



Preoperative evaluation for postoperative pulmonary complications

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Postoperative pulmonary complications are associated with substantial mortality and morbidity. Nearly one fourth of deaths occurring within 6 days postoperatively are related to postoperative pulmonary complications [1]. Estimates of the incidence and prevalence of these complications vary greatly, however, depending on the patient population, type of surgery, and definition of complication. For example, complication rates are higher in patients with severe obstructive lung disease undergoing major abdominal surgery (up to 56%) [2,3] and are also increased with aortic aneurysm repair [4–8], upper abdominal [4,5,9–11], thoracic [2,4,5,12], and neck surgery [4,5,13].

Studies classify atelectasis [9,12,14], pneumonia [1,5,14,33], respiratory failure [4,6,13,14], acute respiratory distress syndrome [11,13], and pleural effusion [14,15] as postoperative pulmonary complications. Although the clinical implications and risk factors of each complication vary, many studies combine distinct complications into an overall pulmonary complication rate [9,12–14]. Preoperative evaluation for pulmonary embolus and hypoxemia risk is not directly addressed in this article.

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A preoperative medical evaluation enables clinicians to accomplish two distinct yet related goals: (1) to predict the risk of postoperative complications, and (2) to reduce the risk of complications. The first goal is usually accomplished through risk assessment indices that predict the incidence of complications. The evidence necessary to develop and validate risk indices is obtained through observational, cohort, and case-control studies. The second goal is accomplished through preoperative and perioperative risk reduction interventions. The evidence necessary to prove that interventions reduce the incidence or severity of complications is obtained through randomized, controlled trials.

Some preoperative tests assist in risk assessment but do not provide targets for risk reduction. For example, low albumin level is a significant risk factor for postoperative respiratory failure and mortality [4,16], although improving the albumin level preoperatively does not improve complication rates [17]. Conversely, other preoperative tests may improve perioperative management but are not needed for accurate risk assessment. For example, preoperative pulmonary function test results may guide perioperative management but do not improve preoperative risk assessment [18].

The primary purpose of this article is to present strategies for preoperative risk assessment of major postoperative pulmonary complications (PPCs) for patients undergoing noncardiac surgery. A secondary purpose is to distinguish between factors that are useful for preoperative risk assessment and those that provide potential targets for reducing the risk of pulmonary complications.

Literature search and identification strategy

This article is based on the results of a broad literature search that systematically identified recent evidence about preoperative risk assessment and perioperative interventions related to postoperative pulmonary complications. We queried Medline from January 1995 to March 2002 for articles indexed with any of the following terms as their primary focus: intraoperative complications, postoperative complications, preoperative care, intraoperative care, and postoperative care. Citations were limited to studies about humans published in English. The following publication types were excluded because of the focus on primary data: letter, editorial, case report, and clinical conference proceedings. Because the article is directed to general internists, studies including pediatric, cardiopulmonary surgery, and/or immunosuppressed patients (eg, organ transplantation, acquired immunodeficiency syndrome) were excluded. We excluded studies from developing countries because of potential differences in respiratory and intensive care technology. Three physician reviewers each evaluated one third of approximately 17,000 citation titles and abstracts to identify potentially relevant publications. These potentially relevant publications were obtained and reviewed for a final determination of relevancy.

Patient-related risk factors

There are numerous patient-related risk factors for PPCs. As outlined in Table 1, these risk factors are related to the patient's general health, nutritional, respiratory, neurologic, fluid, and immune status.

General health and nutritional status

Risk factors for PPCs that are related to general health and nutritional status include increasing age [4,5], lower albumin level [4], dependent functional status [4,5], weight loss [4,5], and possibly obesity [9]. Patients greater than 60 years old are at increased risk for postoperative pneumonia and

Table 1
Risk factors for postoperative pulmonary complications

General health and nutritional status	Incision near diaphragm	Anesthesia duration > 2 hours	Nasogastric tube
Age	Thoracic surgery		Pain control with
Low albumin	Upper abdominal surgery	General anesthesia	parenteral narcotics versus epidural analgesia
Functional status	AAA repair	Not using	
Obesity (?)	Other types of surgery	neuroaxial	
Weight loss > 10%	Neck surgery	blockade	
ASA class	Peripheral vascular surgery	Use of long-acting	
Goldman class	Neurosurgery	neuromuscular	
Charlson Index		blockade	
Respiratory status			
COPD history	Emergency surgery		
Tobacco use			
Sputum production	Surgery technique		
Pneumonia	Open versus		
Dyspnea	laparoscopic		
OSA			
Neurologic status			
Impaired sensorium			
CVA history			
Fluid status			
CHF history			
Renal failure			
Blood urea nitrogen			
Blood transfusion			
Immune status			
Chronic steroid use			
Alcohol use			
Diabetes			

Abbreviations: AAA, abdominal aortic aneurysm; ASA, American Society of Anesthesiologists; CHF, congestive heart failure; COPD, chronic obstructive pulmonary disease; CVA, cerebrovascular accident; OSA, obstructive sleep apnea.

respiratory failure (Table 2) [4,5]. Low serum albumin is associated with respiratory failure [4], as well as higher 30-day postoperative mortality and morbidity rates [11,16]. Moreover, mortality increases exponentially as albumin falls below 4.0 g/dL [16]. Dependent functional status, with respect to activities of daily living, is also associated with an increased risk of PPCs [4,5].

