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Preoperative pulmonary assessment of the older adult

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As individuals live longer and healthier lives, an increasing number of elderly patients are now potential candidates for major surgery. For example, during the period from 1980 to 1995, the rates of operations on the cardiovascular system for patients over age 65 years in the United States tripled [1]. Similarly, from 1987 to 1999, the average age of patients undergoing coronary artery bypass surgery increased from 62.7 to 65.6 years; the percent of such patients who are over 80 years of age increased from 2.4% to 7.9% [2,3]. In 1997, the ten most commonly performed major surgical procedures in the United States accounted for 1,350,000 procedures in the 65 to 84 age group and 233,000 procedures in the 85 and older age group [4].

Due to the increasing number of comorbidities and perceived surgical risk with advancing age, surgeons often request a preoperative medical evaluation for elderly patients. The goals of this consultation are to estimate the risk of the proposed procedure, to optimize the patient's condition, and to propose strategies to decrease the risk of the procedure. This article reviews the contribution of age to postoperative pulmonary complications, the approach to risk stratification based on patient- and procedure-related risk factor analysis, multifactorial risk indices, and strategies to reduce postoperative pulmonary complications in the elderly. The evaluation of candidates for lung resection surgery differs substantially from the evaluation before general surgery and is not discussed in this review.

While preoperative cardiac evaluation has received significant attention since the early work of Goldman and colleagues in their report of a multifactorial cardiac risk index 25 years ago [5], clinicians might be surprised to learn that postoperative pulmonary complications are at least as common and morbid as are postoperative cardiac complications. For example, in a case control study of

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patients undergoing abdominal surgery who had at least one cardiac or pulmonary complication, 59% of patients had a pulmonary complication, 15% had a cardiac complication, and 26% had both complications [6]. Postoperative deaths were more often due to pulmonary than cardiac complications, and the average length of stay for patients who had pulmonary complications was more than twice the length of stay for patients who had cardiac complications (22.5 versus 10.4 days).

In another report that evaluated mortality and postoperative complications after esophagectomy in 269 patients, 47% of patients had a postoperative pulmonary complication while 39% had a cardiac complication [7]. Pulmonary and cardiac complications equally predicted perioperative mortality. In a study that restricted analysis to patients undergoing noncardiac surgery aged 80 years or older, postoperative cardiac and pulmonary complications occurred in 12% and 7% of patients, respectively [8]. Similarly, Pedersen prospectively studied 7306 patients undergoing general surgery [9]. Rates of postoperative cardiac and pulmonary complications requiring treatment were 6.3% and 4.8%, respectively.

Pulmonary complications also contribute importantly to perioperative mortality. Turnbull and colleagues reviewed all deaths within 48 hours of anesthesia among 195,232 anesthetics [10]. This approach might tend to underestimate fatal pulmonary complications because they often occur several days after surgery. Among 30 perioperative deaths that the authors determined to be potentially preventable and not due solely to catastrophic illness before surgery 15 were due to pulmonary complications and 15 were due to cardiac complications. Given the prevalence and importance of postoperative pulmonary complications as contributors to mortality and length of stay, it follows that one must properly identify risk factors for postoperative pulmonary complications and propose risk reduction strategies as part of a preoperative consultation.

The reduction in lung volumes due to anesthesia and surgery is the primary physiologic mechanism that contributes to the development of atelectasis and other postoperative pulmonary complications. A number of definitions have been proposed for postoperative pulmonary complications. A practical and clinically relevant approach is to include only those complications that contribute directly to morbidity or prolonged length of stay [11], which will exclude minor complications such as fever and productive cough. Included are the clinically important postoperative pulmonary complications, which are pneumonia, atelectasis, bronchospasm, respiratory failure with prolonged mechanical ventilation, and exacerbation of underlying obstructive lung disease.

Is age a risk factor for postoperative pulmonary complications?

While unadjusted perioperative mortality increases with advancing age, many studies of the influence of age on perioperative morbidity and mortality are unadjusted for the presence of comorbidities known to be risk factors, which are more common with advancing age. As an example of the influence of comorbidities, an early study stratified patients based on American Society of

Anesthesiologists' (ASA) class [12]. While mortality for patients older than 70 years of age was 1.8-fold higher than for patients aged 50 to 70 years, the mortality for patients in a given ASA class was similar regardless of age.

In 1982 Linn and colleagues reviewed the findings of 108 studies of surgery in the elderly [13]. Overall perioperative mortality rates climbed from 8.4% in patients under age 60 years to 22.1% for patients greater than or equal to 90 years of age. The inflection point for substantial increase in risk occurred at 80 years. The pooled studies were unadjusted for comorbidities and did not separately analyze postoperative pulmonary complication rates.

