, Tarala RA, Hall JL.** A case-control study of postoperative pulmonary complications after laparoscopic and open cholecystectomy. J Laparoendosc Surg. 1996;6:87-92. [PMID: 8735045]
73. **Kocabas A, Kara K, Ozgur G, Sonmez H, Burgut R.** Value of preoperative spirometry to predict postoperative pulmonary complications. Respir Med. 1996;90:25-33. [PMID: 8857323]
74. **Warner DO, Warner MA, Barnes RD, Offord KP, Schroeder DR, Gray DT, et al.** Perioperative respiratory complications in patients with asthma. Anesthesiology. 1996;85:460-7. [PMID: 8853074]
75. **Wolters U, Wolf T, Stützer H, Schröder T.** ASA classification and perioperative variables as predictors of postoperative outcome. Br J Anaesth. 1996;77:217-22. [PMID: 8881629]
76. **Rose DK, Byrick RJ, Cohen MM, Caskennette GM.** Planned and unplanned postoperative admissions to critical care for mechanical ventilation. Can J Anaesth. 1996;43:333-40. [PMID: 8697546]
77. **Ferguson MK, Martin TR, Reeder LB, Olak J.** Mortality after esophagectomy: risk factor analysis. World J Surg. 1997;21:599-603; discussion 603-4. [PMID: 9230656]
78. **Delgado-Rodríguez M, Medina-Cuadros M, Martínez-Gallego G, Sillero-Arenas M.** Usefulness of intrinsic surgical wound infection risk indices as predictors of postoperative pneumonia risk. J Hosp Infect. 1997;35:269-76. [PMID: 9152819]
79. **Schwilk B, Bothner U, Schraag S, Georgieff M.** Perioperative respiratory events in smokers and nonsmokers undergoing general anaesthesia. Acta Anaesthesiol Scand. 1997;41:348-55. [PMID: 9113178]
80. **Gillinov AM, Heitmiller RF.** Strategies to reduce pulmonary complications after transhiatal esophagectomy. Dis Esophagus. 1998;11:43-7. [PMID: 9595232]
81. **Kuwano H, Sumiyoshi K, Sonoda K, Kitamura K, Tsutsui S, Toh Y, et al.** Relationship between preoperative assessment of organ function and postoperative morbidity in patients with oesophageal cancer. Eur J Surg. 1998;164:581-6. [PMID: 9720934]
82. **Midorikawa Y, Kubota K, Takayama T, Toyoda H, Ijichi M, Torzilli G, et al.** A comparative study of postoperative complications after hepatectomy in patients with and without chronic liver disease. Surgery. 1999;126:484-91. [PMID: 10486600]
83. **Manninen PH, Raman SK, Boyle K, el-Beheiry H.** Early postoperative complications following neurosurgical procedures. Can J Anaesth. 1999;46:7-14. [PMID: 10078396]
84. **Reilly DF, McNeely MJ, Doerner D, Greenberg DL, Staiger TO, Geist MJ, et al.** Self-reported exercise tolerance and the risk of serious perioperative complications. Arch Intern Med. 1999;159:2185-92. [PMID: 10527296]
85. **Ziser A, Plevak DJ, Wiesner RH, Rakela J, Offord KP, Brown DL.** Morbidity and mortality in cirrhotic patients undergoing anesthesia and surgery. Anesthesiology. 1999;90:42-53. [PMID: 9915311]
86. **Haga Y, Ikei S, Ogawa M.** Estimation of Physiologic Ability and Surgical Stress (E-PASS) as a new prediction scoring system for postoperative morbidity and mortality following elective gastrointestinal surgery. Surg Today. 1999;29:219-25. [PMID: 10192731]
87. **Carson JL, Altman DG, Duff A, Noveck H, Weinstein MP, Sonnenberg FA, et al.** Risk of bacterial infection associated with allogeneic blood transfusion among patients undergoing hip fracture repair. Transfusion. 1999;39:694-700. [PMID: 10413276]
88. **Gibbs J, Cull W, Henderson W, Daley J, Hur K, Khuri SF.** Preoperative serum albumin level as a predictor of operative mortality and morbidity: results from the National VA Surgical Risk Study. Arch Surg. 1999;134:36-42. [PMID: 9927128]
89. **Brooks-Brunn JA.** Risk factors associated with postoperative pulmonary complications following total abdominal hysterectomy. Clin Nurs Res. 2000;9:27-46. [PMID: 11271045]
90. **Oñate-Ocaña LF, Cortés-Cárdenas SA, Aiello-Crocifoglio V, Mondragón-**

Sánchez R, Ruiz-Molina JM. Preoperative multivariate prediction of morbidity after gastrectomy for adenocarcinoma. Ann Surg Oncol. 2000;7:281-8. [PMID: 10819368]

91. **Yamashita S, Yamaguchi H, Sakaguchi M, Satsumae T, Yamamoto S, Shinya F.** Longer-term diabetic patients have a more frequent incidence of nosocomial infections after elective gastrectomy. Anesth Analg. 2000;91:1176-81. [PMID: 11049905]

92. **Gupta RM, Parvizi J, Hanssen AD, Gay PC.** Postoperative complications in patients with obstructive sleep apnea syndrome undergoing hip or knee replacement: a case-control study. Mayo Clin Proc. 2001;76:897-905. [PMID: 11560300]

93. **Girish M, Trayner E Jr, Dammann O, Pinto-Plata V, Celli B.** Symptom-limited stair climbing as a predictor of postoperative cardiopulmonary complications after high-risk surgery. Chest. 2001;120:1147-51. [PMID: 11591552]

94. **Hajzman Z, Kabelác K, Kaska M, Simkovic D.** Gastric banding: intraoperative and early postoperative complications and their prevention. Obes Surg. 2001;11:220-2. [PMID: 11355030]

95. **Kinugasa S, Tachibana M, Yoshimura H, Dhar DK, Shibakita M, Ohno S, et al.** Esophageal resection in elderly esophageal carcinoma patients: improvement in postoperative complications. Ann Thorac Surg. 2001;71:414-8. [PMID: 11235680]

96. **Polanczyk CA, Rohde LE, Goldman L, Cook EF, Thomas EJ, Marcantonio ER, et al.** Right heart catheterization and cardiac complications in patients undergoing noncardiac surgery: an observational study. JAMA. 2001;286:309-14. [PMID: 11466096]

97. **Polanczyk CA, Marcantonio E, Goldman L, Rohde LE, Orav J, Mangione CM, et al.** Impact of age on perioperative complications and length of stay in patients undergoing noncardiac surgery. Ann Intern Med. 2001;134:637-43. [PMID: 11304103]

98. **Griffin SM, Shaw IH, Dresner SM.** Early complications after Ivor Lewis subtotal esophagectomy with two-field lymphadenectomy: risk factors and management. J Am Coll Surg. 2002;194:285-97. [PMID: 11893132]

99. **Blouw EL, Rudolph AD, Narr BJ, Sarr MG.** The frequency of respiratory failure in patients with morbid obesity undergoing gastric bypass. AANA J. 2003; 71:45-50. [PMID: 12776650]

100. **Garibaldi RA, Britt MR, Coleman ML, Reading JC, Pace NL.** Risk factors for postoperative pneumonia. Am J Med. 1981;70:677-80. [PMID: 7211900]

101. **Windsor JA, Hill GL.** Risk factors for postoperative pneumonia. The importance of protein depletion. Ann Surg. 1988;208:209-14. [PMID: 3401064]

102. **Gerson MC, Hurst JM, Hertzberg VS, Baughman R, Rouan GW, Ellis K.** Prediction of cardiac and pulmonary complications related to elective abdominal and noncardiac thoracic surgery in geriatric patients. Am J Med. 1990;88:101-7. [PMID: 2301435]

103. **Pedersen T, Eliasen K, Henriksen E.** A prospective study of risk factors and cardiopulmonary complications associated with anaesthesia and surgery: risk indicators of cardiopulmonary morbidity. Acta Anaesthesiol Scand. 1990;34:144-55. [PMID: 2305615]

104. **Svensson LG, Hess KR, Coselli JS, Safi HJ, Crawford ES.** A prospective study of respiratory failure after high-risk surgery on the thoracoabdominal aorta. J Vasc Surg. 1991;14:271-82. [PMID: 1880835]

105. **Williams-Russo P, Charlson ME, MacKenzie CR, Gold JP, Shires GT.** Predicting postoperative pulmonary complications. Is it a real problem? Arch Intern Med. 1992;152:1209-13. [PMID: 1599349]

106. **Oller Sales B, Armengol Carrasco M, Roig Cutillas J, de Castro Gutierrez J, Valero Millan J, Julian Ibanez J, et al.** Lower respiratory tract infections after abdominal operations: epidemiology and risk factors. Eur J Surg. 1992;158: 105-8. [PMID: 1350210]

107. **Pedersen T, Viby-Mogensen J, Ringsted C.** Anaesthetic practice and postoperative pulmonary complications. Acta Anaesthesiol Scand. 1992;36:812-8. [PMID: 1466220]

108. **Wong DH, Weber EC, Schell MJ, Wong AB, Anderson CT, Barker SJ.** Factors associated with postoperative pulmonary complications in patients with severe chronic obstructive pulmonary disease. Anesth Analg. 1995;80:276-84. [PMID: 7818113]

109. **Fujita T, Sakurai K.** Multivariate analysis of risk factors for postoperative pneumonia. Am J Surg. 1995;169:304-7. [PMID: 7879831]

110. **Lawrence VA, Dhanda R, Hilsenbeck SG, Page CP.** Risk of pulmonary complications after elective abdominal surgery. Chest. 1996;110:744-50. [PMID: 8797421]

111. **Hall JC, Tarala RA, Hall JL.** Respiratory insufficiency after abdominal surgery. Respirology. 1996;1:133-8. [PMID: 9434329]

112. **Barisione G, Rovida S, Gazzaniga GM, Fontana L.** Upper abdominal surgery: does a lung function test exist to predict early severe postoperative respiratory complications? Eur Respir J. 1997;10:1301-8. [PMID: 9192933]

113. **Brooks-Brunn JA.** Predictors of postoperative pulmonary complications following abdominal surgery. Chest. 1997;111:564-71. [PMID: 9118688]

114. **Bluman LG, Mosca L, Newman N, Simon DG.** Preoperative smoking habits and postoperative pulmonary complications. Chest. 1998;113:883-9. [PMID: 9554620]

115. **Mitchell CK, Smoger SH, Pfeifer MP, Vogel RL, Pandit MK, Donnelly PJ, et al.** Multivariate analysis of factors associated with postoperative pulmonary complications following general elective surgery. Arch Surg. 1998;133:194-8. [PMID: 9484734]

116. **Pereira ED, Fernandes AL, da Silva Anção M, de Araúja Pereres C, Atallah AN, Faresin SM.** Prospective assessment of the risk of postoperative pulmonary complications in patients submitted to upper abdominal surgery. Sao Paulo Med J. 1999;117:151-60. [PMID: 10559850]

117. **Liu LL, Leung JM.** Predicting adverse postoperative outcomes in patients aged 80 years or older. J Am Geriatr Soc. 2000;48:405-12. [PMID: 10798467]

118. **Arozullah AM, Daley J, Henderson WG, Khuri SF.** Multifactorial risk index for predicting postoperative respiratory failure in men after major noncardiac surgery. The National Veterans Administration Surgical Quality Improvement Program. Ann Surg. 2000;232:242-53. [PMID: 10903604]

