

*Current Concepts***PREOPERATIVE PULMONARY
EVALUATION**

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POSTOPERATIVE pulmonary complications are an important part of the risk of surgery and prolong the hospital stay by an average of one to two weeks.¹ Much of the literature on the assessment of perioperative risk has focused on identifying the now well-defined cardiac risk factors. However, clinically significant postoperative pulmonary complications are as common as postoperative cardiac complications. According to one review, pulmonary complications were at least as common as or more common than cardiac complications in 17 of 25 studies of postoperative complications.² This article reviews patient- and procedure-related risk factors, clinical evaluation, pulmonary-function testing, and risk-reduction strategies. The evaluation of candidates for lung resection has been reviewed extensively and is not discussed here.

**DEFINITION OF POSTOPERATIVE
PULMONARY COMPLICATIONS**

Definitions of postoperative pulmonary complications have varied widely. This variation, along with differences in the selection of patients, accounts for most of the differences in the reported incidence of pulmonary complications. Many early definitions included complications of no clinical significance. For example, one study included all patients with a temperature of 37.2°C (99°F) or higher, productive cough, and any new physical signs on chest examination.³ Recent studies have generally included only complications known either to prolong the hospital stay or to contribute to morbidity and mortality.⁴⁻⁶ These important pulmonary complications include pneumonia, respiratory failure with prolonged mechanical ventilation, bronchospasm, atelectasis, and exacerbation of underlying chronic lung disease.

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PATIENT-RELATED RISK FACTORS

Potential patient-related risk factors that may contribute to the risk of postoperative pulmonary complications include smoking, poor general health status, older age, obesity, chronic obstructive pulmonary disease, and asthma (Table 1).

Smoking

Smoking is a risk factor for postoperative pulmonary complications, as has been demonstrated repeatedly since the first report in 1944.⁸ Smoking increases risk even among those without chronic lung disease.³ The relative risk of pulmonary complications among smokers as compared with nonsmokers ranges from 1.4 to 4.3. Unfortunately, the risk declines only after eight weeks of preoperative cessation. Warner et al.²⁰ prospectively studied 200 smokers preparing for coronary bypass surgery and found a lower risk of pulmonary complications among those who had stopped smoking at least eight weeks before surgery than among current smokers (14.5 percent vs. 33 percent). Paradoxically, those who had stopped smoking less than eight weeks earlier had a higher risk than current smokers.

General Health Status

The Goldman cardiac-risk index includes factors from the patient's history, the physical examination, and laboratory data.²¹ This index predicts pulmonary as well as cardiac complications.^{1,22} In addition, the widely used American Society of Anesthesiologists classification, which was developed to evaluate the risk of overall perioperative mortality, is strongly predictive of postoperative pulmonary complications.^{23,24} Poor exercise capacity also identifies patients at risk.²⁵ In a multivariate analysis of patients over 65 years of age who were undergoing abdominal or nonresective thoracic surgery, the inability to perform two minutes of supine bicycle exercise sufficient to raise the heart rate to 99 beats per minute was the strongest predictor of pulmonary complications.²² The inability to exercise predicted 79 percent of pulmonary complications; only 33 percent of patients without pulmonary complications were unable to exercise.

Age

Studies suggesting an increased risk of pulmonary complications with older age have not generally controlled for coexisting conditions. When data are stratified according to the American Society of Anesthesiologists class, the overall perioperative mortality for classes II through V is the same in all age groups.²⁶ In a study of 500 patients over 80 years of age, the

30-day mortality was 6.2 percent for all patients and less than 1 percent for patients in American Society of Anesthesiologists class II.²⁷ Most deaths were from myocardial infarction or infection. Age was not a predictor of postoperative pulmonary complications in two studies of patients with severe chronic obstructive pulmonary disease.^{4,23} Pulmonary complications are more strongly related to coexisting conditions than to chronologic age, and therefore advanced age alone is not a reason to withhold surgery.

Obesity

Despite a common assumption that obesity increases the risk of pulmonary complications, most studies have found no such association (Table 1). For example, a review of 10 series of morbidly obese patients undergoing gastric bypass surgery found an incidence of pneumonia and atelectasis of only 3.9 percent, a rate similar to that for nonobese patients.²⁸ More recently, Phillips and colleagues reported no difference between obese and nonobese patients in the risk of pulmonary complications after laparoscopic cholecystectomy.²⁹ Obesity is not a significant risk factor for pulmonary complications.