Table 1 lists studies that divided patients into elderly and non-elderly groups and reported the incidence of postoperative pulmonary complications in each group. Due to small sample sizes, many of the differences in individual studies (when reported) do not achieve statistical significance. Using pooled data from all studies, the unadjusted relative risk is 2.5. All of these studies are unadjusted for comorbidities that might be more common with age. Thus, it is difficult to determine the component of risk directly attributed to age by review of large case series in the literature.

Several recent studies have used multivariate analysis to estimate the risk of pulmonary complications attributable to age alone. Polanczyk and colleagues prospectively evaluated 4315 patients over age 50 years undergoing major nonemergent surgery and determined the incidence of major postoperative complications, mortality, and length of stay [14]. As expected, comorbidities increased with advancing age. The percentages of patients in ASA class III or IV for ages 50 to 59 years, 60 to 69 years, 70 to 79 years, and 80 years or older were 30%, 39%, 48%, and 53%, respectively. Major perioperative complications occurred in 4.3%, 5.7%, 9.6%, and 12.5%, respectively. The incidence of postoperative pulmonary complications, defined as bacterial pneumonia or respiratory failure requiring intubation, also showed an increase with advancing age. The incidence across the same age categories was 2.0%, 1.8%, 4.0%, and 6.0%. In a multivariate analysis that adjusted for comorbidities, the relative risk of any major postoperative complication for patients 80 years or older was only 2.1 (CI 1.2–3.6) when compared with patients aged 50 to 59 years. Age was also an independent, though minor predictor of length of stay and death. The authors did not perform a separate multivariate analysis to determine the risk of pulmonary complications attributable to age alone.

In a study of 17,638 patients undergoing ambulatory surgery, Chung and colleagues compared the incidence of intraoperative and immediate postoperative complications in the post-anesthesia care unit between patients aged less than 65 years and 65 years or older [15]. These ambulatory procedures disproportionately involved low-risk surgical sites (gynecologic, orthopedic) rather than higher-risk abdominal surgeries. There was no difference in the low incidence (< 1%) of pulmonary complications between the two age groups.

Arozullah and colleagues developed a multifactorial risk index for predicting postoperative respiratory failure in men after major noncardiac surgery [16]. An age of 70 years or older conferred a 2.6-fold increase in the risk of respiratory

Table 1
Unadjusted contribution of age to postoperative pulmonary complication rates

Study	Year	Type of study	Surgical procedure	Number of elderly patients/ total number of patients	Age criteria for elderly (y)	Postoperative pulmonary complication rate (%)		Unadjusted relative risk
						Elderly	Young	
Wightman [58]	1968	Prospective	Any	85/785	70	16.5	8.9	1.9
Garibaldi [41][a]	1981	Prospective	Thoracic or abdominal	54/520	70	17	17.6	1.0
Sugimachi [59]	1985	Prospective	Esophagectomy	151/231	60	43	33.8	1.3
Poe [60]	1988	Prospective	Open cholecystectomy	23/209	60	22	14	1.6
Pedersen [43]	1990	Prospective	Any	1179/7306	70	9.2	3.8	2.4
Pacelli [61]	1991	Prospective	Gastrectomy	27/84	65	18.5	3.5	5.3
Hall [17]	1991	Prospective	Abdominal	438/1000	60	36.3	13	2.8
Svensson [62]	1991	Prospective	Aortic	18/98	70	44	42.5	1.0
Calligaro [63]	1993	Retrospective	Aortic	72/181	70	22	12	1.8
Ido [64]	1995	Retrospective	Laparoscopic cholecystectomy	57/712	70	0	0.2	0.0
Hall [65][b]	1996	Prospective	Abdominal	596/1332	60	4.9	1.6	3.1
Thomas [66]	1996	Retrospective	Esophagectomy	56/386	70	17.9	20.6	0.9
Brooks-Brunn [67]	1997	Prospective	Abdominal	147/400	60	32	17	1.9
Pereira [68]	1999	Prospective	Upper abdominal	273/408	50	17	8.9	1.9
Total				3176/13,652		16.4	6.5	2.5

[a] Postoperative complication = pneumonia
[b] Postoperative complication = hypoxemia or mechanical ventilation > 24 h

failure; when adjusted by multivariate analysis the odds ratio was 1.91 (compared with < 60 years as the reference). Of seven independent predictors in the multifactorial index, advanced age was one of the least powerful predictors. In a separate prospective report of 1000 patients undergoing laparotomy, age greater than 59 years conferred a relative risk of postoperative pulmonary complications of 2.8; this value continued to be significant after regression analysis to eliminate potential confounders, although ASA class and surgical site were both more powerful predictors [17].

The literature therefore suggests that age is a minor risk factor for postoperative pulmonary complications after controlling for comorbidities. The relative risk due to advanced age, in the range of two-fold, is sufficiently small that clinicians should not deny surgery to an elderly patient solely because of concern for postoperative pulmonary complications. Rather, if the indication for surgery is compelling and no other important factors exist to substantially increase the risk of cardiac or other major postoperative complications, the consultant should identify and treat risk factors, employ strategies to reduce risk, and allow the patient to proceed to surgery at the lowest possible risk for his or her age.