119. **Møller AM, Maaløe R, Pedersen T.** Postoperative intensive care admittance: the role of tobacco smoking. Acta Anaesthesiol Scand. 2001;45:345-8. [PMID: 11207472]

120. **Arozullah AM, Khuri SF, Henderson WG, Daley J.** Development and validation of a multifactorial risk index for predicting postoperative pneumonia after major noncardiac surgery. Ann Intern Med. 2001;135:847-57. [PMID: 11712875]

121. **Leung JM, Dzankic S.** Relative importance of preoperative health status versus intraoperative factors in predicting postoperative adverse outcomes in geriatric surgical patients. J Am Geriatr Soc. 2001;49:1080-5. [PMID: 11555070]

122. **Canturk NZ, Canturk Z, Okay E, Yirmibesoglu O, Eraldemir B.** Risk of nosocomial infections and effects of total cholesterol, HDL cholesterol in surgical patients. Clin Nutr. 2002;21:431-6. [PMID: 12381342]

123. **O'Brien MM, Gonzales R, Shroyer AL, Grunwald GK, Daley J, Henderson WG, et al.** Modest serum creatinine elevation affects adverse outcome after general surgery. Kidney Int. 2002;62:585-92. [PMID: 12110022]

124. **Ferguson MK, Durkin AE.** Preoperative prediction of the risk of pulmonary complications after esophagectomy for cancer. J Thorac Cardiovasc Surg. 2002;123:661-9. [PMID: 11986593]

125. **Elkouri S, Gloviczki P, McKusick MA, Panneton JM, Andrews J, Bower TC, et al.** Perioperative complications and early outcome after endovascular and open surgical repair of abdominal aortic aneurysms. J Vasc Surg. 2004;39:497-505. [PMID: 14981437]

126. **McAlister FA, Bertsch K, Man J, Bradley J, Jacka M.** Incidence of and risk factors for pulmonary complications after nonthoracic surgery. Am J Respir Crit Care Med. 2005;171:514-7. [PMID: 15563632]

127. **Khuri SF, Daley J, Henderson W, Barbour G, Lowry P, Irvin G, 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; 180:519-31. [PMID: 7749526]

128. **Duane DT, Howard SJ, Kraayenbrink M.** Incidence and predictors of bulbar palsy after surgery for acoustic neuroma. J Neurosurg Anesthesiol. 1997; 9:263-8. [PMID: 9239590]

129. **Yamashita S, Yamaguchi H, Sakaguchi M, Yamamoto S, Aoki K, Shiga Y, et al.** Effect of smoking on intraoperative sputum and postoperative pulmonary complication in minor surgical patients. Respir Med. 2004;98:760-6. [PMID: 15303641]

130. **Owens WD, Felts JA, Spitznagel EL Jr.** ASA physical status classifications: a study of consistency of ratings. Anesthesiology. 1978;49:239-43. [PMID: 697077]

131. **Charlson ME, Pompei P, Ales KL, MacKenzie CR.** A new method of classifying prognostic comorbidity in longitudinal studies: development and validation. J Chronic Dis. 1987;40:373-83. [PMID: 3558716]

132. **Smetana GW.** Preoperative pulmonary evaluation. N Engl J Med. 1999; 340:937-44. [PMID: 10089188]

133. **Sterling RK.** Management of gastrointestinal disease in liver transplant recipients. Gastrointest Endosc Clin N Am. 2001;11:185-97. [PMID: 11175981]

134. **Lee TH, Marcantonio ER, Mangione CM, Thomas EJ, Polanczyk CA, Cook EF, et al.** Derivation and prospective validation of a simple index for prediction of cardiac risk of major noncardiac surgery. Circulation. 1999;100:1043-9. [PMID: 10477528]
135. **Lawrence VA, Page CP, Harris GD.** Preoperative spirometry before abdominal operations. A critical appraisal of its predictive value. Arch Intern Med. 1989;149:280-5. [PMID: 2644901]
136. **De Nino LA, Lawrence VA, Averyt EC, Hilsenbeck SG, Dhanda R, Page CP.** Preoperative spirometry and laparotomy: blowing away dollars. Chest. 1997;111:1536-41. [PMID: 9187170]
137. **Poe RH, Dass T, Celebic A.** Small airway testing and smoking in predicting risk in surgical patients. Am J Med Sci. 1982;283:57-63. [PMID: 7064995]
138. **Windsor JA, Hill GL.** Protein depletion and surgical risk. Aust N Z J Surg. 1988;58:711-5. [PMID: 3250431]
139. **Cooper MH, Primrose JN.** The value of postoperative chest radiology after major abdominal surgery. Anaesthesia. 1989;44:306-9. [PMID: 2719202]
140. **Fuso L, Cisternino L, Di Napoli A, Di Cosmo V, Tramaglino LM, Basso S, et al.** Role of spirometric and arterial gas data in predicting pulmonary complications after abdominal surgery. Respir Med. 2000;94:1171-6. [PMID: 11192952]
141. **Smetana GW, Macpherson DS.** The case against routine preoperative laboratory testing. Med Clin North Am. 2003;87:7-40. [PMID: 12575882]
142. **Archer C, Levy AR, McGregor M.** Value of routine preoperative chest x-rays: a meta-analysis. Can J Anaesth. 1993;40:1022-7. [PMID: 8269561]
143. **McHale JE, Barth MM.** Nursing care after pneumonectomy in patients with invasive pulmonary aspergillosis. Crit Care Nurse. 2000;20:37-44. [PMID: 11871524]
144. **Stühmeier KD, Mainzer B, Cierpka J, Sandmann W, Tarnow J.** Small, oral dose of clonidine reduces the incidence of intraoperative myocardial ischemia in patients having vascular surgery. Anesthesiology. 1996;85:706-12. [PMID: 8873539]
145. **Fan ST, Lau WY, Yip WC, Poon GP, Yeung C, Lam WK, et al.** Prediction of postoperative pulmonary complications in oesophagogastric cancer surgery. Br J Surg. 1987;74:408-10. [PMID: 3594139]
146. **Epstein SK, Faling LJ, Daly BD, Celli BR.** Predicting complications after pulmonary resection. Preoperative exercise testing vs a multifactorial cardiopulmonary risk index. Chest. 1993;104:694-700. [PMID: 8365278]
147. **Melendez JA, Carlon VA.** Cardiopulmonary risk index does not predict complications after thoracic surgery. Chest. 1998;114:69-75. [PMID: 9674449]
148. **Brooks-Brunn JA.** Validation of a predictive model for postoperative pulmonary complications. Heart Lung. 1998;27:151-8. [PMID: 9622401]
149. **Terrin N, Schmid CH, Lau J, Olkin I.** Adjusting for publication bias in the presence of heterogeneity. Stat Med. 2003;22:2113-26. [PMID: 12820277]

Ad Libitum

"The world goes by my cage and never sees me."
—"The Woman in the Washington Zoo"
Randall Jarrell

The Girl in the National Gallery

**She moves through the gallery like a wraith
Trailing images from museum walls—
A rapt El Greco in an act of faith,
A Jan Van Eyck that no one else recalls,
Sometimes she stops before a nude Corot
Or Breughel's peasant dance to contemplate—
With hand on hip, her tilted head just so,
She strikes a pose the eye might correlate.
But then she steps into the corridor
And glides from room to room so silently
Her footfalls barely seem to touch the floor
Or hardly echo through the gallery.
Her true self-portrait gradually appears
Among discreet Cassatts, demure Vermeers.**

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Appendix

Details of Literature Search and Selection Criteria

We used a broad literature search strategy to identify relevant publications from 1 January 1980 through 8 October 2003. We tested 3 search strategies, as MeSH terms in this area are imprecise. First, we tested an inclusive strategy by using the following MEDLINE indexing terms: *intraoperative complications*, *postoperative complications*, *preoperative care*, *intraoperative care*, *anesthesia*, or *analgesia*. The result was an unmanageable 63 000 citations with an estimated yield less than 2%. The second approach was more tailored, using any of the following terms and specifying them as the article's primary focus: *intraoperative complications*, *postoperative complications*, *preoperative care*, *intraoperative care*, and *postoperative care*, plus *perioperative complications* as text in the title or abstract. This strategy produced 15 466 citations. Third, we tested a narrow strategy by combining the second strategy with terms specific to pulmonary diseases and complications and identified 2860 potentially relevant citations.

We determined the degree of agreement between the second and third searches. Title review of the second, broader strategy results indicated 395 potentially relevant citations of 15 466 (2%) citations. Of these, the third, narrow strategy identified only 157 citations, leaving 238 potentially relevant citations that were missed by the narrow strategy. We reviewed the abstracts of the 238 missed citations in more detail, and 120 of them were potentially relevant. We then reviewed MeSH terms for these 120 citations to identify additional terms to improve the specificity of the second search without sacrificing sensitivity. These included terms for pulmonary, respiratory, or cardiopulmonary diseases, conditions, or complications and terms for oxygenation, chest roentgenography, and lung expansion modalities, such as incentive spirometry.

On the basis of recent systematic reviews and seminal randomized trials, we performed 7 additional focused searches that were tailored to specific topics: preoperative chest radiography, preoperative spirometry, laparoscopic versus open major abdominal procedures, general versus spinal or epidural anesthesia, intraoperative neuromuscular blockade, management of postoperative pain, and postoperative lung expansion techniques. We identified additional references by reviewing bibliographies of retrieved studies.

We limited the review of intervention strategies to randomized, controlled trials and previously published systematic reviews. We subsequently updated searches for studies of risk factors that included multivariable results and randomized, controlled trials of interventions to prevent postoperative pulmonary complications through 30 June 2005. We included only English-language publications and excluded publications without primary data from detailed abstraction (that is, letters, editorials, case reports, conference proceedings, and narrative reviews). We excluded 1) studies with fewer than 25 participants per study group; 2) studies that used only administrative data (for example, ICD-9-CM codes) because of recent data showing poor validity of administrative data for postoperative complications (150–152); 3) studies from developing countries because of potential differences in respiratory and intensive care technology (according to lists from the Organisation for Economic Co-operation and Development and the International Monetary Fund) (153, 154); 4) studies that lacked explicit criteria or definitions for pulmonary complications; 5) studies of ambulatory surgery; 6) studies in which outcomes were physiologic rather than clinical (for example, lung volumes and flow, oximetry); 7) studies of gastric pH manipulation; 8) studies of complications unique to a particular type of surgery (for example, upper airway obstruction after uvulectomy); 9) studies of cardiopulmonary or pediatric surgery; and 10) studies of organ transplantation because of profoundly immunosuppressive drugs. For studies using multivariable logistic regression analysis, we required at least 5 outcome occurrences for each covariate entered into the model. We based this criterion on evidence for minimum thresholds for model stability and reliability when estimating odds ratios and CIs (155). We excluded the few studies that used discriminant analysis because we could not compare the results with odds ratios generated by logistic regression. We did not require eligible studies to provide explicit boundary criteria for risk factors (for example, severity of chronic obstructive pulmonary disease) or for severity of postoperative pulmonary complications (for example, severity of atelectasis). When studies provided such information, we included this in our summary of study characteristics (**Appendix Tables 1**, **2**, and **8**).

An investigator evaluated each citation according to the following strategy: title and abstract review, then review of the full reference if necessary. If a reviewer was uncertain, we made the final decision by consensus.