Patients with greater than 10% weight loss in the 6 months prior to surgery are at increased risk for respiratory failure and pneumonia [4,5]. Obese patients (body mass index greater than 27 kg/m²) undergoing abdominal surgery are at greater risk for developing atelectasis and pneumonia [9]. Among thoracic surgery patients, however, the risk of PPCs is not increased when stratified by body mass index [12]. The conflicting evidence about obesity as a risk factor reflects differences in the measurement of co-morbid conditions in prior studies [19].

Respiratory status

Risk factors for PPCs related to respiratory status include chronic obstructive pulmonary disease (COPD), smoking, preoperative sputum production and pneumonia, dyspnea, and obstructive sleep apnea (Table 1). Stable patients with COPD may become unstable in the perioperative period because of the detrimental respiratory effects of surgery and anesthesia [2,3]. Among noncardiac surgery patients, active smokers within 2 weeks of surgery are at increased risk for respiratory failure [4], and those who smoked within 1 year of surgery are at increased risk for pneumonia [5] (Table 2). Among abdominal surgery patients, higher pack-years of smoking are associated with increased risk of PPCs in univariate analysis but are not statistically significant in multivariable analysis [10]. Preoperative sputum production [14] and preoperative pneumonia [4] are independent risk factors for PPCs among patients undergoing elective noncardiothoracic surgery. Dyspnea, at rest or on minimal exertion, is also associated with an increased incidence of respiratory failure [4].

Obstructive sleep apnea (OSA) is associated with an increased risk of PPCs. In OSA patients undergoing hip or knee replacement surgery, 39% of patients with OSA (versus 18% in the control group) develop a serious pulmonary or cardiac complication [20]. Common PPCs include acute hypercapnia and episodic hypoxemia, with the majority occurring within 24 hours postoperatively. Serious complications necessitating ICU transfer occur in 24% of patients with OSA versus 9% in the control group.

Neurologic status

Risk factors related to neurologic status associated with PPCs include impaired sensorium [4,5,9] and previous stroke [4,5]. Patients with impaired sensorium or stroke with residual deficit have an odds ratio of 1.5 for

pneumonia risk and 1.2 for respiratory failure risk (Table 2). These patients are less mobile postoperatively leading to a higher risk of atelectasis. They are also unable to protect their airway leading to higher risks of aspiration pneumonia and respiratory failure.

Fluid status

Risk factors for PPCs associated with fluid status include congestive heart failure [4], acute renal failure [4,7,8], and blood transfusion [4,5,21]. Patients with these conditions are at increased risk for pulmonary edema and pleural effusions that may lead to atelectasis, pneumonia, and even respiratory failure. High and low blood urea nitrogen levels are associated with pulmonary complications [4,5], implying that careful fluid management is needed in high-risk patients. In addition, patients with primary pulmonary hypertension are particularly sensitive to volume changes and may be difficult to manage once acute right heart failure occurs [22].

Immune status

Chronic steroid use is associated with an increased risk of postoperative pneumonia, but not respiratory failure (Table 2). The increased risk of pneumonia may be secondary to immune suppression from the steroid medications in addition to the impact of diseases treated with steroids such as rheumatoid arthritis. Patients with alcohol use (greater than 2 drinks per day) within 2 weeks of surgery have 20% increased odds of pneumonia and respiratory failure (Table 2). Chronic alcohol use may be associated with diminished B-cell mediated immunity leading to an increased risk of pneumonia. Patients with insulin-treated diabetes mellitus are at slightly increased risk for respiratory failure, but not for pneumonia (Table 2).

Operation-related risk factors

Several operation-related risk factors including surgical incision site, type of surgery, and surgical technique are associated with increased risk for PPCs (Table 1). Though these risk factors may not be modifiable, they are important to identify a priori for risk stratification.

