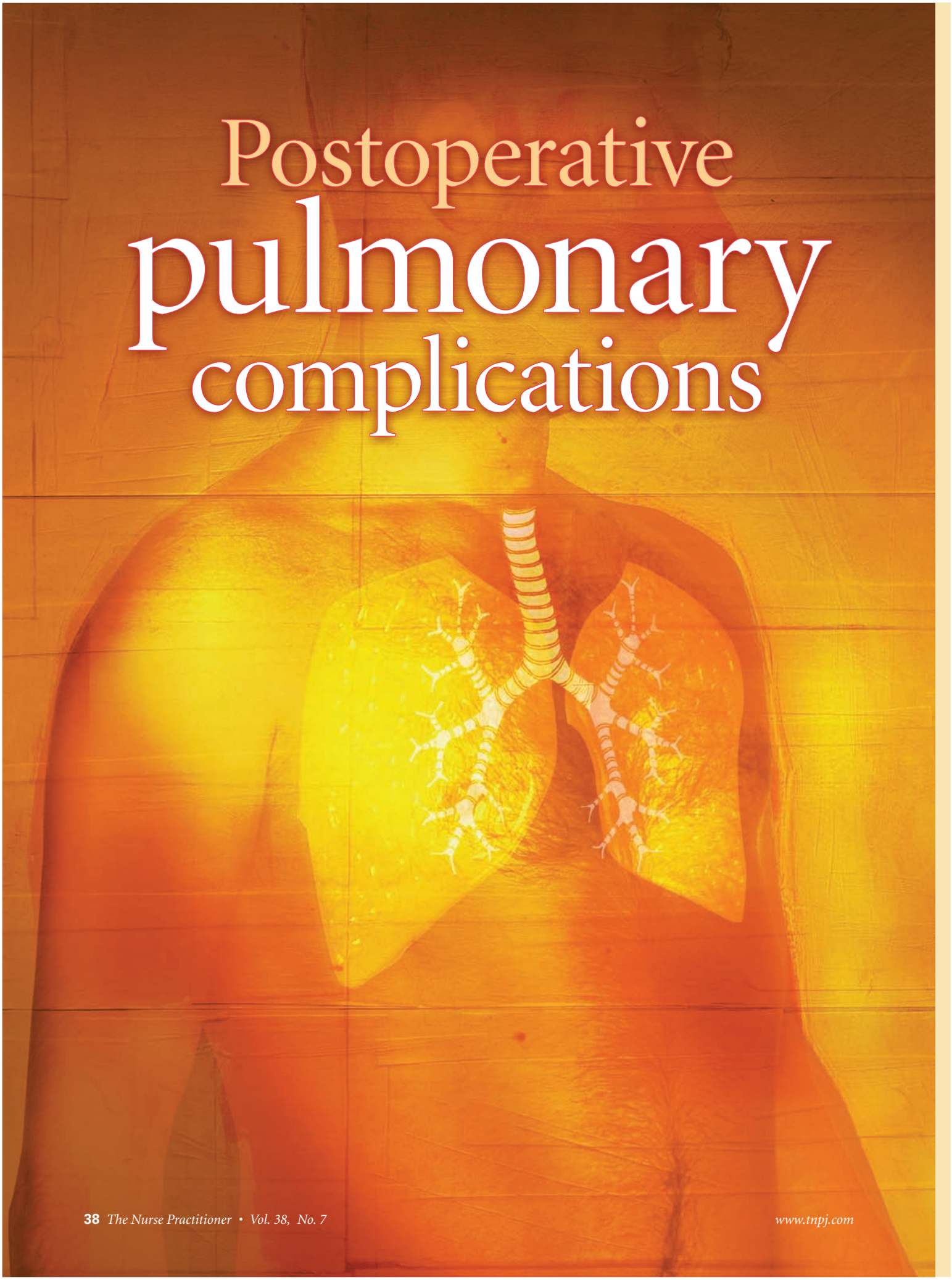
Postoperative pulmonary complications



CE 2.8 CONTACT HOURS

Reducing risks for noncardiac surgery

Abstract: Postoperative pulmonary complications (PPCs) are a major contributor to the overall risk of noncardiac surgery that may lead to serious postoperative morbidity and long-term mortality. Nurse practitioners should be familiar with risk indices for PPCs, clinical guidelines, and risk reduction strategies to prevent PPCs and improve PPC outcomes.