Of 16 959 citations identified by the search, 1223 were duplicates and 14 793 were not relevant on title and abstract review (**Figure**). Of the remaining 943 potentially relevant citations, we excluded 626 citations after review of the full publication, abstracted 145 citations in detail, and used 172 citations as background references. We systematically abstracted data from eligible studies into standardized electronic data forms. Eligible studies varied in their definitions of the postoperative period. Most commonly, authors defined the postoperative period as the hospital stay, ranging from 4 hours to 3 months after surgery.

Assessing Study Quality

We used the USPSTF criteria for assigning hierarchy of research design and grading a study's internal validity as our basis for assessing study quality (12). A good-quality cohort or case-series study, at a minimum, adjusted for key confounders of age, chronic obstructive pulmonary disease, and surgical type; showed little or no differential loss to follow-up; explicitly masked outcome assessment, and provided explicit definitions for what constituted a postoperative pulmonary complication. A fair-quality cohort or case-series study adjusted for key confounders, showed little or no differential loss to follow-up, and provided a clear definition for a postoperative pulmonary complication but was unclear about masking of outcome assessment. A poor-quality cohort or case-series study did not include 1 or more of the key confounders, showed statistically significant differential loss to follow-up, provided vague or no definitions for a postoperative pulmonary complication, explicitly did not mask outcome assessments, or a combination of these criteria. We assigned summary strength of recommendations for each risk factor and laboratory test according to modified criteria proposed by the USPSTF (12). We modified the criteria for the review on preoperative risk stratification to reflect the absence of a risk–benefit equation when considering a risk factor rather than an intervention. When both univariate and multivariate data were available about a potential risk factor, we considered most strongly the effect of the multivariate data when assigning strength of recommendations. When the effect of a risk factor was based on only 1 multivariate study or was limited to univariate data, we considered the evidence to be insufficient to determine that the factor contributed to postoperative pulmonary complication risk.

A good-quality randomized, controlled trial met all of the following criteria: comparable groups assembled initially and maintained throughout the study, follow-up of at least 80% of participants, reliable and valid measurement instruments applied equally to all groups, clearly described interventions, consideration of important and relevant outcomes, appropriate attention to confounders in analysis, and intention-to-treat analyses. We graded studies as fair if any of the following problems occurred: generally comparable groups assembled initially but some (although not major) possible differences occurring in follow-up, generally acceptable (although not the best) measurement instruments generally applied equally, some but not all important outcomes considered, some but not all potential confounders accounted for in analysis, and intention-to-treat analyses. Studies were poor if any of the following "fatal" flaws occurred: sufficiently comparable groups not assembled initially nor maintained throughout the study, unreliable or invalid measurement instruments, measurement instruments not applied equally among groups during follow-up (including unblended outcome assessment), follow-up of less than 80% of participants, little or no attention to key confounders, and intention-to-treat analyses not done.

We also graded systematic reviews as good, fair, or poor on the basis of extent of literature searched, inclusion or exclusion of non–English-language publications, statements of inclusion and exclusion criteria, protocols for appraisal of study quality and data abstraction, data synthesis methods, presentation of results, and discussion of clinical inferences and future research needs. Components of good quality included searching of MEDLINE plus other important databases (for example, EMBASE, Cochrane Library, or Clinical Trials Registry), inclusion of non–English-language publications, and a clear statement of acceptable inclusion criteria (for example, population, intervention, primary outcomes, study design, and assessment of agreement among reviewers). Good-quality reviews had good protocols for appraisal of study quality (for example, randomization, allocation concealment, blinding, independent assessment by $\geq$ 2 reviewers, assessment of interreviewer agreement, and process for resolution of agreement stated) and data abstraction (for example, independent assessment by $\geq$ 2 reviewers, interreviewer agreement, resolution process for disagreement, and standardized data abstraction forms). Components of good-quality quantitative synthesis included random-effects models, assessment of statistical heterogeneity, handling of missing data, rationale for a priori sensitivity and subgroup analyses, and assessment of publication bias. Good-quality presentation of results included a flow diagram for results of the literature search with numbers and reasons for exclusions, adequate reporting of characteristics of included studies (for example, study design, participant characteristics, quality score, details of intervention, outcome definitions, and assessment of clinical heterogeneity), and summary results with effect sizes and CIs. A good-quality discussion included summarization of key findings, clinical inferences based on internal and external validity of studies, interpretation of results on the totality of the evidence, potential biases, and a future research agenda. We graded systematic reviews and meta-analyses as fair if they were of fair to good quality on most components and as poor if they achieved only poor quality on most components.

Statistical Methods

Our literature search yielded primarily unadjusted estimates for most laboratory factors of interest. Limited multivariable, adjusted estimates were available for albumin level less than 30 g/L and elevated blood urea nitrogen level. However, rather than attempt to compute a potentially biased summary estimate, we provided narrative descriptions of the pattern of results for these potential risk factors.

The eligible multivariable risk factor studies varied considerably in the number and type of competing risks and confounders included in the analyses. Extensive use of prescreening methods and variable selection algorithms often limited reporting to the subset of risk factors that were determined as statistically significant in a given sample. The result is the introduction of a subtle form of publication bias, which we verified by examination of the funnel plots for each risk factor.

We extracted odds ratios from each study, along with their respective SEs, 95% confidence limits, or both. When necessary, we estimated SEs from the 95% confidence limits (156). We used the I^2 statistic (13) and the Cochran Q statistic (14) to assess study heterogeneity. We also recomputed pooled estimates with and without studies that produced extreme results. The I^2 statistic is the proportion of the total variance in the pooled estimate that is attributable to between-study variance. It is the maximum of (0, $(Q - df)/Q$), where the degrees of freedom (df) are the number of studies minus 1. This situation occurs when we have only 2 studies. An I^2 statistic of 50% or greater indicates substantial heterogeneity among study estimates. We used the DerSimonian–Laird method to compute random-effects estimates when the set of studies was heterogeneous (15). In cases where 3 or more studies contributed estimates for a risk factor, we used the trim-and-fill method to adjust pooled estimates of a risk factor's effect on postoperative pulmonary complications for publication bias (16).

For the review on intervention strategies, we performed simple means and chi-square testing when eligible studies did not provide CIs or *P* values for statistical significance. We did not perform quantitative pooling or meta-analyses because we identified previously published meta-analyses and found insufficient additional evidence to warrant repooling. In other cases, studies were too few or were too clinically heterogeneous for meta-analysis.

Other Factors That Do Not Influence Risk

Exercise Capacity

We identified only 1 eligible study that evaluated the value of self-reported exercise capacity as a predictor of postoperative pulmonary complication rates (84). In the report, investigators asked 600 consecutive patients who were referred to a preoperative medical consultation clinic to estimate the number of blocks on level ground that they could walk and the number of flights of stairs that they could climb without rest. By using a definition of 4 blocks or 2 flights of stairs as good exercise capacity, the investigators found that postoperative pulmonary complication rates for patients with good and poor exercise capacity were 6.3% and 9.0%, respectively ($P = 0.21$). The unadjusted odds ratio showed a non–statistically significant trend toward poor self-reported exercise capacity as a predictor of postoperative pulmonary complication rates (odds ratio, 1.43 [CI, 0.81 to 2.53]).

Diabetes

Five studies ($n = 1017$) reported the unadjusted (univariate) postoperative pulmonary complication risk attributable to diabetes (**Appendix Table 6**). The postoperative pulmonary complication rate among patients with diabetes was 15.9%. Event rates in 1 study (91) were too low to reliably estimate the odds ratio. The unadjusted summary estimate after pooling the remaining 4 studies is not statistically significant (odds ratio, 1.7 [CI, 0.9 to 3.1]) for diabetes. No eligible study using multivariable analyses reported diabetes to be an independent, statistically significant risk factor for postoperative pulmonary complication.

Asthma

Only 1 of 4 studies examining postoperative pulmonary complication rates among patients with asthma included a control group of patients without asthma; therefore, we could not calculate odds ratios. However, the postoperative pulmonary complication rate among patients with asthma ($n = 895$) was 3.0%, which is similar to the crude adjusted postoperative pulmonary complication rate for all studies in our review (3.4%). The low postoperative pulmonary complication rate probably resulted in part from a younger, healthier population than among unselected surgical patients. For example, in the largest study of patients with asthma, by Warner and colleagues (74), the mean age was 18 years (interquartile range, 9.9 years to 36.4 years) and 87% of patients were ASA class I or II. The study also included minor postoperative pulmonary complications of little clinical significance and minimal morbidity, such as bronchospasm and laryngospasm.

In Warner and colleagues' study, asthma severity, defined by need for asthma medications in the 30 days before surgery, and asthma control, defined by emergency department or office visits in the 30 days before surgery, both correlated with postoperative pulmonary complication rates. Postoperative pulmonary complication rates stratified by recent asthma medication use were 5.1% vs. 0.4%, and those stratified by recent emergency department or office visit were 28% vs. 1.3%. These differences were statistically significant.

HIV Infection

We identified only 1 eligible study that reported postoperative pulmonary complication risk among patients with HIV infection (76). Among 15 059 patients, 5 of 89 (5.6%) HIV-infected patients required an unplanned postoperative critical care admission for mechanical ventilation. The overall rate of unplanned critical care admissions was 0.3%, and HIV infection was the only comorbid condition that statistically significantly predicted risk. This observation, however, was based on a small number of patients.

Oropharyngeal Culture

One eligible univariate study evaluated the value of preoperative oropharyngeal culture to predict postoperative pulmonary complication risk before upper abdominal surgery (51). In the report, investigators obtained throat swabs before elective surgery. Nine of 17 patients whose preoperative cultures grew *Haemophilus influenzae* developed postoperative chest infection, while only 15 of 91 patients with negative cultures developed postoperative chest infection. While provocative, the evidence suggests that clinicians should await confirmation by other studies before considering this as a strategy for postoperative pulmonary complication risk stratification.

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150. **Romano PS, Chan BK, Schembri ME, Rainwater JA.** Can administrative data be used to compare postoperative complication rates across hospitals? Med Care. 2002;40:856-67. [PMID: 12395020]
151. **Romano PS, Schembri ME, Rainwater JA.** Can administrative data be used to ascertain clinically significant postoperative complications? Am J Med Qual. 2002;17:145-54. [PMID: 12153067]
152. **Best WR, Khuri SF, Phelan M, Hur K, Henderson WG, Demakis JG, et al.** Identifying patient preoperative risk factors and postoperative adverse events in administrative databases: results from the Department of Veterans Affairs National Surgical Quality Improvement Program. J Am Coll Surg. 2002;194:257-66. [PMID: 11893128]
153. **Organisation for Economic Co-operation and Development.** Accessed at www.oecd.org/home on 14 November 2005.
154. **International Monetary Fund.** Accessed at www.imf.org on 14 November 2005.
155. **Peduzzi P, Concato J, Kemper E, Holford TR, Feinstein AR.** A simulation study of the number of events per variable in logistic regression analysis. J Clin Epidemiol. 1996;49:1373-9. [PMID: 8970487]
156. **Sutton AJ, Abrams KR, Jones DR, Sheldon TA, Song F.** Methods for Meta-Analysis in Medical Research. Chichester, United Kingdom: J Wiley; 2000.