Patient-related risk factors

Both patient- and procedure-related factors contribute to the risk of postoperative pulmonary complications in the elderly. Studies of risk factors use differing definitions of postoperative pulmonary complications; this contributes to some of the variability in risk estimates of a particular factor. Most clinical series that have evaluated risk factors have not limited their analysis to elderly patients or determined the relative importance of a particular factor for younger versus older patients. The mean age of patients in most of the primary literature series is in the 60s, however, which supports cautious generalization of the findings to the population of elderly patients preparing for surgery. Potential patient-related factors—in addition to age, as previously discussed—include cigarette use, chronic obstructive pulmonary disease (COPD), asthma, obesity, general health status, metabolic factors, and exercise capacity.

Cigarette use

Current smoking is a risk factor for postoperative pulmonary complications and increases the risk by three-fold [11]. This risk exists even among patients who do not have superimposed chronic lung disease. Three studies have analyzed the risk of postoperative pulmonary complication attributed to smoking, and all three studies have reported the same counterintuitive result: recent quitters have a higher rate of pulmonary complications than do current smokers. The average age of patients in these studies was 62 years. Warner and colleagues prospectively studied 200 patients undergoing coronary artery bypass grafting and found similar rates of pulmonary complications between smokers who had stopped

smoking for at least 2 months and those who never smoked (14.5% versus 11.9%, respectively) [18]. However, recent smokers who had stopped for less than 2 months had a pulmonary complication rate of 57.1%.

Bluman and colleagues reported a relative risk of pulmonary complication of 6.7 for smokers who had recently quit or reduced cigarette use when compared with current smokers undergoing noncardiac surgery [19]. Most of these patients had quit or reduced smoking within 1 month before surgery. Those who reduced smoking closer to the date of surgery had higher complication rates. Nakagawa and colleagues likewise reported higher pulmonary complication rates among patients undergoing pulmonary surgery who had quit within 4 weeks of surgery (54%) than among current smokers (43%) or those who had stopped smoking for more than 4 weeks (35%) [20].

The mechanism for this repeated finding is unknown but it might relate to the clinical observation that many smokers experience an increase in the quantity of cough and sputum in the 1 to 2 months after stopping cigarette use or to selection bias in that sicker patients were more likely to attempt cigarette cessation or reduction before surgery. As a practical conclusion, smoking cessation must begin at least 1 to 2 months before elective surgery to confer a reduction in pulmonary complications. Physicians seeing patients less than 1 month before surgery should not recommend cigarette cessation in the belief that this will reduce the likelihood of complications.

Chronic obstructive pulmonary disease

COPD is the single most important patient-related risk factor for the development of postoperative pulmonary complications. The relative risk of pulmonary complications attributable to COPD is three- to four-fold [11]. Table 2 cites the rates of postoperative pulmonary complications and mortality among patients with COPD with a mean age of 66 years. Inclusion criteria were either a clinical diagnosis of COPD or a threshold value for forced expiratory volume in 1 second (FEV_1) or forced vital capacity (FVC). Clinically significant COPD is more prevalent with advancing age and is an important risk factor in elderly patients. Postoperative pulmonary complications occurred in 25% of patients, and overall mortality was 7%. In a recent multifactorial index to predict postoperative respiratory failure, the unadjusted and adjusted odds ratios for complications due to COPD were 2.3 and 1.8, respectively [16].

The treatment and preparation of patients who have COPD before elective surgery are the same as those in nonoperative settings. Clinicians should not employ treatments due solely to an upcoming surgery unless they are otherwise indicated independent of the need for surgery. Multimodality treatment programs including chest physical therapy, bronchodilators, smoking cessation, and antibiotics and corticosteroids (when indicated) reduce the risk of postoperative pulmonary complications in patients who have COPD [21–23]. Few studies report the value of individual treatment strategies. Standard therapy for COPD includes use of ipratropium for patients who have daily symptoms plus the

Table 2
Postoperative pulmonary complication and mortality rates among patients with COPD

Study	Year	Type of surgery	Number of patients with COPD	Mean age (y)	Inclusion criteria	Postoperative pulmonary complication rate (%)	Mortality (%)
Wightman [58]	1968	All	53	NA	Clinical diagnosis	26	NA
Tarhan [23]	1973	All	464	65	Clinical diagnosis	29	8
Gracey [21]	1979	All	157	66	Clinical diagnosis	19	8
Kroenke [42]	1992	All	107	66	$FEV_1 < 50\%$ predicted; $FEV_1/FVC < 70\%$	32	6
Kroenke [51]	1993	Thoracic and abdominal	78	64	$FEV_1 < 80\%$ predicted, $FEV_1/FVC < 70\%$	14[a]	9
Pedersen [9]	1994	Non-thoracic	201	NA	Clinical diagnosis	12	5
Wong [69]	1995	Non-cardiothoracic	105	68	$FEV_1 < 1.2$ L, $FEV_1/FVC < 75\%$	37	7
Cohen [70]	1995	CABG	37	64	Clinical diagnosis	76	5
Samuels [71]	1998	CABG	191	69	$FEV_1 < 75\%$ predicted; undergoing treatment for COPD	15	7
Warner [52]	1999	Abdominal	135	69	$FEV_1 < 40\%$ predicted, >20 pack/ smoking history	25	1
Total			1528			25	7