Chronic Obstructive Pulmonary Disease

Patients with chronic obstructive pulmonary disease have an increased risk of postoperative pulmonary complications. The incidence varies according to the definition of a complication and the severity of lung disease; relative risks range from 2.7 to 4.7 (Table 1).

Physicians should aggressively treat patients with chronic obstructive pulmonary disease who, before surgery, do not have optimal reduction of symptoms and airflow obstruction on physical examination and who do not have optimal exercise capacity. Elective surgery should be deferred if acute exacerbation is present. The treatments are the same as those for patients who are not about to have an operation. Combinations of bronchodilators, physical therapy, antibiotics, smoking cessation, and corticosteroids reduce the risk of postoperative pulmonary complications.^{19,30} There are few data on the preoperative benefit of individual agents.

Patients with symptomatic chronic obstructive pulmonary disease should be treated with inhaled ipratropium. Inhaled beta-adrenergic-receptor agonists, used up to four times daily, should be added as needed for symptoms. The two agents have an additive effect.³¹ Theophylline reduces dyspnea in patients in stable condition who continue to have symptoms despite the use of inhaled beta-agonists and anticholinergic drugs³² and may be added preoperatively for such patients. Although not all patients with chronic obstructive pulmonary disease respond to corticosteroid therapy, a two-week preoperative course of systemic corticosteroids is reasonable for patients who continue to have symptoms despite bronchodilator therapy and who are not at their best personal base-line level as determined by symptoms, chest examination, and spirometry.³³

Clinicians should reserve preoperative antibiotics

TABLE 1. POTENTIAL PATIENT-RELATED RISK FACTORS FOR POSTOPERATIVE PULMONARY COMPLICATIONS.

POTENTIAL RISK FACTOR*	TYPE OF SURGERY	STUDY	INCIDENCE OF PULMONARY COMPLICATIONS		UNADJUSTED RELATIVE RISK ASSOCIATED WITH FACTOR
			WHEN FACTOR WAS PRESENT	WHEN FACTOR WAS ABSENT	
percent					
Smoking	Coronary bypass	Warner et al. ⁷	39	11	3.4
	Abdominal	Wightman, ³ Morton, ⁸ Brooks-Brunn ⁹	15-46	6-21	1.4-4.3
ASA class >II	Unselected	Wolters et al. ¹⁰	26	16	1.7
	Thoracic or abdominal	Brooks-Brunn, ⁹ Kroenke et al., ¹¹ Hall et al., ¹² Garibaldi et al. ¹³	26-44	13-18	1.5-3.2
Age >70 yr	Unselected	Wightman, ³ Pedersen ¹⁴	9-17	4-9	1.9-2.4
	Thoracic or abdominal	Garibaldi et al., ¹³ Thomas et al., ¹⁵ Calligaro et al. ¹⁶	17-22	12-21	0.9-1.9
Obesity	Unselected	Wightman ³	11	9	1.3
	Thoracic or abdominal	Brooks-Brunn, ⁹ Hall et al., ¹² Garibaldi et al., ¹³ Moulton et al., ¹⁷ Dales et al. ¹⁸	19-36	17-27	0.8-1.7
COPD	Unselected	Wightman, ³ Pedersen et al., ⁵ Tarhan et al. ¹⁹	6-26	2-8	2.7-3.6
	Thoracic or abdominal	Kroenke et al. ¹¹	18	4	4.7

*ASA denotes American Society of Anesthesiologists, and COPD chronic obstructive pulmonary disease.

for outpatients in whom the presence of infection is suggested by a change in the character or amount of sputum. The indiscriminate use of preoperative antibiotics does not reduce the risk of postoperative pneumonia in patients undergoing nonthoracic surgery.³⁴ The risk of postoperative pulmonary complications in patients with viral upper respiratory infections is unknown. A study of patients with asthma found no increase in postoperative pulmonary complications among patients who had had symptoms of upper respiratory infection within the previous 30 days.²⁴ No studies, however, have evaluated high-risk patients undergoing major abdominal or thoracic surgery. It is reasonable to delay truly elective surgery in patients with upper respiratory infection.