Surgical incision site and type of surgery

Operations with incision sites near the diaphragm, such as thoracic and upper abdominal surgeries, are associated with the highest risk for PPCs [19]. Perioperative changes in lung volumes and ventilation patterns can lead to hypoxemia and atelectasis [23,24]. Diaphragmatic dysfunction contributes to these perioperative changes, even with adequate pain relief [25,26]. Depending on the PPC definition used, PPC rates range from 10–40% for

Table 2
Comparison of the risk factors included in The Postoperative Pneumonia and Respiratory Failure Risk Indices

Risk factors	Postoperative Pneumonia Risk Index (OR [95% CI])	Point value	Respiratory Failure Risk Index (OR [95% CI])	Point value
Type of surgery				
AAA repair	4.29 (3.34–5.50)	15	14.3 (12.0–16.9)	27
Thoracic	3.92 (3.36–4.57)	14	8.14 (7.17–9.25)	21
Upper abdominal	2.68 (2.38–3.03)	10	4.21 (3.80–4.67)	14
Neck	2.30 (1.73–3.05)	8	3.10 (2.40–4.01)	11
Neurosurgery	2.14 (1.66–2.75)	8	4.21 (3.80–4.67)	14
Vascular	1.29 (1.10–1.52)	3	4.21 (3.80–4.67)	14
Emergency surgery	1.33 (1.16–1.54)	3	3.12 (2.83–3.43)	11
General anesthesia	1.56 (1.36–1.80)	4	1.91 (1.64–2.21)	—
Age				
≥80 years	5.63 (4.62–6.84)	17	—	—
70–79 years	3.58 (2.97–4.33)	13	—	—
60–69 years	2.38 (1.98–2.87)	9	—	—
50–59 years	1.49 (1.23–1.81)	4	—	—
≤50 years	1.00 (referent)	—	—	—
≥70 years	—	—	1.91 (1.71–2.13)	6
60–69 years	—	—	1.51 (1.36–1.69)	4
≤60 years	—	—	1.00 (referent)	—
Functional status				
Totally dependent	2.83 (2.33–3.43)	10	1.92 (1.74–2.11)	7
Partially dependent	1.83 (1.63–2.06)	6	1.92 (1.74–2.11)	7
Independent	1.00 (referent)	—	1.00 (referent)	—
Albumin				
< 3.0 g/dL	—	—	2.53 (2.28–2.80)	9
> 3.0 g/dL	—	—	1.00 (referent)	—
Weight loss > 10% (within 6 months)	1.92 (1.68–2.18)	7	1.37 (1.19–1.57) ^a	—
Chronic steroid use	1.33 (1.12–1.58)	3	—	—
Alcohol > 2 drinks/day (within 2 weeks)	1.24 (1.08–1.42)	2	1.19 (1.07–1.33) ^a	—
Diabetes—insulin treated	—	—	1.15 (1.00–1.33) ^a	—
History of COPD	1.72 (1.55–1.91)	5	1.81 (1.66–1.98)	6
Current smoker				
Within 1 year	1.28 (1.17–1.42)	3	—	—
Within 2 weeks	—	—	1.24 (1.14–1.36) ^a	—
Preoperative pneumonia	—	—	1.70 (1.35–2.13) ^a	—
Dyspnea				
At rest	—	—	1.69 (1.36–2.09) ^a	—
On minimal exertion	—	—	1.21 (1.09–1.34) ^a	—
No dyspnea	—	—	1.00 (referent)	—

Table 2 (continued)

Risk factors	Postoperative Pneumonia Risk Index (OR [95% CI])	Point value	Respiratory Failure Risk Index (OR [95% CI])	Point value
Impaired sensorium	1.51 (1.26–1.82)	4	1.22 (1.04–1.43) ^a	—
History of CVA	1.47 (1.28–1.68)	4	1.20 (1.05–1.38) ^a	—
History of CHF	—	—	1.25 (1.07–1.47) ^a	—
Blood urea nitrogen				
< 8 mg/dL	1.47 (1.26–1.72)	4	1.00 (referent)	—
8–21 mg/dL	1.00 (referent)	—	1.00 (referent)	—
22–30 mg/dL	1.24 (1.11–1.39)	2	1.00 (referent)	—
> 30 mg/dL	1.41 (1.22–1.64)	3	2.29 (2.04–2.56)	8
Preoperative renal failure	—	—	1.67 (1.23–2.27) ^a	—
Preoperative transfusion (> 4 units)	1.35 (1.07–1.72)	3	1.56 (1.28–1.91) ^a	—

Adapted from Arozullah AM, et al. Development and validation of a multifactorial risk index for predicting postoperative pneumonia after major noncardiac surgery. *Annals of Internal Medicine* 2001;135:847–57, and from Arozullah AM, et al. Multifactorial risk index for predicting postoperative respiratory failure in men after major noncardiac surgery. *Annals of Surgery* 2000;232(2):242–53; with permission.

^a Risk factor was statistically significant in multivariable analysis but was not included in the Respiratory Failure Risk Index.

thoracic surgery and 13–33% for upper abdominal surgery, compared with 0–16% for lower abdominal surgery [19].

Two validated multifactorial risk indices from the largest surgical cohort to date reinforce the importance of the incision location and type of surgery (Table 2). Type of surgery is the strongest predictor of PPCs in both The Postoperative Respiratory Failure Risk Index and The Postoperative Pneumonia Risk Index (Table 2) [4,5]. In these indices, abdominal aortic aneurysm repair, thoracic surgery, and upper abdominal surgery carry the highest risk, confirming results from previous smaller studies. In addition, neck, peripheral vascular, neurosurgery, and emergency surgery are independently associated with increased PPC risk. Neurosurgery and neck surgery may be associated with increased risk for perioperative aspiration pneumonia.