Appendix Table 1. **Study Characteristics of Univariate Studies of Clinical Risk Factors***

Author, Year (Reference)	Study Type†	Timeline	Type of Surgery	Specific PPCs Studied	Inclusion Criteria
Fasth et al., 1980 (19)	Cohort	Prospective	Bowel resection for Crohn disease	Pneumonia	
Warren and Grimwood, 1980 (20)	Cohort	Retrospective	Open cholecystectomy	Atelectasis, pneumonia	
Wirén and Janzon, 1983 (21)	Cohort	Retrospective	Gall bladder or peptic ulcer surgery	Pneumonia or atelectasis	Elective
Seymour and Pringle, 1983 (22)	Cohort	Prospective	General surgery	Pneumonia	Age > 65 y
Diehl et al., 1983 (23)	Cohort	Retrospective	AAA repair	Pneumonia, respiratory failure	
Buckwalter and Herbst, 1983 (24)	Cohort	Prospective	Gastric bypass	All that prolonged hospitalization or required treatment	
Galicier and Richet, 1985 (25)	Cohort	Prospective	All	Pneumonia	
Beard et al., 1986 (26)	Cohort	Prospective	All	Respiratory depression, bronchospasm, cyanosis, respiratory congestion, dyspnea, pneumothorax, atelectasis, laryngospasm	
Matsumata et al., 1987 (27)	Case series 25–99	Retrospective	Hepatic resection	Pleural effusion	
Fogh et al., 1987 (28)	Cohort	Prospective	Major abdominal	Pneumonia, atelectasis, respiratory failure	
Zelcher and Wells, 1987 (29)	Cohort	Prospective	All	Cyanosis, bronchospasm, laryngospasm, aspiration, reintubation, hypoventilation	
Fasth et al., 1987 (30)	RCT	Prospective	Colorectal surgery	Pneumonia	
Hollier et al., 1988 (31)	Cohort	Retrospective	Thoracoabdominal aortic aneurysm repair	Respiratory failure	
Poe et al., 1988 (32)	Cohort	Prospective	Elective cholecystectomy	Atelectasis, pneumonia, purulent bronchitis	
Jørgensen et al., 1988 (33)	Cohort	Retrospective	Abdominal	Pneumonia	All patients had fever
Roberts et al., 1988 (34)	Cohort	Prospective	Elective abdominal	Atelectasis	
Tartter, 1988 (35)	Cohort	Retrospective	Colorectal cancer	Pneumonia	
Mellors et al., 1988 (36)	Cohort	Prospective	Abdominal	Pneumonia	
Pien et al., 1988 (37)	Cohort with comparison	Retrospective	All	Asthma exacerbation, pneumonia	Asthma prompting preoperative medical consultation, use of inhaled steroids or alternate-day prednisone
Nielsen et al., 1989 (38)	Cohort	Prospective	Upper abdominal	Pleural effusion, atelectasis	Elective upper abdominal surgery
Ejlertsten et al., 1989 (39)	Cohort	Retrospective	Elective upper abdominal	Pneumonia	
Vodinh et al., 1989 (40)	Cohort	Prospective	Vascular	Pneumonia, atelectasis, pleural effusion, respiratory failure	
Seymour and Vaz, 1989 (41)	Cohort	Prospective	Noncardiac	Pneumonia, atelectasis	Age > 65 y

Appendix Table 1—**Continued**

Exclusion Criteria	Other Footnotes	Hierarchy of Research Design‡	Study Quality	Considered All Key Confounders: Type of Surgery, Age, COPD	Patients, *n*	PPCs, *n*	Mean Age, *y*	Men, %
None		II-3	Fair	No	153	2		
None		II-3	Poor	No	194	42	52	70
None		II-3	Poor	No	52	28	53	100
None		II-3	Poor	No	258	102	NA	57
None		II-3	Poor	No	557	33	63	81
None		II-3	Poor	No	565	3	40	36
ACS class IV (dirty) procedures		II-3	Poor	No	693	23	NA	NA
None	Studied only immediate postoperative complications in PACU	II-2	Poor	No	2293	44	NA	NA
Postoperative subphrenic abscess, thoracoabdominal incision		II-3	Poor	No	80	40	56	74
None		II-3	Poor	No	125	23	NA	NA
None	Studied only immediate postoperative complications in PACU	II-2	Poor	No	443	10	NA	NA
None		II-3	Poor	No	92	5	NA	NA
None		II-3	Poor	No	101	33	69	60
None		II-2	Fair	No	209	31		26
Surgery < 1 h duration		II-3	Fair	No	259	47	NA	NA
None		II-3	Good	No	270	154		
Liver or other metastatic lesions		II-2	Fair	No	343	6	69	50
Gynecologic surgery, age < 16 y		II-2	Fair	No	434	4		
None		II-2	Poor	No	4121	36	51	32
Medical treatment for heart or lung disease, elevated serum creatinine level, CHF on preoperative chest radiograph		II-2	Poor	No	128	89	59	37
Preoperative pulmonary, cardiovascular, renal, or hepatic disease		II-2	Poor	No	130	11	53.1	NA
Life-threatening emergency surgery, carotid surgery, varicose vein surgery		II-2	Poor	No	151	56	61	85
None		II-3	Poor	No	288	40	NA	NA

Appendix Table 1—**Continued**

Author, Year (Reference)	Study Type†	Timeline	Type of Surgery	Specific PPCs Studied	Inclusion Criteria
Koness et al., 1990 (42)	Cohort	Retrospective	Perforated peptic ulcer	Respiratory failure	
Patrick et al., 1990 (43)	Cohort	Retrospective	All	Pneumonia, respiratory failure	Neuromuscular restrictive pulmonary physiology requiring continuous or intermittent mechanical ventilation at baseline
Verdeil et al., 1990 (44)	Cohort	Prospective	Vascular	Pneumonia	
Arriaga et al., 1990 (45)	Cohort	Retrospective	Laryngectomy	Respiratory failure	
Pinto et al., 1991 (46)	Cohort	Retrospective	Gastric cancer	Pneumonia	
Hall et al., 1991 (47)	Cohort	Prospective	Abdominal	Atelectasis, pneumonia	Manipulation of abdominal viscera
Greco et al., 1991 (48)	Cohort	Prospective	All	Pneumonia	Any surgery
Katz et al., 1992 (49)	Case series 25–99	Prospective	Aortic	Pneumonia, respiratory failure	Elective aortic reconstruction
Kroenke et al., 1992 (50)	Cohort	Retrospective	All	All	Severe COPD with $FEV_1 < 50\%$, predicted and FEV_1:FVC $< 70\%$
Dilworth et al., 1991 (51)	Cohort	Prospective	Upper abdominal	Pneumonia	
Kispert et al., 1992 (52)	Cohort	Retrospective	Major vascular	Pneumonia, respiratory failure, ARDS	Elective
Brooks-Brunn, 1992 (53)	Cohort	Retrospective	Open cholecystectomy	Pneumonia, atelectasis	
Braga et al., 1992 (54)	Cohort	Retrospective	Gastric, colorectal, or pancreatic cancer	Pneumonia	
Evaldson et al., 1992 (55)	Cohort	Prospective	Obstetric and gynecologic	Pneumonia	Obstetric and gynecologic
Iwamoto et al., 1993 (56)	Case series	Retrospective	Thoracic, abdominal, or neurosurgery	Pneumonia	
Jayr et al., 1993 (57)	Cohort	Prospective	Intraabdominal vascular	Respiratory failure	Midline incision
Kroenke et al., 1993 (58)	Cohort	Retrospective	Major abdominal and nonresective thoracic	Atelectasis, bronchospasm, pneumonia, respiratory failure	Severe COPD with $FEV_1 < 50\%$, predicted and FEV_1:FVC, $< 70\%$

Appendix Table 1—**Continued**

Exclusion Criteria	Other Footnotes	Hierarchy of Research Design‡	Study Quality	Considered All Key Confounders: Type of Surgery, Age, COPD	Patients, *n*	PPCs, *n*	Mean Age, *y*	Men, %
None	Can't assess effect of risk factors because analysis only evaluated effect of risk factors on mortality	II-3	Poor	No	109	16	67	55
None		II-3	Poor	No	142	17	NA	NA
None		II-3	Poor	No	329	5	NA	NA
None		II-3	Poor	No	414	74	62	NA
Hospital stay < 7 d	Can't assess effect of risk factors because all infectious complications were combined	II-3	Fair	No	196	18	67	60
Hernia repair, declined consent, ICU care immediately after surgery		II-2	Fair	No	1000	232	54	53
Inadequate data collection	Included only preintervention patients	II-3	Poor	No	4096	119	47	
None		II-3	Poor	No	64	24	67	44
None		II-2	Fair	Yes	107	34	66	72
None		II-2	Poor	No	127	26	56	39
None		II-2	Poor	No	147	19	65	77
Age < 12 y, surgeries other than cholecystectomy at same time, preoperative pneumonia or atelectasis	Did not abstract risk factor data because author chose to include only a sampling (54 of 209) of patients with no PPC for risk factor analysis	II-2	Poor	No	263	54	NA	NA
Age > 80 y, antibiotic use in previous 2 d, emergency surgery, palliative surgery		II-2	Fair	No	285	8	59	46
Dilation and curettage, abortion, noncesarean obstetric procedures	Can't assess effect of risk factors because all infectious complications were combined	II-3	Poor	No	2361	8	NA	0
Age < 20 y	PPC was postoperative pneumonia identified by discharge diagnoses only	II-3	Poor	No	4380	30		
None		II-2	Poor	No	51	12		65
None	Excluded risk factor analysis that looked at risk for severe PPC or death; subcategorized COPD into severe (PPC rate: 17/26) and mild or moderate (PPC rate: 27/52)	II-2	Good	Yes	130	64	63	68

Appendix Table 1—**Continued**

Author, Year (Reference)	Study Type†	Timeline	Type of Surgery	Specific PPCs Studied	Inclusion Criteria
Ephgrave et al., 1993 (59)	Cohort	Prospective	Any requiring postoperative nasogastric tube	Pneumonia	Postoperative nasogastric tube, male veterans
Calligaro et al., 1993 (60)	Cohort	Retrospective	AAA repair	Pneumonia, respiratory failure	AAA repair
Heiss et al., 1993 (61)	RCT	Prospective	Colorectal cancer	Pneumonia	Hemoglobin level > 125 g/L
Weber et al., 1993 (62)	RCT	Prospective	Head and neck oncologic surgery	Pneumonia, bronchitis	
Money et al., 1994 (63)	Cohort	Retrospective	Thoracoabdominal aortic aneurysm repair	Respiratory failure	
Charash et al., 1994 (64)	Cohort	Retrospective	Femur fracture repair	Pulmonary contusion, pneumonia, fat embolism, pulmonary embolism	Blunt midshaft femur fracture stabilized with intramedullary nail, injury severity score > 17
Gefke et al., 1994 (65)	Cohort	Retrospective	Abdominal aortic	Respiratory failure	
Arvidsson et al., 1994 (66)	Cohort	Prospective	Elective	Respiratory arrest, aspiration, respiratory distress, pneumonia, pleuritis, hydrothorax, pneumothorax, atelectasis, asthmatic obstruction	Adults, surgery requiring incision, anticipated hospital stay at least 24 h
Lawrence et al., 1995 (67)	Case–control	Retrospective	Abdominal	Pneumonia, respiratory failure, bronchospasm, bronchitis, pleural effusion	
Kabalin et al., 1995 (68)	Case series 25–99	Retrospective	All	Asthma exacerbation	Asthma prompting preoperative medical consultation
Gilling-Smith et al., 1995 (69)	Cohort	Retrospective	Thoracoabdominal aortic aneurysm repair	Pneumonia, respiratory failure	
Liedman et al., 1995 (70)	Cohort	Retrospective	Esophageal or gastric cancer	Pneumonia, respiratory failure	
Choban et al., 1995 (71)	Cohort with comparison	Retrospective	General, urologic, gynecologic, or thoracic	Pneumonia	
Hall et al., 1996 (72)	Case–control	Retrospective	Open cholecystectomy	Lung collapse or consolidation	ASA class I–II, general anesthesia
Kocabas et al., 1996 (73)	Cohort	Prospective	Elective upper abdominal	Pneumonia, bronchitis, atelectasis, pulmonary embolism	
Warner et al., 1996 (74)	Cohort	Retrospective	All	Bronchospasm, laryngospasm	General anesthesia or neuraxial blockade
Wolters et al., 1996 (75)	Cohort	Prospective	General or vascular	Pneumonia, atelectasis, pleural effusion	
Rose et al., 1996 (76)	Cohort	Prospective	Inpatient	Unplanned mechanical ventilation	
Ferguson et al., 1997 (77)	Cohort	Retrospective	Esophagectomy	Pneumonia, respiratory failure, atelectasis	
Delgado-Rodríguez et al., 1997 (78)	Cohort	Prospective	General surgery	Pneumonia	
Thomas et al., 1997 (3)	Cohort with comparison	Prospective	Elective noncardiac	Respiratory failure, pneumonia	Age > 50 y, expected length of stay at least 2 d