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Nurse practitioners (NPs) frequently evaluate patients prior to surgery to assess their risk of cardiopulmonary complications. Although postoperative pulmonary complications (PPCs) are more common than cardiac complications and associated with a substantial increase in morbidity and mortality, most preoperative clinical assessments involve cardiac risk stratification.[1-3] There has been far less research, evidence-based guidelines, and consensus statements on assessment and interventions to prevent these complications.[3,4-8] PPCs are a major contributor to the overall risk of noncardiac surgery, cause the most costly, deleterious clinical outcomes after surgery, may lead to serious health issues, and contribute to long-term mortality.[1-3] The purpose of this article is to review PPCs, risk stratification, evidence-based guidelines, and risk-reduction strategies for PPCs in patients undergoing noncardiac surgery.

Introduction to PPCs

The rate of PPCs is approximately 7% and can vary between 5% and 70% depending on the definition of PPCs, the type surgical procedure, and the type of patients included in the study.[8-12] PPCs, which are defined as any condition that adversely affects the respiratory tract and can lead to adverse clinical outcomes after surgery, account for 25% of postoperative mortality.[9,10] PPCs may be transient, self-limiting, and clinically insignificant complications that vary from minor atelectasis, bronchospasm, or tracheobronchitis, to severe, major pulmonary complications. These complications include pneumonia, exacerbation of chronic obstructive pulmonary disease (COPD), pneumothorax, or acute respiratory failure, requiring either reintubation after postoperative extubation or mechanical ventilation for more than 48 hours (see *Overview and sequelae of PPCs*).[3,8,9] Atelectasis is a common respiratory complication that may contribute to hypoxemia, pneumonia, and acute respiratory failure.[11] Postoperative hypoxemia may complicate a patient's recovery and could lead to increased frequency of endotracheal intubation, mechanical ventilation, ICU stay, and mortality.[12] Respiratory failure is a serious postoperative complication that could lead to poor clinical outcomes, such as deep vein thrombosis, pulmonary embolism, myocardial

Keywords: clinical guidelines, postoperative pulmonary complications, risk indices, risk reduction strategies

infarction, acute renal failure, pneumonia, and mortality within 30 days.[2,13]

The causes of PPCs are multifactorial and involve preoperative, intraoperative, and postoperative factors. Preoperative factors are related to a patient's general health, underlying pulmonary status, and other comorbidities. Intraoperative contributors are surgery-related factors, such as type of anesthesia, type of surgery, and elective or emergency procedure. Postoperative factors are related to postoperative pulmonary physiologic changes, which include hypoventilation from anesthetics, disruption of respiratory muscles, limited respiratory excursion from pain, neurally mediated diaphragmatic dysfunction from visceral manipulation, and positional dependence.[3] These physiologic changes can lead to major alterations in pulmonary mechanics, including restrictive lung volume loss, decreased tidal volume, loss of sighing breaths, loss of respiratory drive and coughing, and impaired mucociliary clearance.[9] There may be a 30% reduction in functional residual capacity (FRC) and a 60% reduction in forced vital capacity (FVC) persistent for up to 1 week after surgery, which can lead to atelectasis, pneumonia, ventilation and perfusion mismatch, and postoperative hypoxemia.[12] It is important to understand the impact of patient-related and surgery-related factors, as they are major determinants of PPCs.[3] Unlike cardiac complications, PPCs may be attributed more to surgery-related rather than patient-related risk factors.[8]

Overview and sequelae of PPCs

PPCs

Minor pulmonary complications
- Atelectasis
- Bronchospasm
- Tracheobronchitis

Major pulmonary complications
- Pleural effusion
- Pneumothorax
- Exacerbation of COPD
- Pneumonia
- Acute respiratory failure requiring either reintubation after postoperative extubation or mechanical ventilation for >48 hours

Sequelae of PPCs

Atelectasis
- ↑ Postoperative hypoxemia
- ↑ Pneumonia
- ↑ Acute respiratory failure

Postoperative hypoxemia
- ↑ Frequency of endotracheal intubation
- ↑ Frequency of mechanical ventilation
- ↑ ICU stay
- ↑ Mortality

Respiratory failure
- ↑ Deep vein thrombosis
- ↑ Pulmonary embolism
- ↑ Myocardial infarction
- ↑ Acute renal failure
- ↑ Mortality within 30 days