Surgical technique

Modifying the surgical approach or extent of surgery may reduce operative time and incision-related risk in high-risk patients. In addition, randomized trials indicate that some laparoscopic procedures, despite longer anesthesia time, have lower PPC risk compared with open procedures. The PPC rate for patients undergoing laparoscopic cholecystectomy is 2.7% versus 17.2% for those undergoing open cholecystectomy [27]. In a randomized

trial of laparoscopic versus open fundoplication, laparoscopic fundoplication is associated with significantly better FEV₁ and FVC, shorter hospital stay, and decreased need for analgesics [28]. In two small cohort studies of open versus laparoscopic colectomy, however, there is no difference in pneumonia rates, but there is shorter hospital stay in the laparoscopic group [29,30].

Anesthesia-related risk factors

Though internists usually restrict recommendations to their area of expertise, knowledge of anesthesia-related risk factors can optimize patient care through improved communication between the medical, surgical, and anesthesia teams. General and spinal anesthesia are associated with reduction in vital capacity and functional residual capacity. Perioperative impairment of mucociliary clearance mechanisms can also increase the risk of postoperative infection [1]. The immediate postoperative period may be associated with hypoventilation from residual anesthetic effect and deep breathing impairment secondary to incision pain.

These routine anesthesia-related changes do not typically result in clinical complications. Nevertheless, duration, route of administration, and type of anesthesia are risk factors for PPCs. Duration of anesthesia is a well-established risk factor for PPCs [15], with studies showing an increasing incidence of PPCs with longer anesthesia especially greater than 2–6 hours [3,6,14,31–34].

Route and type of anesthesia administration

There is debate about the efficacy of regional (epidural or spinal) anesthesia versus general anesthesia in reducing PPCs. In a large observational study of over 9,000 elderly patients with hip fracture, 30-day mortality and pneumonia rates are similar between regional and general anesthesia groups [35]. Conversely, a meta-analysis of 16 hip fracture surgery trials found that regional anesthesia, compared with general anesthesia, is associated with decreased mortality at 1 month [36].

The “stress response” caused by general anesthesia increases sympathetic and neuroendocrine activity, but it may be attenuated with regional anesthesia delivered through spinal or epidural anesthesia [37]. A systematic review of 141 trials that randomized patients to epidural or spinal anesthesia (with or without general anesthesia) versus general anesthesia alone supports the use of epidural or spinal anesthesia [38]. Most trials included were published before 1991 with samples of less than 50 patients. The review finds that epidural or spinal anesthesia, compared with general anesthesia, is associated with a 40% reduction in postoperative pneumonia and nearly one third reduction in 30-day mortality. The incidence of deep venous thrombosis, pulmonary embolism, myocardial infarction, renal failure, transfusion requirements, and respiratory depression also decreases with regional anes-

thetia. The authors conclude that the addition of regional anesthesia, not the avoidance of general anesthesia, imparts benefit. The increasing use of combined general and regional anesthesia as well as postoperative epidural analgesia may antiquate the debate about general anesthesia alone versus regional anesthesia alone [39].

Another anesthesia-related risk factor for PPCs is the use of long-acting neuromuscular blocking agents that result in hypoventilation [40]. A prospective, randomized trial compared the incidence of PPCs following the use of pancuronium (long-acting neuromuscular blocker) versus two intermediate-acting agents, atracurium and vecuronium [41]. The incidence of residual neuromuscular block was 26% in the pancuronium group versus 5.3% in the intermediate-acting group. In the pancuronium group, patients with residual block were approximately four times more likely to develop PPCs than patients without residual block. In the intermediate-acting group, the incidence of PPCs was not significantly different between those with or without residual block.

Risk factors related to postoperative care

Risk factors for PPCs related to postoperative care include nasogastric tube use and pain control using parenteral narcotics. In a systematic review of blinded studies predicting PPCs, postoperative nasogastric tube placement is one of only two predictors that are significant in more than one study [15]. One of these studies, however, has a small sample size ($n = 148$) with only 16 PPCs and no independent validation of the findings [14]. Furthermore, the final multivariable model reported did not include age, type of surgery, smoking, or other potential confounding variables—making the positive association between nasogastric tube placement and PPCs suspect [14]. Contrary to these findings, pre-emptive gastrointestinal (GI) tract management, including intraoperative nasogastric tube placement, in patients undergoing elective thoracotomy decreases aspiration and respiratory mortality rates [42]. The benefit of preventing large-volume aspiration through nasogastric tube placement may outweigh the risks of ineffective coughing and oropharyngeal aspiration in high-risk patients.