Asthma

An early study reported overall rates of postoperative complications of 24 percent in patients with asthma and 14 percent in controls.³⁵ Recent studies have not confirmed this risk. For example, in a study of 706 patients with asthma, 33 percent of whom had received bronchodilators within the previous 30 days, the overall incidence of perioperative bronchospasm was only 1.7 percent.²⁴ Before surgery, patients should be free of wheezing, with a peak flow greater than 80 percent of the predicted or personal best value.³⁶ If necessary, the patient should receive oral corticosteroids (60 mg of prednisone daily or the equivalent) to achieve this goal. A short course of perioperative corticosteroids does not increase the

incidence of infection or other postoperative complications in patients with asthma.^{37,38}

PROCEDURE-RELATED RISK FACTORS

The surgical site is the most important predictor of pulmonary risk (Table 2). Risk increases as the incision approaches the diaphragm. Upper abdominal and thoracic surgery carries the greatest risk of postoperative pulmonary complications, ranging from 10 to 40 percent. The risk is much lower for laparoscopic cholecystectomy (0.3 to 0.4 percent) than for open cholecystectomy (13 to 33 percent). Postoperative pulmonary complications are rare after operations outside the thorax or abdomen.

Table 3 summarizes studies of other procedure-related risk factors. Surgical procedures lasting more than three hours are associated with a higher risk of pulmonary complications.^{9,44} Whenever possible, one should consider shorter procedures for patients who have unmodifiable factors that place them at high risk.

Most studies have reported a lower risk of pulmonary complications with epidural or spinal anesthesia than with general anesthesia (Table 3), although the results are mixed.²⁵ For example, in an early retrospective study of patients with chronic obstructive pulmonary disease, 8 percent of 464 patients undergoing general anesthesia died of respiratory failure, whereas there were no deaths among 121 patients receiving spinal or epidural anesthesia.¹⁹ No studies reported a higher risk of pulmonary complications

TABLE 2. INFLUENCE OF SURGICAL SITE ON RATES OF POSTOPERATIVE PULMONARY COMPLICATIONS.

STUDY	YEAR	TYPE OF SURGERY				
		UPPER ABDOMINAL	LOWER ABDOMINAL	LAPAROSCOPIC CHOLECYSTECTOMY	THORACIC	ALL OTHER
% of cases with complications (total no. of cases)						
Pooler ³⁹	1949	19 (331)	11 (1334)			0.7 (4204)
Wightman ³	1968	19 (130)	6 (323)			0.6 (330)
Tarhan et al. ^{19*}	1973	13 (75)	7 (45)		10 (112)	3 (396)
Gracey et al. ^{6†}	1979	25 (57)	0 (7)		19 (21)	17 (72)
Garibaldi et al. ^{13‡}	1981	17 (201)	5 (208)		40 (102)	
Pedersen et al. ⁵	1990	33 (419)	16 (200)			3 (6687)
Southern Surgeons Club ⁴⁰	1991			0.3 (1518)		
Phillips et al. ²⁹	1994			0.4 (841)		
Brooks-Brunn ⁹	1997	28 (238)	15 (162)			

*Patients had moderate-to-severe chronic obstructive pulmonary disease. Complication was defined as postoperative death.

†Patients had chronic obstructive pulmonary disease.

‡Complication was defined as pneumonia.

TABLE 3. PROCEDURE-RELATED RISK FACTORS FOR POSTOPERATIVE PULMONARY COMPLICATIONS.

RISK FACTOR	TYPE OF SURGERY	STUDY	INCIDENCE OF PULMONARY COMPLICATIONS		UNADJUSTED RELATIVE RISK ASSOCIATED WITH FACTOR
			WHEN FACTOR WAS PRESENT	WHEN FACTOR WAS ABSENT	
			percent		
Surgery lasting >3 hr	Unselected	Kroenke et al., ⁴ Pedersen et al., ⁵ Tarhan et al. ¹⁹	10–53	3–15	1.6–5.2
	Thoracic or abdominal	Garibaldi et al. ¹³	40	11	3.6
General anesthesia	Unselected	Gracey et al., ⁶ Tarhan et al. ¹⁹	8–19	0–17	1.2–∞
	Thoracic, abdominal, or vascular	Christopherson et al., ⁴¹ Yeager et al. ⁴²	28–32	11–12	2.2–3.0
Intraoperative pancuronium	Unselected	Berg et al. ⁴³	17*	5	3.2

*The value is the incidence among patients with residual neuromuscular blockade.

with spinal anesthesia. One should consider spinal or epidural anesthesia, if possible, for surgery in patients at high risk for pulmonary complications. Regional anesthesia, such as an axillary block, carries a lower risk than either spinal or general anesthesia.

A recent study reported a higher risk of pulmonary complications among patients receiving the long-acting neuromuscular blocker pancuronium than among those receiving the shorter-acting atracurium or vecuronium.⁴³ This prospective study of 691 patients found three times as many pulmonary complications among the patients receiving pancuronium who had postoperative residual neuromuscular block as among those who did not. The increased rate of pulmonary complications was due to more frequent and prolonged residual neuromuscular blockade, which resulted in postoperative hypoventilation. The intensity of monitoring was equal in all groups. The use of pancuronium should be avoided in patients at high risk for pulmonary complications.