Surgery-related risk factors

Surgery-related risk factors are major contributors to PPCs, and the surgical site is the most important risk factor.[8] The development of PPCs is inversely related to the distance of the surgical incision from the diaphragm. The closer the incision to the diaphragm, the more effect it has on the respiratory muscles and diaphragmatic function. Based on the importance of surgical site, thoracic, upper abdominal, and aortic surgeries are procedures at the highest risk for causing PPCs.[7,8,14] Other high-risk surgeries include neurosurgery, head and neck surgery, and emergency surgery. This may be attributed to potential impaired cognitive function after neurosurgery, upper airway dysfunction associated with head and neck surgery, and lack of time to provide proper pulmonary assessment or interventions prior to emergency surgery.[7,15] The duration of surgery and type of anesthesia and neuromuscular blockades may also substantially contribute to PPCs because these factors are more likely to alter the patient's respiratory effort.[3,15]

Patient-related risk factors

Important patient-related risks are advanced age, mental and functional status, and poor health as assessed by the American Society of Anesthesiologist's (ASA) class 2 or greater (see *ASA physical status classification*).[8,16] Additional risk factors include a history of COPD, smoking, obstructive sleep apnea, pulmonary hypertension, CHD, and renal dysfunction.[8,16] Although patients with underlying pulmonary diseases have low pulmonary reserve and are naturally expected to be at higher risk for PPCs, other comorbidities, patient-specific risks, and metabolic factors contribute to PPCs as often as (or more than) underlying pulmonary disease.[3,15] A number of risk indices have been developed to provide comprehensive risk stratification for PPCs after noncardiac surgery.[2,14,17-21]

Risk stratification

Identifying patients at risk for developing PPCs is essential to preventing them. Predictors for PPCs as whole or specific subsets such as respiratory failure or pneumonia have been identified, including cardiopulmonary, pulmonary, pneumonia, and respiratory failure risk indices.

Cardiopulmonary risk index

The cardiopulmonary risk index (CPRI) is one of the earlier multifactorial indices that attempted to predict PPCs in

combination with cardiac complications after pulmonary resection (see *Risk indices for PPCs*).[20] The CPRI is made up of the original Goldman cardiac risk index (CRI) and six new pulmonary risk factors.[20,22] The original CRI categorized patients into four groups based on their risk scores, 5 or less, 6 to 12, 13 to 25, and 26 or more, that were derived from nine risk factors.[20] A new score is assigned to each of these four categories before incorporating it into the CPRI: 1 for CRI of 5 points or less; 2 for CRI of 6 to 12 points; 3 for CRI of 13 to 25 points; and 4 for CRI of 26 points or more.[20,22] Six pulmonary risks were identified: obesity (body mass index 27 kg/m^2 or more), smoking within 8 weeks of surgery, productive cough within 5 days of surgery, diffuse wheezing within 5 days of surgery, FEV_1/FVC less than 70%, and a $Paco_2$ more than 45 mm Hg. Each pulmonary risk factor is assigned 1 point for a possible total 6 points for pulmonary risk. The possible maximal total CPRI score is 10, and the incidence of complications increases with higher scores; a threshold of 4 points or more yields the best predictive value, indicating the likelihood of developing PPCs by 19-fold.[20]

Pulmonary risk index

Brooks-Brunn identified six independent predictors of PPCs after abdominal surgery from a group of 23 risk factors, which included age 60 years and older, obesity, smoking within less than 8 weeks of surgery, history of cancer, impaired cognitive function, and upper abdominal incision.[19] Cancer history significance was attributed to a large number of patients requiring surgery for abdominal cancers at two of their centers, while impaired cognitive function was attributed to the inability to cough and manage secretions. These predictors correctly estimated PPCs in their patients (78.5%) with 94.5% specificity.[19]

More recent studies have explored predictors for PPCs and reported different findings. McAlister et al. reported four risk factors independently associated with PPCs in their prospective study of 1,055 patients, including age 65 and older (odds ratio = 5.9), positive cough test defined as recurrent coughing after the first cough following a deep inspiration (odds ratio = 3.8), perioperative nasogastric tube (odds ratio = 7.7), and duration of surgery 2.5 hours or greater (odds ratio = 3.3).[21] Canet and associates identified 11 independent risk predictors for PPCs (seven categories) after cardiac and noncardiac surgery. Intrathoracic surgery (odds ratio = 11.4), low preoperative Spo_2 of 90% or less (odds ratio = 10.7), and prolonged surgery over 3 hours (odds ratio = 9.7) were major contributors to PPCs in their patients.[14] Risk scores were assigned to these 11 risk factors based on a logistic regression model, and they were added to make up PPC risk score with possible maximal score of 123. The scores were classified into three risk groups: low risk (score less than 26) with PPC incidence of 1.6%, intermediate risk (score 26 to 44) with PPC incidence of 13.3%, and high risk (score greater than 44) with PPC incidence of 44.9%.