Pain control is particularly important for patients with incisions close to the diaphragm. Though adequate pain control improves deep breathing, resulting in decreased atelectasis and pneumonia, narcotic pain medications may increase aspiration risk through GI slowing and also increase the risk of PPCs by reducing the ventilatory response to hypoxia and hypercapnia [43]. In a retrospective review of elective abdominal aortic aneurysm repairs, patients receiving an epidural catheter for postoperative pain control have significantly fewer pulmonary and cardiac complications than those receiving standard parenteral opioid analgesia [44]. In addition, patients receiving epidural analgesia have fewer ICU days, less intubation time, and lower hospital charges compared with the standard treatment group [44].

Other methods for controlling postoperative pain and reducing PPCs include fascial infiltration of local anesthetic at incision closure and intercostal block. However, neither method is consistently found to reduce PPCs. In a randomized, controlled trial of elective laparotomy patients, fascial infiltration of bupivacaine (long-acting local anesthetic) fails to show any benefit over controls in atelectasis rate, change in vital capacity or expiratory reserve volume, or total analgesic amount taken [45]. In patients undergoing biliary surgery through a subcostal incision, those receiving intercostal blocks have a PPC rate of 6% compared with 11% for those given centrally acting analgesics [46]. In the same study, however, patients with a midline incision receiving intercostal blocks have a higher rate of PPCs.

Risk indices for preoperative assessment

Risk indices are used routinely for preoperative cardiac risk assessment. Similarly, several risk indices predict PPCs, including modified versions of indices originally developed for predicting mortality, cardiac complications, or wound infections [47,48]. These indices are limited to specific types of surgery, rarely validated in independent samples, and combined pulmonary complications with different clinical implications into a single outcome [47–49].

Using data from a large, multi-center, observational study, Arozullah et al developed and validated separate risk indices and scoring systems for predicting postoperative pneumonia and respiratory failure [4,5]. The large sample size enables the investigators to examine many potential risk factors simultaneously and to validate their findings in independent samples. The risk factors in The Postoperative Pneumonia and Respiratory Failure Risk Indices, their associated odds ratios, and assigned point values are displayed in Table 2. These risk indices can provide preoperative PPC risk estimates using the scoring system and risk class assignment displayed in Table 3.

Table 3
Risk class assignment by Postoperative Pneumonia and Respiratory Failure Risk Index Scores

Risk class	Postoperative Pneumonia Risk Index (point total)	Predicted probability of pneumonia (%)	Respiratory Failure Risk Index (point total)	Predicted probability of respiratory failure (%)
1	0–15	0.2	0–10	0.5
2	16–25	1.2	11–19	2.2
3	26–40	4.0	20–27	5.0
4	41–55	9.4	28–40	11.6
5	> 55	15.3	> 40	30.5

Adapted from Arozullah AM, et al. Development and validation of a multifactorial risk index for predicting postoperative pneumonia after major noncardiac surgery. *Annals of Internal Medicine* 2001;135:847–57, and from Arozullah AM, et al. Multifactorial risk index for predicting postoperative respiratory failure in men after major noncardiac surgery. *Annals of Surgery* 2000;232(2):242–53; with permission.

The main limitation of these risk indices is that they are developed and validated using observational and retrospective chart review data from Veterans Administration hospitals. The patients are predominantly male and have high levels of comorbid conditions so that the risk indices may not generalize to healthier populations. Although risk factors such as age and smoking are likely to be significant risk factors in women, risk index calibration may not accurately predict PPC risk in this population. The validation of these risk indices in independent patient samples, however, provides some confidence in their usefulness for providing reasonable estimates of preoperative risk.

Preoperative testing

Chest radiography

As discussed in an earlier article, routine preoperative chest roentgenograms in healthy adults add minimal incremental value to a thorough history and physical for predicting PPCs and rarely change perioperative management. Whereas chest roentgenograms do not improve preoperative risk assessment, they may provide baseline findings useful for postoperative care in chronic lung disease or frail, elderly patients when a history is difficult to obtain.

Arterial blood gas analysis

Routine arterial blood gas analysis does not appear to improve preoperative pulmonary risk assessment. Small case series identify hypercarbia as a risk factor for the development of PPCs [50,51]. But these patients may be identified as high risk by other factors that do not require arterial blood gas analysis. A systematic review of blinded studies does not find hypercarbia to be a useful predictor of PPCs [15].

Pulmonary function testing

The role of pulmonary function testing in risk assessment prior to non-cardiothoracic surgery is not clear. Spirometry flow rates that are commonly measured include forced expiratory volume in one second (FEV₁) and forced vital capacity (FVC). Spirometry accurately diagnoses airflow obstruction and its severity [52] despite variability in flow rates and substantial individual day-to-day variability [53]. Though patients with significant obstructive lung disease have more PPCs compared with normal patients, individual pulmonary function test abnormalities do not predict PPC risk.