[a] Severe pulmonary complications only, defined as pneumonia, temporary reintubation, or ventilatory failure.

addition of inhaled β-agonists as needed for symptoms [24]. Theophylline improves FEV_1 and dyspnea in stable patients who have COPD who remain symptomatic despite inhaled therapies [25,26]. Approximately 20% to 30% of patients with COPD respond to the use of systemic corticosteroids. Unless a patient has been previously shown to be a non-responder, clinicians should use systemic corticosteroids for patients who have COPD before surgery if airflow obstruction has not been maximally reduced and the patients are not at their best baseline despite other therapies, as determined by symptoms and peak flow. There is no role for routine antibiotics before surgery; clinicians should recommend antibiotics only if a change in the chest radiograph or the character or amount of sputum suggest lower respiratory tract infection. In these cases, elective surgery should be canceled until the patient has returned to the baseline level of function.

Asthma

Despite earlier studies suggesting that patients with asthma were at risk for postoperative pulmonary complications [27], studies in the modern era have found no increase in risk of clinically important complications. Warner and colleagues reviewed the records of 703 patients with asthma undergoing surgery [28]. Perioperative bronchospasm occurred in only 1.7% of patients. Respiratory failure occurred in one patient and laryngospasm occurred in two patients. There were no other clinically significant postoperative pulmonary complications or deaths in the entire group. Physicians should prepare patients who have asthma for surgery in the same fashion as optimization of airway obstruction and reactivity in the non-surgical setting. In particular, a 1-week course of systemic corticosteroids (eg, prednisone 40–60 mg daily) can be safely used as needed without an increase in the risk of respiratory infection or wound complications [29–31]. The goal of treatment is to render the patient wheeze-free and asymptomatic if possible, and to achieve a peak flow rate of greater than 80% of predicted or personal best.

Obesity

Obesity is not a risk factor for postoperative pulmonary complications. While this observation might deviate from general clinical thinking, studies have consistently shown no significant increase in risk, even for morbid obesity. For example, in a large series of 2964 patients undergoing elective noncardiac surgery, obese patients (body mass index [BMI] >30) had no increase in the risk of pneumonia or respiratory failure when compared with non-obese patients [32]. This also held true if BMI greater than 34 was used as the threshold for defining obesity. In a review of 10 series of patients undergoing gastric bypass surgery for morbid obesity, the incidence of postoperative pneumonia or atelectasis was only 3.9% [33]. Table 3 presents the postoperative pulmonary complication rates among 14 primary series of obese and non-obese patients. Age varied in these

Table 3
The impact of obesity on postoperative pulmonary complication rates

Study	Year	Type of surgery	Number of obese patients/ total number of patients	Mean age (y)	Definition of obesity	Postoperative pulmonary complication rate (%)		Unadjusted relative risk
						Obese	Non-obese	
Wightman [58]	1968	Noncardiac	149/785	NA	NA	11	5	2.2
Pemberton [72]	1971	Cholecystectomy	66/400	NA	[a]	11	20	0.6
Garibaldi [41]	1981	Thoracic and abdominal	62/520	NA	>200 lb	23	18	1.3
Poe [60]	1988	Cholecystectomy	52/209	NA	>120% ideal wt	12	16	0.8
Hall [17]	1991	Laparotomy	102/1000	54	BMI > 25	27	23	1.2
Calligaro [63]	1993	Aortic	26/128	68	>125% ideal wt	27	17	1.6
Phillips [73]	1994	Laparoscopic cholecystectomy	179/841	50	BMI > 30	0	0.5	0.0
Moulton [74]	1996	Cardiac	567/2299	62	BMI > 30	19	23	0.8
Thomas [32]	1997	Noncardiac	528/2964	67	BMI > 30	1.9	1.8	1.1
Brooks-Brunn [67]	1997	Abdominal	181/400	53	BMI > 27	29	17	1.7
Ranucci [75]	1999	CABG	116/345	63	BMI > 30[b]	28	13	2.2
Perka [76]	2000	Total hip arthroplasty	120/229	65	BMI > 25	4	3	1.3
Benoist [77]	2000	Colectomy	158/584	65	BMI > 27	0.5	5.4	0.1
Total			2306/10,704			12	9	1.3

[a] males: >200 lb, females: >175 lb
[b] Females: BMI > 28.6

reports, but the two largest studies included patients with mean ages of 62 and 67 years, making these data relevant to the evaluation of the elderly surgical patient. The incidence of pulmonary complications among obese patients was 12% across pooled studies with a relative risk of 1.3 compared with non-obese patients. This value is not clinically significant and indicates that obesity should not influence the decision to proceed with surgery.