ASA physical status classification[16]

ASA class	Definitions
1	A normal healthy patient
2	A patient with mild systemic disease
3	A patient with severe systemic disease
4	A patient with severe systemic disease that is a constant threat to life
5	A moribund patient who is not expected to survive without the surgery
6	A declared brain-dead patient whose organs are being removed for donor purposes

Pneumonia risk index

Arozullha and associates developed a multifactorial pneumonia risk index, which was modeled after the CRI (see *Risk indices for postoperative pneumonia and respiratory failure*).[18] This model was derived and validated from a large Veterans Administration (VA) database from 1991 to 1994. A risk score was developed from 14 independent predictors (28 items), which were assigned points based on their strength on multivariate analysis; each patient's age contributed to the prediction as much as the type of surgery. A total possible point for the index is 89, and the index was separated into five risk categories; the probability for postoperative pneumonia was 0.24% for low risk (15 points or less) and 15.9% for high risk group (more than 55 points).

Respiratory failure risk index

A respiratory failure risk index (RFRI) was developed from a large VA database to predict the risk of developing postoperative respiratory failure defined as mechanical ventilation required for 48 hours or more after surgery or as reintubation after the initial extubation.[17] Women and patients with minor procedures or major transplants were excluded. The index included seven independent variables (13 items), which were assigned points based on their strength on multivariate analysis. The possible maximal total point is 74 for the index, which was categorized into five groups, predicting risk of respiratory failure of 0.5% in low-risk groups (10 points or less) and 26.6% in high-risk groups (greater than 40 points). The type of surgery was the most important predictor for postoperative respiratory failure–especially abdominal aortic aneurysm repair, thoracic surgery and neurosurgery, and upper abdominal or vascular surgery.

Risk indices for PPCs

Cardiopulmonary risk index

Epstein et al., 1993[20]
Pulmonary and cardiopulmonary complications

Variables	
CRI	**Score**
• heart failure (S3, JVD, LVEF<40%)	11
• MI during previous 6 months	10
• Preoperative PVCs >5/minute	7
• Preoperative rhythm other than NSR or PACs	7
• Age >70 years	5
• Important valvular aortic stenosis	3
• Poor general medical condition	3
Possible total points for CRI	**3-46**
CRI Score for 0-5 points	1
6-12 points	2
12-25 points	3
>25 points	4
Pulmonary risk index (PRI)	
• Obesity (BMI ≥27)	1
• Smoking within 8 weeks of surgery	1
• Productive cough within 5 days of surgery	1
• Wheezing within 5 days of surgery	1
• FEV1/FVC <70%	1
• $Paco_2$ >45 mm Hg	1
Range of score	
CRI	1-4
PRI	0-6
Possible total score	
CPRI score = CRI + PRI	10
Risk for complications	
Score ≥4:	
• Odds for PPCs	19
• Odds for cardiopulmonary complications	22
Definition	
Pulmonary complications:	
• Elevated $Paco_2$	
• Lobar atelectasis	
• Pneumonia	
• Prolonged mechanical ventilation	
Cardiac complications:	
• Dysrhythmia	
• Heart failure	
• Unstable angina	
Death	

Pulmonary risk index

Brooks-Brunn, 1997[19]
Pulmonary complications

Variables		
Surgery-related risk	**OR**	
• Abdominal surgery	2.3	
Patient-related risks		
• Age ≥60 years	1.9	
• Smoking in past 8 weeks	2.3	
• History of cancer	2.2	
• BMI ≥27	2.8	
• Impaired CF	5.9	
Range of score	NA	
Possible total score	NA	
Risk for complications		
Odds for PPCs	1.9-5.9	
Definition		
• Atelectasis		
• Pneumonia		