Pulmonary function tests (PFTs) became a routine part of the preoperative evaluation because of the erroneous assumption that accurate diagnosis of COPD translates into improved preoperative risk assessment. One influential study shows an increased risk of PPCs among abdominal surgical patients with abnormal spirometry [54]. In spite of major limitations, including small

sample size, lack of standard definitions for PPCs, and no blinding of outcome assessments, several subsequent studies recommend preoperative PFTs for patients undergoing elective abdominal surgery [55–58].

In a 1990 consensus statement, The American College of Physicians (ACP) recommends preoperative PFTs in patients undergoing lung resection, coronary bypass surgery, or upper abdominal surgery with a history of tobacco use or dyspnea, patients undergoing lower abdominal surgery if there were unexplained pulmonary disease with anticipated prolonged or extensive surgery, or patients undergoing head and neck or orthopedic surgery with unexplained pulmonary disease [59]. The aggregate expense of ordering routine PFTs can be wasteful. One economic analysis estimates that roughly 40% of PFTs ordered do not meet ACP guidelines [60]. Improving guideline adherence in ordering PFTs may provide potential annual savings of \$29–100 million overall and \$8–20 million for Medicare [60].

More recent studies about the utility of spirometry before abdominal operations reach conflicting conclusions. Studies concluding that spirometry is predictive of PPCs rely on univariate analysis without adequate adjustment for potential confounding risk factors [6,61,62]. One study demonstrates the value of spirometry in smokers with severe airflow obstruction, but only for predicting bronchospasm [63]. A critical review concludes that preoperative spirometry is not useful in predicting pulmonary complications after abdominal operations [18]. The review concludes that previous studies have important methodological flaws, including poor standardization, inadequate blinding of observers, selection bias, inadequate control for co-interventions, and inclusion of questionable clinical outcomes such as microatelectasis. In another systematic review, preoperative PFTs predict PPCs in only one out of five blinded studies [15].

Several studies demonstrate the superiority of clinical findings over PFTs in predicting PPCs. Two investigations of patients with severe COPD ($FEV_1 < 50\%$ predicted) conclude that preoperative PFTs do not predict PPCs [2,32]. By contrast, overall general medical condition (described by ASA class) is helpful in predicting PPCs. One prospective study finds that PFTs are weakly predictive of PPCs, whereas chronic mucous hypersecretion is a stronger independent predictor [64]. In a case-control study of abdominal surgery patients, no component of spirometry predicts PPCs, though abnormal results of lung examination (decreased breath sounds, prolonged expiration, rales, wheezes, or rhonchi), abnormal chest radiograph, cardiac, and overall comorbidity are all significant risk factors for PPCs [10].

In summary, routine PFTs should not be ordered solely for risk assessment purposes prior to abdominal surgery or other high-risk surgeries. It is reasonable, however, to obtain preoperative PFTs for unexplained dyspnea or exercise intolerance, as recommended in the nonoperative setting. Preoperative PFTs may enhance postoperative management in patients with obstructive lung disease by providing measurement of baseline airflow obstruction, but PFTs do not appear to predict PPC risk.

Risk reduction strategies

A preoperative medical evaluation enables clinicians to recommend preoperative and perioperative risk reduction strategies. But the evidence available to support risk reduction strategies is limited compared with the evidence available regarding risk assessment for PPCs. Preoperative smoking cessation, perioperative lung expansion maneuvers, and postoperative analgesia are risk reduction strategies supported by some evidence. Clinically intuitive strategies for elective surgery include optimization of pulmonary function in patients with COPD and asthma, and delaying surgery for patients with acute exacerbations of chronic lung disease or upper respiratory infection. There is no clear role for prophylactic antibiotic use in preventing PPCs.

Preoperative smoking cessation

Conflicting evidence exists regarding the benefits and ideal timing for preoperative smoking cessation. Short-term smoking cessation reduces carboxyhemoglobin and nicotine blood levels, and results in gradual improvement in mucociliary function and upper-airway hypersensitivity [65–67]. Brief abstinence before surgery, however, is associated with a paradoxical increase in PPCs. One cohort study in veterans undergoing noncardiac surgery finds that smoking cessation within 1 month of surgery is not associated with a reduction in PPCs [68]. Current smokers who reduce smoking are almost seven times more likely to develop PPCs, with the greatest risk among those who reduce smoking closest to the surgery date.

Another cohort study of 200 consecutive patients undergoing coronary artery bypass grafting finds that patients who smoke for 2 months or less prior to surgery have a fourfold increased risk of PPCs compared with those abstaining for longer than 2 months (57.1% versus 14.5%) [69]. Patients not smoking for more than 6 months have a rate similar to patients who never smoked (11.1% versus 11.9%). The rate of PPCs is highest in patients who stop smoking 2–4 weeks prior to surgery. The authors conclude that abstinence from smoking for greater than 8 weeks prior to coronary artery bypass grafting (CABG) is needed to reduce the incidence of PPCs. This study does not control, however, for many patient-related risk factors, and the most common PPCs are bronchospasm requiring bronchodilator therapy and respiratory secretions requiring more than the usual chest physical therapy or inhalation therapy. It is unclear if these complications are self-limited or progress to more serious complications.