Appendix Table 1—**Continued**

Exclusion Criteria	Other Footnotes	Hierarchy of Research Design‡	Study Quality	Considered All Key Confounders: Type of Surgery, Age, COPD	Patients, *n*	PPCs, *n*	Mean Age, *y*	Men, %
None		II-2	Poor	No	140	26	63	100
Emergency surgery, concomitant nonvascular surgery, retroperitoneal incision		II-3	Poor	No	181	97		
Acute infection, age > 75 y, history of seizures, unstable CAD, ASA class > III, unresectable tumor	Can't assess effect of risk factors because all infectious complications were combined	I	Fair	No	120	3	60	51
None		II-2	Fair	No	225	22	59	79
Death within 12 h of surgery, incomplete database	No quantifiable risk factor data	II-3	Fair	Yes	90	19	66.8	
Death due to head trauma or hemorrhagic shock		II-3	Poor	No	138	33	30	71
None		II-3	Poor	No	553	77	NA	NA
None	Can't assess effect of risk factors because all complications were combined	II-2	Poor	No	1361	39	57	55
Atelectasis		II-2	Good	No	2291	82	65	NA
None		II-2	Poor	No	89	3	46	24
None		II-3	Poor	No	130	49	67	73
None		II-2	Fair	No	213	62	66	69
Pregnant, postpartum, incomplete database		II-3	Poor	No	849	1	50	NA
No consent, age < 14 y, preexisting pulmonary complication, known chronic airway disease		II-2	Poor	No	95	12	48	24
None		II-3	Poor	No	60	21	48.3	60
None		II-2	Poor	No	706	12	18	52
None		II-2	Good	Yes	6301	399	52	59
Cardiac surgery, neurosurgery, preoperative ICU stay		II-2	Poor	No	15 059	41	NA	50
None		II-2	Fair	No	269	125	57.5	70
Hospital stay < 1 d		II-2	Fair	Yes	1483	19	53	47
None		II-2	Fair	No	2964	53	67	0.48

Appendix Table 1—**Continued**

Author, Year (Reference)	Study Type†	Timeline	Type of Surgery	Specific PPCs Studied	Inclusion Criteria
Schwilk et al., 1997 (79)	Cohort with comparison	Prospective	All	Reintubation, laryngospasm, bronchospasm, aspiration, hypoventilation	
Gillinov and Heitmiller, 1998 (80)	Cohort	Retrospective	Transhiatal esophagectomy	Pneumonia, pleural effusion requiring drainage, COPD exacerbation	
Kuwano et al., 1998 (81)	Cohort	Retrospective	Esophagectomy	Pneumonia, respiratory failure, hypoxemia	Right thoracoabdominal approach to esophagectomy
Midorikawa et al., 1999 (82)	Cohort	Retrospective	Hepatic resection	Pneumonia, atelectasis, pleural effusion	Hepatic tumor
Manninen et al., 1999 (83)	Cohort	Prospective	Neurosurgery	Respiratory rate < 8 breaths/min, oxygen saturation < 90%, dyspnea, bronchospasm, reintubation, pulmonary edema	
Reilly et al., 1999 (84)	Cohort	Prospective	Noncardiac	Pneumonia, respiratory failure, ARDS, hypoxia, bronchospasm	
Ziser et al., 1999 (85)	Cohort	Retrospective	All	Respiratory failure, pneumonia, ARDS	Cirrhosis by liver biopsy or impaired liver function tests plus abnormal imaging results
Haga et al., 1999 (86)	Cohort	Retrospective	All	Pneumonia	
Carson et al., 1999 (87)	Cohort	Retrospective	Hip fracture repair	Pneumonia	
Gibbs et al., 1999 (88)	Cohort	Prospective	Noncardiac	Pneumonia, respiratory failure	
Brooks-Brunn, 2000 (89)	Cohort	Retrospective	Total abdominal hysterectomy	Pneumonia, atelectasis, lasting at least 48 h	Elective surgery, anticipated stay > 48 h
Oñate-Ocaña et al., 2000 (90)	Cohort	Retrospective	Gastric cancer	Pneumonia, respiratory distress	
Yamashita et al., 2000 (91)	Cohort	Retrospective	Gastric cancer	Pneumonia	Elective gastrectomy
Gupta et al., 2001 (92)	Case–control	Retrospective	Hip or knee replacement	Reintubation, hypercapnia, hypoxemia	Symptoms and signs of OSA, abnormal sleep study or suggestive overnight oximetry
Girish et al., 2001 (93)	Case series 25–99	Prospective	Thoracotomy, sternotomy, or upper abdominal surgery	Pneumonia, respiratory failure, atelectasis	
Hajzman et al., 2001 (94)	Cohort	Retrospective	Gastric banding for obesity surgery	Respiratory failure, chronic bronchitis exacerbation	Morbid obesity
Kinugasa et al., 2001 (95)	Cohort	Retrospective	Esophagectomy	Pneumonia, pulmonary edema, atelectasis, hypoxia requiring reintubation	Squamous-cell cancer of thoracic esophagus
Polanczyk et al., 2001 (96)	Cohort	Prospective	Major elective noncardiac	Pneumonia, respiratory failure	Age > 50 y; major nonemergent, noncardiac surgery
Polanczyk et al., 2001 (97)	Cohort	Prospective	Nonemergent major noncardiac	Pneumonia, respiratory failure	Age > 50 y; major nonemergent, noncardiac surgery
Griffin et al., 2002 (98)	Cohort	Prospective	Ivor Lewis subtotal esophagectomy	Pneumonia, respiratory failure	

Appendix Table 1—**Continued**

Exclusion Criteria	Other Footnotes	Hierarchy of Research Design‡	Study Quality	Considered All Key Confounders: Type of Surgery, Age, COPD	Patients, *n*	PPCs, *n*	Mean Age, *y*	Men, %
Age < 16 y, emergency surgery		II-2	Poor	No	26 961	1114	NA	NA
None	Major pulmonary complications only	II-2	Poor	No	101	11	60	89
		II-3	Poor	No	178	23	63	88
Bile duct carcinoma, gall bladder carcinoma		II-3	Poor	No	277	82	61	75
Surgery for chronic pain or movement disorder, postoperative ventilation > 4 h		II-2	Poor	No	486	31	52	53
Minor procedures	Poor functional status was inability to walk 4 blocks or climb 2 flights by self-report	II-1	Good	Yes	600	48	63	41
Liver transplantation		II-2	Good	Yes	733	91	59.4	54
None		II-2	Good	Yes	1281	27	60	48
Declined blood transfusion, metastatic cancer, several traumatic injuries		II-2	Good	Yes	9598	337	80.3	21
Minor procedures, organ transplantation	Estimated number of PPCs	II-2	Fair	Yes	54 215	6470	61	97
Age < 18 y		II-2	Poor	No	120	13	47	0
Age < 18 y		II-3	Fair	No	208	8	58	49
Preoperative infection, immunocompromised, pancreatic resection, colon resection, postoperative deaths unrelated to infection	Can't assess effect of risk factors because all infectious complications were combined	II-3	Poor	No	367	7		
None		II-2	Poor	No	202	40	68	70
No lung resection if predicted FEV_1 < 800 mL or 40%		II-2	Fair	Yes	83	25	67	63
None		II-3	Poor	No	114	4	40	14
None		II-2	Poor	No	246	54	NA	77
AAA repair		II-2	Good	Yes	4059	91	66	53
Non–English-speaking, unable to give consent		II-2	Good	Yes	4315	122	67	48
None		II-3	Poor	No	228	39	64	70

Appendix Table 1—Continued

Author, Year (Reference)	Study Type†	Timeline	Type of Surgery	Specific PPCs Studied	Inclusion Criteria
Lawrence et al., 2002 (2)	Cohort	Retrospective	Hip fracture repair	Pneumonia, respiratory failure	Age ≥ 60 y
Blouw et al., 2003 (99)	Cohort	Retrospective	Gastric bypass	Atelectasis, respiratory failure, aspiration	

* AAA = abdominal aortic aneurysm; ACS = American College of Surgeons; ARDS = acute respiratory distress syndrome; ASA = American Society of Anesthesiologists; CAD = coronary artery disease; CHF = congestive heart failure; COPD = chronic obstructive pulmonary disease; ICU = intensive care unit; NA = not available; OSA = obstructive sleep apnea; PACU = post-anesthesia care unit; PPC = postoperative pulmonary complication; RCT = randomized, controlled trial.
† Numbers are numbers of participants.
‡ Based on criteria from the U.S. Preventive Services Task Force (12).