McAlister et al., 2005[21]
Pulmonary complications

Variables		
Surgery-related risk	**OR**	
• Duration of anesthesia >2.5 hrs	3.3	
Patient-related risks		
• Age >65 years	5.9	
• Positive cough test	3.8	
• Perioperative NG tube	7.7	
Range of score	NA	
Possible total score	NA	
Risk for complications		
Odds for PPCs	3.3-7.7	
Definition		
• Atelectasis requiring bronchoscopic intervention		
• Pneumothorax requiring intervention		
• Postoperative pneumonia		
• Respiratory failure requiring ventilator support		

Canet et al., 2010[14]
Pulmonary complications

Variables		
Surgery-related risk	**OR**	**Score**
• Upper abdominal	4.4	15
• Intrathoracic	11.4	24
• Emergency surgery	2.2	8
• Surgical duration:		
<2-3 hrs	4.9	16
>3 hrs	9.7	23
Patient-related risks		
• Age		
51-80 years	1.4	3
>80 years	5.1	16
• Respiratory infection in ≤1 month	5.5	17
• Preoperative anemia Hb<10 g/dL	3.0	11
• Postoperative Spo_2:		
91-95	10.7	8
≤90	10.7	24
Range of score		3-24
Possible total score		123
Risk for complications		
Low risk for PPCs– Score <26		1.6%
Medium risk for PPCs– Score 26-44		13.3%
High risk for PPCs– Score ≥45		44.9%
Definition		
• Bronchospasm		
• Atelectasis		
• Pneumothorax		
• Respiratory infection		
• Aspiration pneumonitis		
• Pleural effusion		
• Respiratory failure		

BMI = body mass index; CF = cognitive function; FEV = forced expiratory volume; Hb = hemoglobin; hrs = hours; JVD = jugular venous distention; LVEF = left ventricular ejection fraction; NG = nasogastric; NSR = normal sinus rhythm; OR = odds ratio; PACs = premature atrial contractions; PVCs = premature ventricular contractions.

Risk indices for postoperative pneumonia and respiratory failure

Pneumonia risk index

Arozullah et al, 2001[18]

Number of variables	**28**
Surgery-related risks	**Score**
• Abdominal aortic aneurysm	15
• Thoracic	14
• Upper abdominal	10
• Neck	8
• Neurosurgery	8
• Vascular	3
• Other	0
• Emergency surgery	3
• General anesthesia used	4
Patient-related risks	
• Age (years)	
>80	17
70-79	13
60-69	9
50-59	4
<50	0
• Functional status	
– Totally dependent	10
– Partially dependent	6
• Weight loss >10% in past 6 months	7
• History of COPD	5
• Impaired sensorium	4
• History of stroke	4
• BUN level	
<8 mg/dL	4
8-21 mg/dL	0
22–30 mg/dL	2
>30 mg/dL	3
• Blood transfusion >4 units	3
• Corticosteroid use for a chronic condition	3
• Current smoker within 1 year	3
• >2 Alcohol drinks/day in past 2 wks	2
Possible total score	84
Score/complication rate	
Score <15:	0.2%
Score 16-25:	1.2%
Score 26-40:	4.6%
Score 41-55:	10.8%
Score >55:	15.9%

Respiratory failure risk index

Arozullah et al, 2000[17]

Number of variables	**13**
Surgery-related risks	**Score**
• Abdominal aortic aneurysm	27
• Thoracic	21
• Neurosurgery, upper abdominal, or peripheral vascular	14
• Neck	11
• Other	0
• Emergency surgery	11
Patient-related risks	
• Age (years)	
>70	6
60-69	4
<60	0
• Albumin <30 g/L	9
• BUN >30 mg/dL	8
• Partially/fully dependent functional status	7
• History of COPD	6
Possible total score	74
Score/complication rate	
Score <10:	0.5%
Score 11-19:	1.8%
Score 20-27:	4.2%
Score 28-40:	10.1%
Score >40:	26.6%

Johnson et al, 2007[2]