In a retrospective study of 288 consecutive patients who underwent pulmonary surgery, the incidence of PPCs is 43.6% for current smokers (smoking within 2 weeks), 53.8% for recent smokers (duration of smoke-free period of 2–4 weeks), 34.7% for ex-smokers (duration of smoke-free period >4 weeks), and 23.9% for never-smokers [70]. The risk of developing PPCs after abstinence for 10 weeks appears to be similar to that in never-smokers.

After controlling for gender, age, PFTs, and duration of surgery, there is a trend toward increased PPC risk for current and recent smokers compared with never-smokers. But the most common PPC is air leak or effusion requiring chest tube drainage for >7 days, making the results less applicable to nonthoracic surgery patients.

A randomized trial of 120 hip and knee replacement patients examines the effect of a smoking-cessation intervention on complications [71]. Patients are randomized 6–8 weeks before surgery to an intervention of counseling and nicotine replacement versus standard care with little or no information about risks of smoking and smoking cessation. The intervention group has significantly fewer complications overall, significantly fewer wound complications, trends toward fewer cardiac complications and need for second surgery, and significantly fewer hospital days on nonorthopedic services. As expected, the rate of PPCs is low with only one case of respiratory insufficiency in each group. The study does not address the question of the ideal time for preoperative smoking cessation.

The paradoxical increase in PPCs observed with short-term abstinence or reduced smoking may be caused by ineffective sputum removal [68,69]. Reduced smoking may decrease bronchial irritation and the stimulus for coughing; at the same time, bronchial hypersecretion of mucus is still present or even transiently increased [68,69,72]. This cascade may result in increased sputum retention. An alternative explanation may be that sicker patients tend to quit smoking closer to surgery [5]. Thus, short-term abstinence may simply be a marker for higher comorbid burden.

In conclusion, the preoperative evaluation presents an opportunity to discuss and encourage life-long smoking cessation. Short-term abstinence or reduced smoking may increase PPCs, although the evidence is marked by methodological limitations. Abstinence for at least 8 weeks prior to surgery probably decreases PPC risk. But clinicians and patients rarely have 8 weeks notice before surgery.

Perioperative lung expansion maneuvers

One long-standing hypothesis is that collapsed areas of the lung provide a nidus for the development of PPCs [1]. Lung expansion maneuvers inflate collapsed areas of the lung and may prevent the development of PPCs. The literature on the efficacy of different types of lung expansion maneuvers is conflicting and difficult to interpret for several reasons: the lack of controlled trials; inadequate descriptions of control arms in controlled studies; inconsistency in administration of lung expansion techniques; and variability in the definition used for PPCs [1]. Lung expansion maneuvers include incentive spirometry and chest physical therapy consisting of various combinations of the following: deep breathing exercises, postural drainage, percussion and vibration, cough, suctioning, and mobilization. Other

lung expansion maneuvers include intermittent positive pressure breathing (IPPB) and continuous positive airway pressure.

Although incentive spirometry is used routinely, a systematic review of 48 studies concludes that current evidence does not support routine incentive spirometry for the prevention of PPCs following cardiac or abdominal surgery [73]. Thirty-five of the 48 studies have significant methodological flaws. Three of the eleven remaining studies evaluate short-term physiologic markers, eg, vital capacity, and do not demonstrate an improvement with incentive spirometry. The results of the remaining 8 trials are summarized in Tables 4 and 5.

Although the authors conclude that the evidence does not support the use of incentive spirometry, it is noteworthy that the majority of studies do not include control groups. Rather, most studies compare incentive spirometry to other lung expansion maneuvers, and, for the most part, incentive spirometry is equal in clinical efficacy. The authors report that one study in the CABG population does have a control arm; however, the control group underwent early mobilization [74]. The other two arms of the study consist

Table 4
Incentive spirometry and cardiac surgery

Trial	Comparison groups	Administration	Outcome	Result
Gale GD, et al [82]	IS ($n = 52$) IPPB ($n = 57$)	20 minutes qid	Atelectasis	No difference
Dull JL, Dull WL [74]	EM ($n = 16$) EM + IS ($n = 17$) EM + DB ($n = 16$)	EM: bid IS/DB: 10 breaths qid	PPCs; PFTs	No difference
Stock MC, et al [83]	IS ($n = 12$) CPAP ($n = 13$) DBC ($n = 13$)	15 min every 2 hrs during waking hours from 2nd to 72nd hr post extubation	PFTs	No difference
Matte P, et al [84]	Chest PT + IS ($n = 30$) Chest PT + CPAP ($n = 30$) Chest PT + Bilevel PAP ($n = 30$)	IS: 20 breaths every 2 hrs CPAP: 1 hr every 3 hrs Bilevel PAP: 1 hr every 3 hrs	PFTs; venous admixture	CPAP, Bilevel PAP superior to IS

Abbreviations: IS, incentive spirometry; IPPB, intermittent positive pressure breathing; EM, early mobilization (included ankle exercises, range of motion to all extremities, 3 maximal coughs, encouragement and assistance for turning side to side, sitting, or standing); DB, deep breathing; DBC, deep breathing and cough; CPAP, continuous positive airway pressure; Chest PT, chest physiotherapy, Bilevel PAP, bilevel positive airway pressure; PFTs, pulmonary function testing; PPCs, postoperative pulmonary complications.