The risk attributable to obstructive sleep apnea (OSA), which is more common among obese patients, is less well understood. While OSA might increase the incidence of airway management problems in the immediate postoperative period in the post-anesthesia care unit, its influence on postoperative pulmonary complication rates as defined in this review is less certain. In a case series of 16 patients with OSA undergoing a variety of surgical procedures, there were four postoperative pulmonary complications and one death [34].

More recently, Gupta and colleagues performed the first rigorous study to estimate the perioperative risk attributed to OSA [35]. In this case control study of 101 patients with OSA who were undergoing hip or knee replacement who were matched to controls without OSA, total postoperative (non surgical site) complications were 2.3-fold greater among patients who had OSA. Pulmonary complications occurred in 30% of patients with OSA as compared with 10% of control patients. All but two of the 30 reported complications were hypercapnia and hypoxemia, however; these do not meet the usual definition of pulmonary complications. Still, 3 $\times$ more patients in the OSA group required an unplanned ICU stay, and overall length of stay was 1.7 days longer in the OSA group. This risk also extended to patients who had clinically undiagnosed OSA. While further study is necessary, this report suggests that OSA might be a risk factor for postoperative pulmonary complications and prolonged length of stay.

General health status

Several measures of general health and functional status predict the risk of postoperative pulmonary complications. ASA class greater than two predicts a two-fold increase in risk [11]. This commonly used classification scheme was devised to estimate overall mortality but also predicts pulmonary events. Similarly, the Goldman cardiac risk index also predicts postoperative pulmonary complications [36,37]. While self-reported poor exercise capacity (defined as the inability to walk 4 blocks and climb 2 flights of stairs) predicts in one study all serious postoperative complications and cardiac complications, it did not predict a significantly higher likelihood of pulmonary complications [38]. Two laboratory abnormalities were recently shown to predict pulmonary complications. In a multifactorial risk index of postoperative respiratory failure, albumin levels of less than 3.0 gm/dL and blood urea nitrogen levels greater than 30 mg/dL were each significant predictors; odds ratios were 2.53 and 2.29, respectively [16]. These laboratory values predicted risk to a greater extent than did clinical factors, including dependent functional status, COPD, and age. This observation has not yet been confirmed by other studies.

Procedure-related risk factors

As is the case with estimation of perioperative cardiac risk, risk factors related to the nature of the surgery and anesthesia also contribute to the risk of postoperative pulmonary complications. When these factors are present in a high-risk patient, one can consider changing the type of surgery or anesthesia to a lower-risk procedure or anesthetic to reduce the risk of pulmonary complications. Procedure-related risk factors include the surgical site and duration, type of anesthesia, and type of neuromuscular blocker.

Type of surgery

The surgical site is the single most important risk factor for the development of postoperative pulmonary complications and outweighs all patient-related risk factors. As a general rule, the closer the incision is to the diaphragm, the higher the likelihood of pulmonary complications. This is due to splinting, diaphragmatic dysfunction, and decreased ability to take deep breaths. Therefore, upper abdominal surgery carries more risk than lower abdominal surgery; thoracic surgery is also high risk. Pulmonary complication rates for upper abdominal, lower abdominal, and thoracic surgery range from 13% to 33%, 0% to 16%, and 10% to 40%, respectively [11]. Laparoscopic cholecystectomy carries a much lower risk of pulmonary complications than does traditional open cholecystectomy. For example, in two large series comprising a total of 5779 patients, pulmonary complication rates were 0.2% [39,40].

In a multivariate risk analysis, the type of surgery was the single strongest predictor [16]. In addition to the previously recognized high-risk surgeries, neurosurgery, peripheral vascular, abdominal aortic aneurysm, and neck surgery were also high risk. The inclusion of neck surgery was unexpected and might relate in part to the higher incidence of smoking histories and COPD among patients undergoing neck surgery, despite controlling for confounders in the multivariate analysis.

Postoperative pulmonary complications are more common for surgeries that last more than 3 hours than for briefer procedures [41–43]. In a high-risk patient with few other opportunities for risk reduction strategies, one might consider, when possible, a less ambitious, briefer procedure to reduce risk.