Number of variables	**35**
Surgery-related risks	**Score**
• Integumentary vs hernia	1
• Respiratory, hemic vs hernia	3
• Heart vs hernia	2
• Aneurysm vs hernia	2
• Mouth, palate vs hernia	7
• Stomach, intestines vs hernia	2
• Endocrine vs hernia	2
• Emergency surgery	2
• Contaminated/infected wound	1
• Work RVU	
10-17 vs <10	2
>17 vs <10	4
Patient-related risks	
• Age ≥40 years vs <40	2
• Gender—male vs female	1
• Weight loss >10%	1
• >2 alcohol drinks/d in past 2 wks	1
• Smoker	1
• Dyspnea	1
• History of severe COPD	2
• Bleeding disorders	1
• HF <30 day before surgery	1
• Stroke	1
• Impaired sensorium	1
• Ascites	1
• ASA score	
3 vs 1-2	3
4-5 vs 1-2	5
• Preoperative sepsis	2
• Preoperative acute renal failure	1
• Preoperative hematocrit ≤38%	1
• Preoperative WBC <2.5 or >10 x10^3/mm^3	1
• Preoperative platelet count <150,000/mm^3	1
• Preoperative serum sodium >145 mEq/L	2
• Preoperative creatinine >1.5 mg/dL	1
• Preoperative AST >40 units/L	1
• Preoperative albumin <3.5 vs >3.5 g/L	1
• Preoperative bilirubin >1.0 mg/dL	1
Possible total score	44
Score/complication rate	
Low risk—Score <8:	0.1%
Medium risk—Score 8-12:	1.0%
High risk—Score >12:	6.8%

AST = aspartate transaminase; BUN = blood urea nitrogen; COPD = chronic obstructive pulmonary disease; HF = Heart failure; RVU = relative value units; vs = versus; WBC = white blood cell; wks - weeks.

This index was recently updated to include a more general patient population, including female patients.[2] Twenty-eight variables (40 items) were independently associated with postoperative respiratory failure, and they were assigned points from 1 to 7 based on their strength on the multivariate analysis; orofacial surgery, ASA class 4 or greater, and high-complexity procedures were designated with highest scores. The RFRI was calculated by summing up all the applicable scores, and three risk categories were identified: RFRI score less than 8 with 0.1% complication rate (low risk); 8 to 12 with 1% complication rate (medium risk), and greater than 12 with 6.8% complication rate (high risk).

The above respiratory failure risk indices are complex and may not be readily suitable for clinical applications. Gupta and colleagues developed a risk calculator predicting postoperative respiratory failure with a large multicenter data set from the American College of Surgeons National Surgical Quality Improvement Program.[23] The initial analysis explored 62 variables from 7 variable categories, including demographics, lifestyles, comorbidities, lab variables, emergency surgery, types of elective surgery, and other factors.[23] Multivariate logistic regression identified five predictors for postoperative respiratory failure, including types of elective surgery, emergency surgery, sepsis, dependent functional status, and higher ASA class. These variables are incorporated in an interactive risk calculator, which provides a model-based percent estimate of postoperative respiratory failure; the risk calculator is available online for free.[24]

Systematic reviews

The difference in the incidence of PPCs and their predictors in the literature may be attributed to variations in the definition of PPCs, selected patient population, surgical procedures, and small sample size in some studies. In an attempt to achieve a more consistent conclusion, Fisher and associates conducted a systematic review of seven blinded studies for PPCs after noncardiac surgery between 1996 and 2001.[4] The authors confirmed different definitions of PPCs among studies and reported varying incidence of PPCs from 2% to 19%. They found that 16 variables were significantly associated with PPCs, and the duration of anesthesia and postoperative nasogastric tube placement were the only significant variables in more than one study.

Smetana and associates performed a systematic review of 27 studies between 1980 and 2005 and reported that advanced age 60 years and older, poor health consistent with ASA class 2 or greater, functional dependence, COPD, smoking, and heart failure were patient-related risks.[15] Aortic aneurysm repair, nonresective thoracic surgery, abdominal surgery, neurosurgery, emergency surgery, head and neck surgery, vascular surgery, general anesthesia, and prolonged surgery were surgical-related risks for PPCs.[7] A serum albumin level less than 30 g/L is the only lab predictor for PPCs. There is insufficient evidence to support preoperative spirometry as a tool to stratify risk.[7,15] This review by Smetana and associates provides the best evidence for preoperative pulmonary risk stratification, and it is used by the American College of Physicians (ACP) to develop clinical guidelines to identify patients at risk who are likely to benefit from risk-reduction strategies.[7,15]

Clinical guidelines

The ACP developed a clinical guideline for preoperative pulmonary assessment and strategies to reduce PPCs after noncardiothoracic surgery (see *A guideline from the ACP*).[7] All patients should be evaluated for five patient-related risk factors, including age 60 years and older, ASA 2 or greater, functional dependence, COPD, and heart failure. These concomitant risk factors are significant contributors to PPCs particularly if patients are scheduled to have high-risk surgery, prolonged surgery 3 hours or more, or general anesthesia. Hypoalbuminemia (less than 3.5 mg/dL) is a powerful predictor for PPCs and should be measured in all patients clinically suspected of having low serum albumin level or those with 1 or more risk factors for PPCs. There is evidence that appropriate risk reduction strategies such as deep breathing exercises and incentive spirometry substantially reduce the incidence of PPCs. Finally, right heart catheterization has not been shown to improve postoperative pneumonia or in-hospital, all-cause mortality and should not be utilized for the sole purpose of reducing PPCs.