PREOPERATIVE CLINICAL EVALUATION

A careful history taking and physical examination are the most important parts of preoperative pulmonary risk assessment. One should seek a history of exercise intolerance,²² chronic cough, or unexplained dyspnea. The physical examination may identify findings suggestive of unrecognized pulmonary disease. Among such findings, decreased breath sounds, dullness to percussion, wheezes, rhonchi, and a prolonged expiratory phase predict an increase in the risk of pulmonary complications.^{1,45}

PREOPERATIVE PULMONARY-FUNCTION TESTING

The value of routine preoperative pulmonary-function testing remains controversial. There is con-

sensus that all candidates for lung resection should undergo preoperative pulmonary-function testing. Such testing should be performed selectively in patients undergoing other surgical procedures. It has been suggested that an increased risk of pulmonary complications is associated with a forced expiratory volume in one second (FEV₁) or forced vital capacity (FVC) of less than 70 percent of the predicted value, or a ratio of FEV₁ to FVC of less than 65 percent.⁴⁶

In 1990 a position paper of the American College of Physicians recommended spirometry for patients with a history of tobacco use or dyspnea who are undergoing coronary bypass or upper abdominal surgery, patients with unexplained dyspnea or pulmonary symptoms who are undergoing head and neck, orthopedic, or lower abdominal surgery, and all patients who are undergoing lung resection.⁴⁷ However, a critical appraisal of 22 early studies of preoperative spirometry found methodologic flaws in every study.⁴⁸

Recent studies show that spirometry has a variable predictive value (Table 4). In addition, clinical findings are generally more predictive of pulmonary complications than spirometric results in the few studies that have evaluated both factors.^{11,25,57} However, no prospective, randomized trials have addressed this question. For example, in a case-control study of 164 patients undergoing elective abdominal surgery, abnormal findings on chest examination were highly associated with the risk of pulmonary complications, whereas abnormal spirometric findings were not predictive (odds ratios, 5.8 and 1.0, respectively).¹

One potential rationale for preoperative pulmonary-function testing is to identify patients in whom the risk is so high that surgery should be canceled. However, even patients at very high risk as defined spirometrically can undergo surgery with an accept-

TABLE 4. USE OF PREOPERATIVE SPIROMETRY TO PREDICT POSTOPERATIVE PULMONARY COMPLICATIONS.

STUDY	YEAR	TYPE OF SURGERY	INCIDENCE OF PULMONARY COMPLICATIONS		RR ASSOCIATED WITH ABNORMAL FINDINGS (95% CI)*
			AMONG PATIENTS WITH ABNORMAL SPIROMETRIC FINDINGS	AMONG PATIENTS WITH NORMAL SPIROMETRIC FINDINGS	
			% (total no. of cases)		
Collins et al. ⁴⁹	1968	Upper abdominal	44 (25)	17 (95)	2.6 (1.4–4.9)
Stein and Cassara ⁵⁰	1970	Unselected	42 (48)	10 (29)	4.0 (1.3–12.4)
Appleberg et al. ⁵⁰	1974	Unselected	16 (76)	8 (24)	1.9 (0.5–7.9)
Fogh et al. ⁵¹	1987	Abdominal	27 (22)	16 (100)	1.7 (0.8–3.9)
Poe et al. ⁵²	1988	Cholecystectomy	34 (38)	11 (171)	3.3 (1.8–6.1)
Svensson et al. ^{53†‡}	1991	Aortic	49 (47)	32 (44)	1.5 (0.9–2.6)
Kispert et al. ⁵⁴	1992	Vascular	23 (62)	6 (85)	3.8 (1.5–10.1)
Kroenke et al. ^{11§}	1993	Abdominal and thoracic	52 (52)	39 (52)	1.4 (0.9–2.1)
Kocabas et al. ⁴⁵	1996	Upper abdominal	50 (16)	30 (44)	1.7 (0.9–3.3)
Bando et al. ^{55‡}	1997	Cardiac	11 (67)	10 (301)	1.0 (0.5–2.2)
Jacob et al. ⁵⁶	1997	Coronary bypass	45 (107)	50 (56)	0.9 (0.6–1.3)

*RR denotes relative risk, and CI confidence interval.

†Abnormal findings were defined as an FEV₁ of less than 73 percent of the predicted value.