Type of anesthesia

The contribution of risk from the type of anesthesia itself has been controversial. Many studies have found a lower risk of pulmonary complications among patients receiving spinal or epidural anesthesia than among those receiving general anesthesia, but the results have been inconsistent and the effect small. Recently, Rodgers and colleagues performed a rigorous systematic review of 141 trials involving 9559 patients, with a mean age of 63 years, who had been randomized to receive neuraxial blockade (either epidural or spinal anesthesia) or general anesthesia [44]. When patients received balanced anesthesia with both

techniques, the authors included such patients in the neuraxial blockade group. In addition to a lower overall mortality in the neuraxial blockade group (2.1% versus 3.1%), rates of pneumonia and respiratory depression were significantly lower in the neuraxial blockade group. The relative risks for these two events in the neuraxial blockade group were 0.61 (CI 0.48–0.81) and 0.41 (CI 0.23–0.73), respectively. Absolute risks for pneumonia and respiratory depression in the neuraxial blockade group were 3.1% and 0.6%, respectively. Unless future large scale randomized trials reach different conclusions, one can now confidently recommend spinal or epidural anesthesia, whenever possible, for patients who are otherwise at high risk for postoperative pulmonary complications.

Neuromuscular blocking agent

As a reduction in lung volume after surgery is the principal physiologic mechanism that leads to postoperative pulmonary complications, it would be intuitive that prolonged neuromuscular blockade and resulting hypoventilation might increase this risk. Berg and others performed a trial of 691 patients undergoing surgery with general anesthesia and randomized them to pancuronium (long acting), atracurium (shorter acting), and vecuronium (shorter acting) as the neuromuscular blocker [45]. The incidence of residual neuromuscular blockade after surgery was 26% in the pancuronium group and 5% in the group receiving shorter acting agents. Among the patients receiving pancuronium who had residual neuromuscular blockade, there was a 3.5-fold increase in the risk of postoperative pulmonary complications. While this report awaits confirmation by other investigators, it is reasonable to avoid pancuronium in patients who are at high risk for pulmonary complications.

Multifactorial risk indices

In 1993 Epstein and colleagues reported the predictive value of a new cardiopulmonary risk index that included a modified Goldman cardiac risk index plus potential pulmonary risk factors of obesity, cigarette use within 8 weeks, productive cough within 5 days, wheezing or rhonchi, FEV_1/FVC less than 70%, and $PaCO_2$ greater than 45 mmHg [46]. In the original series of 42 patients undergoing lung resection, patients with a score of four or greater (out of 10 total points) had an odds ratio of 19 for pulmonary complications when compared with those with a score of less than four. In a subsequent larger analysis of 180 patients undergoing thoracic surgery, this index did not predict death or any pulmonary complication, however. The lack of predictive value of this index in the larger follow-up study might relate to the observations that obesity is not a risk factor for pulmonary complications and that spirometry is no more predictive than clinical data in stratifying risk (see pulmonary function testing section below).

Lawrence and colleagues used a nested case–control design to analyze risk factors for pulmonary complications after elective abdominal surgery [37].

Variables that independently predicted pulmonary complications included abnormal physical examination (decreased breath sounds, prolonged expiration, rales, rhonchi, or wheezes), abnormal chest radiograph, and increasing scores (per point) on the Goldman risk index and Charlson comorbidity index [47]. Odds ratios were 5.8, 3.2, 2.04, and 1.6, respectively. This simple model, which incorporates readily available clinical information, provides useful guidance to clinicians.

Using the widely cited cardiac risk indices as a model, Arozullah and colleagues recently developed the first validated multifactorial risk index for postoperative respiratory failure [16]. In their prospective cohort study of 181,000 male veterans, seven factors independently predicted risk. Using the strength in the multivariate analysis, the authors developed a weighted score for each factor in a risk index (Table 4). Procedure-related risk factors dominate the analysis. Among patient-related risk factors, low albumin and renal insufficiency were stronger predictors than were clinical factors including dependent functional status, COPD, and an age of over 60 years. In a validation cohort, the index accurately predicted the risk of respiratory failure, with complication rates ranging from 0.5% (class 1) to 26.6% (class 4).

This rigorously developed index advances the science of preoperative pulmonary evaluation and will be an important tool for clinicians. It remains to be

Table 4
Arozullah multifactorial risk index for predicting postoperative respiratory failure

Variable	Odds ratio (95% CI)	Point value
Type of surgery		
Abdominal aortic aneurysm	14.3 (12.0–16.9)	27
Thoracic	8.14 (7.17–9.25)	21
Neurosurgery, upper abdominal, or peripheral vascular	4.21 (3.80–467)	14
Neck	3.10 (2.40–4.01)	11
Emergency surgery	3.12 (2.83–3.43)	11
Albumin <3.0 gm/dL	2.53 (2.28–2.80)	9
Blood urea nitrogen >30 mg/dL	2.29 (2.04–2.56)	8
Partial or fully dependent functional status	1.92 (1.74–2.11)	7
History of COPD	1.81 (1.66–1.98)	6
Age (y) >69	1.91 (1.71–2.13)	6
60–69	1.51 (1.26–1.69)	4

Class	Point total	Postoperative pulmonary complication rates (validation cohort)
1	<11	0.5%
2	11–19	1.8%
3	20–27	4.2%
4	28–40	10.1%
5	>40	26.6%

Adapted from Arozullah AM, Daley J, Henderson WG, et al. Multifactorial risk index for predicting postoperative respiratory failure in men after major noncardiac surgery. Ann Surg 2000;232:242–53.

determined if this index will equally predict pulmonary complications other than respiratory failure. Unfortunately, none of the predictive factors are modifiable, other than potentially changing the proposed procedure to a less ambitious and lower-risk surgery. As a result, this index is more valuable to predict risk and to determine candidacy for surgery than as a tool for risk reduction strategies.