Risk reduction strategies

Lawrence and associates conducted a systematic review of interventions to prevent pulmonary complications and found that selective, rather than routine, use of nasogastric tubes after abdominal surgery, and short-acting, rather than long-acting intraoperative neuromuscular blocking agents, reduce PPC risk.[3] There is no definitive evidence that epidural anesthesia, epidural analgesia, or laparoscopic (versus open) surgical procedures have any positive influence on PPCs.[3] While malnutrition is associated with increased pulmonary risk, routine total enteral or parenteral nutrition does not reduce risk, although enteral formulations designed to improve immune status, such as immunonutrition, may prevent postoperative pneumonia.[3]

Current smokers have increased PPCs and delayed wound healing, and there is some evidence that preoperative smoking cessation may decrease PPCs.[7,25-27] The notion that smoking abstinence within a few weeks of surgery may lead to more pulmonary complications as a result of decreasing cough-promoting effects of smoking and sputum clearance

has not been substantiated. Meyers and colleagues performed a systematic review and meta-analysis of nine studies and found no evidence that smoking cessation within a few weeks before surgery worsened postoperative outcomes.[27] Despite these inconclusive findings, providers should continue to encourage smoking cessation prior to surgery.[7,25-27]

Many pre- and post-operative lung expansion interventions may benefit high-risk patients and should be prescribed early before and after surgery, including inspiratory muscle training, deep-breathing exercise, incentive spirometry, continuous positive airway pressure, and postoperative bronchodilator treatment.[3,7]

Inspiratory muscle training

Inspiratory muscle training is designed to increase the strength and endurance of the inspiratory muscles.[28,29] The training program consists of inspiratory muscle training for 15 to 20 minutes, 6 to 7 days a week for at least 2 weeks before surgery. Patients are trained to use an inspiratory threshold-loading device. With this device, patients inspire against a threshold load, and expiration is unimpeded. The patients start breathing at a resistance equal to 20% to 30% of their maximal inspiratory mouth pressure. The resistance is increased incrementally by 5% to 10%, based on the rate of measured exertion score. This type of preoperative inspiratory muscle training has been shown to increase postoperative inspiratory pressure by 10% and reduce PPCs in patients with elective abdominal aortic aneurysm surgery or CABG.[28,29] No adverse effects were observed, and patients considered this inspiratory muscle training a good preparation for surgery.[28]

Deep-breathing exercise

Periodic voluntary deep breaths effectively counteract the quiet, shallow breathing pattern and are used to prevent the development of atelectasis and pneumonia. Deep-breathing exercises should begin 1 hour after extubation and incorporate three sets of 10 deep breaths with a 30-to 60-second pause between each set, once per hour when awake (in daytime) for the first 4 postoperative days in the sitting position.[30] Patients may be asked to cough during the pause to mobilize secretions. Positive expiratory pressure equipment that creates an expiratory resistance of +10 cm H_2o may be used with this breathing exercise to minimize airway closure and alveolar collapse. Expiration is set to stop approximately at FRC, and patients are instructed to perform slow maximal inspirations when they are using this equipment.

Incentive spirometry

Incentive spirometry, also referred to as sustained maximal inspiration, is designed to mimic natural sighing from long, slow, deep breaths.[31] This is accomplished by using a device that provides feedback when the patient inhales at a predetermined flow or volume and sustains the inflation for at least 5 seconds. The patient is instructed to hold the spirometer in an upright position, place the lips tightly around the mouthpiece, inhale slowly to raise the ball (flow-oriented) or the piston/ plate (volume-oriented) in the chamber to a set target, and exhale normally after removing the mouthpiece, followed by briefly holding a breath. This breathing maneuver decreases pleural pressure and promotes lung expansion and better gas exchange. It may prevent or reverse postoperative atelectasis with repetitive treatment on a regular basis.