Appendix Table 1—**Continued**

Exclusion Criteria	Other Footnotes	Hierarchy of Research Design‡	Study Quality	Considered All Key Confounders: Type of Surgery, Age, COPD	Patients, *n*	PPCs, *n*	Mean Age, *y*	Men, %
Declined blood transfusion, metastatic cancer, multiple myeloma, several traumatic injuries, additional operation besides hip fracture repair, leg amputation above the knee, paraplegia or quadriplegia		II-2	Poor	No	8930	344	80.2	79
No patient consent for chart review, reoperation		II-2	Poor	No	197	23	47	31

Appendix Table 2. **Study Characteristics of Multivariate Studies of Clinical Predictors***

Author, Year (Reference)	Study Type	Timeline	Type of Surgery	Specific PPCs Studied	Inclusion Criteria
Garibaldi et al., 1981 (100)	Cohort	Prospective	Thoracic and abdominal	Pneumonia	
Windsor and Hill, 1988 (101)	Cohort	Prospective	Elective gastrointestinal resection	Pneumonia, atelectasis	
Gerson et al., 1990 (102)	Cohort	Prospective	Abdominal and noncardiac thoracic	Pneumonia, noncardiogenic pulmonary edema, pulmonary embolus	Age > 65 y
Pedersen et al., 1990 (103)	Cohort	Prospective	All	Intubated > 24 h	
Svensson et al., 1991 (104)	Cohort	Prospective	Thoracoabdominal aortic	Respiratory failure	
Williams-Russo et al., 1992 (105)	Cohort	Prospective	Noncardiac	Pneumonia, atelectasis	Diabetes or hypertension
Oller Sales et al., 1992 (106)	Cohort	Prospective	Abdominal	Pneumonia	
Pedersen et al., 1992 (107)	Cohort	Prospective	Noncardiac	Respiratory failure, atelectasis, pneumonia	
Wong et al., 1995 (108)	Cohort	Prospective	Noncardiothoracic	Pneumonia, respiratory failure, bronchospasm	COPD, FEV_1 < 1.2 L, FEV_1:FVC < 75%
Fujita and Sakurai, 1995 (109)	Cohort	Retrospective	Abdominal	Atelectasis, pneumonia	
Lawrence et al., 1996 (110)	Case–control	Retrospective	Elective abdominal	Pneumonia, respiratory failure, bronchospasm, bronchitis, pleural effusion	
Hall et al., 1996 (111)	Cohort	Prospective	Abdominal	Pneumonia, respiratory failure	
Barisione et al., 1997 (112)	Cohort	Prospective	Abdominal	Pneumonia, atelectasis, respiratory failure	
Brooks-Brunn, 1997 (113)	Cohort	Retrospective	Abdominal	Pneumonia, atelectasis	
Bluman et al., 1998 (114)	Cohort	Prospective	Elective	Pneumonia, bronchospasm, reintubation, pulmonary death	General or spinal anesthesia
Mitchell et al., 1998 (115)	Cohort	Prospective	Elective nonthoracic	Bronchitis, bronchospasm, atelectasis, pneumonia, ARDS, pleural effusion, pneumothorax, respiratory failure	
Pereira et al., 1999 (116)	Cohort	Prospective	Abdominal	Pneumonia, bronchitis, atelectasis, respiratory failure, bronchospasm	
Liu and Leung, 2000 (117)	Cohort	Retrospective	Noncardiac	Respiratory failure, pneumonia, ARDS	Age ≥ 80 y
Arozullah et al., 2000 (118)	Cohort	Prospective	Noncardiac	Respiratory failure	General, spinal, or epidural anesthesia
Møller et al., 2001 (119)	Cohort	Prospective	Abdominal, urologic, or orthopedic	Pneumonia, atelectasis, pneumothorax, respiratory failure	
Arozullah et al., 2001 (120)	Cohort	Prospective	Noncardiac	Pneumonia	General, spinal, or epidural anesthesia
Leung and Dzankic, 2001 (121)	Cohort without comparison	Prospective	Mixed	Pulmonary edema, reintubation, pulmonary consolidation on chest radiograph, pneumothorax, pleural effusion	Consecutive patients age ≥70 y, noncardiac elective (86%), emergency (14%), general (24%), orthopedic (18%), neurosurgical (13%), urologic (13%), head and neck (9%), gynecologic (9%), vascular (8%), thoracic (5%), cosmetic (1%)
Canturk et al., 2002 (122)	Cohort	Prospective	General	Pneumonia	
O'Brien et al., 2002 (123)	Cohort	Prospective	Noncardiac	Respiratory failure, pneumonia	General, spinal, or epidural anesthesia

Appendix Table 2—**Continued**

Exclusion Criteria	Hierarchy of Research Design†	Study Quality	Considered All Key Confounders: Type of Surgery, Age, COPD	Patients, *n*	PPCs, *n*	Mean Age, *y*	Men, %
	II-2	Poor	Yes	520	91		38
Sepsis, immunocompromised, or preoperative intravenous nutrition essential	II-3/C	Fair	Yes	80	Pneumonia, 11; atelectasis, 36		
	II-2	Poor	No	177	24	73	49
	II-2/B-C	Fair	Yes	7306	348		36
	II-2	Fair	Yes	98	59	63.5	61
	II-2	Fair	Yes	278	16		39
Thoracoabdominal incision, splenectomy	II-2/B-C	Fair	Yes	2083	269		21
Regional anesthesia, incomplete database	II-2	Fair	Yes	7029	290		
Preexisting tracheostomy, thoracic surgery	II-2	Fair	Yes	105	39	68	96
	II-3	Poor	No	2969	89		
Atelectasis as sole pulmonary complication	II-2	Good	Yes	164	NA	65	
Hernia repair, age < 14 y, preexisting pulmonary complication	II-2	Good	Yes	1322	199	56	48
None	II-3	Fair	Yes	361	49	64	69
Age < 18 y, laparoscopy, postoperative mechanical ventilation, preoperative pneumonia or atelectasis	II-2	Good	Yes	400	90	52.5	35
Otolaryngology surgery, neurosurgery, pipe or cigar smokers	II-2	Fair	Yes	410	59	59	97
Regional anesthesia	II-2	Fair	Unclear	148	16	61.2	
	II-1	Fair	Yes	408	92	55	50
Ambulatory surgery	II-2	Poor	No	367	27	84.4	38
Organ transplantation, female patients, ventilator-dependent, DNR	II-2	Good	Yes	81 719	2746		
Age < 15 y	II-2	Poor	No	4725	204		47
Low-risk surgery, organ transplantation	II-2	Good	Yes	160 805	2466	62	95
	II-2/C	Poor	No	544	30		44
Hospital stay < 1 d	II-2	Poor	Yes	418	23		43
Low-risk surgery, organ transplantation	II-2	Fair	Partially (emergent vs. elective surgery)	49 091	3805	61.6	97

Appendix Table 2—**Continued**

Author, Year (Reference)	Study Type	Timeline	Type of Surgery	Specific PPCs Studied	Inclusion Criteria
Ferguson and Durkin, 2002 (124)	Cohort	Retrospective	Esophagectomy	Pneumonia, respiratory failure	
Elkhouri et al., 2004 (125)	Cohort	Retrospective	Aortic aneurysm	Pneumonia, respiratory insufficiency, pulmonary embolus	Infrarenal degenerative AAA
McAllister et al., 2005 (126)	Cohort without comparison	Prospective	Nonthoracic	Respiratory failure, pneumonia, atelectasis, pneumothorax or pleural effusion requiring intervention	Elective nonthoracic

* AAA = abdominal aortic aneurysm; ARDS = acute respiratory distress syndrome; COPD = chronic obstructive pulmonary disease; DNR = do not resuscitate; ICU = intensive care unit; NA = not available; PPC = postoperative pulmonary complication.
† Based on criteria from the U.S. Preventive Services Task Force (12).

Appendix Table 2—**Continued**

Exclusion Criteria	Hierarchy of Research Design†	Study Quality	Considered All Key Confounders: Type of Surgery, Age, COPD	Patients, *n*	PPCs, *n*	Mean Age, *y*	Men, %
	II-B/C	Poor	No	292	78	60	79
	II-2	Poor	Yes	355	45	73	88
Hospitalized, mechanically ventilated, planned ICU admission, sleep apnea, neuromuscular disease, medical problems that precluded participation	II-2	Good	Yes	1055	28	55	50

Appendix Table 3. **Significant Clinical Predictors in Multivariate Studies***

Author, Year (Reference)	RR (95% CI)	*P* Value
Arozullah et al., 2001 (120)		
Significant factors		
AAA repair	4.29 (3.34–5.50)	
Thoracic	3.92 (3.36–4.57)	
Upper abdominal	2.68 (2.38–3.03)	
Neck	2.3 (1.73–3.05)	
Neurosurgery	2.14 (1.66–2.75)	
Vascular	1.29 (1.10–1.52)	
Age ≥ 80 y	5.63 (4.62–6.84)	
Age 70–79 y	3.58 (2.97–4.33)	
Age 60–69 y	2.38 (1.98–2.87)	
Age 50–59 y	1.49 (1.23–1.81)	
Totally dependent	2.83 (2.33–3.43)	
Partially dependent	1.83 (1.63–2.06)	
Weight loss > 10% in 6 mo	1.92 (1.68–2.18)	
COPD	1.72 (1.55–1.91)	
General anesthesia	1.56 (1.36–1.80)	
Impaired sensorium	1.51 (1.26–1.82)	
History of CVA	1.47 (1.28–1.68)	
BUN level < 8 mg/dL	1.47 (1.26–1.72)	
BUN level, 22–30 mg/dL	1.24 (1.11–1.39)	
BUN level ≥ 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	1.33 (1.12–1.58)	
Current smoker within 1 y	1.28 (1.17–1.42)	
Alcohol > 2 drinks per day in past 2 wk	1.24 (1.08–1.42)	
Leung and Dzankic, 2001 (121)		
Significant factors		
Emergency surgery	3.6 (1.6–8.3)	0.003
History of CHF	5.7 (2.1–16)	0.001
Invasive monitoring	9.7 (3.7–25.4)	<0.001
Møller et al., 2001 (119)		
Significant factors		
Age > 65 y	1.63 (1.45–1.84)	
COPD	4.21 (2.77–6.41)	
Arozullah et al., 2000 (118)		
Significant factors		
Albumin level < 20 g/L	4.33 (3.99–5.52)	
Albumin level, 20–30 g/L	2.16 (1.86–2.51)	
Albumin level, 31–40 g/L	1.17 (1.05–1.31)	
Age ≥ 70 y	2.60 (2.21–3.05)	
Age 60–69 y	1.99 (1.70–2.33)	
Age 50–59 y	1.50 (1.25–1.79)	
Totally dependent	2.24 (1.88–2.66)	
Partially dependent	1.50 (1.25–1.79)	
Weight loss > 10% in 6 mo	1.37 (1.19–1.57)	
Alcohol > 2 drinks per day	1.19 (1.07–1.33)	
Diabetes	1.15 (1.00–1.33)	
BUN level > 40 mg/dL	2.35 (2.00–2.76)	
BUN level, 31–40 mg/dL	2.09 (1.78–2.45)	
BUN level, 21–30 mg/dL	1.31 (1.18–1.46)	
Preoperative renal failure	1.67 (1.23–2.27)	
Transfusion > 4 units	1.56 (1.28–1.91)	
Preoperative pneumonia	1.70 (1.35–2.13)	
Dyspnea at rest	1.69 (1.36–2.09)	
Dyspnea on minimal exertion	1.21 (1.09–1.34)	
COPD	1.58 (1.44–1.75)	
Recent smoking	1.24 (1.14–1.36)	
CHF	1.25 (1.07–1.47)	
Impaired sensorium	1.22 (1.04–1.43)	
CVA	1.20 (1.05–1.38)	