‡Complication was defined as the need for mechanical ventilation for more than 48 hours.

§Abnormal findings were defined as an FEV₁ that was 50 to 79 percent of the predicted value and an FEV₁:FVC of less than 70 percent.

able risk of pulmonary complications. Kroenke and colleagues studied 107 operations in patients with severe chronic obstructive pulmonary disease as defined by an FEV₁ of less than 50 percent of the predicted value and a ratio of FEV₁ to FVC of less than 70 percent.⁴ Postoperative pulmonary complications occurred in only 29 percent of the patients, with only 1 death among 97 patients undergoing noncoronary procedures. This study and others of patients at high risk suggest no threshold beyond which the risk of surgery is prohibitive.^{11,23}

Physicians should use a variety of strategies to reduce the risk of pulmonary complications in patients at high risk after a thorough clinical evaluation and review of risk factors. No data suggest that spirometry identifies a high-risk group with abnormal spirometric findings but no clinical evidence of pulmonary disease or other risk factors for pulmonary complications. Clinicians may reserve preoperative spirometry for patients who are to undergo thoracic or upper abdominal surgery and who have symptoms of cough, dyspnea, or exercise intolerance that remain unexplained after a careful history taking and physical examination. In addition, spirometry may be helpful in a patient with chronic obstructive pulmonary disease or asthma if, after clinical assessment, it is uncertain whether the degree of airflow

obstruction has been optimally reduced. The results of preoperative pulmonary-function testing should not be used to deny a patient surgery.

On the basis of small case series, several authors have found a partial pressure of arterial carbon dioxide (PaCO₂) greater than 45 mm Hg to be a strong risk factor for pulmonary complications.^{58,59} In these studies, all patients with an elevated PaCO₂ also had substantial airway obstruction on spirometry, although symptoms and exercise capacity were not reported. Physicians would probably identify these patients as being at high risk on clinical grounds alone. A more recent prospective study did not find an elevated PaCO₂ to be a risk factor among candidates for lung resection.⁶⁰ Clinicians should not use arterial-blood gas analyses to identify patients for whom the risk of surgery is prohibitive.

PULMONARY-RISK INDEXES

Clinicians have used cardiac-risk indexes to estimate perioperative risk for more than two decades.²¹ In 1993, Epstein and colleagues developed a cardiopulmonary-risk index that is the sum of a modified Goldman index and pulmonary risk factors, including obesity, smoking, productive cough, diffuse wheezing or rhonchi, an FEV₁:FVC ratio of less than 70 percent, and a PaCO₂ greater than 45 mm Hg.⁶¹

In the original series of candidates for lung resection, the odds ratio for pulmonary complications was 13 for patients with scores of 4 or more (of 10 possible points), as compared with those with scores of 3 or less. This index has not been validated in patients undergoing abdominal surgery. A drawback of this index is the need for routine preoperative pulmonary-function testing and arterial-blood gas analysis.

In a case-control study of patients undergoing abdominal surgery,¹ a multivariate analysis found that, in descending order of importance, abnormal results on chest examination, an abnormal chest radiograph, a high score on the Goldman cardiac-risk index, and a high score on the Charlson comorbidity index were independently associated with an elevated pulmonary risk. This scheme has several advantages. It does not require routine spirometry or arterial-blood gas analysis, and it was developed in a population of patients undergoing abdominal surgery.

RISK-REDUCTION STRATEGIES

Table 5 summarizes established risk-reduction strategies that can be used throughout the perioperative period. Postoperative strategies include lung-expansion maneuvers and pain control.

Lung-Expansion Maneuvers

Lung-expansion maneuvers are the mainstay of postoperative prevention in patients at high risk. These techniques lower the risk of atelectasis by increasing lung volume. Deep-breathing exercises, which are a component of chest physical therapy, and incentive spirometry have been studied most extensively. A critical review of these techniques found that they consistently reduced the relative risk of pulmonary complications by 50 percent.⁶² Most studies have found no difference in efficacy between these two techniques. For example, a recent meta-analysis of 14 studies of incentive spirometry and deep-breathing exercises, as compared with no intervention, found odds ratios of 0.44 and 0.43 for pulmonary complications, respectively.⁶³ Preoperative education in lung-expansion maneuvers reduces pulmonary complications to a greater degree than instruction that begins after surgery.^{44,64}

Intermittent positive-pressure breathing is also effective, although most physicians have abandoned its routine use for primary prevention because of its relatively high cost and incidence of complications.⁴⁴ Postoperative continuous positive airway pressure is at least as effective as deep breathing and incentive spirometry.⁶⁵ The principal advantage of continuous positive airway pressure is that it is not dependent on the patient's effort. It is costly, however, and requires more intensive involvement by hospital personnel than other methods. Clinicians should restrict the use of continuous positive airway pressure for the primary prevention of pulmonary complications to

TABLE 5. RISK-REDUCTION STRATEGIES.