Pulmonary function testing

While preoperative spirometry has a well established role before lung resection surgery, its benefit before nonresective thoracic and other high-risk surgeries remains vigorously debated. Routine preoperative spirometry would be valuable if it served at least one of three potential goals. First, it should identify high-risk patients more accurately than clinical examination alone. Second, it should identify high-risk patients who have no clinical risk factors and whose risk would otherwise escape detection. Finally, even if these criteria are not met, it could be useful if a threshold value existed below which the risk was so high that surgery should never be performed. Existing data suggest that none of these criteria are met.

Many studies of preoperative spirometry are flawed. In a 1989 review, all 22 retrieved studies of the predictive value of spirometry had important methodological flaws [48]. These flaws included lack of blinding, selection bias, inclusion of minor clinical outcomes as postoperative pulmonary complications, lack of placebo controls, and retrospective analyses that relied on chart documentation to identify complications. Unadjusted relative risks of pulmonary complications for patients with abnormal spirometry in these and other reports have ranged from 0.9 to 4.0 [11]. Most of the studies did not report clinical characteristics of study patients and did not determine whether or not clinical evaluation alone would have been as (or more) predictive of complications than spirometry. Criteria for abnormal spirometry in these studies varied but were commonly an FEV_1 less than 70% of predicted or an FEV_1/FVC ratio of less than 65% [49].

Most helpful in this debate are studies that have evaluated both spirometric values and clinical evaluation in relation to the risk of pulmonary complications. In a study of 278 patients undergoing general surgery, Williams-Russo and colleagues found that abnormal spirometry did not predict complications, whereas chronic bronchitis, asthma, and poor exercise capacity predicted pulmonary events [50]. In another report of patients with mild to severe COPD undergoing thoracic and abdominal surgery, clinical factors including age, ASA class, abnormal chest radiograph, and perioperative bronchodilator use predicted postoperative pulmonary complications, whereas spirometry was not an independent predictor [51].

In the previously mentioned study by Lawrence and colleagues that proposed a risk model including abnormal physical examination, abnormal chest radiograph, the Goldman risk index and the Charlson comorbidity index, spirometric values were the same in both cases with pulmonary complications and controls [37]. Spirometry did not identify patients at risk and was inferior to clinical evaluation.

Recently, Warner and colleagues studied smokers undergoing abdominal surgery who had severe airway obstruction as determined by an FEV_1 of less than 40% predicted and an FEV_1/FVC ratio less than the lower limit of predicted normal [52]. In the past, clinicians had often considered such patients to have a prohibitive risk for surgery. The authors matched these patients against control patients who smoked cigarettes but had normal spirometry. Only bronchospasm was statistically more common among the group of patients who had abnormal spirometry (12.6% versus 2.2%). There were no significant differences in the rates of the more clinically important complications of prolonged intubation, pneumonia, or prolonged ICU stay. The conclusion of these and other studies is that clinical evaluation is more accurate in predicting postoperative pulmonary complications than is abnormal spirometry.

As to the question of prohibitive lung function, even patients with severe airway obstruction (as determined by spirometry) can undergo major surgery with an acceptable degree of risk. In the above cited study by Warner and colleagues, only 25% of patients with and FEV_1 of less than 40% predicted had a postoperative pulmonary complication, and only 2% of patients had perioperative deaths [52]. Kroenke and colleagues' study of 107 patients who had severe COPD and an FEV_1 of less than 50% predicted made a similar observation [42]. Overall mortality was only 1% among non-coronary surgeries, and the incidence of moderate or severe pulmonary complications was 23%. Thus, there is no prohibitive spirometric value below which the risk of surgery is prohibitive.

Given these data, when should clinicians obtain preoperative spirometry in nonthoracic surgery? Routine spirometry is not indicated. Spirometry is recommended if a patient has poorly characterized dyspnea or exercise intolerance and diagnostic uncertainty exists between a cardiac or pulmonary limitation and simple deconditioning. In addition, spirometry might be useful in patients who have established obstructive lung disease if it is not clear from the clinical evaluation if patients are at the best possible baseline.

Perioperative respiratory management

Table 5 summarizes definite risk factors for postoperative pulmonary complications. Preoperative and intraoperative strategies to reduce the risk of pulmonary complications follow logically from the established risk factors. Before surgery, one should recommend smoking cessation for at least 8 weeks, optimize airflow, treat exacerbations for patients who have COPD or asthma, treat bacterial lower respiratory tract infection with appropriate antibiotics, and begin teaching lung expansion maneuvers (see discussion below) [53]. Intraoperative strategies involve collaboration with anesthesia and surgery colleagues. These strategies include selecting a lower risk or briefer (< 3 hours) procedure for high-risk patients with few opportunities for risk reduction, recommending laparoscopic rather than open abdominal surgeries when possible, using spinal or epidural anesthesia in lieu of general anesthesia, and avoiding pancuronium.