Appendix Table 3—**Continued**

Author, Year (Reference)	RR (95% CI)	*P* Value
AAA surgery	11.00 (9.20–13.10)	
Thoracic surgery	5.91 (5.15–6.78)	
Peripheral vascular surgery	3.40 (2.96–3.91)	
Upper abdomen surgery	3.36 (2.96–3.80)	
Neurosurgery	2.96 (2.35–3.73)	
Neck surgery	2.13 (1.63–2.77)	
Emergency surgery	2.81 (2.54–3.11)	
General anesthesia	1.91 (1.64–2.21)	
Liu and Leung, 2000 (117)		
Significant factors		
CHF	4.3 (2.3–6.9)	
Neurologic disease	3.4 (1.4–8.0)	
Arrhythmia	2.9 (1.1–7.5)	
Intraoperative vasopressor use	12.4 (2.5–63.0)	
Emergent surgery	3.0 (1.2–7.6)	
Pereira et al., 1999 (116)		
Significant factors		
COPD	2.24 (1.66–2.97)	
Surgery > 210 min	1.58 (1.15–2.18)	
Comorbid condition (hypertension, diabetes, or heart disease)	1.48 (1.10–1.97)	
Bluman et al., 1998 (114)		
Significant factors		
Current smoker	4.2 (1.2–14.8)	
General anesthesia	5.7 (2.5–12.6)	
Abnormal chest radiograph	6.3 (2.6–15.2)	
COPD	3.8 (1.8–7.8)	
High school graduate	2.0 (1.0–4.0)	
Barisione et al., 1997 (112)		
Significant factors		
Chronic bronchitis	133 (14.8–1199)	<0.001
FEV_1 (% predicted)	0.93 (0.88–0.98)	<0.01
RV (L)	3.11 (1.25–7.75)	0.01
DLco (% predicted)	0.91 (0.10-8.16)	<0.001
Brooks-Brunn, 1997 (113)		
Significant factors		
Age ≥ 60 y	1.89 (1.02–3.24)	
BMI ≥ 27 kg/m^2	2.82 (1.66–4.78)	
Impaired cognition	5.93 (0.92–38.19)	
History of cancer	2.23 (1.30–3.81)	
Cigarette use in past 8 wk	2.27 (1.23–4.21)	
Upper abdominal incision	2.30 (1.33–4.01)	
Hall et al., 1996 (111)		
Significant factors		
ASA class III–IV	NA	
Chronic bronchitis	NA	
Preoperative stay > 5 d	NA	
Current smoker	NA	
Lawrence et al., 1996 (110)		
Significant factors		
Abnormal chest examination	5.8 (1.04–32.1)	
Abnormal chest radiograph	3.2 (1.07–9.4)	
Goldman cardiac risk index, per point	2.01 (1.17–3.6)	
Charlson comorbidity index, per point	1.6 (1.004–2.6)	

Appendix Table 3—Continued

Author, Year (Reference)	RR (95% CI)	*P* Value
Fujita and Sakurai, 1995 (109)		
Significant factors		
Age > 65 y	NA	
Blood loss > 1.2 L	NA	
Preoperative inhalational therapy	NA	
Pedersen et al., 1992 (107)		
Significant factors		
Age ≥ 70 y	7.24 (3.72–14.10)	
Age 50–69 y	4.01 (2.14–7.52)	
Age 30–49 y	2.23 (1.14–4.33)	
COPD	3.06 (1.88–5.00)	
Pancuronium use	3.00 (2.07–4.36)	
Atracurium use	1.35 (0.78–2.34)	
Surgery > 3 h	3.22 (2.31–4.50)	
Abdominal surgery	3.63 (2.41–5.48)	
Major orthopedic surgery	4.27 (0.71–2.29)	
Emergency surgery	3.39 (2.48–4.63)	
Williams-Russo et al., 1992 (105)		
Significant factors		
AAA repair	NA	
COPD	NA	
Oller Sales et al., 1992 (106)		
Significant factors		
Duration of anesthesia	"Associated"	
ASA class	"Associated"	
Gastric surgery	"As were"	
Intestinal surgery	"Lesser extent"	
Age	"Weak"	
Svensson et al., 1991 (104)		
Significant factors		
COPD	4.86	0.0084
Cigarette use	10.3	0.0084
Cardiac complication	19.1	0.0091
Renal complication	21.3	0.004
Gerson et al., 1990 (102)		
Significant factor		
Poor exercise capacity	7.1 (5.10–9.89)	
Windsor and Hill, 1998 (101)		
Significant factors		
Upper vs. lower abdominal incision	9.68 (1.53–61.09)	0.015
Protein depletion	278.66 (0.14–570575.06)	0.14
Age	1.03 (0.97–1.09)	0.34
Duration of surgery	1.34 (0.66–2.71)	0.42
Obesity	2.75 (0.11–69.69)	0.54
Smoking	1.48 (0.28–7.81)	0.64
Garibaldi et al., 1981 (100)		
Significant factors		
Longer duration of surgery	NA	
Upper abdominal surgery	NA	
Abnormal serum albumin level	NA	
History of cigarette smoking	NA	
Mitchell et al., 1998 (115)		
Significant factors		
Postoperative nasogastric tube	21.8	
Preoperative sputum production	4.6	
Anesthesia time	No data	

Appendix Table 3—Continued

Author, Year (Reference)	RR (95% CI)	*P* Value
Pedersen et al., 1990 (103)		
Significant factors		
Age 50–69 y	4.26 (2.37–7.68)	<0.001
Age ≥ 70 y	5.70 (3.04–10.67)	<0.001
COPD	2.92 (1.86–4.58)	<0.001
Major operation	4.85 (3.35–7.05)	<0.001
Emergency operation	2.51 (1.87–3.37)	<0.001
General anesthesia with muscle relaxant	2.83 (1.99–4.03)	<0.001
Ferguson and Durkin, 2002 (124)		
Significant factors		
Age per 10-y increment	1.31 (0.99–1.74)	0.059
FEV_1 per 10% decrement	1.21 (1.07–1.38)	0.003
Thoracotomy and laparotomy	2.49 (1.30–4.76)	0.006
O'Brien et al., 2002 (123)		
Significant factors		
Creatinine level, 1.5–2.0 mg/dL	1.42 (1.22–1.64)	
Creatinine level, 2.0–2.5 mg/dL	1.39 (1.11–1.75)	
Creatinine level, 2.5–3.0 mg/dL	1.60 (1.23–2.07)	
Creatinine level > 3.0 mg/dL	1.58 (1.31–1.89)	
Canturk et al., 2002 (122)		
Significant factors		
Surgery > 1 h duration	1.06 (1.05–1.13)	0.034
HDL cholesterol level ≤ 35 mg/dL	1.16 (1.05–1.29)	0.05
COPD	2.5 (1.1–5.5)	0.04
Wong et al., 1995 (108)		
Significant factors		
Abdominal incision	18 (1.2–97.1)	0.0001
Anesthesia duration (per hour)	1.78 (1.14–2.71)	0.0001
ASA physical status 4 or 5	41 (5.8–292.4)	0.0002
General anesthesia	20 (3.1–127.0)	0.0008
FEV_1:FVC ≤ 0.5	16 (2.7–88.4)	0.0020
Shapiro score ≥ 5	10 (1.1–89.4)	0.0345
Elkhouri et al., 2004 (125)		
Significant factors		
Endovascular aortic repair (compared with open surgery)	0.14 (0.04–0.47)	0.002
McAllister et al., 2005 (126)		
Significant factors		
Age ≥ 65 y	5.9	<0.001
Positive cough test result	3.8	0.01
Perioperative nasogastric tube	7.7	<0.001
Duration ≥ 2.5 h	3.3	0.008

* To convert BUN values to mmol/L, multiply by 0.357. To convert creatinine values to μmol/L, multiply by 88.4. To convert HDL cholesterol values to mmol/L, multiply by 0.02586. AAA = abdominal aortic aneurysm; ASA = American Society of Anesthesiologists; BMI = body mass index; BUN = blood urea nitrogen; CHF = congestive heart failure; COPD = chronic obstructive pulmonary disease; CVA = cerebrovascular accident; DLCO = diffusing capacity of carbon monoxide; HDL = high-density lipoprotein; NA = not available; RR = relative risk; RV = residual volume.

Appendix Table 4. **Detailed Results of Univariate Studies on the Influence of Age on Postoperative Pulmonary Complication Rates***

Author, Year (Reference)	Patients, *n*	PPCs, *n*	Mean Age if PPC, *y*	Mean Age if No PPC, *y*	Patients Age < 60 y with PPC, *n*	Total Patients Age < 60 y, *n*	Patients Age > 60 y with PPC, *n*	Total Patients Age > 60 y, *n*
Warren and Grimwood, 1980 (20)	194	42	58.1	47.7				
Seymour and Pringle, 1983 (22)	258	102						
Beard et al., 1986 (26)	2293	44						
Fogh et al., 1987 (28)	125	125			14	57	6	68
Seymour and Vaz, 1989 (41)	288	40						
Vodinh et al., 1989 (40)	151	56	62	60.4				
Ejlertsten et al., 1989 (39)	130	11	54.7	53.3				
Nielsen et al., 1989 (38)	128	89	58.7	50.4				
Arriaga et al., 1990 (45)	414	74						
Hall et al., 1991 (47)	1000	232			73	562	159	438
Evaldson et al., 1992 (55)	2361	8						
Kispert et al., 1992 (52)	147	19						
Dilworth et al., 1991 (51)	127	23						
Kroenke et al., 1992 (50)	107	34	65	66				
Iwamoto et al., 1993 (56)	4380	30						
Calligaro et al., 1993 (60)	181	97						
Ephgrave et al., 1993 (59)	140	26	63.1	64.8				
Lawrence et al., 1995 (67)	2291	82	65	65				
Wong et al., 1995 (108)	105	39						
Rose et al., 1996 (76)	15 059	41			28	9442	13	5617
Kocabas et al., 1996 (73)	60	21	55.5	44.3				
Delgado-Rodríguez et al., 1997 (78)	1483	19						
Gillinov and Heitmiller, 1998 (80)	101	11	69.3	59.2				
Brooks-Brunn, 2000 (89)	120	13	56.1	46.3	7	96	6	24
Polanczyk et al., 2001 (97)	4315	122			20	1015	102	3300
Kinugasa et al., 2001 (95)	246	54						
Griffin et al., 2002 (98)	228	39	60.7	63				

* PPC = postoperative pulmonary complication.

Appendix Table 4—**Continued**

Patients Age < 65 y with PPC, *n*	Total Patients Age < 65 y, *n*	Patients Age > 65 y with PPC, *n*	Total Patients Age > 65 y, *n*	Patients Age < 70 y with PPC, *n*	Total Patients Age < 70 y, *n*	Patients Age > 70 y with PPC, *n*	Total Patients Age > 70 y, *n*
0	0	102	285				
				34	1936	10	357
				17	85	6	40
0	0	40	288				
28	212	46	172				
				24	112	2	15
14	3224	16	1156				
				13	109	16	72
18	43	21	62				
10	1077	9	396				
				49	2661	73	1654
				29	149	25	55

Appendix Table 5. **Detailed Results of Univariate Studies of the Influence of American Society of Anesthesiologists' Class on Postoperative Pulmonary Complication Rates***

Author, Year (Reference)	Patients, *n*	PPCs, *n*	ASA Class I, *n*		ASA Class II, *n*		ASA Class III, *n*		ASA Class IV, *n*	
			PPCs	Patients	PPCs	Patients	PPCs	Patients	PPCs	Patients
Seymour and Vaz, 1989 (41)	288	112			44	157	53	97	15	24
Kroenke et al., 1992 (50)	107	34		0	1	10	18	65	12	26
Calligaro et al., 1993 (60)	181	97		0	4	32	19	139	5	10
Wong et al., 1995 (108)	105	39							21	28
Kocabas et al., 1996 (73)	60	21	2	18	8	24	11	18		0
Rose et al., 1996 (76)	15 059	41							6	438
Warner et al., 1996 (74)	706	12	2	319	2	297	7	81	2	8
Wolters et al., 1996 (75)	6301	399	13	1133	115	2685	207	2181	29	290
Delgado-Rodríguez et al., 1997 (78)	1483	19					12	272		

* ASA = American Society of Anesthesiologists; PPC = postoperative pulmonary complication.