PREOPERATIVE

- Encourage cessation of cigarette smoking for at least 8 wk
- Treat airflow obstruction in patients with chronic obstructive pulmonary disease or asthma
- Administer antibiotics and delay surgery if respiratory infection is present
- Begin patient education regarding lung-expansion maneuvers

INTRAOPERATIVE

- Limit duration of surgery to less than 3 hr
- Use spinal or epidural anesthesia*
- Avoid use of pancuronium
- Use laparoscopic procedures when possible
- Substitute less ambitious procedure for upper abdominal or thoracic surgery when possible

POSTOPERATIVE

- Use deep-breathing exercises or incentive spirometry
- Use continuous positive airway pressure
- Use epidural analgesia*
- Use intercostal nerve blocks*

*This strategy is recommended, although variable efficacy has been reported in the literature.

patients who are unable to perform deep-breathing exercises or incentive spirometry.

Nasal bilevel positive airway pressure minimizes the expected decline in lung volume after surgery and may reduce postoperative pulmonary complications. In a study of 29 medical and postoperative patients with impending respiratory failure, 76 percent of those treated with bilevel positive airway pressure did not require intubation.⁶⁶ Bilevel positive airway pressure is effective for the treatment of postoperative atelectasis and respiratory failure. Because less costly lung-expansion maneuvers are available, physicians should not use bilevel positive airway pressure routinely for the primary prevention of complications.

Pain Control

Postoperative epidural analgesia reduces the rate of pulmonary complications in patients at high risk. In one study, for example, 75 patients undergoing cholecystectomy, including 31 with pulmonary disease, were randomly assigned to receive epidural analgesia or parenteral narcotics.⁶⁷ The rates of pulmonary complications were 24 percent and 56 percent, respectively. Not all reports have shown a similar reduction in risk, although no studies have found excess pulmonary morbidity with epidural analgesia. Epidural analgesia is safe. Among 1106 patients treated with postoperative epidural morphine in one study,

there were only two episodes of respiratory depression.⁶⁸ Hypotension is more common among patients receiving epidural analgesia, but it responds to treatment and is not a cause of morbidity. Postoperative epidural analgesia is recommended after high-risk thoracic, abdominal, and major vascular procedures.

A meta-analysis of the use of postoperative intercostal nerve blocks reported a relative risk of 0.47 for all pulmonary complications, but the risk reduction did not achieve statistical significance.⁶⁹ This treatment is an option if epidural analgesia is ineffective or technically difficult.