Adapted from Overend TJ, et al. The effect of incentive spirometry on postoperative pulmonary complications: a systematic review. *Chest* 2001;20(3):971–8; with permission.

Table 5
Incentive spirometry and abdominal surgery

Trial	Comparison groups	Administration	Outcome	Results
Celli BR, et al [75]	No treatment (n = 44) IS (n = 42) IPPB (n = 45) DBE (n = 41)	IS: 10 breaths (over 15 min) qid IPPB: 15 min qid DBE: 10 maneuvers qid	PPCs	IS, IPPB, DBE Better than no treatment IS, IPPB, DBE Equal in efficacy
Stock MC, et al [85]	CDB (n = 20) IS (n = 22) CPAP (n = 23)	15 minutes every 2 hours during waking period	PPCs; PFTs	No difference
Schwieger I, et al [76]	No treatment (n = 20) IS (n = 20)	IS: 150–200 breaths/day	PPCs	No difference
Rickstein SE, et al [86]	Chest PT + IS (n = 15) Chest PT + PEP (n = 15) Chest PT + CPAP (n = 13)	Chest PT: BID IS/PEP/CPAP: 30 breaths every 1 waking hour	Radiography, Gas exchange, Lung volumes	CPAP and PEP superior to IS

Adapted from Overend TJ, et al. The effect of incentive spirometry on postoperative pulmonary complications: a systematic review. *Chest* 2001;20(3):971–78; with permission.

of early mobilization, plus incentive spirometry or deep breaths. There are no significant differences among the three groups.

There are two abdominal surgery studies including a control group [75,76]. One study of incentive spirometry versus no respiratory therapy in elective cholecystectomy finds no significant differences in PPCs [76]. Conversely, the second study finds that the use of incentive spirometry is associated with a reduction in PPCs following abdominal surgery [75]. Incentive spirometry use versus no respiratory therapy is also associated with decreased length of hospital stay in upper abdominal surgery. The proportion of smokers is higher, however, in the second study—implying that incentive spirometry may be beneficial only in high-risk patients undergoing abdominal surgery.

Chest physical therapy appears to be beneficial for reducing PPCs depending on the type of surgery. Fagevik et al demonstrate the superiority of chest physical therapy, consisting of breathing exercises with pursed lips, huffing, and coughing hourly, and information about the importance of changing position in bed and early mobilization versus no respiratory therapy for upper abdominal surgery [77]. But there is no difference between chest physical therapy and no respiratory therapy in patients undergoing laparoscopic abdominal surgery [78].

Intermittent positive pressure breathing assists patients in achieving an involuntary maximal inspiration but has the side effect of abdominal distension [75]. A meta-analysis evaluating incentive spirometry, deep breathing exercises, and intermittent positive pressure breathing after upper abdominal surgery finds that the three modalities are similar in efficacy and better than no respiratory therapy [79]. The definition of PPCs includes atelectasis or pneumonia, but if radiographic results are unclear or unavailable, a combination of historical and physical findings is used to define a PPC. Thus, some reported PPCs might be of limited clinical significance. Continuous positive airway pressure (CPAP) appears to be equally effective or better than these three modalities, with the advantage that it is effort-independent. CPAP is expensive, however, requires special equipment, and causes patient discomfort, gastric distension, hypoventilation, and barotrauma [80].

In summary, the use of incentive spirometry following abdominal surgery may reduce PPCs, particularly in high-risk patients. No specific lung expansion maneuver is clearly superior, but CPAP may be beneficial in patients unable to perform deep breathing exercises or incentive spirometry. Patient education in lung maneuvers initiated preoperatively is more effective in reducing pulmonary complications versus education initiated postoperatively [77,81].

Summary

Preoperative risk assessment for postoperative pulmonary complications is essential when counseling patients about the risks of surgery because of their significant associated morbidity and mortality. There are many patient-related, operation-related, and anesthesia-related risk factors for the development of PPCs. Though many of these risk factors are not modifiable, they can be useful in evaluating preoperative risk, especially when combined into formal risk indices [4,5]. Preoperative risk assessment enables clinicians to target preoperative testing and perioperative risk reduction strategies to high-risk patients. Reducing PPC risk at the patient level will require a greater understanding of the impact of modifying risk factors through interventional trials. Reducing hospital PPC rates will require future research into the processes of care associated with PPCs through controlled observational and interventional trials.

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