Appendix Table 6. **Detailed Results of Univariate Studies of the Influence of Obesity and Diabetes on Postoperative Pulmonary Complication Rates***

Author, Year (Reference)	Patients, *n*	PPCs, *n*	Patients with Diabetes		Definition of Obesity	Patients with Obesity	
			Total, *n*	PPCs, *n*		Total, *n*	PPCs, *n*
Poe et al., 1988 (32)	209	31			>120% ideal body weight	52	6
Hall et al., 1991 (47)	1000	232			BMI > 25 kg/m^2	102	27
Dilworth et al., 1991 (51)	127	26			BMI > 1 SD above mean	92	15
Kroenke et al., 1992 (50)	107	34	25	10			
Calligaro et al., 1993 (60)	181	97			>120% ideal body weight	36	7
Ephgrave et al., 1993 (59)	140	26	19	4			
Weber et al., 1993 (62)	225	22	16	3			
Choban et al., 1995 (71)	849	1			BMI ≥ 27 kg/m^2	313	1
Delgado-Rodríguez et al., 1997 (78)	1483	19			BMI > 33.75 kg/m^2	142	6
Thomas et al., 1997 (3)	2964	53			BMI ≥ 30 kg/m^2	528	10
Kuwano et al., 1998 (81)	178	23	8	2			
Yamashita et al., 2000 (91)	367	7	83	5			
Hajzman et al., 2001 (94)	114	4			Morbid obesity	114	4
Blouw et al., 2003 (99)	207	23			Morbid obesity	197	23

* BMI = body mass index; PPC = postoperative pulmonary complication.

Appendix Table 7. **Detailed Results of Univariate Postoperative Pulmonary Complication Rates Stratified by Surgical Site***										
Author, Year (Reference)	Patients, *n*	PPCs, *n*	Any Abdominal Surgery		Vertical Abdominal Incision		Upper Abdominal Surgery		Lower Abdominal Surgery	
			Patients with PPC, *n*	Patients, *n*	Patients with PPC, *n*	Patients, *n*	Patients with PPC, *n*	Patients, *n*	Patients with PPC, *n*	Patients, *n*
Fasth et al., 1980 (19)	153	2							2	153
Warren and Grimwood, 1980 (20)	194	42	42	194			42	194		
Buckwalter and Herbst, 1983 (24)	565	3	3	565						
Diehl et al., 1983 (23)	557	33								
Seymour and Pringle, 1983 (22)	258	102	53	111			32	64	21	47
Wirén and Janzon, 1983 (21)	52	28	28	52			28	52		
Fasth et al., 1987 (30)	92	5	5	92					5	92
Fogh et al., 1987 (28)	125	23	23	125						
Matsumata et al., 1987 (27)	80	40	40	80			40	80		
Hollier et al., 1988 (31)	101	33	154	270						
Jørgensen et al., 1988 (33)	259	47	47	259						
Mellors et al., 1988 (36)	434	4	4	434						
Poe et al., 1988 (32)	209	31	31	209	9	58	31	209		
Tartter, 1988 (35)	343	6	3	343					6	343
Ejlertsten et al., 1989 (39)	130	11	11	130			11	130		
Nielsen et al., 1989 (38)	128	89	89	128			89	128		
Seymour and Vaz, 1989 (41)	288	40	73	129			45	70	28	59
Vodinh et al., 1989 (40)	151	56								
Arriaga et al., 1990 (45)	414	74								
Koness et al., 1990 (42)	109	16	16	109						
Hall et al., 1991 (47)	1000	232	232	1000			161	439	81	477
Pinto et al., 1991 (46)	196	18	18	196			18	196		
Braga et al., 1992 (54)	285	8	8	285						
Dilworth et al., 1991 (51)	127	26	23	127	14	44	26	127		
Evaldson et al., 1992 (55)	2361	8	8	2361					8	2361
Katz et al., 1992 (49)	64	24								
Kispert et al., 1992 (52)	147	19								
Brooks-Brunn, 1992 (53)	263	54	54	263			54	263		
Kroenke et al., 1992 (50)	107	34	11	16			4	8		
Calligaro et al., 1993 (60)	181	97								
Ephgrave et al., 1993 (59)	140	26	5	66						
Heiss et al., 1993 (61)	120	3	3	120					3	120
Jayr et al., 1993 (57)	51	12								
Weber et al., 1993 (62)	225	22								
Charash et al., 1994 (64)	138	33								
Gefke et al., 1994 (65)	553	77								
Money et al., 1994 (63)	90	19								
Gilling-Smith et al., 1995 (69)	130	49								
Lawrence et al., 1995 (67)	2291	82	82	2291						
Liedman et al., 1995 (70)	213	62	32	132			32	132		
Wong et al., 1995 (108)	105	39	25	36					25	36

Appendix Table 7—Continued

Aortic or Intra-Abdominal Vascular		Head and Neck		Esophageal		Hip		Urologic or Gynecologic	
Patients with PPC, *n*	Patients, *n*	Patients with PPC, *n*	Patients, *n*	Patients with PPC, *n*	Patients, *n*	Patients with PPC, *n*	Patients, *n*	Patients with PPC, *n*	Patients, *n*
33	557								
33	101								
39	70								
		74	414						
								8	2361
24	64								
15	67								
1	3	3	11			3	6	2	20
97	181								
7	36	9	28						
12	51								
		22	225						
						33	138		
77	553								
19	90								
49	130								
				30	81				

Appendix Table 7—Continued

Author, Year (Reference)	Patients, *n*	PPCs, *n*	Any Abdominal Surgery		Vertical Abdominal Incision		Upper Abdominal Surgery		Lower Abdominal Surgery	
			Patients with PPC, *n*	Patients, *n*	Patients with PPC, *n*	Patients, *n*	Patients with PPC, *n*	Patients, *n*	Patients with PPC, *n*	Patients, *n*
Hall et al., 1996 (72)	95	12	10	58			10	58		
Kocabas et al., 1996 (73)	60	21	21	60	18	48	21	60		
Rose et al., 1996 (76)	15 059	41	12	2700						
Delgado-Rodríguez et al., 1997 (78)	1483	19	19	1187			13	350		
Ferguson et al., 1997 (77)	269	125								
Gillinov and Heitmiller, 1998 (80)	101	11								
Kuwano et al., 1998 (81)	178	23								
Carson et al., 1999 (87)	9598	337								
Midorikawa et al., 1999 (82)	277	82	82	277			82	277		
Brooks-Brunn, 2000 (89)	120	13	120	13	8	37			13	120
Oñate-Ocaña et al., 2000 (90)	208	8	8	208			8	208		
Yamashita et al., 2000 (91)	367	7	7	367						
Kinugasa et al., 2001 (95)	246	54								
Griffin et al., 2002 (98)	228	39								
Lawrence et al., 2002 (2)	8930	344								

* PPC = postoperative pulmonary complication.

Appendix Table 7—**Continued**

Aortic or Intra-Abdominal Vascular		Head and Neck		Esophageal		Hip		Urologic or Gynecologic	
Patients with PPC, *n*	**Patients, *n***	**Patients with PPC, *n***	**Patients, *n***	**Patients with PPC, *n***	**Patients, *n***	**Patients with PPC, *n***	**Patients, *n***	**Patients with PPC, *n***	**Patients, *n***
				125	269				
				11	101				
				23	178				
						337	9598		
				54	246				
				39	228				
						344	8930		

Appendix Table 8. **Characteristics of Studies of Laboratory Predictors***

Author, Year (Reference)	Study Type	Timeline	Type of Surgery	Specific PPCs Studied
Poe et al., 1982 (137)	Cohort	Retrospective	Upper abdominal, appendectomy, hernia repair, gynecologic, breast, thyroid, major orthopedic	Respiratory infection, atelectasis
Fogh et al., 1987 (28)	Cohort without comparison group	Prospective	Major abdominal	Pneumonia, atelectasis, respiratory failure
Windsor and Hill, 1988 (138)	Cohort with comparison	Prospective	Elective major gastrointestinal resection	Pneumonia
Cooper and Primrose, 1989 (139)	Cohort	Prospective	Major elective abdominal	Atelectasis, pneumonia
Gerson et al., 1990 (102)	Cohort without comparison group	Prospective	Abdominal and noncardiac thoracic	Pneumonia, noncardiogenic pulmonary edema, pulmonary embolus
Kispert et al., 1992 (52)	Cohort without comparison group	Retrospective	Major vascular	Pneumonia, respiratory failure, ARDS
Kroenke et al., 1992 (50)	Cohort without comparison group	Retrospective	All	All
Calligaro et al., 1993 (60)	Cohort without comparison group	Retrospective	AAA repair	Pneumonia, respiratory failure
Jayr et al., 1993 (57)	Cohort without comparison group	Prospective	Intra-abdominal vascular	Respiratory failure
Wong et al., 1995 (108)	Cohort without comparison group	Prospective	Noncardiothoracic	Pneumonia, respiratory failure, bronchospasm
Kocabas et al., 1996 (73)	Cohort without comparison group	Prospective	Elective upper abdominal	Pneumonia, bronchitis, atelectasis, pulmonary embolism
Barisione et al., 1997 (112)	Cohort without comparison group	Prospective	Abdominal	Pneumonia, atelectasis, respiratory failure
Mitchell et al., 1998 (115)‡	Cohort without comparison group	Prospective	Elective nonthoracic	Bronchitis, bronchospasm, atelectasis, pneumonia, ARDS, pleural effusion, pneumothorax, respiratory failure
Fuso et al., 2000 (140)	Cohort	Retrospective	Elective abdominal	Pneumonia, pneumothorax, pleural effusion, respiratory failure

* AAA = abdominal aortic aneurysm; ARDS = acute respiratory distress syndrome; COPD = chronic obstructive pulmonary disease; NA = not available; PFT = pulmonary function test; PPC = postoperative pulmonary complication.
† Based on criteria from the U.S. Preventive Services Task Force.
‡ COPD was preoperative sputum production.

Appendix Table 8—**Continued**

Inclusion Criteria	Exclusion Criteria	Included All Patients during Study Period or Only at Discretion of Ordering Physician	Hierarchy of Research Design†	Mean Age, *y*	Men, %
Elective surgery, current or never smokers, negative questionnaire for respiratory symptoms or history of respiratory disease	Productive cough, preoperative diagnosis of asthma, COPD, other chronic respiratory disease, previous smoker, local or nonspinal regional anesthesia, thoracic surgery	All	II-2	NA	41
		All	II-3	NA	NA
	Preoperative intravenous nutrition not essential	No PFTs	II-2	61	46
		No PFTs	II-3/C	NA	NA
Age > 65 y		Discretion	II-2	73	49
Elective		All	II-2	65	77
Severe COPD with FEV_1 < 50% predicted and FEV_1:FVC < 70%		Discretion	II-2	66	72
	Emergency surgery, concomitant nonvascular surgery, retroperitoneal incision	Discretion	II-3	NA	NA
Midline incision		All	II-2	NA	65
COPD, FEV_1 < 1.2 L, FEV_1:FVC < 75%	Preexisting tracheostomy, thoracic surgery	All	II-2	68	96
		All	II-3	48	60
	None	All	II-3	64	69
	Regional anesthesia	All	II-2	61.2	NA
Increased preoperative pulmonary risk	Laparoscopy	Discretion	II-2	63	53