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REFERENCES

1. Lawrence VA, Dhanda R, Hilsenbeck SG, Page CP. Risk of pulmonary complications after elective abdominal surgery. *Chest* 1996;110:744-50.
2. 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.
3. Wightman JA. A prospective survey of the incidence of postoperative pulmonary complications. *Br J Surg* 1968;55:85-91.
4. Kroenke K, Lawrence VA, Theroux JF, Tuley MR. Operative risk in patients with severe obstructive pulmonary disease. *Arch Intern Med* 1992;152:967-71.
5. Pedersen T, Eliassen 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.
6. Gracey DR, Divertie MB, Didier EP. Preoperative pulmonary preparation of patients with chronic obstructive pulmonary disease: a prospective study. *Chest* 1979;76:123-9.
7. Warner MA, Divertie MB, Tinker JH. Preoperative cessation of smoking and pulmonary complications in coronary artery bypass patients. *Anesthesiology* 1984;60:380-3.
8. Morton HJV. Tobacco smoking and pulmonary complications after surgery. *Lancet* 1944;1:368-70.
9. Brooks-Brunn JA. Predictors of postoperative pulmonary complications following abdominal surgery. *Chest* 1997;111:564-71.
10. Wolters U, Wolf T, Stutzer H, Schroder T. ASA classification and perioperative variables as predictors of postoperative outcome. *Br J Anaesth* 1996;77:217-22.
11. 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.
12. Hall JC, Tarala RA, Hall JL, Mander J. A multivariate analysis of the risk of pulmonary complications after laparotomy. *Chest* 1991;99:923-7.
13. Garibaldi RA, Britt MR, Coleman ML, Reading JC, Page NL. Risk factors for postoperative pneumonia. *Am J Med* 1981;70:677-80.
14. 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.
15. Thomas P, Doddoli C, Neville P, et al. Esophageal cancer resection in the elderly. *Eur J Cardiothorac Surg* 1996;10:941-6.
16. Calligaro KD, Azurin DJ, Dougherty MJ, et al. Pulmonary risk factors of elective abdominal aortic surgery. *J Vasc Surg* 1993;18:914-21.
17. Moulton MJ, Creswell LL, Mackey ME, Cox JL, Rosenbloom M. Obesity is not a risk factor for significant adverse outcomes after cardiac surgery. *Circulation* 1996;94:Suppl II:II-87-II-92.
18. Dales RE, Dionne G, Leech JA, Lunau M, Schweitzer I. Preoperative prediction of pulmonary complications following thoracic surgery. *Chest* 1993;104:155-9.
19. Tarhan S, Moffitt EA, Sessler AD, Douglas WW, Taylor WF. Risk of anesthesia and surgery in patients with chronic bronchitis and chronic obstructive pulmonary disease. *Surgery* 1973;74:720-6.
20. Warner MA, Offord KP, Warner ME, Lennon RL, Conover MA, Janssen-Schumacher U. Role of preoperative cessation of smoking and other factors in postoperative pulmonary complications: a blinded prospective study of coronary artery bypass patients. *Mayo Clin Proc* 1989;64:609-16.
21. Goldman L, Caldera DL, Nussbaum SR, et al. Multifactorial index of cardiac risk in noncardiac surgical procedures. *N Engl J Med* 1977;297:845-50.
22. 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.
23. Wong D, 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.
24. Warner DO, Warner MA, Barnes RD, et al. Perioperative respiratory complications in patients with asthma. *Anesthesiology* 1996;85:460-7.
25. 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.
26. Marx GF, Mateo CV, Orkin LR. Computer analysis of postanesthetic deaths. *Anesthesiology* 1973;39:54-8.
27. Djokovic JL, Hedley-Whyte J. Prediction of outcome of surgery and anesthesia in patients over 80. *JAMA* 1979;242:2301-6.
28. Pasulka PS, Bistran BR, Benotti PN, Blackburn GL. The risks of surgery in obese patients. *Ann Intern Med* 1986;104:540-6.
29. Phillips EH, Carroll BJ, Fallas MJ, Pearlstein AR. Comparison of laparoscopic cholecystectomy in obese and non-obese patients. *Am Surg* 1994;60:316-21.
30. Stein M, Cassara EL. Preoperative pulmonary evaluation and therapy for surgery patients. *JAMA* 1970;211:787-90.
31. The COMBIVENT Inhalation Aerosol Study Group. In chronic obstructive pulmonary disease, a combination of ipratropium and albuterol is more effective than either agent alone: an 85-day multicenter trial. *Chest* 1994;105:1411-9.
32. Vaz Fragoso CA, Miller MA. Review of the clinical efficacy of theophylline in the treatment of chronic obstructive pulmonary disease. *Am Rev Respir Dis* 1993;147:S40-S47.
33. Mendella LA, Manfreda J, Warren CP, Anthonisen NR. Steroid response in stable chronic obstructive pulmonary disease. *Ann Intern Med* 1982;96:17-21.
34. Lazlo G, Archer GG, Darrell JH, Dawson JM, Fletcher CM. The diagnosis and prophylaxis of pulmonary complications of surgical operations. *Br J Surg* 1973;60:129-34.
35. Gold MI, Helrich M. A study of complications related to anesthesia in asthmatic patients. *Anesth Analg* 1963;42:238-93.
36. Guidelines for the diagnosis and management of asthma. National Heart, Lung, and Blood Institute, National Asthma Education Program, expert panel report. X. Special considerations. *J Allergy Clin Immunol* 1991;88:Suppl:523-34.
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.
38. Kabalain CS, Yarnold PR, Grammer LC. Low complication rate of corticosteroid-treated asthmatics undergoing surgical procedures. *Arch Intern Med* 1995;155:1379-84.
39. Pooler HE. Relief of post-operative pain and its influence on vital capacity. *BMJ* 1949;2:1200-3.
40. The Southern Surgeons Club. A prospective analysis of 1518 laparoscopic cholecystectomies. *N Engl J Med* 1991;324:1073-8. [Erratum, *N Engl J Med* 1991;325:1517-8.]
41. Christopherson R, Beattie C, Frank SM, et al. Perioperative morbidity in patients randomized to epidural or general anesthesia for lower extremity vascular surgery. *Anesthesiology* 1993;79:422-34.
42. Yeager MP, Glass DD, Neff RK, Brink-Johnsen T. Epidural anesthesia and analgesia in high-risk surgical patients. *Anesthesiology* 1987;66:729-36.
43. Berg H, Viby-Mogensen J, Roed J, et al. Residual neuromuscular block is a risk factor for postoperative pulmonary complications: a prospective, randomised, and blinded study of postoperative pulmonary complications after atracurium, vecuronium, and pancuronium. *Acta Anaesthesiol Scand* 1997;41:1095-103.
44. Celli BR, Rodriguez KS, Snider GL. A controlled trial of intermittent positive pressure breathing, incentive spirometry, and deep breathing exercises in preventing pulmonary complications after abdominal surgery. *Am Rev Respir Dis* 1984;130:12-5.
45. 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.
46. Gass GD, Olsen GN. Preoperative pulmonary function testing to predict postoperative morbidity and mortality. *Chest* 1986;89:127-35.