Table 5
Risk factors for postoperative pulmonary complications

Patient-related risk factors	Procedure-related risk factors
Chronic obstructive pulmonary disease	Surgical site
Cigarette use < 8 wk before surgery	Thoracic surgery
ASA class >2	Abdominal aortic aneurysm surgery
Goldman class 2–4	Upper abdominal surgery
Age >60	Neurosurgery
Dependent functional status	Peripheral vascular surgery
Albumin <3.0 gm/dL	General anesthesia
Blood urea nitrogen >30 gm/dL	Pancuronium use
Abnormal chest radiograph	Emergency surgery
	Surgery lasting >3 h

Postoperative strategies differ from the above strategies, which reduce or avoid risk factors. Strategies after surgery involve lung expansion maneuvers and pain control; both strategies work to minimize the expected fall in lung volumes after surgery and therefore decrease pulmonary complication rates. Lung expansion maneuvers range from simple but effort dependent strategies such as incentive spirometry and deep breathing (a component of chest physical therapy) to more complex, expensive, and effort-independent strategies such as continuous positive airway pressure (CPAP). In a meta-analysis of differing lung expansion techniques, Thomas and McIntosh reported odds ratios for pulmonary complications for incentive spirometry and deep breathing exercises of 0.44 and 0.43, respectively [54].

Using a more rigorous study selection strategy that excluded all studies with a methodological flaw, Overend and colleagues found 35 of 46 retrieved articles on incentive spirometry to be flawed [55]. Of the remaining 11, only five studies used pulmonary complications as an endpoint, and two of these showed a benefit of incentive spirometry. While the literature contains flawed studies, incentive spirometry and deep breathing exercises are low risk, inexpensive, and are recommended as a strategy to reduce risk. The combination of these two interventions is no more effective than either one alone. Postoperative CPAP is an equally effective strategy. For example, Stock and colleagues randomly assigned patients after upper abdominal surgery to postoperative CPAP, incentive spirometry, or coughing and deep breathing [56]. Atelectasis was less common in the CPAP group than in either of the other two groups (23% versus 42%). Because CPAP is more costly and carries a small risk of barotrauma, it is reasonable to reserve this intervention for patients who are unable to cooperate with effort-dependent strategies.

Pain control strategies, including epidural analgesia and intercostal nerve blocks, reduce splinting and promote the ability to take deep breaths after thoracic, aortic, and upper abdominal surgeries. While pain control is improved when compared with systemic opioids, studies of their ability to reduce postoperative pulmonary complications have shown conflicting results. In a systematic review and meta-analysis, Ballantyne and colleagues helped to determine the benefit of

specific pain control strategies [57]. Epidural opioids and intercostal nerve blocks showed a non-significant trend toward reduced pulmonary complications while epidural local anesthetics reduced both pulmonary infection rates (RR 0.36, CI 0.21–0.65) and total pulmonary complications (RR 0.58, CI 0.42–0.80).

Summary

Postoperative pulmonary complications in the elderly are common and are a significant source of morbidity, mortality, and prolonged length of stay. Risk factors differ from the well-known risk factors for cardiac complications and can be divided into patient- and procedure-related factors. Patient-related factors include COPD, recent cigarette use, poor general health status as defined by Goldman or ASA class, dependent functional status, and laboratory parameters including abnormal chest radiograph, renal insufficiency, and low serum albumin. Age is a minor risk factor when adjusted for comorbidities and confers approximately a two-fold increase in risk. Elderly patients who are otherwise acceptable surgical candidates should not be denied surgery based solely on age and concern for postoperative pulmonary complications. The surgical site is the single most important predictor of pulmonary complications. High-risk surgeries include thoracic, upper abdominal, aortic, neurosurgery, and peripheral vascular. Other procedure-related risk factors include surgery lasting longer than 3 hours, the use of general anesthesia, pancuronium use, and emergency surgery.

Clinicians should not recommend routine preoperative spirometry before high-risk surgery because it is no more accurate in predicting risk than clinical evaluation. Patients who might benefit from preoperative spirometry include those who have unexplained dyspnea or exercise intolerance and those who have COPD or asthma in whom uncertainty exists as to the status of airflow obstruction when compared with baseline.

After identifying patients at risk for postoperative pulmonary complications, clinicians can recommend strategies to reduce risk throughout the operative period. In addition to minimizing or avoiding the above risk factors, optimization of COPD or asthma, deep breathing exercises, incentive spirometry, and epidural local anesthetics reduce the risk of postoperative pulmonary complications in elderly surgical patients.

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