A guideline from the ACP

Recommendation 1—
Evaluate for significant risk factors for PPCs:
- Age ≥60 years
- Functional dependence
- Heart failure
- COPD
- ASA class ≥2
- Insignificant risk factors for PPCs: obesity and mild or moderate asthma.

Recommendation 2—
High risk surgical procedures include:
- Prolonged surgery ≥3 hours
- Abdominal surgery
- Thoracic surgery, neurosurgery, head and neck surgery
- Vascular surgery
- Aortic aneurysm repair
- Emergency surgery
- General anesthesia

Recommendation 3—
Measure serum albumin in patients with:
- Suspected of having hypoalbuminemia
- ≥1 risk factors for PPCs

Recommendation 4—
Risk reduction treatment:
- Deep-breathing exercise
- Incentive spirometry
- Selective use of a nasogastric tube

Recommendation 5—
Preoperative pulmonary function testing or chest radiography may be appropriate for patients with:
- COPD
- Asthma
- Not recommended for routine preoperative testing

Recommendation 6—
Nonrisk reduction procedures/not recommended:
- Right-heart catheterization
- Total parenteral nutrition

Adapted from: Qaseem A, Snow V, Fitterman N, et al. Risk assessment for and strategies to reduce perioperative pulmonary complications for patients undergoing noncardiothoracic surgery: a guideline from the American College of Physicians. *Ann Intern Med.* 2006;144(8):575-580.

Continuous positive airway pressure

Continuous positive airway pressure (CPAP) is a breathing mode where the patient breathes through a pressurized circuit against a threshold resistor at a set, positive airway pressure during inspiration and expiration.[32] Typically, a nasal mask, nasal cannula, or a mask that covers both the nose and the mouth is applied to the upper airway. CPAP may reduce atelectasis and improve oxygenation and has been shown to decrease the incidence of endotracheal intubation and other severe complications, including pneumonia, infection, sepsis, and length of ICU stay in patients who develop hypoxemia after elective major abdominal surgery.[12]

Bronchodilator agents

Postoperative bronchospasm may be attributed to aspiration, medication-induced histamine release, allergic response, or exacerbation of underlying bronchospastic disease. The incidence of severe perioperative bronchospasm is low even in patients with asthma undergoing anesthesia. Short-acting beta$_2$-adrenergic agonists such as albuterol or levalbuterol have been frequently prescribed for patients with asthma or COPD.[32] Their onset of action occurs within 5 to 17 minutes, peaks within 60 to 90 minutes, and lasts from 3 to 6 hours.[33] Levalbuterol is a bronchodilator made of only a dextro isomer that has a high affinity and processes more bronchodilatory, bronchoprotective, and ciliary-stimulatory properties than albuterol, which consists of two equal parts of dextro and levo isomers.[34] Due to a higher proportion of the active ingredient, treatment with levalbuterol requires less medication, has a prolonged therapeutic benefit, causes less paradoxical bronchospasm, and reduces the costs for nebulizer therapy and length of hospital stay.[35]

Pulmonary assessment and the role of the NP

Pulmonary evaluation is paramount to PPC reduction and involves a complete history and physical exam. The NP should evaluate smoking history, respiratory symptoms, preexisting pulmonary disease, and current pulmonary medications.[2,25] Routine pulmonary function testing does not always correctly predict PPCs, and spirometry should be reserved for patients with a clinical diagnosis of COPD without prior spirometric confirmation or suspected COPD diagnosis.[7,36,37] Routine preoperative chest X-ray is not recommended. However, since the prevalence of chest X-ray abnormalities increase with cardiopulmonary comorbidities, severe systemic illnesses, and with age, a preoperative chest X-ray may be of benefit for those with known cardiopulmonary disease or those over 50 years who are scheduled for high-risk surgery.[7] The preoperative pulmonary assessment and the use of risk indices give the NP a good evaluation regarding the likelihood of PPCs.

Moving forward

PPCs are as prevalent as postoperative cardiac complications and contribute to increased length of hospital stay and morbidity. The causes of PPC's are multifactorial, and NPs need to be able to reliably assess a patient's risk for developing PPCs and consider intervening with strategies that may reduce this risk. The NP should become familiar with using risk indices and clinical guidelines that address PPCs. Adequate preoperative assessment including appropriate diagnostics and risk reduction strategies will help improve surgical outcomes and decrease the economic burdens of PPCs. NP

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