47. American College of Physicians. Preoperative pulmonary function testing. *Ann Intern Med* 1990;112:793-4.
48. 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.
49. Collins CD, Darke CS, Knowelden J. Chest complications after upper abdominal surgery: their anticipation and prevention. *BMJ* 1968;1:401-6.
50. Appleberg M, Gordon L, Fatti LP. Preoperative pulmonary evaluation of surgical patients using the vitalograph. *Br J Surg* 1974;61:57-9.
51. Fogh J, Wille-Jorgensen P, Brynjolf I, 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.
52. 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.
53. 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.
54. Kispert JF, Kazmers A, Roitman L. Preoperative spirometry predicts perioperative pulmonary complications after major vascular surgery. *Am Surg* 1992;58:491-5.
55. Bando K, Sun K, Binford RS, Sharp TG. Determinants of longer duration of endotracheal intubation after adult cardiac operations. *Ann Thorac Surg* 1997;63:1026-33.
56. Jacob B, Amoateng-Adjepong Y, Rasakulasurir S, Manthous CA, Haddad R. Preoperative pulmonary function tests do not predict outcome after coronary artery bypass. *Conn Med* 1997;61:327-32.
57. Cain HD, Stevens PM, Adaniya R. Preoperative pulmonary function and complications after cardiovascular surgery. *Chest* 1979;76:130-5.
58. Milledge JS, Nunn JF. Criteria of fitness for anaesthesia in patients with chronic obstructive lung disease. *BMJ* 1975;3:670-3.
59. Stein M, Koota GM, Simon M, Frank HA. Pulmonary evaluation of surgical patients. *JAMA* 1962;181:765-70.
60. Kearney DJ, Lee TH, Reilly JJ, DeCamp MM, Sugarbaker DJ. Assessment of operative risk in patients undergoing lung resection: importance of predicted pulmonary function. *Chest* 1994;105:753-9.
61. 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.
62. Brooks-Brunn JA. Postoperative atelectasis and pneumonia. *Heart Lung* 1995;24:94-115.
63. Thomas JA, McIntosh JM. Are incentive spirometry, intermittent positive pressure breathing, and deep breathing exercises effective in the prevention of postoperative pulmonary complications after upper abdominal surgery? A systematic overview and meta-analysis. *Phys Ther* 1994;74:3-16.
64. Castillo R, Haas A. Chest physical therapy: comparative efficacy of preoperative and postoperative in the elderly. *Arch Phys Med Rehabil* 1985;66:376-9.
65. Stock MC, Downs JB, Gauer PK, Alster JM, Imrey PB. Prevention of postoperative pulmonary complications with CPAP, incentive spirometry, and conservative therapy. *Chest* 1985;87:151-7.
66. Pennock BE, Kaplan PD, Carlin BW, Sabangan JS, Magovern JA. Pressure support ventilation with a simplified ventilatory support system administered with a nasal mask in patients with respiratory failure. *Chest* 1991;100:1371-6.
67. Cuschieri RJ, Morran CG, Howie JC, McArdle CS. Postoperative pain and pulmonary complications: comparison of three analgesic regimens. *Br J Surg* 1985;72:495-8.
68. Ready LB, Loper KA, Nessly M, Wild L. Postoperative epidural morphine is safe on surgical wards. *Anesthesiology* 1991;75:452-6.
69. Ballantyne JC, Carr DB, deFerranti S, et al. The comparative effects of postoperative analgesic therapies on pulmonary outcome: cumulative meta-analyses of randomized, controlled trials. *Anesth Analg* 1998;86:598-612.